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Nakladnik

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet
Prilaz baruna Filipovića 28a, 10000 Zagreb

Glavna urednica

Prof. dr. sc. Sanja Ercegović Ražić, voditeljica doktorskog studija

Urednički odbor

Prof. dr. sc. Martina Glogar, zamjenica voditeljice doktorskog studija

Prof. dr. sc. Anica Hursa Šajatović, članica

Izv. prof. dr. sc. Ksenija Smoljak Kalamir, članica

Izv. prof. dr. sc. Bosiljka Šaravanja, članica

Izv. prof. dr. sc. Ivana Špelić, članica

Prof. dr. sc. Anita Tarbuk, članica

Prof. dr. sc. Snježana Firšt Rogale, članica

Prof. dr. sc. Katarina Nina Simončič, članica

Prof. dr. sc. Vesna Marija Potočić Matković, članica

Grafička priprema

Prof. dr. sc. Sanja Ercegović Ražić

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Uvod

Doktorski studij **Tekstilna znanost i tehnologija** nastavak je sveučilišnog diplomskog studija koji združuje teorijska znanja, istraživački rad i iskustvo u rješavanju problema temeljenih na poznavanju suvremenih proizvodnih sustava. Sveučilište u Zagrebu Tekstilno-tehnološki fakultet je nositelj ovog studija iz znanstvenog područja tehničkih znanosti, znanstvenog polja tekstilna tehnologija.

Doktorski studij Tekstilna znanost i tehnologija (<https://www.ttf.unizg.hr/tekstilna-znanost-i-tehnologija/226>) je jedini doktorski studij u području tekstilne znanosti i tehnologije u Republici Hrvatskoj te najznačajniji u regiji. Osnovni cilj studija je osposobljavanje doktoranada za samostalni znanstvenoistraživački rad, poticanje inovativnosti i transfer rezultata znanstvenih istraživanja na unaprjeđenje suvremenih proizvodnih procesa u tekstilnoj i odjevnoj industriji. Napredak u području tehničkih znanosti posebno je usmjeren na istraživanje materijala i njihovih karakteristika, s naglaskom na primjenu biotehnologije i nanotehnologije. Značajan iskorak u tome predstavljaju napredni materijali i kompoziti, multifunkcionalna zaštitna i inteligentna odjeća i obuća. Međunarodni savjet akademija tehničkih znanosti (CAETS) svrstao je istraživanje materijala, pa tako i tekstilnih, na listu prioriteta.

Doktorski studij **Tekstilna znanost i tehnologija** omogućuje doktorandima nastavak rada u istraživačkim institucijama, institucijama s parcijalnim udjelom istraživačke djelatnosti, javnom i privatnom sektoru i gospodarstvu. Završetkom studija pristupnici su osposobljeni za timski rad te samostalno vođenje nacionalnih, bilateralnih i europskih znanstvenih i stručnih projekata iz područja istraživanja u okviru dokorskog studija. Stečena znanja i istraživački potencijal omogućuju im nastavak znanstveno-istraživačkog rada putem dokorskog usavršavanja.

Voditeljica dokorskog studija

prof. dr. (sc.) Sanja Ercegović Ražić

Dekanica Sveučilišta u Zagrebu
Tekstilno-tehnološkog fakulteta

prof. dr. sc. Anica Hursa Šajatović

Predgovor

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet kao nositelj doktorskog studija ***Tekstilna znanost i tehnologija*** organizira znanstvenu konferenciju **Dan doktoranada**. Ova znanstvena manifestacija s ponosom predstavlja znanstveno-istraživački rad svojih doktorskih kandidata pod vodstvom njihovih cijenjenih mentora istudijskih savjetnika.

U Zborniku radova Dana doktoranada 2026. godine objavljeno je 20 proširenih sažetaka doktoranada pisanih hrvatskim i engleskim jezikom. Uz proširene sažetke doktoranada, objavljeni su cjeloviti radovi osam (8) doktora znanosti koji su doktorirali na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultet nakon prethodno održanog Dana doktoranada 2026. godine.

Zbornik radova pruža uvid u raznolikost i kvalitetu znanstveno-istraživačkih tema te uključenost naših doktoranada u razvoj novih, inovativnih metoda, materijala i tehnologija kroz implementaciju i primjenu novih ideja i inženjerskih rješenja.

Voditeljica doktorskog studija

prof. dr. sc. Sanja Ercegović Ražić

**Ivana Čorak Ribić****Životopis**

Diplomirala je na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu (TTF) 2015. Na TTF-u je radila kao asistentica na projektu HRZZ-DOK-2018-09-4254 Bio-inovirani poliesterski materijal za ciljanu primjenu u bolničkom okruženju. Bila je suradnica na HRZZ UIP-05-2019-8780 HPROTEX, bilateralnom znanstveno-istraživačkom projektu Bio-inovirani poliesteri između Hrvatske i Srbije te Erasmus+ projektima Sustainable Design and Process in Textiles for Higher Education (GreenTEX) i AEQUALIS4TCLF Blueprint project. Dobila je nagradu o.d. Dekanice za izvrsnost na poslijediplomskom sveučilišnom studiju TZT 2019./2020., Nagradu TSRC 2021. za najuspješniji znanstveno-istraživački rad iz područja tekstila u kategoriji I: za mlade istraživače TTF-a te Nagradu mladom znanstveniku „Vera Johanides“ za 2024. godinu. Od 2025. je zaposlena kao viša asistentica na TTF-u u području teorije boje i tiska.

Naslov teme doktorskog rada

Bio-inovirani poliesterski materijal za ciljanu primjenu u bolničkom okruženju

Mentorica

Prof. dr. sc. Anita Tarbuk

Datum obrane doktorskog rada

22. studenoga 2024.

BIO-INO VIRANI POLIESTERSKI MATERIJAL ZA CILJANU PRIMJENU U BOLNIČKOM OKRUŽJU

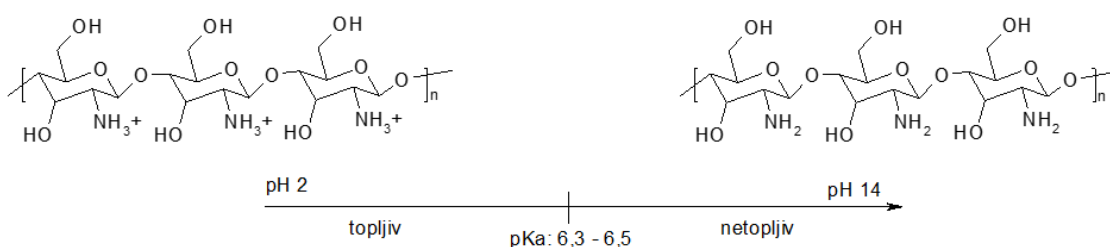
Ivana ČORAK RIBIĆ

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića 28a, Zagreb,
ivana.corak@tff.unizg.hr

Sažetak: Istraživanja u okviru doktorskog rada obuhvaćaju razvoj bio-inoviranih poliesterskih materijala za ciljanu primjenu u bolničkom okružju. Aktivacija površine poliesterske tkanine provedena je hidrolizom lužinom pri sniženoj temperaturi uz dodatak akceleratora te ekološki prihvatljivim enzimima amano lipazama. Provedena je funkcionalizacija kitozanom homogeniziranim u vodenoj otopini octene kiseline metodom impregnacija-sušenje-kondenzacija. Udobnost tkanine nakon obrade kao i njena postojanost potvrđena je mjerenjem osjeta opipa i nakon 10 ciklusa prilagođenog pranja.

1. Uvod

Poliester čini gotovo 80 % ukupne proizvodnje sintetskih vlakana, od kojih je poli(etilen tereftalat), PET, najčešći, a karakterizira ga hidrofobna površina uslijed velike kristaličnosti. Radi toga se provode površinske modifikacije poput hidrolize koja uzrokuje cijepanje na esterskim vezama i rezultira povećanim brojem hidroksilnih i karboksilnih skupina pri čemu tkanine imaju bolju adsorptivnost. U odnosu na ekološki nepovoljnu alkalnu hidrolizu koja može trajno oštetiti vlakna, enzimska hidroliza omogućuje selektivnu obradu polimernih materijala pri niskoj temperaturi. Enzimi zbog veličine djeluju isključivo na površini vlakna pa ne dovode do oštećenja. Za enzimsku hidrolizu PET-a koriste se različiti enzimi, no najbolji učinci postižu se lipazama i kutinazama [1, 2]. Kitozan je prirodni biopolimer pretežno građen iz 2-amino-2-deoksi-D-glukopiranoznih jedinica, povezanih β -1,4-vezama. Unatoč brojnim postojećim antimikrobnim sredstvima, svijest javnosti i politike EU-a istaknuli su potrebu za novim bio-sredstvima u razvoju bolničkih materijala. Velik interes za primjenu kitozana u bolničkom okružju proizlazi iz njegovih svojstava: biokompatibilnosti, biorazgradivosti, netoksičnosti, antimikrobne, hemostatske i hidratantne učinkovitosti [3]. Razvoj bio-inoviranih poliesterskih materijala namijenjenih upotrebi u bolničkom okružju istražen je korištenjem Amano lipaze i kitozana. Kitozan je naslojen na aktiviranu površinu tkanine metodom impregnacija-sušenje-kondenzacija homogeniziranom otopinom kitozana u octenoj kiselini, slika 1.



Slika 1: Shematski prikaz kitozana u vodenoj otopini u ovisnosti o vrijednosti pH

2. Eksperimentalni dio

Za istraživanja je korištena komercijalna poliesterska tkanina iz 100 % poli(etilen-tereftalata) površinske mase 60 g/m² (Belira). Hidroliza je provedena u 1,5 M NaOH na 80 °C u vremenu od 10 min uz dodatak 2 g/l akceleratora, kationskog tenzida heksadeciltrimetil amonijeva klorida (HDTMAC, 25 % vodena otopina, Fluka). Enzimska hidroliza je provedena s 0,2 g/l Amano Lipase A (*Aspergillus niger*) tvrtke Sigma-Aldrich pri vrijednosti pH 9 na 60 °C u vremenu 60 min. Za funkcionalizaciju je korišten kitozan dobiven iz micelija gljive bukovače tvrtke Chibio BioTECH. Tkanine su impregnirane u homogeniziranoj otopini kitozana u octenoj kiselini (3 g/l), sušene na 110 °C u vremenu 2 min i termokondenzirane na temperaturi 170 °C u vremenu 90 sekundi. Oznake i obrade tkanina korištenih u istraživanju prikazane su u tablici 1.

Tablica 1: Oznake i obrade tkanina korištenih u istraživanju

Oznaka	Obrada
PET	Komercijalna PET tkanina
_H	Alkalno hidrolizirana tkanina uz dodatak HDTMAC
_ALA	Enzimski hidrolizirana tkanina pomoću Amano Lipase A iz <i>A. niger</i>
_K	3 g/l homogeniziranog kitozana
_1W ili 10W	1. ili 10. ciklus pranja

Kako bi se utvrdila udobnost obrade, kao i njena postojanost, provedena su sljedeća ispitivanja. Mjerenje zeta potencijala provedeno je na elektrokinetičkom analizatoru SurPASS (Anton Paar GmbH) metodom potencijala strujanja. Elektrokinetički potencijal (zeta, ζ) mjeren je kao funkcija vrijednosti pH od 1 mmol/l KCl pomoću ćelije s podesivim razmakom i određena je izoelektrična točka (engl. *Isoelectric Point*, IEP) [4]. Ispitivanje sposobnosti upravljanja kapljevitom vlagom izvršeno je prema AATCC TM 195-2021: *Liquid Moisture Management Properties of Textile Fabrics* na uređaju Moisture Management Tester (MMT), M290 MMT, tvrtke SDL Atlas. Prije mjerenja, uzorci su kondicionirani u stabilitetnoj klima komori, model KBF-S 240 E6, 9020-0366, Binder GmbH na 21 ± 2 °C i relativnoj vlažnosti zraka 65 ± 5 % [5, 6]. Opip je određen mjerenjem fizikalnih svojstava tkanina vezanih uz osjet dodira na uređaju Fabric Touch Tester (FTT M293) tvrtke SDL Atlas. Izmjerena svojstva daju 13 različitih FTT indeksa plošnog tekstilnog materijala, a zatim FTT softver izračunava module (gladak, mekan, topao) i ukupnu udobnost plošnog tekstilnog materijala. Uzorci su kondicionirani u standardnim uvjetima prije postupka mjerenja [7, 8]. Ispitivanja su provedena nakon 1. i 10. ciklusa prilagođenog pranja u perilici rublja Wascator FOM71 CLS (Electrolux). Pranje je provedeno u mekanoj vodi uz dodatak deterdženta s optičkim bjelilom (ISO 15797:2002) uz naknadno dodavanje PAP-a, ϵ -ftalimido) peroksi heksanske kiseline, na 50 °C po posebno izrađenom programu. Sušenje je provedeno u sušilici T5130-LAB – Type A1 (Electrolux) u trajanju od 30 min u programu NORMAL LAB.

3. Rezultati i rasprava

Vrijednosti zeta potencijala i izoelektrične točke ispitivanih uzoraka prikazane su u tablici 2. Niske vrijednosti zeta potencijala PET tkanine u lužnatom mediju rezultat su njegove hidrofobne površine uzrokovane visokom kristaličnošću vlakna i malim brojem aktivnih skupina. Funkcionalizacijom kitozanom zeta potencijal ima više vrijednosti u lužnatom i neutralnom mediju radi prisutnosti amino skupina kitozana [3]. Alkalnom hidrolizom poliestera došlo je do stvaranja većeg broja aktivnih skupina i povećanja površine adsorpcije na kojoj se adsorbirao homogenizirani kitozan, što je dovelo do pozitivnijeg zeta potencijala u lužnatom mediju i pomaka IEP prema višim vrijednostima pH u odnosu na nehidrolizirani poliestar. Vidljivo je da se zeta potencijal sa svakim provedenim ciklusom pranja smanjuje što ukazuje da se adsorbirani homogenizirani kitozan skida s površine. Enzimsko hidrolizom dolazi do ljuštenja površine što nije vidljivo u promjeni IEP. Međutim, funkcionalizacija kitozanom ukazuje da je enzimska hidroliza bila uspješna jer su vrijednosti zeta potencijala više u usporedbi s nehidroliziranim PET-om. Enzimski hidrolizirana PET tkanina enzimom ALA ima bolju postojanost na pranje u odnosu na alkalno hidroliziranu i početnu PET tkaninu na što ukazuje IEP.

Tablica 2: Zeta potencijal (ζ) i izoelektrična točka (IEP)

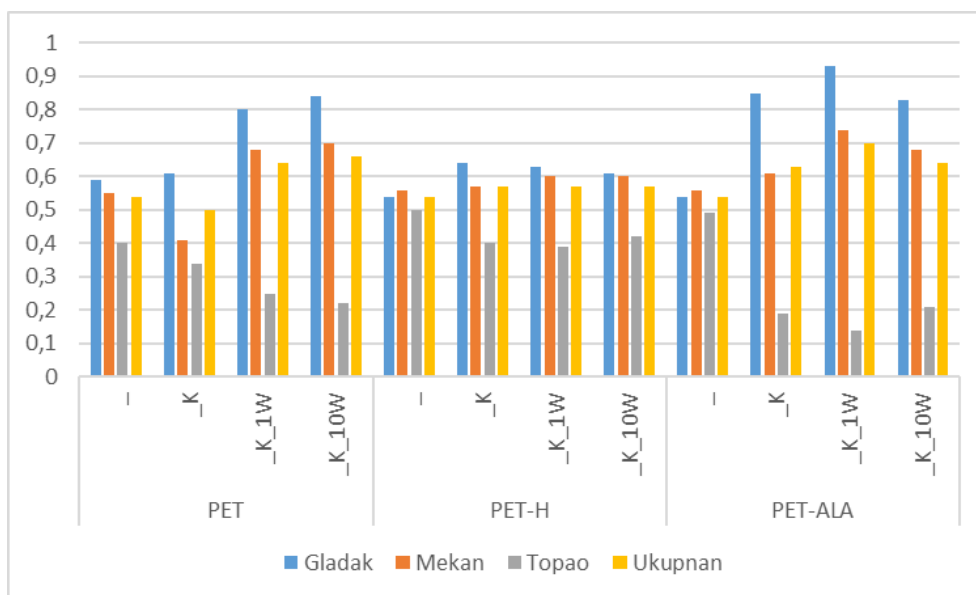
Uzorak	PET			PET-H			PET-ALA		
	$\zeta_{pH 4}$ [mV]	$\zeta_{pH 8}$ [mV]	IEP	$\zeta_{pH 4}$ [mV]	$\zeta_{pH 8}$ [mV]	IEP	$\zeta_{pH 4}$ [mV]	$\zeta_{pH 8}$ [mV]	IEP
–	-44,24	-69,46	< 2	-23,78	-61,15	2,62	-54,40	-71,11	< 2
_K	26,65	-50,82	4,97	36,33	-37,67	5,40	32,35	-43,57	5,59
_K_1W	25,21	-50,18	4,96	33,25	-40,70	4,81	29,77	-50,51	4,88
_K_10W	-15,68	-30,12	2,59	-25,50	-60,49	2,70	-35,05	-62,86	3,15

Tip tkanine ispitivanih uzoraka određen ispitivanjem sposobnosti upravljanja kapljevitom vlagom prikazan je u tablici 3. Tipovi tekstilnih materijala i opis njihovih svojstava [5, 6] prikazani u tablici su sljedeći: tekstilni materijal sa sposobnošću prodiranja vode, WPF (engl. *Water Penetration Fabric*) - malo područje razlijevanja, izvrstan jednosmjernan prijenos; tekstilni materijal sa sposobnošću upravljanja vlagom, MMF (engl. *Moisture Management Fabric*) - srednje do brzo kvašenje, srednja do brza apsorpcija, veliko područje razlijevanja po donjoj površini, brzo razlijevanje po donjoj površini, dobar do izvrstan jednosmjernan prijenos; brzo apsorbirajući i brzo sušeci tekstilni materijal, FAQDF (engl. *Fast Absorbing and Quick Drying Fabric*) - srednje do brzo kvašenje, srednja do brza apsorpcija, veliko područje razlijevanja, brzo razlijevanje, slabi jednosmjernan prijenos. Alkalno hidrolizirani uzorci s kitozanom pokazuju najbolju sposobnost upravljanja vlagom te su okarakterizirani kao brzo apsorbirajući i brzo sušeci tekstilni materijali.

Tablica 3: Tip tkanine ispitivanih uzoraka određen ispitivanjem sposobnosti upravljanja kapljevitom vlagom

Uzorak	Tip tkanine		
	PET	PET-H	PET-ALA
–	MMF	WPF	MMF
_K	WPF	MMF	WPF
_K_1W	MMF	FAQDF	MMF
_K_10W	MMF	FAQDF	MMF

Osjet opipa dobiven na osnovu indeksa određenih na FTT-u prikazan je na slici 2. Osjet opipa može imati vrijednosti između 0 i 1 pri čemu vrijednost 0 označava najgrublju, najtvrdju ili najhladniju tkaninu, a 1 označava najgladju, najmekšu ili najtopliju tkaninu [9].



Slika 2: Osjet opipa dobiven na osnovu indeksa određenih na FTT-u

Vidljivo je da PET tkanina prije i nakon funkcionalizacije kitozanom ima najniži ukupan opip. Postupkom pranja uzorcima funkcionaliziranim kitozanom dolazi do povećanja glatkoće i mekoće što povećava i ukupan opip same tkanine. Alkalno hidrolizirana tkanina ima veću udobnost u odnosu na nehidroliziranu tkaninu, međutim, funkcionalizacijom kitozanom ukupan osjet opipa ostaje gotovo isti. Enzimskom hidrolizom također ne dolazi do povećanja osjeta opipa, međutim funkcionalizacijom kitozanom uzorak postaje gladi, poglavito nakon prvog ciklusa pranja. Nakon 10. ciklusa pranja dolazi do smanjenja glatkoće i mekoće, tkanina zadržava hladan opip, ali ukupan osjet opipa je i dalje iznad 0,6 što je više u usporedbi s nehidroliziranim uzorkom.

4. Zaključci

Pravilnim odabirom parametara procesa može se na ekološki, energetski i ekonomski prihvatljiv način provesti hidroliza površine komercijalne poliesterske tkanine. Postupak impregnacija-sušenje-kondenzacija homogeniziranom otopinom kitozana u octenoj kiselini je postojan i nakon višestrukih ciklusa pranja. Stvaraju se vodikove i ionske veze između protoniranog kitozana (NH_3^+) i karboksilnih i hidroksilnih skupina PET vlakna. Ukupna udobnost enzimski hidroliziranog uzorka je zadovoljavajuća i nakon 10 ciklusa pranja što je važno ukoliko bi se odjeća višestruko nosila. S obzirom na sve dobivene rezultate, prihvatljivijim se pokazao bio-inovirani postupak aktivacije površine PET tkanina enzimskom hidrolizom amanolipazom A iz *Aspergillus niger* (ALA) funkcionaliziran homogeniziranim kitozonom postupkom impregnacija-sušenje-kondenzacija.

Zahvala



Rad doktorandice Ivane Čorak sufinanciran je iz „Projekta razvoja karijera mladih istraživača – izobrazba novih doktora znanosti“ Hrvatske zaklade za znanost (HRZZ-DOK-2018-09-4254). Mišljenja, nalazi i zaključci ili preporuke navedene u ovom materijalu isključiva su odgovornost autora i ne odražavaju nužno stajališta Hrvatske zaklade za znanost. Rad je sufinancirala HRZZ projektom UIP-2017-05-8780 “Bolničke zaštitne tekstilije”.

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**Franka Karin****Životopis**

Franka Karin, dr. sc., rođena je u Zagrebu gdje je završila osnovnu i srednju školu. Na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu 2009. godine završila je prijediplomski studij Tekstilni i modni dizajn, a 2012. godine diplomski studij Tekstilna tehnologija i inženjerstvo. Poslijediplomski doktorski studij Tekstilna znanost i tehnologija završila je 2025. godine kada je obranila doktorski rad pod nazivom Razvoj osnovnih silueta ženske odjeće prilagođene temeljnim postavkama održivosti u modi. Od 2017. godine zaposlena je na Tekstilno- tehnološkom fakultetu u suradničkom zvanju asistenta na Zavodu za dizajn tekstila i odjeće. Znanstveno istraživački rad vezan je za koncept bez otpada i njegovu primjenu u modnom dizajnu u svrhu održivog razvoja i definiranje novih metoda konstrukcije, modeliranja i izrade odjeće koji smanjuju međukrojni gubitak tijekom proizvodnje.

Naslov teme doktorskog rada

Razvoj osnovnih silueta ženske odjeće prilagođene temeljnim postavkama održivosti u modi

Mentorica

Izv. prof. dr. sc. Blaženka Brlobašić Šajatović

Datum obrane doktorskog rada

29. siječnja 2025.

TAXI METODA KAO ODRŽIVO RJEŠENJE ZA SMANJENJE MEĐUKROJNOG GUBITKA OSNOVNE „X“ SILUETE ŽENSKJE ODJEĆE

Franka KARIN

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28 a, franka.karin@tff.unizg.hr

Sažetak: Međukrojni gubitak nastao u proizvodnim procesima proizvodnje odjeće predstavlja sve veći izazov za odjevnu industriju, zbog čega se razvijaju novi pristupi u dizajnu odjeće temeljeni na održivom razvoju i konceptu bez otpada. U radu se prikazuje razvoj ženske haljine osnovne „X“ siluete primjenom inovativne TAXI metode. Temeljni kroj prema temeljnoj konstrukciji odjeće usporedio se s temeljnim krojem i krojem prema prijedlogu dizajna TAXI metode. Analiziralo se iskorištenje tkanine za obje metode. Rezultati pokazuju da osnovna „X“ silueta dizajnirana prema TAXI metodi ostvaruje 99,8 % iskorištenja tkanine, što je 32,5 % više u usporedbi s temeljnim krojem. Predložena TAXI metoda omogućuje maksimalno moguće iskorištenje tkanine bez narušavanja estetske komponente. Ostvaruje dobro pristajanje prema tijelu i postiže prepoznatljive siluete odjevnog predmeta.

1. Uvod

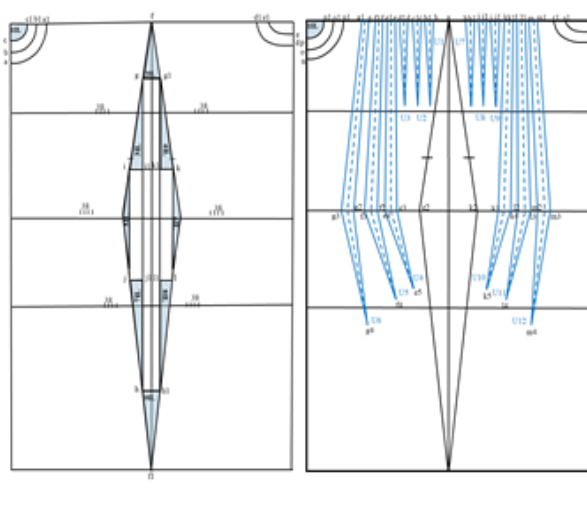
Održivi razvoj u dizajnu odjeće i primjena koncepta bez otpada imaju ključnu ulogu u smanjenju međukrojnog gubitka i zaštiti prirodnih resursa. Modna industrija jedan je od najvećih uzročnika tekstilnog otpada zbog međukrojnog gubitka koji nastaje tijekom procesa proizvodnje odjevnih predmeta. Cilj koncepta bez otpada u dizajnu odjeće usmjeren je na racionalno iskorištenje tkanine i produljenje životnog ciklusa odjevnih predmeta, pri čemu dizajneri imaju značajnu ulogu u dizajnerskom i proizvodnom procesu.

Dosadašnja istraživanja metoda koncepta bez otpada pokazala su značajan napredak u smanjenju međukrojnog gubitka, no istodobno su uočena ograničenja vezana uz pristajanje odjevnih predmeta prema osnovnim siluetama ženske odjeće. Silueta odjevnog predmeta važna je u dizajnu odjeće jer definira oblik i način na koji odjevni predmet pristaje prema tijelu. U ovom radu prikazana je usporedba međukrojnih gubitaka temeljnog kroja i kroja prema prijedlogu dizajna prema temeljnoj konstrukciji odjeće i razvijenoj TAXI metodi za žensku haljinu „X“ osnovne siluete. TAXI metoda usmjerena je na zadržavanje oblika osnovne siluete ženskih odjevnih i smanjenje međukrojnog gubitka. Istraživanje rezultira definiranjem postupka temeljnog kroja i postupka prema prijedlogu dizajna za „X“ osnovnu siluetu ženske haljine prema razvijenoj TAXI metodi, čime se doprinosi unapređenju održivog razvoja u proizvodnji odjeće i razvoju inovativnih metoda u području dizajna[1-5].

2. Eksperimentalni dio

U okviru istraživanja analizirane su postojeće metode dizajna odjeće prema konceptu bez otpada na temelju čega je razvijena nova TAXI metoda u području dizajna i konstrukcije odjeće. Predložena metoda omogućuje izradu temeljnog kroja i njegovu prilagodbu osnovnim siluetama ženske odjeće, a da se pri tome zadovolje pet osnovnih kriterija održivog razvoja, to su: estetika, pristalost, trošak, smanjenje međukrojnog gubitka i mogućnost proizvodnje.

Nova metoda temelji se na osnovnim siluetama ženske odjeće („T“, „A“, „X“ i „I“). U radu je prikazan razvoj temeljnog kroja i kroja prema prijedlogu dizajna osnovne siluete „X“ ženske haljine primjenom nove metode koja ima jasno definirana pravila i postupak izrade temeljnih krojeva, slika 1a i 1b. Postupak polazi od mreže koja je definirana širinom tkanine koja iznosi 70 cm, duljinom odjevnog predmeta koja iznosi 100 cm i glavnim dužinskim mjerama. Matematički izrazi konstrukcijskih tjelesnih mjera preuzeti su iz temeljne konstrukcije i modificirani su, dok su pojedine mjere definirane prema TAXI metodi [6].

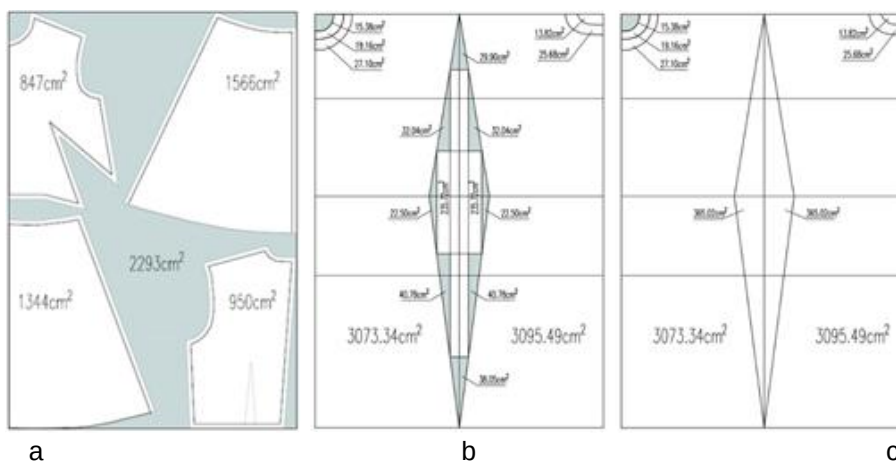


Slika 1: Konstrukcija ženske haljine prema TAXI metodi: a) temeljni kroj haljine osnovne „X“ siluete, b) kroj prema prijedlogu dizajna ženske haljine osnovne „X“ siluete [6].

Krojevi su izrađeni u računalnom programu AutoCAD, pri čemu su precizno definirane površine krojnih dijelova i međukrojnog gubitka. Modeliranjem temeljnih krojeva prema TAXI metodi razvijen je postupak prema prijedlogu dizajna koji omogućuje prilagodbu osnovnih silueta uz maksimalno iskorištenje tkanine primjenom konstrukcijskih elemenata u području struka, bokova, ramena i duljine odjevnog predmeta. Međukrojni gubitci usporedili su se za obje metode kako bi se utvrdilo da li je moguće predloženom metodom koncepta bez otpada smanjiti međukrojni gubitak u odnosu na temeljnu konstrukciju odjeće. Pristalost „X“ osnovne siluete ispitana je u računalnom programu Clo 3D [6].

3. Rezultati i rasprava

U radu su prikazani rezultati analize površina međukrojnih gubitaka za osnovnu siluetu „X“ ženske haljine, modelirane prema temeljnoj konstrukciji odjeće prikazano na slici 2a, prema prijedlogu TAXI metode prikazano na slici 2b i prema prijedlogu dizajna TAXI metode prikazano na slici 2c. Temeljna konstrukcija ženske haljine izrađena je za konfekcijsku veličinu 38 te je modelirana s ciljem dobivanja osnovne siluete „X“ [6].



Slika 2: Površine međukrojnih gubitaka: a) površina međukrojnog gubitka ženske haljine „X“ osnovne siluete prema temeljnoj konstrukciji odjeće, b) površina međukrojnog gubitka ženske haljine „X“ osnovne siluete temeljnog kroja prema TAXI metodi, c) površina međukrojnog gubitka ženske haljine „X“ osnovne siluete prijedloga dizajna prema TAXI metodi [6].

Ukupna površina krojne slike prema temeljnoj konstrukciji odjeće iznosi 7000 cm². Za osnovnu „X“ siluetu ženske haljine, površina prednjih i stražnjih krojnih dijelova iznosi 4707 cm², a međukrojni gubitak iznosi 2293 cm². U temeljnom kroju osnovne „X“ siluete ženske haljine prema TAXI metodi površina prednjeg i stražnjeg krojnog dijela iznosi 6168,83 cm², površina podlistaka prednjeg i stražnjeg vratnog izreza, orukavlja i duljine haljine iznosi 557,2 cm², a međukrojni gubitak iznosi 341,93 cm². Prema prijedlogu dizajna TAXI metode,

površina prednjeg i stražnjeg krojnog dijela iznosi 6168,83 cm², a površina međukrojnog gubitka iznosi 15,38 cm². Iskorištenje tkanine za „X“ osnovnu siluetu ženske haljine prema temeljnoj konstrukciji iznosi 67,3 %, dok se prema TAXI metodi povećava na 96 %, a prema prijedlogu dizajna TAXI metode iznosi 99,8 %, što je 32,5 % bolje iskorištenje. Međukrojni gubitak smanjen je s 32,7 % na 0,2 %. Ovi rezultati potvrđuju da TAXI metoda značajno smanjuje tekstilni otpad.

U računalnom programu Clo 3D napravljena je simulacija ženskih haljina „X“ osnovne siluete kako bi se usporedila pristalost prema temeljnoj konstrukciji odjeće i prema TAXI metodi, slika 3a i 3b. Na temelju simulacije može se zaključiti da je pristalost prema predloženoj TAXI metodi jednako dobra kao i prema temeljnoj konstrukciji odjeće [6].



Slika 3: „X“ osnovna silueta ženske haljine u računalnom programu Clo 3d: a) simulacija „X“ osnovne siluete ženske haljine prema temeljnoj konstrukciji odjeće, b) simulacija „X“ osnovne siluete ženske haljine prema prijedlogu dizajna TAXI metode [6].

4. Zaključak

Analiza postojećih metoda koncepta bez otpada pokazala je da odjevni predmeti nemaju prepoznatljive osnovne siluete, iako postižu maksimalno moguće iskorištenje tkanine. Predložena TAXI metoda bez postiže iskorištenje tkanine od 99,8 % i zadovoljava osnovne kriterije održivog razvoja. Međukrojni gubitak definiran u temeljnom kroju, nastaje kao razlika između oblika siluete i zbroja glavnih tjelesnih mjera u području prsa, struka i bokova iskorišten je za konstrukcijske elemente u prijedlogu dizajna kako bi se dodatno naglasila „X“ silueta i njezino pristajanje prema tijelu. Osnovna „X“ silueta prema TAXI metodi postiže vrlo visoko iskorištenje tkanine uz minimalne međukrojne gubitke, znatno bolje nego kod silueta prema osnovnoj konstrukciji odjeće. Rezultati potvrđuju da TAXI metoda nudi održivo i praktično rješenje za proizvodnju ženskih odjevnih predmeta, smanjujući tekstilni otpad i omogućujući primjenu u masovnoj proizvodnji.

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**Mateo Miguel Kodrić Kesovia****Životopis**

Rođen 1987. u Dubrovniku. Diplomirao konzervaciju-restauraciju tekstila na Sveučilištu u Dubrovniku, gdje se zapošljava i 2021. stječe zvanje docenta. Nositelj je nekoliko kolegija na Odjelu za umjetnost i restauraciju Sveučilišta u Dubrovniku, te djeluje kao gostujući nastavnik na Univerzitetu Crne Gore. Doktorski studij iz Tekstilne znanosti i tehnologije završava 2025. na Tekstilno-tehnološkom fakultetu Sveučilišta u Zagrebu. Usavršavao svoje vještine i znanja na institucijama u Italiji, Austriji i Švicarskoj. Suradivao na brojnim domaćim i međunarodnim projektima konzervacije-restauracije. Autor nekoliko znanstvenih i stručnih radova. Aktivno sudjeluje u domaćim i međunarodnim stručnim povjerenstvima i odborima organizacija (HRD, ECCO, ENCoRE). Znanstveni interesi mu obuhvaćaju povijest tekstilne tehnologije i digitalizaciju kulturne baštine.

Naslov teme doktorskog rada

Metodologija analize i digitalizacije tehnološke dokumentacije povijesnih damasta s dubrovačkoga područja

Mentori

Prof. dr. sc. Željka Penava / prof. dr. sc. Katarina Nina Simončić

Datum obrane doktorskog rada

21. srpnja 2025.

METODA ANALIZE I DIGITALIZACIJE TEHNOLOŠKE DOKUMENTACIJE POVIJESNIH DAMASTNIH TKANINA S DUBROVAČKOGA PODRUČJA

Mateo Miguel KODRIČ KESOVIA

Sveučilište u Dubrovniku, Branitelja Dubrovnika 41, mmkesov@unidu.hr

Sažetak: Ovom disertacijom predstavljen je inovativan pristup istraživanju i dokumentiranju povijesnih tkanina u digitalnom okruženju. Kroz interdisciplinarni pristup, rad povezuje različita znanstvena područja kako bi se osigurala sveobuhvatna analiza i interpretacija povijesnih damasta.

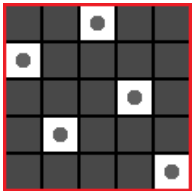
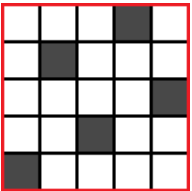
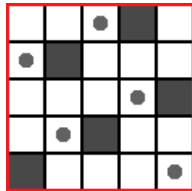
1. Uvod

Tkanine s uzorcima, kao oblik izražavanja ljudske kreativnosti, nastaju zanimljivom interakcijom dizajnera i tkalca u svim fazama njihove realizacije te predstavljaju složenu, ali savršenu simbiozu tekstilne umjetnosti i tehnologije. Među povijesnim uzorkovanim tkaninama posebno se ističe damast, u kojima se likovno-ornamentalna rješenja ostvaruju isključivo kroz konstrukciju tkanine, koji se zbog svoje konstrukcijske logike i vizualnih mogućnosti koristi kontinuirano od ranoga srednjeg vijeka do danas.

Osnovno obilježje damasta proizlazi iz izmjene lica i naličja tkanine, pri čemu se uzorak formira promjenom veza u tkanju, najčešće unutar istog tipa veza. Takva tehnika tkanja omogućuje postizanje bogatih dekorativnih rješenja bez dodatnih materijala, što je u povijesnom kontekstu imalo značajne ekonomske i tehnološke prednosti [1].

Analiza povijesnih damastnih tkanina u okviru ovoga istraživanja obuhvatila je iznimno reprezentativan skup primjeraka, pri čemu su na ispitanim tkaninama evidentirane gotovo sve poznate tipologije damasta. Iznimku čine isključivo starokineski prototipovi, koji zbog svoje rijetkosti te specifičnog povijesnog, kulturnog i geografskog konteksta nisu bili zastupljeni u analiziranom korpusu. Takva zastupljenost omogućila je cjelovit uvid u raznolikost konstrukcijskih rješenja i njihov utjecaj na konačni izgled damasta. U okviru ovoga istraživanja po prvi je put provedena sustavna sistematizacija tipologije damasta, popraćena grafičkim prikazima svih struktura kao i kompatibilnosti između temeljnog veza i veza uzorka (Tablica 1). Takav pristup do sada nije evidentiran u stručnoj literaturi te predstavlja važan doprinos razumijevanju konstrukcijskih principa i prepoznavanju raznolikosti tipologija damasta.

Tablica 1: Grafički prikaz strukture vezova u klasičnom 5-veznom damastu

Temeljni vez	Vez uzorka	Kompatibilnost vezova
 Atlas 4/1 (2) u osnovi	 Atlas 1/4 (2) u potki	

Povijesni damasti čine važan dio muzejske i crkvene tekstilne baštine na području Dubrovnika, gdje su sačuvani kao dio liturgijskog i reprezentativnog inventara. Međutim, velik dio tih primjeraka sačuvan je bez izvorne tehnološke dokumentacije ili predložaka za tkanje, što otežava njihovu atribuciju, dataciju i interpretaciju.

Istraživanje povijesnih damasta dodatno je otežano njihovom osjetljivošću i krhkošću, zbog čega primjena invazivnih metoda analize nije prihvatljiva. Stoga se potreba za neinvazivnim, ali preciznim metodama tehnološke analize i dokumentiranja nameće kao ključna u suvremenim istraživanjima tekstilne baštine [2].

Poseban izazov predstavlja i problematika stručne terminologije u hrvatskom jeziku, osobito u području opisa konstrukcije, vezova u tkanju i dizajna. U ovome istraživanju korišteni su postojeći stručni pojmovi, uz njihovu prilagodbu i jasno definiranje u skladu s međunarodno prihvaćenim CIETA standardima, pri čemu se terminološka problematika promatra kao važan kontekst, ali ne i primarni cilj rada [3].

Cilj ovoga rada jest prikazati doktorsko istraživanje usmjereno na razvoj metodologije analize i digitalizacije tehnološke dokumentacije povijesnih damastnih tkanina te ukazati na mogućnosti primjene prikupljenih podataka u znanstvenom i stručnom kontekstu.

2. Eksperimentalni dio

Eksperimentalni dio istraživanja proveden je na povijesnim damastnim tkaninama iz muzejskih i crkvenih zbirki s područja Dubrovnika i okolice. Ukupno su analizirane 53 povijesne damastne tkanine, koje se razlikuju prema vremenu nastanka, stupnju očuvanosti i konstrukcijskim obilježjima. Budući da je riječ o jedinstvenim i fragilnim tekstilnim artefaktima, sve faze analize provedene su uz poseban oprez, poštujući temeljne konzervatorsko-restauratorske smjernice. Primijenjene metode odabrane su s ciljem minimiziranja fizičkog kontakta s izvornikom, a naglasak je stavljen na vizualnu analizu i digitalno bilježenje podataka [4].

2.1. Tehnološka analiza i dokumentacija povijesnih damasta

U okviru istraživanja razvijen je hodogram metodologije rada prilagođen analizi povijesnih damastnih tkanina, koji objedinjuje slijed koraka od početnog vizualnog pregleda do izrade digitalne dokumentacije. Tehnološka analiza obuhvatila je vizualno ispitivanje, analizu strukture vezova u tkanju te identifikaciju osnovnih konstrukcijskih i obilježja uzorka. Hodogram je osmišljen s ciljem osiguravanja ponovljivosti postupka i dosljednosti prikupljenih podataka. Dobiveni podatci sustavno su bilježeni i strukturirani, čime je osigurana dosljedna osnova za izradu tehnološke dokumentacije i njezinu daljnju digitalnu obradu.

2.2. Digitalni model obrasca i prototip baze podataka

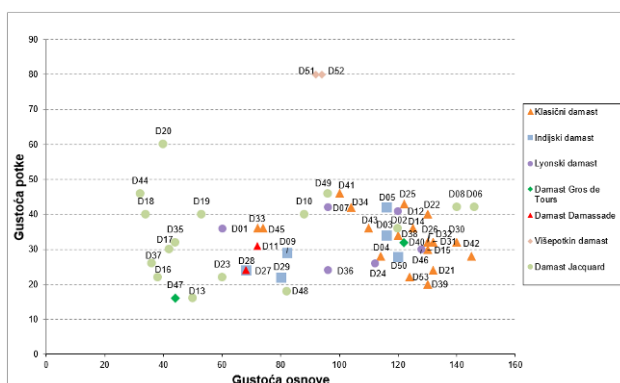
Inovativni digitalni obrazac i prototip baze podataka razvijeni su isključivo za potrebe ovoga istraživanja, u suradnji interdisciplinarnog tima stručnjaka iz područja tekstilne tehnologije, povijesti umjetnosti, konzervacije-restauracije i digitalnih tehnologija. Interdisciplinarni pristup omogućio je integraciju različitih znanstvenih i stručnih perspektiva u jedinstveni dokumentacijski sustav, strukturiran u četiri dijela: osnovne podatke o tkanini, likovno-stilsku analizu ornamenta, tehničke podatke te bilješke.

Digitalni model obrasca tehnološke dokumentacije osmišljen je kao standardizirani alat za bilježenje podataka o povijesnim uzorkovanim tkaninama. Posebna pažnja posvećena je prilagodbi obrasca radu s povijesnim tkaninama, pri čemu je izbjegnuto uvođenje parametara koji bi zahtijevali invazivne zahvate. Time je osigurana primjenjivost obrasca u znanstvene svrhe, ali i u muzejskoj i konzervatorsko-restauratorskoj praksi. Model je primijenjen na analizirane povijesne damastne tkanine, čime je potvrđena njegova primjenjivost i fleksibilnost.

2.3. Metode primjene podataka

Razvijeni sustav pokazao se primjenjivim u različitim znanstvenim područjima, uključujući tekstilnu tehnologiju, povijest umjetnosti i digitalnu humanistiku, ali i u industrijskom kontekstu, osobito u području rekonstrukcije povijesnih uzoraka i suvremene (re)produkcije tekstila.

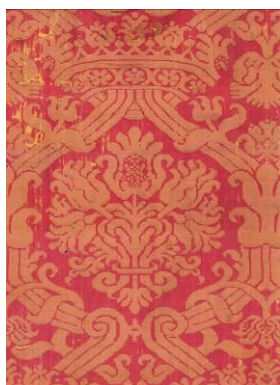
Prikupljeni i digitalno obrađeni podatci korišteni su za komparaciju, atribuciju i dataciju povijesnih damastnih tkanina. Analizirani su odnosi između uzorka i konstrukcije, kao i varijacije u primjeni veza. Analiza je dodatno uključila usporedbu varijabilnosti unutar istih tipoloških skupina, čime su uočene razlike u izvedbi koje nisu vidljive isključivo na razini ornamenta. Takav pristup omogućio je dublje razumijevanje tehnoloških odluka u povijesnoj proizvodnji. Grafički prikazi omogućili su vizualnu identifikaciju skupina uzoraka s visokim stupnjem međusobne srodnosti (Grafikon 1).



Grafikon 1: Grafički prikaz raspšenja analiziranih damasta prema gustoći niti osnove i potke

Dobiveni rezultati pokazali su da kombinacija kvantitativnih i kvalitativnih parametara značajno povećava pouzdanost komparativne analize. Vizualizacija podataka dodatno je olakšala interdisciplinarnu interpretaciju odnosa među analiziranim damastima [5].

Na temelju dokumentiranih podataka provedena je i rekonstrukcija predložaka za tkanje metodom obrnutog inženjeringa, što je omogućilo izradu suvremenih reprodukcija damastnih tkanina i provjeru ispravnosti primijenjene metodologije.



a



b

Slika 1: Eksperimentalna reprodukcija: a) Klasični svileni damast, Italija, 16-17 stoljeće. inv. DUM KPM T-40
b) rekonstruiran predložak i otkana replika povijesnog damasta

2.4. Anketno istraživanje

Razvijeni digitalni model evaluiran je putem anketnog istraživanja provedenog među 32 stručnjaka koji se bave nekim oblikom proučavanja i/ili očuvanja povijesnih tkanina. Svi ispitanici (100%) smatraju da digitalni model obuhvaća sve važne parametre povijesnih tkanina, dok 96,9% ispitanika navodi veliku ili izrazito veliku vjerojatnost njegove praktične primjene.

3. Zaključci

Tekstilna baština predstavlja nepresušan spremnik ljudske umjetničke kreativnosti i tehnoloških dostignuća koja, nažalost, još uvijek nije dovoljno istražena. Najveći razlog tome leži u nedostatku standardiziranih metoda za analizu i dokumentaciju takve složene i osjetljive materije.

Znanstveni doprinos ovog doktorskog rada ostvaren je sustavnom obradom relevantne stručne i znanstvene literature, analizom postojećih modela dokumentacije, anketiranjem domaćih stručnjaka, te na temelju osobnog iskustva, s ciljem razvoja inovativnog oblika digitalne dokumentacije povijesnih uzorkovanih tkanina. U okviru rada su potvrđene postavljene hipoteze, a definirani ciljevi ostvareni. Interdisciplinarni karakter istraživanja omogućio je povezivanje teorijskih i primijenjenih znanja te otvara mogućnosti primjene rezultata u različitim područjima znanosti, kulture i kreativnih industrija - osobito u kontekstu muzejske dokumentacije i konzervatorsko-restauratorske prakse.

Razvijena metodologija analize i digitalizacije povijesnih tkanina pokazala se učinkovitom u istraživanju povijesnih damasta. Digitalni model tehnološke dokumentacije omogućuje sustavno bilježenje i primjenu podataka te predstavlja vrijedan doprinos očuvanju i interpretaciji tekstilne baštine. Provedene analize, razvoj modela digitalne tehnološke dokumentacije i njegova praktična primjena pokazuju učinkovitost integriranog tehnološkog i digitalnog pristupa. Standardizirani digitalni obrazac omogućuje ponovljivost i usporedivost rezultata, što predstavlja važan korak prema sustavnom istraživanju povijesnih uzorkovanih tkanina. Daljnji razvoj sustava može uključivati proširenje baze podataka i integraciju s međunarodnim digitalnim platformama.

Zahvala

Iskrene zahvale upućujem svojim mentorima na stručnom vodstvu, savjetima i kontinuiranoj podršci tijekom izrade doktorskog istraživanja. Zahvaljujem se također institucijama i stručnjacima koji su ljubazno omogućili pristup povijesnim tekstilnim zbirkama i time doprinijeli realizaciji ovoga rada.

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**Mislav MAJDAK****Životopis**

Mislav Majdak je rođen 4.6.1995. godine u Zagrebu. 2020. godine završava diplomski sveučilišni studij Tekstilna tehnologija i inženjerstvo smjer Tekstilna kemija, materijali i ekologija na Sveučilištu u Zagrebu, Tekstilno-tehnološkom fakultetu. 2021. godine upisuje poslijediplomski sveučilišni studij Tekstilna znanost i tehnologija na Sveučilištu u Zagrebu, Tekstilno-tehnološkom fakultetu. Iste godine zapošljava se na projektu Antibakterijska prevlaka za biorazgradive medicinske materijale, pod vodstvom prof. dr. dr. sc. Ive Rezić. 22.2.2023. uspješno je obranio temu doktorskog rada Antimikrobne prevlake s nanočesticama za biorazgradljive polimere i tekstilne materijale. 12.9.2025. uspješno je obranio doktorski rad.

Naslov teme doktorskog rada

Antimikrobne prevlake s nanočesticama za biorazgradljive polimere i tekstilne materijale

Mentorica

Prof. dr. sc. Iva Rezić Meštrović

Datum obrane doktorskog rada

12. rujna 2025.

ANTIMIKROBNE PREVLAKE S NANOČESTICAMA ZA BIORAZGRADLJIVE POLIMERE I TEKSTILNE MATERIJALE

Mislav MAJDAK

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, Zagreb, mislav.majdak@ttf.unizg.hr

Sažetak: U sklopu ovog doktorskog rada razvijane su nove i napredne antimikrobne formulacije primjenom inovativnih tehnologija. S daljnjom obradom konvencionalnih tekstilnih medicinskih materijala, poput zavoja i gaza, ali i netekstilnih materijala poput plastičnih medicinskih pomagala sa spomenutim formulacijama, omogućuje se izrada funkcionalnih antimikrobnih medicinskih materijala. Rezultati su pokazali da antimikrobne prevlake inkapsuliranih nanočestica srebra učinkovito suzbijaju štetne mikroorganizme.

1. Uvod

Nepravilna i učestala primjena lijekova dovela je do porasta broja sojeva bakterija otpornih na antibiotike, kao i gljivica otpornih na antifungalne lijekove, što predstavlja značajan teret za zdravstvene sustave diljem svijeta. Predviđa se da će do 2050. godine broj smrtnih slučajeva uzrokovanih otpornim bakterijama nadmašiti broj smrtnih slučajeva uzrokovanih AIDS-om i tuberkulozom, dok je trenutačni broj smrtnih slučajeva uzrokovan otpornim gljivicama usporediv s brojem smrtnih slučajeva uzrokovanih tuberkulozom [1]. U svrhu učinkovitog suzbijanja rastuće prijetnje mikroorganizama, osobito bakterija i gljivica, znanstvena zajednica usmjerila je značajne napore na razvoj izrađenih od tekstilnih materijala i biorazgradljivih polimera funkcionaliziranih nanočesticama metala i metalnih oksida, poput srebra (Ag), cinkovog oksida (ZnO), titanijevog dioksida (TiO₂), magnetita (Fe₃O₄) i bakra (Cu) [2].

Nanočestica metala i metalnih oksida, osobito srebro, imaju odlična antimikrobna svojstva, zahvaljujući izrazito malim dimenzijama, velikom omjeru slobodne površine u odnosu na volumen, te specifičnoj morfologiji čestica s oštrim bridovima [3]. Štoviše, tekstilni medicinski materijali s antimikrobnim formulacijama na bazi srebra (nanočestice ili srebrov nitrat) već se neko vrijeme koriste za liječenje kroničnih rana i suzbijanje štetnih mikroorganizama [4, 5]. Kako bi se postiglo kontrolirano, ciljano i postepeno otpuštanje antimikrobnih nanočestica, neophodna je upotreba specifičnih metoda poput inkapsulacije [6]. Inkapsulacijom primjenom ionskog geliranja i polielektrolitske kompleksacije omogućena je izrada mikrokapsula čija struktura ovojnice omogućuje poboljšanu kontrolu otpuštanja [7, 8]. Za uspješni razvoj antimikrobnih medicinskih materijala potrebna je detaljna karakterizacija antimikrobnih prevlaka primjenom ultraljubičaste i vidljive spektroskopije (UV-VIS) i pretražnog elektronskog mikroskopa s disperzivnom rendgenskom spektroskopijom (SEM-EDS), kao i biološkog testova antimikrobnog učinka. Primjenom spomenutih metoda potvrđuje se uspješnost funkcionalizacije, kao i učinkovitost suzbijanja mikroorganizama [9, 10].

2. Eksperimentalni dio

Nanočestice Ag te srebrov nitrat (Gram-mol) su bili inkapsulirani primjenom ionskog geliranja i polielektrolitske kompleksacije s Büchi B-390 inkapsulatora (BÜCHI Labortechnik AG) uz primjenu Natrijeva alginata (Sigma-Aldrich), cinkovog sulfata heptahidrata (Gram-mol) te kitozana (Sigma-Aldrich). Primjenom ionskog geliranja unutar ovojnice nastale kompleksacijom natrijeva alginata i cinkova sulfata heptahidrata, bile su inkapsulirane antimikrobne formulacije. Primjenom polielektrolitske kompleksacije s kitozanom, na površini mikrokapsula nastala je dodatna ovojnica čija je namjena usporavanje otpuštanja. Mikrokapsule su bile karakterizirane primjenom SEM-EDS-a SEM TESCAN VEGA TS5136LS SEM-EDS (Tescan Vega Co.). Otpuštanje sadržaja mikrokapsula je praćeno primjenom UV-VIS spektroskopije s Lambda 20 (Perkin Elmer). U okviru istraživanja doktorskog rada, za uspješno suzbijanje Meticilin-rezistentnog *Staphylococcus aureus*-a (MFBF 10679) i Meticilin-osjetljivog *Staphylococcus aureus*-a (ATCC 29213) sojeva, korištene su nanočestice metala i metalnih oksida različitih dimenzija navedene u tablici 1.

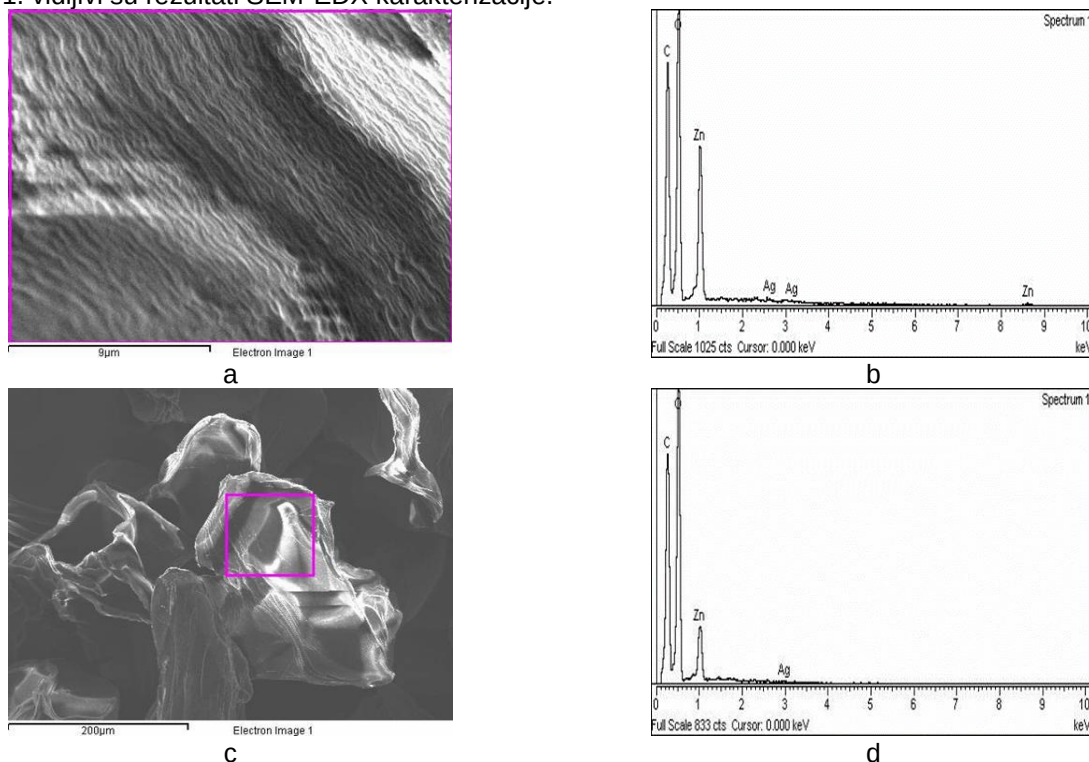
Tablica 1: Korištene nanočestice metala i metalnih oksida

Nanočestice	Veličina [nm]	Nanočestice	Veličina [nm]	Proizvođač
Srebro (Ag)	10; 40	Cirkonijev dioksid (ZrO ₂)	100	Sigma-Aldrich
Titanijev dioksid (TiO ₂)	100	Platina (Pt)	4	
Cink oksid (ZnO)	40; 100	Itrijev(III) oksid (Y ₂ O ₃)	100	

Ispitivanje antimikrobnog učinka antimikrobnih nanočestica je provedeno primjenom metode bujon dilucije, metode koja daje uvid u interakciju mikroorganizama s antimikrobnim formulacijama u realnijim uvjetima upotrebe. U svrhu ispitivanja, uz nanočestice navedene u tablici 1., korišten je Gentamicin sulfat (Sigma Aldrich) kao pozitivna kontrola.

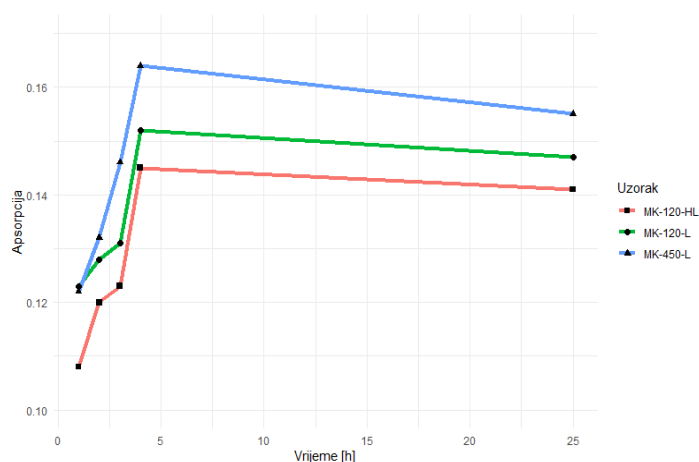
3. Rezultati i rasprava

Na slici 1. vidljivi su rezultati SEM-EDX karakterizacije.



Slika 1: Rezultati SEM-EDX analize: a) mikrokapsula bez ovojnice od kitozana, b) EDX spektar mikrokapsule bez ovojnice kitozana, c) mikrokapsula s ovojnicom od kitozana, d) EDX spektar mikrokapsule s ovojnicom od kitozana

Iz dobivenih rezultata je vidljivo da mikrokapsule, nakon liofilizacije u svrhu analize nemaju narušenu strukturu, odnosno mikrokapsule su pogodne za dugoročno očuvanje antimikrobnih formulacija. Primjenom EDX karakterizacije je vidljivo prisustvo srebra u jezgri mikrokapsula, što je dokaz učinkovitosti inkapsulacije. Nadalje, rezultati praćenja otpuštanja sadržaja mikrokapsula su prikazani na slici 2.



Slika 2: Krivulje otpuštanja srebra za liofilizirane uzorke s i bez kitozana dobiveni primjenom mlaznica od 120 i 450 μm

Praćenjem otpuštanja iona srebra iz mikrokapsula u vodi, u vremenu od 25 sati, kao što je vidljivo na slici 3, moguće je ustanoviti da unutar prvih pet sati mjerenja dolazi do naglog porasta otpuštanja. Nakon tog perioda, uslijedio je period sa usporenijim meta stabilnim tokom otpuštanja. Ujedno, na slici 3 je jasno vidljivo da primjenom dodatne ovojnice od kitozana, izmjerene koncentracije srebra u vodi su manje od izmjerenih koncentracija srebra kod uzoraka bez ovojnice od kitozana, što je od velike važnosti za postizanje visoke učinkovitosti tijekom realne primjene.

U završnom koraku, ispitivana je antimikrobna učinkovitost ispitivanih nanočestica prema modelnim organizmima. Rezultati ispitivanja su navedeni u tablicama 2 i 3.

Tablica 2. Rezultati ispitivanja antimikrobne učinkovitosti nanočestica metala i metalnih oksida prema modelnim organizmima *S. aureus* ATCC 29213 (MSSA) metodom bujon dilucije

Nanočestice	Minimalna inhibicijska koncentracija [$\mu\text{g}/\text{cm}^3$]	Minimalna baktericidna koncentracija [$\mu\text{g}/\text{cm}^3$]
Pt (4 nm)	$0,06 \pm 0,04$	$0,20 \pm 0,17$
Ag (10 nm)	$0,09 \pm 0,07$	$0,31 \pm 0,27$
Ag (40 nm)	$0,02 \pm 0,02$	$1,04 \pm 1,26$
ZnO (100 nm)	$0,03 \pm 0,00$	$0,14 \pm 0,06$
TiO ₂ (100 nm)	$40,28 \pm 0,00$	$80,57 \pm 0,0$
Y ₂ O ₃ (100 nm)	$<12,21$	$12,21 \pm 0,00$
ZrO ₂ (100 nm)	$<0,06$	$>12,500,00$
Gentamicin sulfat		$0,63 \pm 0,00$

Tablica 3. Rezultati ispitivanja antimikrobne učinkovitosti nanočestica metala i metalnih oksida prema modelnim organizmima *S. aureus* MFBF 10679 (MRSA) metodom bujon dilucije

Nanočestice	Minimalna inhibicijska koncentracija [$\mu\text{g}/\text{cm}^3$]	Minimalna baktericidna koncentracija [$\mu\text{g}/\text{cm}^3$]
Ag (10 nm)	$0,47 \pm 0,27$	$2,50 \pm 0,00$
ZnO (100 nm)	$3,28 \pm 0,55$	$3,28 \pm 0,00$
TiO ₂ (100 nm)	$20,14 \pm 0,00$	$93,00 \pm 61,53$
Gentamicin sulfat		$1,00 \pm 0,40$

Dobiveni rezultati pokazuju da su nanočestice metala i metalnih oksida izvrsna antimikrobna sredstva, pri čemu su nanočestice Ag pokazale najbolji antimikrobni učinak. Štoviše, iz dobivenih rezultata vidljivo je da osim ovisno o sirovinskom sastavu, antimikrobni učinak nanočestica uvelike ovisi i o dimenzijama, odnosno, manje nanočestice imaju veću inhibicijsku i baktericidnu učinkovitost u odnosu na veće nanočestice.

4. Zaključak

Porast otpornih mikroorganizama je danas globalni problem koji zahtjeva inovativna rješenja. Stoga je neophodno razvijati i istraživati nove i napredne antimikrobne formulacije primjenom inovativnih tehnologija. U sklopu ovog doktorskog rada razvijane su takve formulacije. S daljnjom obradom konvencionalnih tekstilnih medicinskih materijala, poput zavoja i gaza, ali i netekstilnih materijala poput plastičnih medicinskih pomagala sa spomenutim formulacijama, omogućuje se izrada funkcionalnih antimikrobnih medicinskih materijala, ali se isto tako otvara mogućnost širenja primjene za izradu specijalne zaštitne odjeće i ambalaže za hranu.

Zahvala



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**Maja MAHNIĆ NAGLIĆ****Životopis**

Rođena 1984. u Slavonskom Brodu. Na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu, završila je preddiplomski studij Tekstilna tehnologija i inženjerstvo smjer Odjevno inženjerstvo, diplomski studij smjer Industrijski dizajn odjeće te sveučilišni poslijediplomski doktorski studij Tekstilna znanost i tehnologija. Od 2015. je zaposlena u Zavodu za odjevnju tehnologiju, na grupaciji kolegija iz područja računalne konstrukcije, 2D/3D projektiranja odjeće, CAD/CAM sustava u odjevnom inženjerstvu i Digitalne kostimografije. Do sada je kao koautor objavila 11 znanstvenih radova u časopisima indeksiranim u WoS i Scopus bazama, 3 znanstvena rada u drugim časopisima, 1 pregledni rad, 3 poglavlja u znanstvenim knjigama te 21 znanstveni rad u zbornicima radova s međunarodnih i domaćih skupova.

Naslov teme doktorskog rada

Dinamičko ponašanje odjeće pod utjecajem biomehanike tijela

Mentorica

Prof. dr. sc. Slavenka Petrak

Datum obrane doktorskog rada

28. svibnja 2024.

DINAMIČKO PONAŠANJE ODJEĆE POD UTJECAJEM BIOMEHANIKE TIJELA

Maja MAHNIĆ NAGLIĆ

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, Zagreb maja.mahnic@tff.unizg.hr

Sažetak: U okviru doktorskog rada provedeno je istraživanje u području računalnog 2D/3D projektiranja odjeće, pri čemu je postavljena nova metodologija za analizu pristalosti i dinamičkog ponašanja odjeće pod utjecajem biomehanike tijela. Istraživanje integrira antropometrijsku analizu ženskog tijela, algoritamsku klasifikaciju tipova oblika i držanja te analizu deformacija tijela u pokretu primjenom optičkog 3D mjernog sustava Aramis, po prvi puta primijenjenog u području dinamičke antropometrije. Na temelju dobivenih rezultata razvijeni su parametarski krojevi s 50 izvorno definiranih matematičkih izraza za automatsku prilagodbu individualnim antropometrijskim karakteristikama i funkcionalnim dodacima, temeljeni na vrijednostima deformacija površine tijela u pokretu. Povezivanjem 3D skeniranja i parametarskog SMPL (Skinned Multi-Person Linear Model) modela tijela razvijeni su animirani 3D avatari za simulaciju odjeće na tijelu u zadanim pokretima, čime je omogućena analiza dinamičke pristalosti i vrednovanje u odnosu na primjenjene parametre mehaničkih svojstava tekstilnih materijala. Postavljena metodologija razvoja i analize dinamičke pristalosti digitalnih 3D prototipova, verificirana je komparativnom analizom sa realno izrađenim prototipovima, pri čemu je primjenom optičkog 3D mjernog sustava za dinamičku analizu deformacija Aramis, po prvi puta analizirana dinamička pristalost realnih prototipova odjeće.

1. Uvod

Ljudsko tijelo, odnosno njegov oblik i kinematika kretanja, temelj su istraživanja u području dizajna i razvoja novih modela odjevnih predmeta [1]. Različiti mjerni sustavi za analizu ljudskog tijela, poput 3D i 4D skenera, omogućuju detaljnu analizu antropometrijskih i kinematičkih karakteristika tijela te primjenu njihovih parametara u procesu konstrukcije krojeva i razvoja računalnih 3D prototipova odjeće [2]. Pristalost odjeće tijelu u dinamičkim uvjetima jedna je od najatraktivnijih tema u području odjevnog tehnologije posljednjih godina. Dinamička pristalost direktno utječe na funkcionalnost odjevnog predmeta, kao jednog od najvažnijih elemenata u procesu projektiranja odjeće. Ljudsko tijelo u pokretu mijenja se u smislu promjena dimenzija na površini pri čemu se mijenjaju i tjelesne mjere, što zahtjeva dodatnu prilagodbu na korespondentnim dijelovima odjevnog predmeta [1-3]. Računalna analiza pristalosti odjevnog predmeta u statičkim ili dinamičkim uvjetima temelji se na fizikalnoj simulaciji i razvoju 3D prototipova, na kojima se analiziraju deformacije geometrije površine modela odjevnog predmeta u kontaktu s 3D modelom tijela, određene parametrima fizikalnih i mehaničkih svojstava ciljanog tekstilnog materijala. U tom smislu, postavljene su hipoteze doktorskog rada:

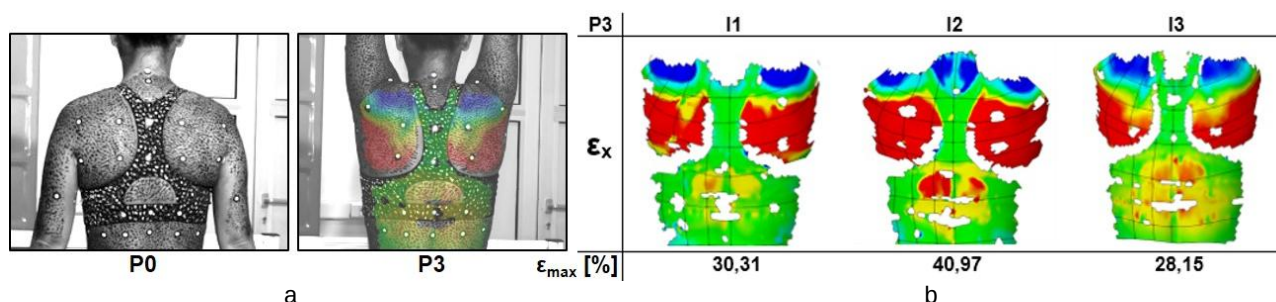
H1: Deformacije površine tijela u pokretu ovise o razvijenosti i obliku tijela te se razvojem i primjenom matematičkih modela za prilagodbu kinematičkih točaka na tijelu i deformaciju segmenata površine, ovisno o pojedinom tipu tijela, može ostvariti realistična animacija skeniranog modela tijela, primjenjiva za računalnu 3D simulaciju odjeće u dinamičkim uvjetima.

H2: Matematičkim modeliranjem mehaničkog ponašanja tkanine pri simulaciji odjevnog predmeta temeljem vrijednosti određenih mehaničkih svojstava, ostvarit će se deformabilnost površine odjevnog predmeta u korelaciji s deformabilnošću tipa tijela u zadanom pokretu.

H3: Na temelju analize deformacija geometrije računalnog modela odjevnog predmeta u interakciji s modelom tijela u pokretu, može se vjerodostojno vrednovati naprezanje odjevnog predmeta u dinamičkim uvjetima.

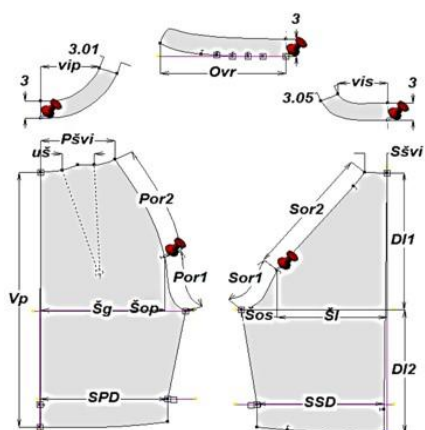
2. Eksperimentalni dio

Na temelju postavljenih hipoteza, definirana je metodologija doktorskog istraživanja podijeljena u sedam sustavno povezanih cjelina. Prva cjelina obuhvaća antropometrijsku analizu ženskog tijela primjenom 3D skenera te razvoj algoritma za klasifikaciju tipova oblika i držanja tijela na temelju skeniranih 3D modela. Druga cjelina obuhvaća istraživanje i analizu karakteristika dinamičke antropometrije, pri čemu je po prvi puta definirana metodologija za primjenu optičkog 3D mjernog sustava za dinamičku analizu deformacija Aramis [4], u području dinamičke antropometrije. Ispitivanje je provedeno na tri ispitanice, predstavnice različitih tipova tijela, u pet pokreta definiranih kinematičkim lancima koji opisuju dovođenje tijela iz uspravnog stojećeg u pet karakterističnih položaja tijela, relevantnih za analizu pristalosti odjeće. Analizirane su deformacije u transverzalnom (x/potka) i longitudinalnom (y/osnova) smjeru te su utvrđene zone najvećih deformacija u pojedinom pokretu, sl. 1.



Slika 1: Analiza deformacija površine tijela: a) prikaz snimljenih podataka ispitanice I3 u početnom položaju P0 i krajnjem položaju P3, b) utvrđene vrijednosti maksimalne deformacije površine tijela u položaju P3 za sve tri ispitanice (I1, I2, I3)

Treća cjelina istraživanja obuhvaća razvoj animiranih 3D avatara prilagođenih prema tri odabrane ispitanice različitih tipova oblika tijela. U programu Autodesk Maya2022 postavljena je metoda prilagodbe univerzalnog SMPL modela tijela kao predložka [5], prema ciljanim antropometrijskim i kinematičkim karakteristikama utvrđenim 3D skeniranjem, temeljena na skript datotekama razvijenim u programu Python v.2. Četvrta cjelina istraživanja obuhvaća analizu fizikalnih i mehaničkih svojstava dva tekstilna materijala, odabrana za izradu modela ženskih odjevnih predmeta, primjenom četiri metode ispitivanja: sustavom Kawabata Evaluation System KES-FB [6], ispitivanjem prekidne sile i prekidnog istezanja metodom trake prema HRN EN ISO 13934-1:2013, prilagođenom metodom prema parametrima Fabric Kit mjernog sustava [6] i digitalizacijom tekstilnih materijala pomoću SEDDI Textura UI aplikacije [7]. U okviru pete cjeline, primjenom programa Modulate v.15.1 CAD sustava Optitex, razvijeni su parametarski krojevi za pet modela odjevnih predmeta: temeljnog modela bluze i hlaća, radnog kombinezona, uskog trikoa te radnog kombinezona dizajniranog kako bi zadovoljio kriterije funkcionalnosti s aspekta dinamičke antropometrije. Na temelju rezultata antropometrijske analize tipova tijela i dinamičkih deformacija površine tijela u pokretu, razvijeno je 50 matematičkih izraza koji omogućuju automatsku prilagodbu krojeva, uzimajući u obzir prilagodbu vrijednosti udjela pojedinog segmenta u ukupnoj tjelesnoj mjeri ovisno o tipu tijela te funkcionalni dodatak koji prilagođava dimenzije ciljanih segmenata i osigurava dodatnu komociju na utvrđenim zonama maksimalne deformacije površine tijela u pokretu, sl. 2. Šesta cjelina istraživanja obuhvaća razvoj računalnih 3D prototipova modela odjevnih predmeta i ispitivanje pristalosti na tijelu u pokretu, za što je korišten program CLO. Kao ulazni podaci za izvođenje 3D simulacija korišteni su prilagođeni parametarski krojevi modela odjevnih predmeta i animirani 3D avatari prilagođeni za tri odabrane ispitanice različitih tipova oblika tijela. Istražene su mogućnosti definiranja parametara mehaničkih svojstava primjenom vrijednosti utvrđenih ispitivanjem realnih uzoraka tkanina različitim metodama vrednovanja, na temelju čega su definirane i referentne vrijednosti za vrednovanje dinamičke pristalosti digitalnih 3D prototipova. Simulacijom modela odjevnih predmeta na animiranim avatarima, analizirano je istezanje simuliranih tekstilnih materijala, u smjeru potke (x smjer) i/ili osnove (y smjer), ovisno o položaju tijela i zoni odjevnog predmeta. Mape istezanja i deformacije površina praćene su tijekom cijelog izvođenja pokreta te su kao rezultat izdvojene vrijednosti očitane u krajnjim karakterističnim položajima. Sa svrhom verifikacije rezultata analize pristalosti digitalnih 3D prototipova u dinamičkim uvjetima i cjelokupne postavljene metode u okviru istraživanja, izrađeni su realni prototipovi na kojima je provedeno snimanje primjenom sustava Aramis u zadanim pokretima. Snimljeni podaci su obrađeni i analizirani analogno metodi analize deformacija tijela u pokretu te su na temelju utvrđenih rezultata analizirani i vrednovani rezultati analize pristalosti razvijenih digitalnih 3D prototipova.



a

$$Og_{kroj} = 2[(0,203 \cdot Og_{tijela} + 0,25 \cdot D_{komocija}) + (0,042 \cdot Og_{tijela}) + (0,083 \cdot Og_{tijela}) + (0,086 \cdot Og_{tijela} \cdot fd + 0,125 \cdot D_{komocija}) + (0,086 \cdot Og_{tijela} + 0,125 \cdot D_{komocija})]$$

$$Og_{kroj} = 2[0,203 \cdot 90,3 + 1,5) + (0,042 \cdot 90,3) + (0,083 \cdot 90,3) + (0,086 \cdot 90,3 \cdot 1,345 + 0,75) + (0,086 \cdot 90,3 + 0,75)] = 2(19,84 + 3,79 + 7,49 + 11,20 + 8,52) = 101,68 \text{ cm} \Rightarrow 11,38 \text{ cm ukupne komocije}$$

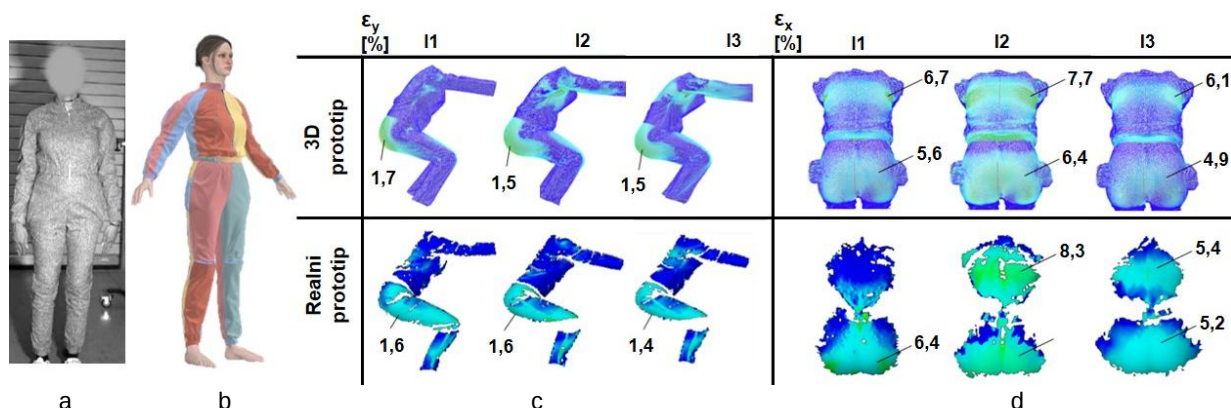
b

Legenda: Šg – širina grudi, Šop – širina orukavlja na prednjem dijelu, SPD – struk prednji dio, Vp – visina prednjice, uš – ušitak, Pšvi – prednja širina vratnog izreza, Por1/Por2 – duljina krivulje orukavlja na prednjem dijelu, Šl – širina leđa, Šos – širina orukavlja na stražnjem dijelu, SSD – struk stražnji dio, DI1/DI2 – duljina leđa, Sor1/Sor2 – duljina krivulje orukavlja na stražnjem dijelu, Sšvi – stražnja širina vratnog izreza, Ovr – duljina ovratnika

Slika 2: Razvoj parametarskog kroja: a) parametarski kraj gornjeg dijela radnog kombinezona dizajniranog s aspekta dinamičke antropometrije, b) razvijeni matematički izraz za prilagodbu opsega grudi i primjer izračuna vrijednosti za ispitanicu I1

3. Rezultati i rasprava

Postavljena metodologija snimanja i analize deformacija geometrije površine tijela u pokretu, primjenom optičkog 3D mjernog sustava Aramis, omogućila je praćenje deformacija površine tijela tijekom cijelog izvođenja pokreta i analizu promjena dimenzija po zonama i segmentima površine, što predstavlja puno cjelovitiji pristup istraživanju u odnosu na analizu promjena linearnih segmenata tjelesnih mjera na skeniranim modelima tijela u karakterističnim položajima. Utvrđeni su podaci značajni za konstrukciju i projektiranje odjeće, na temelju kojih je razvijena metoda parametризacije krojeva modela odjevnih predmeta. Rezultati su pokazali da postavljeni matematički izrazi za prilagodbu dimenzija segmenata kroja prema karakteristikama tri različita tipa tijela u dinamičkim uvjetima, omogućuju puno kompleksniju i cjelovitiju prilagodbu s aspekta pristalosti i funkcionalnosti odjevnog predmeta. Rezultati razvoja animiranih avatara i metode za prilagodbu unutarnjeg kinematičkog kostura preko skript datoteka, omogućeno je direktno povezivanje sustava za 3D skeniranje i procesa animacije, što značajno ubrzava dugotrajan i kompleksan proces razvoja animiranih modela prema ciljanim antropometrijskim karakteristikama. Izvođenjem 3D simulacija na animiranim avatarima, omogućena je analiza deformacija računalnih 3D prototipova u dinamičkim uvjetima. Predloženi pristup vrednovanju digitalnih 3D prototipova preko definiranih parametara mehaničkih svojstava ciljanih materijala, predstavlja iskorak u području računalnog 3D projektiranja odjeće, obzirom da u dosadašnjim istraživanjima nije zabilježena egzaktno definirana metodologija vrednovanja pristalosti, nego se vrednovanje uglavnom svodi na subjektivnu procjenu od strane stručnjaka. Rezultati analize pristalosti potvrđuju dobru prilagodbu krojeva razvijenom metodom parametризacije i definiranim matematičkim izrazima koji u obzir uzimaju dodatni iznos komocije s aspekta prilagodbe prema dinamičkim deformacijama tijela u pokretu. Rezultati analize dinamičke pristalosti realnih prototipova modela odjevnih predmeta, primjenom optičkog 3D mjernog sustava Aramis, omogućili su verifikaciju rezultata razvoja i analize pristalosti digitalnih 3D prototipova preko objektivno mjerljivih pokazatelja. Utvrđene razlike u vrijednostima deformacijama između digitalnih i realnih prototipova od 0,4 do 3%, ovisno o modelu i promatranoj zoni deformacije odjevnog predmeta, ukazuju na visoku razinu mogućnosti predviđanja ponašanja odjevnih predmeta u dinamičkim uvjetima na temelju digitalnih prototipova razvijenih primjenom postavljene metode, što predstavlja značajan doprinos u području odjevnih tehnologija i razvoja odjeće s visokim funkcionalnim zahtjevima, sl. 3.



Slika 3: Rezultati analize dinamičke pristalosti digitalnih i realnih prototipova funkcionalnog radnog kombinezona u položaju čučnja (P5): a) realni prototip – ispitanica I1, b) digitalni 3D prototip – ispitanica I1, c) utvrđene vrijednosti maksimalnih longitudinalnih deformacija površine - smjer osnove (ϵ_y) za tri ispitanice I1, I2 i I3, d) utvrđene vrijednosti maksimalnih transverzalnih deformacija površine - smjer potke (ϵ_x) za tri ispitanice I1, I2 i I3

4. Zaključci

Analizom kinematičkih parametara skeniranih 3D modela tijela u programu Anthroscan, utvrđeni su podaci o hijerarhijskoj strukturi i koordinatama točaka zglobova, koji se mogu primjeniti u procesu prilagodbe unutarnjeg kinematičkog modela kostura prema obliku i dimenzijama površinskog modela. Razvijenom metodom automatske prilagodbe pozicija zglobova unutarnjeg kinematičkog kostura, prema skeniranom 3D modelu tijela preko skript datoteka, potvrđena je postavljena hipoteza H1. Na digitalnim 3D prototipovima odjevnih predmeta, razvijenim prema metodi postavljenoj u doktorskom radu, prilikom simulacije na 3D avatarima prilagođenim karakteristikama ispitanica različitih tipova tijela, utvrđene su razlike u vrijednostima zona najvećih deformacija, kao i obliku segmenata površine odjevnih predmeta zahvaćenih deformacijom, čime je dodatno potvrđena postavljena hipoteza H1. 3D simulacijama modela odjevnih predmeta, na temelju definiranih parametara svojstava, utvrđenih ispitivanjem na realnim uzorcima ciljanih tekstilnih materijala, ostvarene su realistične deformacije površina digitalnih 3D prototipova, u odnosu na dimenzije i deformacije 3D modela tijela različitih tipova u dinamičkim uvjetima, čime je potvrđena postavljena hipoteza H2. Analizom digitalnih 3D prototipova utvrđeni su vrlo dobri rezultati i zadovoljavajuća razina realističnosti ostvarenih deformacija površina 3D prototipova u odnosu na rezultate ispitivanja realnih prototipova modela, čime je potvrđena postavljena hipoteza H3, kao i primjenjivost postavljene metode za razvoj i analizu digitalnih 3D prototipova u dinamičkim uvjetima, razvijene u okviru dokorskog istraživanja.

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**Paula Štampalija****Životopis**

Paula Štampalija (rođ. Marasović), rođena 24. listopada 1994. u Šibeniku, završila je diplomski studij Tekstilne tehnologije i inženjerstva na smjeru Projektiranje i menadžment tekstila te doktorski studij Tekstilne znanosti i tehnologije na Sveučilištu u Zagrebu. Tijekom studija bila je demonstratorica na kolegijima Netkani i tehnički tekstili i Predenje. Od 2018. do 2019. radila je kao planerica proizvodnje u tvrtki Kelteks d.o.o. Od 2021. godine doktorandica je na projektu „Razvoj biorazgradivih netkanih agrotexila iz prirodnih i obnovljivih izvora“, a od 2024. zaposlena je kao asistentica na Tekstilno-tehnološkom fakultetu, Zavodu za dizajn i menadžment tekstila. U sklopu ERASMUS+ stručne prakse 2023. godine boravila je tri mjeseca na Tehničkom sveučilištu u Łódžu. Objavila je 11 znanstvenih radova u časopisima indeksiranim u bazama WoS i Scopus te je na međunarodnim znanstvenim konferencijama izložila 16 znanstvenih radova. Dobitnica je nagrade Mladi istraživač za znanstvenu izvrsnost u akademskoj godini 2023./2024.

Naslov teme doktorskog rada

Razvoj netkanog agrotexila iz prirodnih i obnovljivih izvora za primjenu u malčiranju

Studijski savjetnik

Prof. dr. sc. Dragana kopitar

Datum obrane doktorskog rada

2. lipnja 2025.

RAZVOJ NETKANOG AGROTEXTILA IZ PRIRODNIH I OBNOVLJIVIH IZVORA ZA PRIMJENU U MALČIRANJU

Paula ŠTAMPALIJA

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, Zagreb, paula.stampalija@tff.unizg.hr

Sažetak: U doktorskoj disertaciji istražio se razvoj biorazgradivih netkanih malčeva izrađenih od vlakana iz prirodnih i obnovljivih izvora kao održive alternative konvencionalnim polietilenskim (PE) agrofolijama. Provedena su dva terenska eksperimenta radi istraživanja mehanizma biorazgradnje netkanih malčeva, njihove učinkovitosti u suzbijanju korova i utjecaja na kvalitetu tla te utjecaj malčeva na rast, prinos i sastav salate. Netkani malčevi proizvedeni od vlakana viskoze (CV), jute, konoplje, polilaktične kiseline (PLA) i njihovih mješavina na grebenalji učvršćenim procesom iglanja. Netkani malčevi izloženi poljskim uvjetima pokazali su značajne strukturne promjene i kontroliranu biorazgradnju potvrđenu SEM, FTIR i WAXD analizama. U usporedbi s PE agrofolijom i nemalčiranim tlom, biorazgradivi malčevi poboljšano su regulirali temperaturu i vlagu tla, povećali sadržaj organskog ugljika te potaknuli mikrobiološku aktivnost tla. Malčevi proizvedeni od PLA vlakana te malčevi od mješavina celuloznih i PLA vlakana učinkovito su suzbijali rast korova tijekom duljeg razdoblja izloženosti. Dobiveni rezultati potvrđuju da biorazgradivi netkani malčevi mogu uspješno zamijeniti agrofolije iz fosilnih izvora te pridonijeti poboljšanoj kvaliteti tla i većem prinosu salate, a u skladu s načelima održive poljoprivrede.

1. Uvod

Opsežna uporaba malčeva iz fosilnih izvora, posebice polietilenskih (PE) folija za malčiranje, dovela je do ozbiljnih ekoloških problema povezanih s akumulacijom otpada, onečišćenjem tla i nastankom mikroplastike [1–3]. Malčiranje je ključna poljoprivredna praksa koja se koristi za suzbijanje korova, regulaciju temperature i vlage tla, povećanje prinosa i smanjenje potrebe za kemijskim herbicidima [2,4]. Međutim, konvencionalni plastični malčevi nisu biorazgradivi, a njihovo uklanjanje, recikliranje i zbrinjavanje predstavljaju složene i ekonomski nepovoljne procese [5,6].

Nedavna istraživanja potvrđuju da konvencionalni plastični malčevi značajno doprinose poljoprivrednom plastičnom otpadu i onečišćenju tla mikroplastikom, negativno utječu na strukturu tla, mikrobiološku aktivnost i rast biljaka [5–7]. U skladu s načelima održive poljoprivrede i kružnog gospodarstva, sve se veća pozornost posvećuje biorazgradivim alternativama proizvedenima iz prirodnih i obnovljivih izvora [8–10].

Netkani agrotekstili izrađeni od celuloznih vlakana i biopolimera predstavljaju obećavajuće rješenje zbog svoje biorazgradivosti, kompatibilnosti s tlom i povoljnim fizikalnim svojstvima. Međutim, dugoročna terenska istraživanja njihove biorazgradnje, učinkovitosti suzbijanja korova te utjecaja na kvalitetu tla i prinos usjeva još su uvijek ograničena, osobito kada je riječ o netkanim malčevima proizvedenim mehaničkim postupkom na grebenalji učvršćenim iglanjem.

U doktorskoj disertaciji prikazani su rezultati evaluacije netkanih malčeva proizvedenih od prirodnih i obnovljivih vlakana kao održive alternative konvencionalnoj PE agrofoliji, s posebnim naglaskom na njihovo ponašanje u stvarnim uvjetima na polju.

2. Eksperimentalni dio

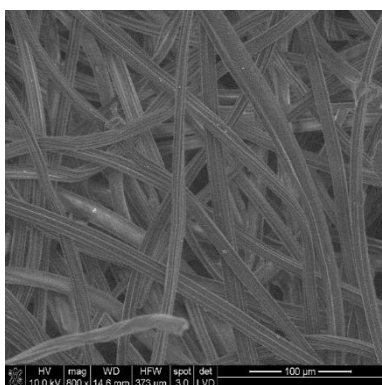
Istraživanje je provedeno kroz dva komplementarna eksperimenta u otvorenim poljskim uvjetima primjenom randomiziranog blok dizajna (RCBD). Netkani malčevi proizvedeni su u tvrtci Renotex d.o.o. mehaničkim postupkom na grebenalji i učvršćeni iglanjem, uz jednake tehnološke parametre radi osiguravanja usporedivosti rezultata. Ispitivani netkani agrotekstili proizvedeni su od vlakana viskoze, jute, konoplje i polilaktične kiseline (PLA) te iz mješavina celuloznih vlakana (CV, juta, konoplja) s PLA vlaknima u omjeru 80:20. Malčevi su proizvedeni u površinskim masama od 200 g m⁻² i 400 g m⁻², ovisno o vrsti vlakna i mogućnosti proizvodnje.

Prvi eksperiment obuhvatio je ispitivanje biorazgradnje, učinkovitosti suzbijanja korova i utjecaja netkanih malčeva na kvalitetu tla tijekom razdoblja izloženosti do 300 i 380 dana. Učinkovitost biorazgradivih malčeva uspoređena je s konvencionalnom PE agrofolijom i ne prekrivenim tlom (kontrolnim poljem). Degradacija i svojstva malčeva praćeni su vizualnom analizom, promjenama dimenzija, površinskom masom (HRN EN ISO 9073-1:2023), debljinom (HRN EN ISO 9073-2:2021), gustoćom, vlačnim svojstvima (HRN EN ISO 9073-

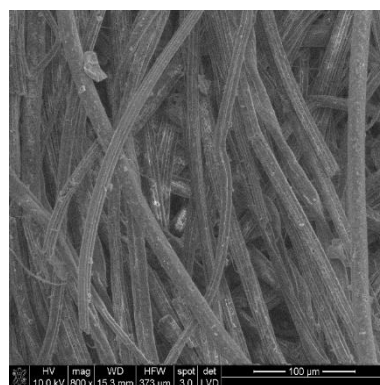
3:2023) i propusnosti zraka (HRN EN ISO 9073-15:2007). Strukturne i molekularne promjene analizirane su SEM, FTIR, WAXD i DSC metodama. Temperatura tla, vlažnost i rast korova kontinuirano su praćeni, a na kraju pokusa provedena je analiza kemijskih svojstava tla i mikrobne aktivnost tla.

3. Rezultati i rasprava

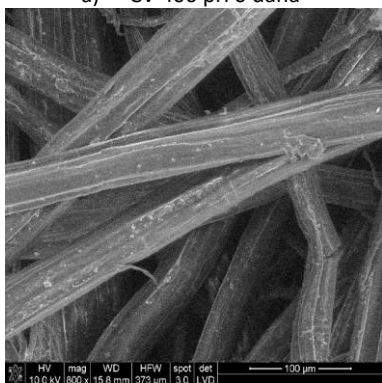
Izloženost poljskim uvjetima uzrokovala je fizikalne, mehaničke i strukturne promjene svih izloženih netkanih malčeva. Malčevi proizvedeni od celuloznih vlakana pokazali su progresivnu razgradnju, očitovanu gubitkom mase, smanjenjem vlačne čvrstoće, povećanjem propusnosti zraka i vidljivim oštećenjima vlakana potvrđenim SEM analizama. FTIR i WAXD analize potvrdile su molekularnu razgradnju celuloznih vlakana kroz smanjenje vodikovih veza, promjene kristaliničnosti i smanjenje stupnja polimerizacije.



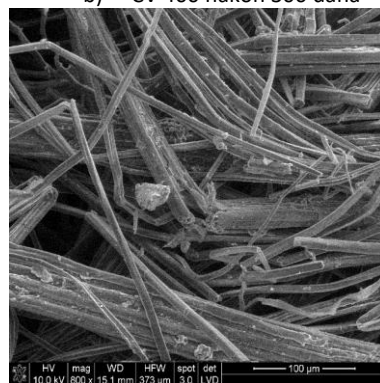
a) CV 400 pri 0 dana



b) CV 400 nakon 300 dana



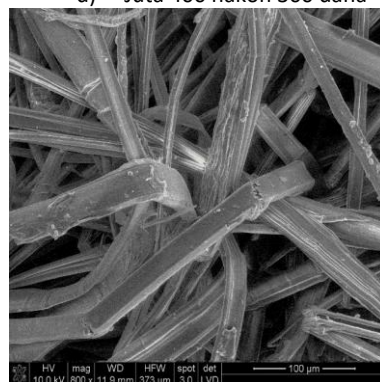
c) Juta 400 pri 0 dana



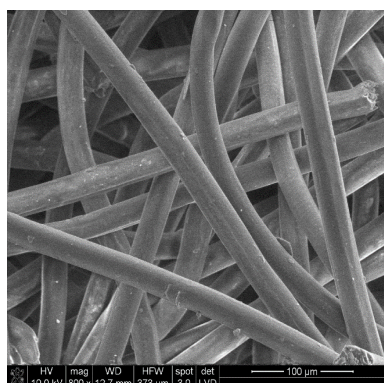
d) Juta 400 nakon 300 dana



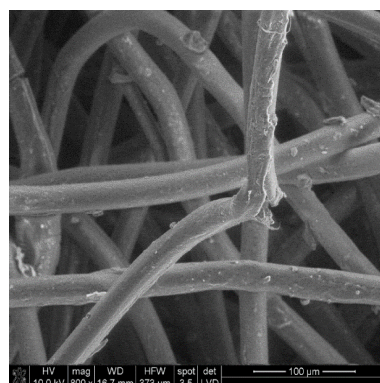
e) Konoplja 400 pri 0 dana



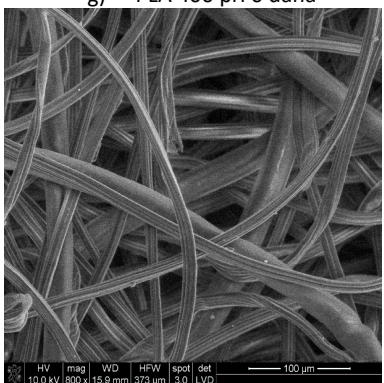
f) Konoplja 400 nakon 300 dana



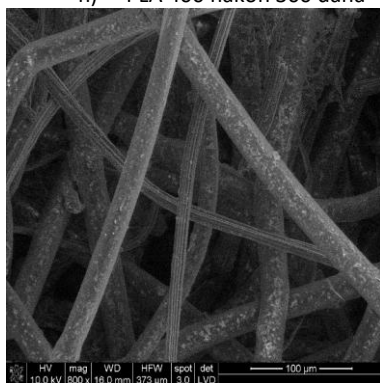
g) PLA 400 pri 0 dana



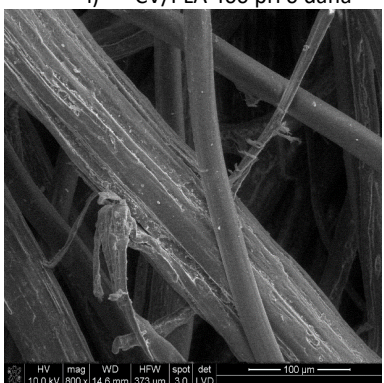
h) PLA 400 nakon 300 dana



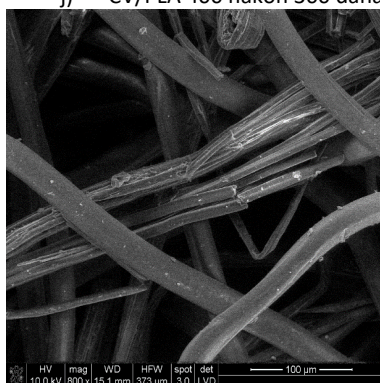
i) CV/PLA 400 pri 0 dana



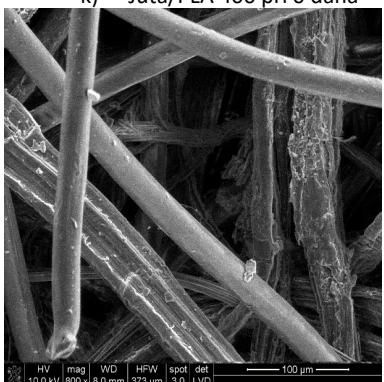
j) CV/PLA 400 nakon 300 dana



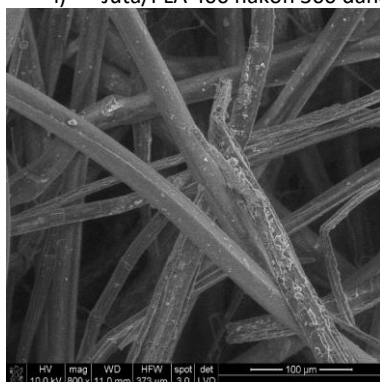
k) Juta/PLA 400 pri 0 dana



l) Juta/PLA 400 nakon 300 dana



m) Konoplja/PLA 400 pri 0 dana



n) Konoplja/PLA 400 nakon 300 dana

Slika 1: SEM slike netkanih malčeva s površinskom masom 400 g m^{-2} pri povećanju od $800\times$

Malčevi proizvedeni iz PLA vlakana pokazali su najveću otpornost na utjecaje okoliša sa sporim stupnjem razgradnje i boljim zadržavanjem mehaničkih svojstava. Netkani agrotekstili proizvedeni iz mješavine

celuloznih i PLA vlakana pokazali su kontroliranu razgradnju i poboljšanu strukturnu stabilnost u usporedbi s netkanim agrotekstilima proizvedenim isključivo iz celuloznih vlakana. Netkani malčevi učinkovito su održavali temperaturu i vlagu tla u usporedbi s nemalčiranim tлом (kontrolno polje) te su često pokazali jednaku ili bolju učinkovitost u usporedbi s PE agrofolijom. Analiza kvalitete tla pokazala je povećan sadržaj ukupnog organskog ugljika i pojačanu mikrobiološku aktivnost tla ispod biorazgradivih malčeva, što ukazuje na pozitivnu interakciju s tлом. Učinkovitost suzbijanja korova potvrđena je kod svih malčeva u ranoj fazi izloženosti, dok su celulozni malčevi postupno gubili učinkovitost zbog strukturne razgradnje, u usporedbi s malčevima od PLA vlakana kao i njihovih mješavina.

U uzgoju salate, biorazgradivi netkani malčevi značajno su poboljšali rast i prinos u odnosu na kontrolno polje. Malčevi proizvedeni od mješavine CV/PLA i juta/PLA vlakana pokazale su bolje rezultate u usporedbi s PE agrofolijom u pogledu biomase, prinosa i hranjivog sastava salate, uz istovremeno poboljšanje pokazatelja kvalitete tla.

4. Zaključak

Istraživanje potvrđuje da netkani malčevi izrađeni od prirodnih i obnovljivih vlakana predstavljaju održivu i funkcionalnu alternativu konvencionalnim PE agrofolijama. Rezultati prvog eksperimenta pokazuju da biorazgradivi netkani malčevi učinkovito suzbijaju korov, razgrađuju se u poljskim uvjetima bez negativnog utjecaja na kvalitetu tla te potiču mikrobiološku aktivnost tla. Drugi eksperiment potvrđuje pozitivan učinak netkanih malčeva na rast, prinos te mikro i makroelemente salate. Malčevi koji sadrže PLA vlakna, osobito u mješavinama s celuloznim vlaknima, pružaju optimalnu ravnotežu između trajnosti tijekom uporabe i biorazgradivosti nakon primjene. Primjena prirodnih malčeva smanjuje plastični otpad u poljoprivredi, eliminira potrebu za uklanjanjem malča i pridonosi zdravlju tla te održivoj poljoprivrednoj proizvodnji.

Zahvala

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**Anja Ludaš Dujmić****Životopis**

Anja Ludaš Dujmić (Zagreb, 1993.) doktorirala je 2025. na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu, gdje je zaposlena kao asistentica, od 2019. godine. Znanstveni i nastavni rad vezan joj je uz ekstruziju vlakana iz recikliranih polimera, ispitivanje tekstila, modifikacije površine tekstilnih materijala primjenom ekološki prihvatljive hladne plazme te primjenu prirodnih ekstrakata za obradu tekstilnih materijala. Izvodi Erasmus+ nastavu na engleskom jeziku. Neposredni je voditelj na 8 završnih i diplomskih radova. Suradnica je na nacionalnim i međunarodnim projektima, u znanstvenim društvima i popularizaciji znanosti, fakultetskim tijelima i organizacijskim odborima kongresa. Članica je uredničkog odbora časopisa Inženjerski glasnik. Autorica 11 znanstvenih, 2 stručna te 16 radova s konferencija. Dobitnica je 2 nagrade Dekanice Sveučilišta u Zagrebu Tekstilno-tehnološkog fakulteta.

Naslov teme doktorskog rada

Modifikacija svojstava umjetnih vlakana ispredenih iz taline recikliranoga PA 6 polimera dodatkom bioaktivnih tvari i naknadnom obradom hladnom plazmom

Mentorica

Prof. dr. sc. Sanja Ercegović Ražić

Datum obrane doktorskog rada

16. listopada 2025.

MODIFIKACIJA SVOJSTAVA UMJETNIH VLAKANA ISPREDENIH IZ TALINE RECIKLIRANOGA PA 6 POLIMERA DODATKOM BIOAKTIVNIH TVARI I NAKNADNOM OBRADOM HLADNOM PLAZMOM

Anja LUDAŠ DUJMIĆ

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, 10000 Zagreb, Hrvatska, anja.ludas@tff.unizg.hr

Sažetak: Istražena je mogućnost proizvodnje modificiranih filamenata od recikliranog PA 6 polimera kemijskim predenjem taline. Optimizacijom parametara ekstruzije proizvedeni su homogeni filamenti uz dodatak ZnO, ZnO dobivenog zelenom sintezom, TiO₂ i kitosana. Upotreba ZnO dobivenog zelenom sintezom dodatno je poboljšala ekološku prihvatljivost procesa i toplinsku stabilnost materijala. Testovi genotoksičnosti pokazali su nisku toksičnost, iako nije uočena antimikrobna aktivnost, za razliku od uzoraka s komercijalnim ZnO, koji su bili učinkoviti protiv *Klebsiella pneumoniae*. Naknadna obrada hladnom niskotlačnom plazmom promijenila je površinsku morfologiju i kemijski sastav, omogućujući povećano i kontrolirano oslobađanje bioaktivnih metala, što je potvrđeno ICP analizom.

1. Uvod

Kemijsko ispredanje vlakana iz taline jedan je od najčešće korištenih postupaka proizvodnje zbog svoje jednostavnosti, odsutnosti otapala i povoljnog utjecaja na okoliš, sve veći naglasak stavlja na primjenu recikliranih polimera. Među najzastupljenijim polimerima ističe se poliamid 6 (PA 6), koji se odlikuje dobrim mehaničkim, toplinskim i kemijskim svojstvima, širokom primjenom u tekstilnoj i tehničkoj industriji te mogućnošću recikliranja [1-3]. Istodobno, proizvodnja i uporaba umjetnih vlakana doprinose onečišćenju okoliša mikrofragmentima, što potiče razvoj ekološki prihvatljivijih tehnologija, uključujući smanjenu uporabu aditiva i primjenu zelenih metoda sinteze. U tom kontekstu, nanotehnologija omogućuje razvoj tekstilnih materijala poboljšanih funkcionalnih svojstava, poput antimikrobnosti, UV zaštite i samoočišćenja. Nanočestice cinkovog oksida i titanijevog dioksida te biopolimer kitozan često se koriste kao funkcionalni dodaci zbog svoje učinkovitosti i biokompatibilnosti [4, 5]. Dodatno unapređenje svojstava postiže se primjenom ekoloških površinskih obrada, poput hladne plazme, kojom se modificira samo površinski sloj materijala bez promjene njegovih osnovnih svojstava. Takvi postupci imaju značajnu primjenu u medicinskom, zaštitnom i tehničkom tekstilu te doprinose razvoju održivih i visoko funkcionalnih tekstilnih materijala [6, 7].

2. Eksperimentalni dio

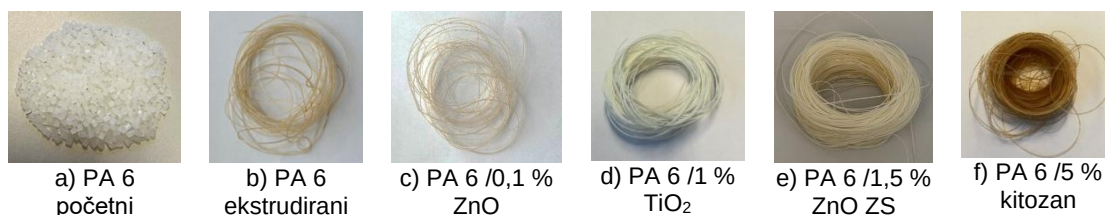
Istraživanja su provedena kroz tri faze:

- (1) Optimirani su parametri postupka kemijskog ispredanja umjetnih vlakana iz taline na uređaju za ispredanje ovisno o toplinskim karakteristikama PA 6 polimera. Potom je provedena ekstruzija modificiranog recikliranog polimera PA 6 s bioaktivnim sredstvima na dvopužnom ekstruderu (Bench Top 21 mm), tt. Rondol Technology (Francuska).
- (2) Optimirana je koncentracija konvencionalnih nanočestica ZnO i TiO₂ te biopolimera kitozana kao i nanočestica ZnO dobivenih zelenom sintezom iz lista biljke nim, na masu PA 6 polimera kako bi se proizveo filament ciljanih modificiranih (antimikrobnih i UV zaštitnih svojstava).
- (3) Dobiveni filamenti su modificirani niskotlačnom plazmom (LP-Nano LF-40kHz), tt. Diener Electronic GmbH (Njemačka) kroz optimirane uvjete, a koja bi mogla doprinijeti otpuštanju aktivne tvari i postizanju željenih svojstava, budući da se njezino djelovanje očituje fizikalno-kemijskim promjenama u površinskom sloju supstrata i modifikacijom svojstava površine ovisno o prirodi plina i načinu djelovanja aktivnih čestica plazme u interakciji s površinom materijala.

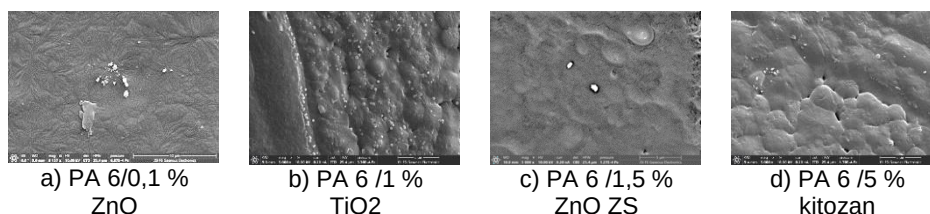
Karakterizacija ispredenih filamenata sa/ bez dodatka bioaktivnih tvari u svrhu procjene stupnja modifikacije i jednoličnosti primjenjive obrade analizirane su primjenom suvremenih metoda analize, karakterizacijom toplinskih (DSC), spektrofotometrijskih, morfoloških (SEM), kemijskih (SEM-EDS, FTIR, ICP-OES), antimikrobnih, genotoksičnih svojstava i postojanosti boje na umjetno svjetlo tako modificiranih filamenata.

3. Rezultati i rasprava

U ovom radu prikazat će se samo dio rezultata. Nakon uspješno provedene optimizacije parametara rada ekstrudera, dobiveni su filamenti od recikliranog PA 6 modificirani različitim koncentracijama aditiva; cinkov oksid, titanov dioksid, cinkov oksid dobiven zelenom sintezom te kitozan (slika 1.). Svaki aditiv dodan je u definiranim prilagođenim omjerima, radi postizanja optimalne disperzije čestica unutar polimerne matrice. Na slici 2. prikazana je SEM analiza PA 6 polimera s različitim koncentracijama aditiva pri povećanju od 5000x, vidljiva je prisutnost aditiva na površini modificiranih filamenata.

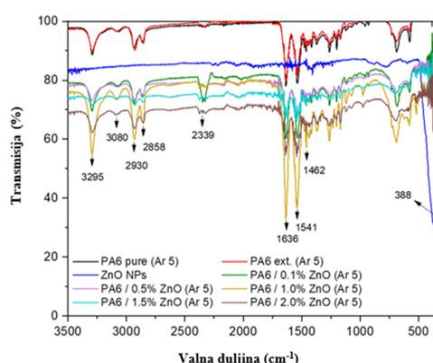


Slika 1: a) početni PA 6, b) ekstrudirani PA 6, c)-f) dobiveni filamenti različitih koncentracija aditiva u kombinaciji s PA 6

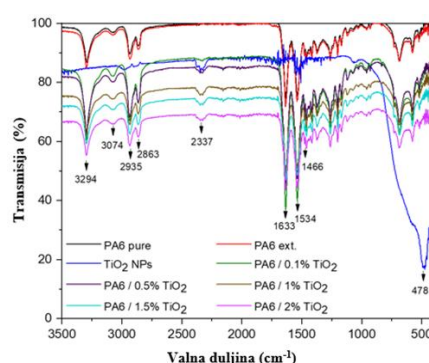


Slika 2: SEM analiza PA 6 polimera s različitim koncentracijama aditiva pri povećanju od 5000x

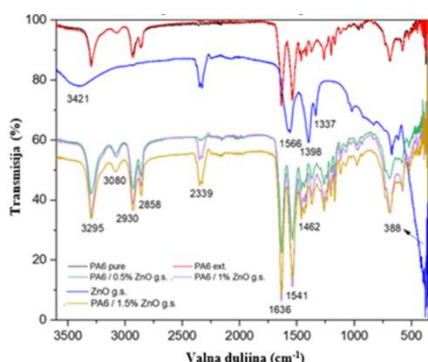
Na slici 3. prikazani su FTIR spektri sa pikovima za dodane aditive koji potvrđuju uspješnu inkorporaciju aditiva u PA 6 polimer; 388 cm^{-1} istezanje Zn-O (3. a)), 478 cm^{-1} Ti-O savijanje (3. b)), 388 cm^{-1} istezanje Zn-O i 3421 cm^{-1} O-H istezanje amidne grupe iz biljnih ekstrakata korištenih u zelenoj sintezi (npr. alkaloidi ili fenoli) (3. c)), 1022 cm^{-1} karakterističan za istezanje P=O iz fosfatnih grupa, istezanje COH i C-N vibracije, specifičan za kitozan (3. d)).



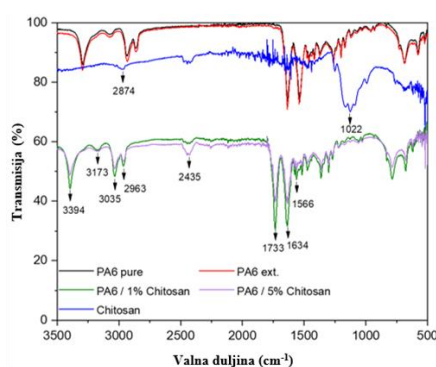
a) FTIR PA 6 s različitim koncentracijama ZnO



b) FTIR PA 6 s različitim koncentracijama TiO2



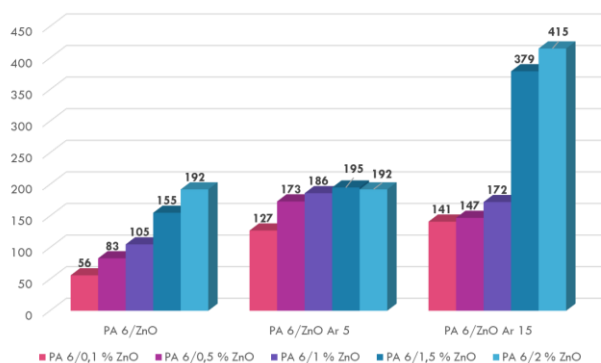
c) FTIR PA 6 s različitim koncentracijama ZnO ZS



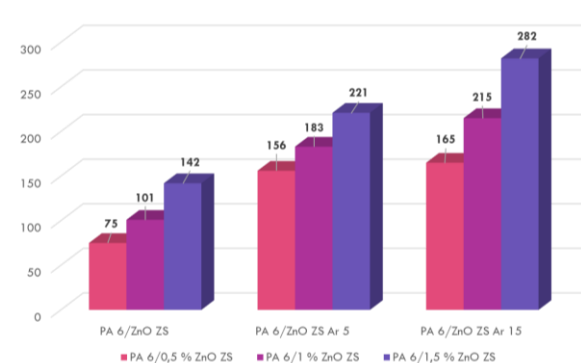
d) FTIR PA 6 s različitim koncentracijama kitozana

Slika 3: FTIR spektri s različitim koncentracijama aditiva

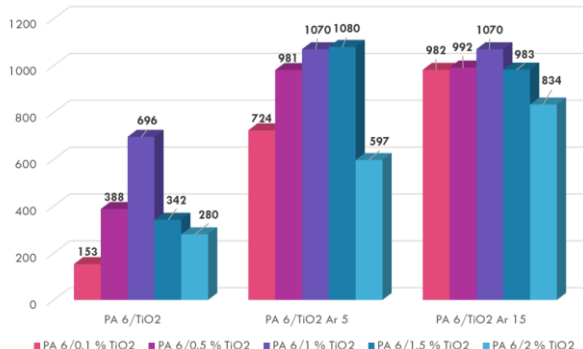
Na slici 4. prikazani su rezultati spektrometrije mase induktivno spregnutom plazmom, ICP leaching. Uzorci bez obrade plazmom pokazuju porast koncentracije otpuštenog cinka s povećanjem udjela ZnO. Obrada argonom plazmom povećava otpuštanje cinka osobito pri višim udjelima ZnO. Sličan trend uočen je i kod uzoraka sa ZnO ZS. Uzorci s TiO_2 bez obrade plazmom pokazuju ograničeno otpuštanje titanija, s maksimumom pri 1 % TiO_2 , što može upućivati na aglomeraciju nanočestica pri višim koncentracijama. Obrada plazmom značajno povećava otpuštanje titanija u odnosu na neobrađene uzorke, pri čemu je najizraženiji učinak zabilježen nakon 5 minuta obrade, dok dulja obrada dovodi do stabilnijih, ali nešto nižih koncentracija, što sugerira zasićenje i promjene u raspodjeli nanočestica.



a) Dobivene koncentracije ($\mu\text{g/L}$) cinka otpuštene iz PA 6 filamenata u vodu



b) Dobivene koncentracije ($\mu\text{g/L}$) cinka otpuštene iz PA 6 filamenata u vodu



c) Dobivene koncentracije ($\mu\text{g/L}$) titana otpuštene iz PA 6 filamenata u vodu

Slika 4: Dobivene koncentracije ($\mu\text{g/L}$) cinka i titana otpuštene iz PA 6 filamenata u vodu

4. Zaključci

Provedenim istraživanjem ostvaren je znanstveni doprinos u razvoju i optimizaciji ekološki prihvatljivog postupka kemijskog ispredanja filamenata iz recikliranog PA 6. Optimizacijom parametara ekstruzije dobiveni su homogeni filamenti s dodatkom ZnO, ZnO dobivenog zelenom sintezom, TiO₂ i kitozana, pri čemu su DSC analizom utvrđene promjene toplinskih svojstava, uključujući povišene temperature kristalizacije i tališta te povećanu kristaliničnost, osobito kod ZnO dobivenog zelenom sintezom. Ugradnja bioaktivnih komponenti potvrđena je FTIR, SEM i SEM-EDS analizama, uz poboljšana optička svojstva filamenata. Primjena ZnO dobivenog zelenom sintezom dodatno je povećala ekološku prihvatljivost procesa i toplinsku stabilnost materijala, a genotoksična ispitivanja pokazala su nisku toksičnost, iako antimikrobna aktivnost nije uočena, za razliku od uzoraka s komercijalnim ZnO koji su pokazali učinkovitost prema *Klebsiella pneumoniae*. Naknadna obrada hladnom niskotlačnom plazmom uzrokovala je promjene površinske morfologije i kemijskog sastava te omogućila povećano i kontrolirano otpuštanje bioaktivnih metala, potvrđeno ICP analizom. Rezultati potvrđuju potencijal razvoja održivih i funkcionalnih tekstilnih materijala iz recikliranih polimera za tehničku, zaštitnu i medicinsku primjenu.

Zahvala



Ovaj rad sufinancirala je Hrvatska zaklada za znanost projektom IP-2019-04-6418: Laserska sinteza nanočestica i primjene (2020. - 2024.).

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**Juro Živičnjak****Životopis**

Juro Živičnjak rođen je 28. veljače 1995. u Zagrebu. Doktorirao je 2025. na Sveučilišta u Zagrebu Tekstilno-tehnološkom fakultetu pod mentorstvom prof. dr. sc. Antonete Tomljenović. Od 1. srpnja 2019. zaposlen je kao asistent na Zavodu za materijale, vlakna i ispitivanje tekstila, gdje vodi laboratorijske vježbe na kolegijima Tekstilni materijali, Ispitivanje tekstila i odjeće, Kvaliteta tekstila i odjeće te Upravljanje kvalitetom. Pod mentorstvom prof. dr. sc. Dubravka Rogalea razvio je višestruko nagrađivani uređaj za mjerenje i generiranje električnog naboja. Njegov znanstveni rad usmjeren je na uporabna svojstva tekstilnih materijala, s naglaskom na elektrostatička svojstva. U koautorstvu je objavio više znanstvenih i stručnih radova. Sudjelovao je kao istraživač na znanstveno-istraživačkom projektu HRZZ te je bio član edukacijskog projekta RAST.

Naslov teme doktorskog rada

Vrjednovanje površinskih nejednolikosti tkanina nastalih trošenjem primjenom unaprijeđene metodike vizualne procjene i analize elektrostatičkih svojstava

Mentorica

Prof. dr. sc. Antoneta Tomljenović

Datum obrane doktorskog rada

17. listopada 2025.

VRJEDNOVANJE POJAVNOSTI PILINGA NA TKANINAMA PRIMJENOM UNAPRIJEĐENE INSTRUMENTALNE METODE

Juro ŽIVIČNJAK

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, Zagreb, juro.zivicnjak@ttf.unizg.hr

Sažetak: Tekstilni materijali su tijekom uporabe skloni trošenju, a time i nastanku površinskih nejednolikosti, poput pilinga. Postupak procjene pojavnosti pilinga provodi se sukladno normiranoj vizualnoj metodi, uz mogućnost primjene instrumentalnih metoda. Unutar doktorskoga rada unaprijeđen je postupak vizualne procjene, konstrukcijom inovativne aparature, koja osigurava izradu digitalnih fotografija cijele površine ispitivanog uzorka tkanine u skladu s uvjetima normirane vizualne metode. Računalnom analizom digitalnih fotografija, utvrđen je niz numeričkih parametara vezanih uz pojavnost pilinga te je izdvojen parametar koji objektivno opisuje njegovu pojavnost. Rezultati istraživanja ukazuju na poboljšanu mogućnost gradiranja ocjena, uz očuvanje visoke razine povezanost između ocjena dodijeljenih vizualnom procjenom i unaprijeđenom instrumentalnom metodom.

1. Uvod

Izgled površine tekstilnog materijala s vremenom se mijenja, a jedan od najčešćih uzroka tome jest habanje, do kojega dolazi uslijed izravnog fizičkog kontakta površine tekstilnog materijala s drugim predmetima iz okoline. Habanje uzrokuje trošenje materijala, ali i pojavu raznih površinskih nejednolikosti, od kojih je najuočljivija pojava pilinga. Piling opisuje pojavu manjih ili većih nakupina zamršenih vlakana koje se nalaze neposredno iznad površine tekstilnog materijala, takve gustoće da pri vizualnom pregledu svjetlost ne prolazi kroz njihovu strukturu te pritom stvara sjenu. Sklonost nastanku pilinga često je ispitivano svojstvo koje se procjenjuje primjenom normirane vizualne metode HRN EN ISO 12945-4:2020, a iskazuje se u obliku ocjene u rasponu od 5 (nepromijenjen izgled površine) do 1 (jako promijenjen izgled površine). Nedostaci ove metode su subjektivnost i moguće neiskustvo ispitivača. U suvremenim istraživanjima sve se češće primjenjuju instrumentalne metode koje je moguće primjenjivati, no uvjeti njihove provedbe nisu u potpunosti definirani normom HRN EN ISO 12945-4:2020.

Primjenom instrumentalne metode, ocjena pojavnosti pilinga donosi se na temelju računalne analize digitalne fotografije površine ispitivanog uzorka. Izrada digitalnih fotografija je prvi i ključni korak instrumentalne metode, jer kvaliteta izrađenih fotografija izravno utječe na razlučivost i reprezentativnost podataka o pojavnosti pilinga [1]. Pregledom dosadašnjih istraživanja uočeno je da se za izradu digitalnih fotografija koriste različiti uređaji (kamere, skeneri, mikroskopi) te da se postupak izrade vrlo često provodi u uvjetima koji odstupaju od normiranih (udaljenost i kut snimanja, položaj uzorka, vrsta osvjetljenja te veličina analizirane površine). Stoga je u okviru doktorskoga rada izrađena inovativna aparatura čija je svrha osigurati izradu digitalnih fotografija cijele površine ispitivanog uzorka pod normiranim uvjetima, a za što je primijenjena kamera digitalnog mikroskopa Dino-Lite AM-413ZT.

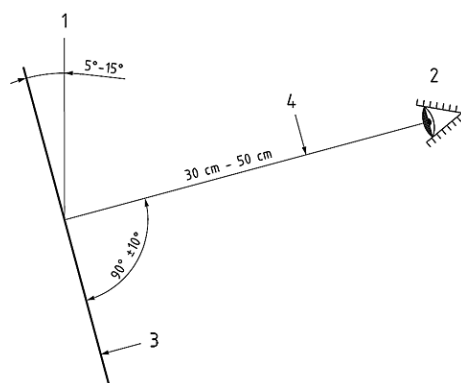
2. Eksperimentalni dio

Istraživanje je provedeno na šest odabranih referentnih jednokomponentnih tkanina, izrađenih od 100 % pamuka, vune, viskoze, poliamida 6.6, poliestera i akrila, nabavljenih od ovlaštenog proizvođača referentnih materijala za ispitivanje tekstila SDC Enterprises Limited, UK. Pojava pilinga na uzorcima tkanina izazvana je primjenom preinačene metode prema Martindale-u (HRN EN ISO 12945-2:2020), pri čemu je postupak habanja proveden o istovrsni uzorak tkanine unutar prostora s referentnom atmosferom za ispitivanje (temperatura 20 ± 2 °C i relativna vlažnost 65 ± 4 %, prema HRN EN ISO 139:2008/A1:2011).

Za potrebe istraživanja definirano je 12 kontrolnih točaka, odnosno habajućih prolaza (od 125, 500, 1000, 2000, 5000, 7000, 10000, 14000, 18000, 22000, 26000 do 30000) te je za svaku od kontrolnih točaka priređen po jedan uzorak ispitivanih tkanina. Postupak procjene pojavnosti pilinga, prvotno je proveden primjenom normirane vizualne procjene (slika 1), a zatim i primjenom unaprijeđene instrumentalne metode (slike 2 i 3).



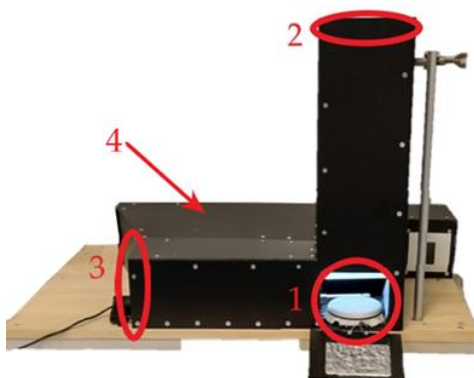
a



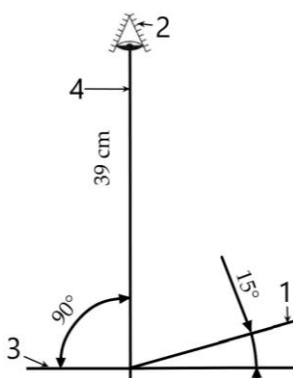
b

Slika 1: Vizualna metoda: a) izrađena aparatura za osvjetljavanje i procjenu izgleda površine uzoraka, b) uvjeti normiranog postupka procjene: 1- izvor svjetlosti, 2- ispitivač, 3- površina ispitivanog uzoraka i 4- udaljenost ispitivača od površine uzorka

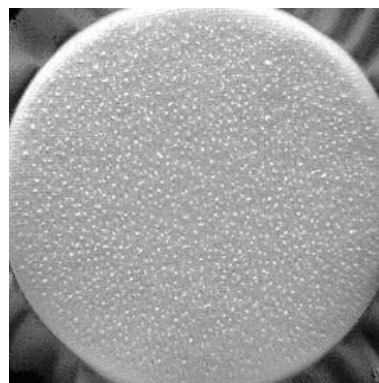
Za potrebe provedbe unaprijeđene instrumentalne metode procjene je osmišljena i konstruirana inovativna aparatura (slika 2a), koja osigurava izradu digitalnih fotografija cijele površine uzorka (slika 2c) pod normiranim uvjetima (slika 2b). Računalna analiza digitalnih fotografija provedena je u programu Fiji, koji omogućava izdvajanje pojavnosti pilinga, primjenom Fast Fourier-ove transformacije (slika 3a) i odgovarajućeg praga binarizacije (slika 3b) te analizu i ispis sljedećih parametra: broj pojedinačnih nakupina zamršenih vlakana, gustoću nakupina zamršenih vlakana na analiziranoj površini, površinu svake pojedinačne nakupine zamršenih vlakana, aritmetičku sredinu svih zabilježenih površina, ukupnu površinu (zbroy) svih nakupina zamršenih vlakana, postotni udio ukupne analizirane površine uzorka prekriven zamršenim vlaknima.



a

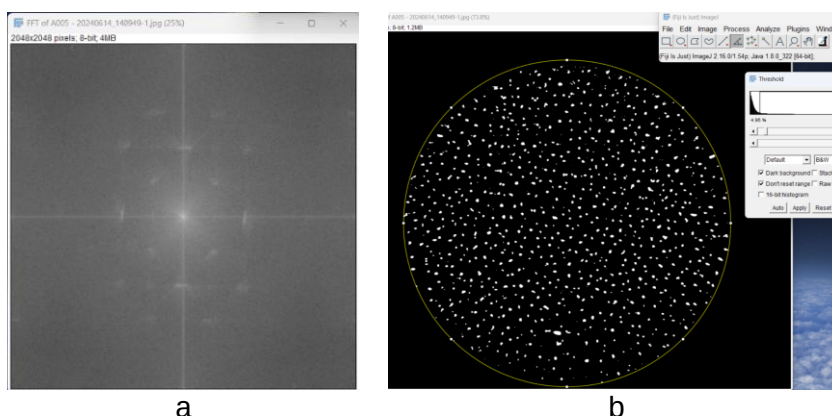


b



c

Slika 2: Unaprijeđena instrumentalna metoda – izrada digitalnih fotografija: a) inovativna aparatura: 1-pozicija uzorka, 2- prva pozicija kamere, 3-druga pozicija kamere i 4-pozicija izvora svjetlosti, b) prva pozicija kamere: 1- izvor svjetlosti, 2- kamera, 3- uzorak i 4- udaljenost kamere od površine uzorka, c) digitalna fotografija površine poliesterske tkanine habane o istovrsnu tkaninu nakon 30000 habajućih prolaza



Slika 3: Unaprijeđena instrumentalna metoda – računalna analiza digitalnih fotografija: a) spektar frekvencija dobiven primjenom Fast Fourier-ove transformacije, b) digitalan fotografija nakon Fast Fourier-ove transformacije s podešenim pragom binarizacije

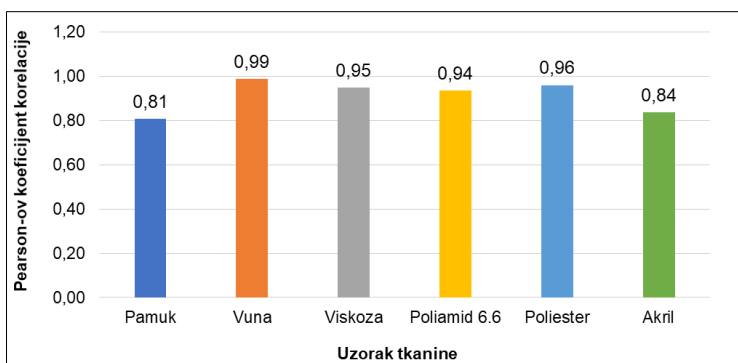
3. Rezultati i rasprava

Računalno izdvojen parametar za koji je utvrđeno da objektivno iskazuje pojavnost nastale razine i intenzivnosti pilinga je postotni udio ukupne analizirane površine uzorka prekriven zamršenim vlaknima. Stoga, je na temelju tog parametra formirano devet ocjenskih razreda (tablica 1), na osnovi kojih je provedeno unaprijeđeno ocjenjivanje pojavnosti pilinga.

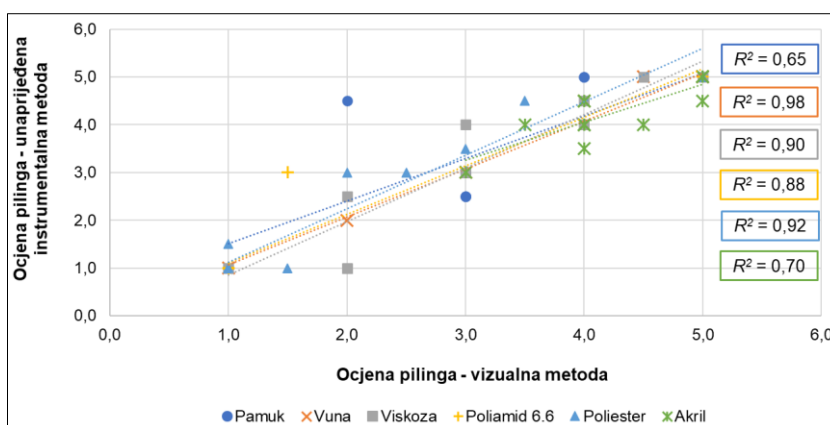
Tablica 1: Devet ocjenskih razreda definiranih na temelju vrijednosti postotnog udjela ukupne analizirane površine uzorka tkanine prekrivene zamršenim vlaknima

Ocjena	Ocjenjski razredi					
	Pamuk	Vuna	Viskoza	Poliamid 6.6	Poliester	Akril
1,0	$\geq 1,409$	$\geq 0,433$	$\geq 1,662$	$\geq 1,518$	$\geq 2,051$	$\geq 2,213$
1,5	1,234–1,408	0,379–0,432	1,456–1,661	1,330–1,517	1,795–2,050	1,938–2,212
2,0	1,059–1,233	0,325–0,378	1,251–1,455	1,142–1,329	1,538–1,794	1,664–1,937
2,5	0,884–1,058	0,271–0,324	1,045–1,250	0,954–1,141	1,282–1,537	1,389–1,663
3,0	0,709–0,883	0,217–0,270	0,84–1,0440	0,766–0,953	1,026–1,281	1,114–1,388
3,5	0,534–0,708	0,162–0,216	0,634–0,839	0,578–0,765	0,769–1,025	0,839–1,113
4,0	0,359–0,533	0,108–0,161	0,428–0,633	0,390–0,577	0,513–0,768	0,565–0,838
4,5	0,184–0,358	0,054–0,107	0,223–0,427	0,202–0,389	0,256–0,512	0,290–0,564
5,0	$\leq 0,183$	$\leq 0,053$	$\leq 0,222$	$\leq 0,201$	$\leq 0,255$	$\leq 0,289$

Ocjenjski razredi definirani su primjenom linearne interpolacije, pri čemu su granične vrijednosti bile vezane uz ocjene pojavnosti pilinga dodijeljene vizualnom metodom, odnosno uzorak tkanine ocjenjen najvišom ocjenom (5,0 - početni uzorak tkanine) i najnižom ocjenom (nakon procesa habanja). Povezanost između ocjena pojavnosti pilinga donesenih na temelju vizualne metode i unaprijeđene instrumentalne metode utvrđena je primjenom Pearson-ovog koeficijenta korelacije (slika 4) i koeficijenta determinacije (slika 5) uz interval pouzdanosti od 95 %. Korelacijskom analizom utvrđena je visoka do vrlo visoka razina povezanosti između ocjena pojavnosti pilinga donesenih na temelju vizualne procjene i primjenom unaprijeđene instrumentalne metode.



Slika 4: Prikaz vrijednosti Pearson-ovog koeficijenta korelacije koje ukazuju na razinu povezanosti između ocjena pojavnosti pilinga donesenih na temelju vizualne procjene i unaprijeđene instrumentalne metode



Slika 5: Dijagram korelacije između ocjena pojavnosti pilinga donesenih na temelju vizualne procjene i unaprijeđene instrumentalne metode

4. Zaključci

Primjenom unaprijeđene instrumentalne metode i izrađene inovativne aparature omogućena je izrada digitalnih fotografija cijele površine uzorka tkanine u skladu s uvjetima normirane vizualne metode te je postignut visok stupanj podudarnosti između izgleda fotografije i površine ispitivanog uzorka tijekom izravnog vizualnog pregleda od strane ispitivača. Kao najpouzdaniji i objektivni parametar za procjenu pilinga pokazao se ukupni postotni udio površine uzorka prekriven zamućenim vlaknima, čijom primjenom je u znatnoj mjeri smanjen utjecaj varijabilnosti veličine pojedinačnih nakupina zamućenih vlakana te omogućeno objektivno vrjednovanje pojavnosti pilinga i bez prethodno izrađene računalne baze podataka.

Zahvala

Ovaj rad je dijelom sufinanciran iz projekta „*Udobnost i antimikrobna svojstva tekstila i obuće*“ Hrvatske zaklade za znanost (HRZZ IP-2016-06-5278), voditelja prof. dr. sc. Zenuna Skenderia.

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**Stefana Begović****Životopis**

Rođena je u Zagrebu 1995. Diplomirala je 2022. na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu (SuZ TTF). Od ožujka 2025. godine zaposlena je na SuZ TTF na suradničkom radnom mjestu asistenta. Akad. god. 2025./2026. upisala je doktorski studij „Tekstilna znanost i tehnologija“ na SuZ TTF. Do sada je u koautorstvu objavila dva znanstvena rada u časopisu, jedan cjeloviti rad u zborniku s međunarodnog skupa, jedno poglavlje u knjizi te dva sažetka. Usmeno je izložila dva rada na međunarodnim skupovima i sudjelovala na događanjima popularizacije znanosti. Suradnik je na institucijskom istraživačkom projektu SuZ TTF „Zelene tehnologije u ekološkom dizajnu i razvoju održivih materijala – ZORA“ financiranom od Europske unije – NextGenerationEU.

Naslov teme doktorskog rada

/

Studijski savjetnik

Prof. dr. sc. Anita Tarbuk

Datum obrane doktorskog rada

/

ENZIMSKA PREDOBRAĐA TKANINE IZ MJEŠAVINE PAMUKA I POLIESTERA

Stefana BEGOVIĆ

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, Zagreb stefana.begovic@tff.unizg.hr

Sažetak: U ovom radu provedena je enzimska predobrada tkanine iz mješavine pamuka i poliestera s ciljem aktiviranja površine i poboljšanja hidrofilnosti poliesterske komponente, koja može negativno utjecati na udobnost nošenja odjevnog predmeta. Za enzimsku predobradu korišteni su komercijalno dostupni enzimi - pektinaze za pamučnu komponentu i lipaze za poliestersku komponentu, s naglaskom na minimiziranje smanjenja čvrstoće. Dobiveni učinci procijenjeni su iz promjene mase, prekidne sile, vremena kvašenja te analizom zeta potencijala. Utvrđeno je da enzimska predobrada dovodi do boljih svojstava tkanine.

1. Uvod

Tekstilije iz poliestera i sirovog pamuka inicijalno pokazuju hidrofobna svojstva, pa je povećanje hidrofilnosti važan korak u njihovoj predobradi. Primjese sirovog pamuka djeluju kao hidrofobna barijera te ih je potrebno ukloniti u postupku iskuhavanja [1,2]. Poliester, primarno poli(etilen-tereftalat) (PET), ima mali broj polarnih funkcionalnih skupina (hidroksilne i karboksilne) odgovornih za formiranje vodikovih veza s molekulama vode [3,4]. Stoga su mješavine poliestera i pamuka postale uobičajene u primjeni, jer pamučna komponenta pridonosi udobnosti i antistatičkim svojstvima, dok poliesterska osigurava mehaničku čvrstoću i igra primarnu ulogu u upravljanju vlagom [5,6]. Konvencionalnim pristupom hidrofilnost pamuka i/ili poliestera postiže se alkalnim obradama (iskuhanje pamuka, alkalna hidroliza poliestera), najčešće primjenom NaOH na povišenim temperaturama [1,4-6]. Ove obrade generiraju značajan utjecaj na okoliš zbog potrošnje energije, vode i potencijalno toksične spojeve. Enzimska obrada predstavlja ekološku alternativu alkalnim obradama jer djeluju na točno određenu tvar pri umjerenim temperaturama i uvjetima neutralnog pH što doprinosi održivosti procesa. Poznato je da pektinaze pospješuju uklanjanje primjesa pamuka otkrivajući hidroksilne skupine celuloze, dok enzimska hidrolizira površine poliesterskog vlakna lipazama povećava broj polarnih skupina [1-5]. Stoga su u ovom istraživanju upotrijebljeni enzimi lipaze i pektinaze na tkanini iz mješavine pamuka i poliestera sa ciljem poboljšanja hidrofilnih svojstva uz minimalne promjene mehaničkih svojstava tkanine.

2. Eksperimentalni dio

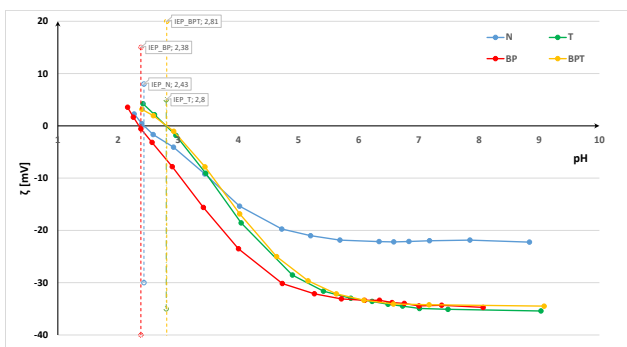
Za istraživanje je korištena tkanina iz mješavine pamuka i poliestera (50/50), u panama vezu (Oznaka N). Tkanina je predobrađena je sa 2 % enzima 60 min na 60°C u bubnju uređaja Polycolor, Mathis: lipazom Texazym PES, Inotex (2 %, Oznaka T), pektinazom Biosol PRO, CHT-Bezema (2 %, Oznaka BP) i njihovom kombinacijom (1 % + 1 %, Oznaka BPT). Plošna masa (m) prema ISO 3801, prekidna sila (F) i produljenje (ε) prema ISO 13934-1, vrijeme kvašenja (WT) prema AATCC TM 195 na MMT M290 (SDL Atlas) te zeta potencijal (ζ) na Surpass (Anton Paar), određeni su prije i nakon enzimске predobrade.

3. Rezultati i rasprava

Rezultati plošne mase, prekidna sila i produljenje, te vrijeme vlaženja tkanine su prije i nakon enzimске predobrade prikazani su u Tablici 1, a zeta potencijala na Slici 1.

Tablica 1: Plošna masa (m), prekidna sila (F) i produljenje (ϵ) te vrijeme vlaženja (WT) tkanina prije i nakon enzimske predobrade

Uzorak	m [g]	F [N]	ϵ [%]	WT [s]
N	169,81	1096,0 $\pm$ 2,5	11,55 $\pm$ 1,84	5,35
T	171,38	1016,5 $\pm$ 1,2	12,60 $\pm$ 3,37	2,39
BP	173,06	1031,0 $\pm$ 2,0	14,25 $\pm$ 1,49	2,44
BPT	176,43	1068,3 $\pm$ 0,4	14,33 $\pm$ 1,86	2,46



Slika 1: Zeta potencijal tkanina prije i nakon enzimske predobrade

Plošna masa se povećala zbog bubrenja pamučne komponente i skupljanja nakon sušenja. Uklanjanjem primjesa pamuka i hidrolize poliestera dolazi do smanjenja prekidne sile, ali istovremeno nastaju i/ili postaju dostupne hidroksilne i karboksilne skupine što povećava hidrofilnost tkanine. Rezultati brzine kvašenja i zeta potencijala to potvrđuju – vrijeme kvašenja je kraće, a zeta potencijal negativniji radi većeg broja elektro-negativnih skupina.

4. Zaključak

Enzimska predobrada pektinazom i lipazom povećava hidrofilnost uz minimalno smanjenje mehaničkih svojstava. Enzim lipaza (Texazym PES) ima veći utjecaj na mehanička svojstva jer hidrolizira poliestar. Kao najbolje sredstvo predobrade pokazala se kupelj s oba enzima jer se postižu najoptimalniji rezultati – bolja hidrofilnost uz zadržavanje mehaničkih svojstava.

Zahvala



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**Darinka Cvetković****Životopis**

Rođena u Zagrebu 22.7.1962., a 1981. godine zapošljava se u Radio industriji Zagreb u IETA (istraživanje u elektrotehnici i telekomunikaciji) u laboratoriju na poslovima snimanja i izrade tehničkih filmova (fotolakovi, suhi film, kemijsko bakrenje dvostranih pločica, na galvanskim kupkama i njihovim analizama), te administrativnim poslovima. 1984. upisuje Fakultet kemijskog inženjerstva uz rad. 1991. upisuje Kemijsko-tehnološki fakultet, smjer obuča na kojem diplomira. 2009. upisuje razlikovni studij na Tekstilno-tehnološkom fakultetu, a 2011. na istom upisuje diplomski studij, smjer tekstilna kemija, materijali i ekologija. Doktorski studij upisuje 2017. na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu, s ciljem unapređenja istraživačkih kompetencija.

Naslov teme doktorskog rada

Razvoj i karakterizacija prevlaka s propolisom i biopolimerima na tekstilu za topikalnu primjenu

Studijski savjetnik

Prof. dr. sc. Maja Somogyi Škoc

Datum obrane doktorskog rada

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RAZVOJ I KARAKTERIZACIJA PREVLAKA S PROPOLISOM I BIOPOLIMERIMA NA TEKSTILU ZA TOPIKALNU PRIMJENU

Darinka CVETKOVIĆ

Gračansko Dolje 44, Zagreb, cvetkovicdarinka@gmail.com

Sažetak: Istraživanje će imati naglasak na razvoju prevlaka na tekstilu za topikalnu primjenu na koži ili mukozi. Razvijati će se i karakterizirati bioaktivne prevlake na bazi prirodnih polisaharida (hitozan, natrij karboksimetil celuloza, alginat) uz dodatak propolisa s ciljem postizanja sinergijskog djelovanja, namijenjene primjeni na tkanini iz celuloznih vlakana i netkanom tekstilu. Varirati će se procesni parametri, a uz pomoć dizajna eksperimenta odabrati će se najbolje formulacije prevlaka. Cilj je doprinijeti razvoju inovativnih, prirodnih i održivih prevlaka na tekstilu za lokalnu primjenu koje mogu doprinijeti ciljanom poticanju zdrave granulacije i epitelizacije u topikalnoj kozmetici.

1. Uvod

Rastući zahtjevi za održivim, funkcionalnim i sigurnim tekstilnim materijalima potiču razvoj inovativnih rješenja u području tehničkog tekstila, a posebice medicinskog. U tom kontekstu, sve se češće istražuju ekološki postupci gdje se sve veća pažnja pridaje uporabi prirodnih tvari poput ljekovitih biljaka te biopolimera dobivenih iz prirodnih izvora, tj. polisaharida poput hitozana, cikodekstrina, dekstrina, alginata i dr. (npr. bioaktivne obloge za kronične rane). Navedeni polisaharidi privlače veliku pozornost zahvaljujući svojim biomedicinskim i fizikalno-kemijskim svojstvima, poput biorazgradivosti, neimunogenosti, mogućnosti funkcionalizacije, higroskopnosti, protuupalnih i antioksidativnih svojstava, a radi kojih su općenito prepoznati kao sigurni (engl. generally regarded as safe, GRAS) te se naširoko koriste i u prehrambenoj industriji [1]. S obzirom na sigurnost korištenja navedenih tvari, one kao takve predstavljaju izvrnu podlogu za razvoj novih biomaterijala i prevlaka u području medicinskog, ali i kozmetičkog tekstila.

Polisaharidi sadrže velik broj hidroksilnih skupina ili drugih hidrofilnih skupina, kao što su karboksilne skupine u alginatu i amino skupine u hitozanu koje omogućuju dodatnu topljivost u vodi i pojačavaju karakteristike bioadhezije, bioprepoznavanja putem nekovalentnog povezivanja (elektrostatsko povezivanje) [2]. Jedini prirodno nabijeni polisaharid je hitozan, koji se kao takav može vezati za negativno nabijene slojeve sluznice putem elektrostatskih interakcija. Obzirom na svoja biokemijska svojstva s ljudskim izvanstaničnim matricama, polisaharidi se lako prepoznaju i metaboliziraju u tijelo [3], pri čemu je otkriveno da mogu biti uključeni u mnoge biološke procese uključujući imunološko prepoznavanje i staničnu signalizaciju [4], a koji su odgovorni za aktivaciju antimikrobnih i protuupalnih odgovora [5].

Osim toga, ovi polisaharidi, podliježu enzimatskoj i/ili hidrolitičkoj razgradnji in vivo, ostavljajući bezopasne proizvode razgradnje koji se mogu ponovno upotrijebiti u biološkim sustavima i očistiti od strane imunološkog sustava. Ukoliko se prevlakama na bazi prethodno spomenutih polisaharida dodaju ekstrakti ljekovitih biljaka ili npr. propolis, može se postići sinergijsko djelovanje uz visoku razinu sigurnosti za ljudsko zdravlje i bez opterećenja za okoliš.

Propolis, pčelinji proizvod bogat flavonoidima i fenolima, poznat je po svojim izraženim antimikrobnim i antioksidativnim svojstvima. Međutim, njegova primjena na tekstilu otežana je zbog hidrofobne prirode i slabe adhezije na vlaknima. U varijantama s biopolimerima kao što su hitozan, alginat, želatina ili zein moguće je postići stabilnije prevlake i omogućiti kontrolirano otpuštanje aktivnih tvari, čime se poboljšava učinkovitost i funkcionalnost obrađenih materijala. Brojna istraživanja potvrđuju potencijal sustava propolis–biopolimer u funkcionalizaciji tekstila.

2. Eksperimentalni dio

U planiranju i izvođenju istraživanja koriste se opća znanja iz područja metodologije znanstvenog rada – priprema istraživanih materijala, provedba istraživanja i obrada rezultata. Koriste se metode i postupci koji omogućuju ponovljivost modifikacija i morfoloških značajki istraživanih materijala uz primjenu suvremenih i pouzdanih mjernih tehnika s ciljem vrednovanja djelotvornosti pojedinačnih učinaka. U obradi, analizi i vrednovanju dobivenih rezultata primjenjuju se odgovarajuće matematičko-statističke metode koje osiguravaju određeni stupanj pouzdanosti u donošenju zaključaka. Kako bi se osigurala ponovljivost provedenih modifikacija za potrebe istraživanja koristit će se pamučna referenta tkanina i netkani tekstil. U svrhu pripreme funkcionalnih prevlaka koristit će se dostupan propolis u ljekarnama i nativni propolis iz lokalnih pčelinjih izvora, čime se osigurava svježina i autentičnost uzorka. Osim propolisa, u istraživanju će se koristiti i biopolimerni materijali, prvenstveno polisaharidnog karaktera (natrij karboksimetilceluloza, hitozan i alginat). Njihova primjena omogućit će poboljšanje mehaničkih i bioloških svojstava prevlaka, uz dodatnu antimikrobnu i dermalno poticajnu funkcionalnost. Istraživanje će biti usmjereno na određivanje optimalnih uvjeta modifikacije tekstilnih materijala variranjem vrste i koncentracije odabranih polisaharida i propolisa.

Optimizacija formulacija provest će se primjenom dizajna eksperimenta (Design of Experiments, DOE), pri čemu će poseban naglasak biti stavljen na očuvanje izvornih tekstilnih svojstava modificiranih tekstilnih materijala. Metodologija istraživanja osmišljena je tako da omogućava sustavno ispitivanje svih relevantnih čimbenika koji utječu na kvalitetu i učinkovitost modificiranih materijala. Prvi korak uključuje karakterizaciju sirovog propolisa, ponajprije fenolnih spojeva i flavonoida (metoda tankoslojne kromatografije (TLC), UV-VIS spektroskopija). Nakon što se pripreme biopolimerne prevlake obogaćene propolisom bit će podvrgnute višestrukoj karakterizaciji kako bi se procijenile njihove morfološke i funkcionalne karakteristike. Svi eksperimenti bit će pažljivo osmišljeni i provedeni s ciljem sveobuhvatnog razumijevanja odnosa između kemijskog sastava, strukturnih karakteristika i biološke aktivnosti razvijenih bioaktivnih sustava na tekstilu. Takav pristup omogućit će sustavnu evaluaciju njihove učinkovitosti i stabilnosti u uvjetima koji simuliraju stvarnu topikalnu primjenu.

3. Zaključak

Znanstveni doprinos predloženog istraživanja ogleda se u sustavnom razvoju i optimiranju formulacija biopolimera i propolisa primjenom dizajna eksperimenta, kao i u funkcionalnoj modifikaciji tekstilnih materijala s ciljem postizanja prevlaka s antimikrobnim svojstvima, prikladnih za topikalnu primjenu. Dodatni doprinos očekuje se kroz analizu i razumijevanje bioadhezivnih svojstava razvijenih formulacija na tekstilu. Prednost ovih formulacija leži u uporabi sastojaka koji su prirodnog podrijetla i sigurni za oralnu primjenu, što ih čini posebno pogodnima i za vanjsku, tj. topikalnu upotrebu.

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**Jasna Dročić****Životopis**

Rođena je 8.1.1979. u Slavonskom Brodu. Diplomirala je 2009. na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu (studij tekstilne tehnologije; smjer: procesni). Od 2004 – 2007 radila u Međunarodnom centru za usluge u kulturi; podružnica: Posudionica i radionica narodnih nošnji na radnom mjestu Preparator narodnih nošnji i kostima. Radila na mnogim projektima tradicijske baštine i kulture kroz razne galerijske i scenske programe, muzejske izložbe. Od travnja 2008. – travnja 2018. radila u Modnoj kući Nebo, na radnom mjestu konstruktora odjeće. Od travnja 2018. zaposlena u Ansamblu narodnih plesova i pjesama Hrvatske Lado na radnom mjestu voditelja fundusa i radionice narodnih nošnji. Radi na projektima edukativnih radionica tradicijskih tehnika veza i načina izrade nošnji. Koautorica je izložbe „Ljepota bebrinske nošnje“ postavljene u Muzeju Prigorja u Sesvetama u trajanju od 3.6. – 25.7.2016. (izložba je predstavljala obiteljsku zbirku odjevnih predmeta i domaćeg tekstila od početka 20. stoljeća do danas).

Naslov teme doktorskog rada

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Studijski savjetnik

Prof. dr. sc. Sanja Ercegović Ražić

Datum obrane doktorskog rada

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ISTRAŽIVANJE MOGUĆNOSTI ZAMJENE VLAKNA SVILE U TRADICIJSKOJ TKANINI SLAVONIJE S CILJEM POVEĆANJA ČVRSTOĆE I TRAJNOSTI NARODNE NOŠNJE

Jasna DROČIĆ

Sveučilište u Zagrebu Tekstilno-tehnološki Fakultet, Prilaz baruna
Filipovića 28a, Zagreb jasna.drocic1@gmail.com

Sažetak: Cilj doktorskog rada je istražiti i definirati optimalnu zamjenu za svileno vlakno u potki tradicijskog tkanog platna, koja će poboljšati mehanička svojstva tkanine, osobito čvrstoću i trajnost, a pritom zadržati estetske i taktilne karakteristike izvorne svile. Poseban naglasak stavljen je na sličnost zamjenskog vlakna u pogledu izgleda, boje, debljine, finoće i ponašanja materijala tijekom vezenja zlatovezom, kako bi se očuvala autentičnost vizualnog identiteta slavonske nošnje.

1. Uvod

Tradicijsko ruho Slavonije, odnosno slavonsko-brodskog područja, predstavlja iznimno vrijedan segment hrvatske kulture i tekstilne baštine. Najsvećaniji dijelovi ženske narodne nošnje izrađivani su od domaćeg tkanog platna u kojem je osnova bila pamučna, dok je potka bila izrađena od svilenih niti. Takva kombinacija materijala omogućavala je izradu finog i estetski izuzetno vrijednog tekstila, osobito pogodnog za ručni vez – zlatovez – kojim je nošnja dodatno ukrašavana. Ovakav tip narodnog ruha bio je izuzetno cijenjen početkom 20. stoljeća te se zbog svoje ljepote i spoznaje o njegovoj vrijednosti nije se često nosio. Žene su ga oblačile svega tri puta godišnje i to pri nedjeljnom odlasku crkvi. Svileni vlakno, iako vizualno i taktilno iznimno atraktivno, pokazuje određena ograničenja u pogledu mehaničke čvrstoće, otpornosti na habanje i dugotrajnosti, što predstavlja izazov u suvremenoj izradi, rekonstrukciji i scenskoj primjeni tradicijskog ruha. Taj je problem osobito izražen kod nošnji koje se intenzivno koriste u izvedbenim uvjetima. Jedan od ključnih projekata u okviru rada fundusa i radionice narodnih nošnji odnosi se na izradu novih tipova nošnji prema primjercima izvornih primjeraka koje Ansambl Lado posjeduje i koristi, a koji zbog svoje starosti, osjetljivosti materijala i stupnja istrošenosti više nisu prikladni za scensku uporabu. Upravo je dugogodišnje praktično iskustvo rada s izvornim materijalima i konstrukcijama nošnji bio poticaj za znanstveno istraživanje predstavljeno u ovom doktorskome radu. Pri rekonstrukciji narodnih nošnji posebno se ističe spoznaja o dugotrajnosti ručne izrade zlatoveza i trudu uloženom u proces izrade, vrijednosti zlatne - srmene niti pređe i ukrasnih dodataka [1-5].

2. Eksperimentalni dio

Istraživanje obuhvaća analizu potencijalnih prirodnih i regeneriranih vlakana kao zamjena za svilu, eksperimentalnu izradu tkanina s pamučnom osnovom i zamjenskim vrstama vlakna u potki te ispitivanje njihovih mehaničkih, fizikalnih i estetskih svojstava. Dobiveni rezultati imati će mogućnost izravne primjene u izradi novih scenskih funkcionalnih nošnji za potrebe Ansambla Lado, uz istodobno poštivanje tradicijskih tehnika i vizualnih obilježja izvorne odjeće.

3. Rezultati i rasprava

Ispitivanjima će se utvrđivati značajnost razlika među tkanina izrađenih različitim vrstama potke te mogućnosti poboljšana mehaničkih svojstva uporabom zamjenskih sirovina u odnosu na svileno vlakno, osobito u pogledu čvrstoće i otpornosti na habanje. Analizirati će se potencijal tekstilnih i taktilnih karakteristika pojedinih zamjena kako bi se zadržao izgled i vizualne karakteristike svilenog vlakna, uz istodobno bolje ponašanje u uvjetima pojačanog mehaničkog opterećenja. Rezultati će biti interpretirani u kontekstu zahtjeva scenske primjene, pri čemu je naglašena važnost kompromisa između autentičnosti i funkcionalnosti.

4. Zaključak

Na temelju provedenog istraživanja moći će se zaključiti da je moguće zamijeniti svileno vlakno u potki tradicijskog tkanog platna odgovarajućim alternativnim vlaknima, uz postizanje poboljšanih mehaničkih svojstava i zadržavanje estetske vrijednosti tkanine. Dobiveni rezultati potvrditi će da znanstveno utemeljen pristup materijalima može značajno doprinijeti očuvanju i suvremenoj primjeni tradicijske narodne nošnje. Rad pruža temelj za daljnja istraživanja i praktičnu primjenu u izradi novih tipova nošnji, osobito za potrebe scenske uporabe, čime se osigurava dugoročno očuvanje kulturne baštine.

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**Selma Imamagić****Životopis**

Selma Imamagić rođena je 1998. godine u Zagrebu. 2022. godine diplomirala je na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu, smjer: odjevno inženjerstvo. Nakon završetka diplomskog studija, iste godine upisuje doktorski studij Tekstilna znanost i tehnologija. Trenutno radi kao asistent na Zavodu za odjevnju tehnologiju Sveučilišta u Zagrebu Tekstilno-tehnološkog fakulteta. U koautorstvu je do sada objavila 4 izvorna znanstvena, 1 pregledni i 2 stručna rada. Područja njenog znanstvenog interesa su: studij rada, zaštitna odjeća te organizacija procesa proizvodnje u odjevnoj industriji.

Naslov teme doktorskog
rada

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Studijski savjetnik

Prof. dr. sc. Anica Hursa Šajatović

Datum obrane doktorskog
rada

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MODEL RASPOREĐIVANJA TEHNOLOŠKIH OPERACIJA PO RADNIM MJESTIMA U PROCESU PROIZVODNJE ODJEĆE

Selma IMAMAGIĆ

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28 a, selma.imamagic@tff.unizg.hr

Sažetak: Raspoređivanje je proces raspodjele ograničenih sredstava određenom skupu aktivnosti u svrhu optimizacije jednog ili više kriterija tog raspoređivanja. U odjevnoj industriji ograničena sredstva su strojevi i ljudska radna snaga dok aktivnosti predstavljaju radni nalozi u proizvodnji. Doktorski rad temelji se na izradi modela raspoređivanja tehnoloških operacija po radnim mjestima u procesu proizvodnje odjeće. Cilj je definirati funkciju cilja kojom će se postići što kraće vrijeme trajanja proizvodnog procesa uz što optimalniji stupanj proizvodnosti radnih mjesta.

1. Uvod

Raspoređivanje (engl. *scheduling*) je proces raspodjele ograničenih sredstava određenom skupu aktivnosti u svrhu optimizacije zadane funkcije cilja, odnosno jednog ili više kriterija tog raspoređivanja. Ovisno o situaciji u kojoj je potrebno provesti raspoređivanje, sredstva i aktivnosti mogu se pojaviti u različitim oblicima [1]. U odjevnoj industriji ograničena sredstva predstavljaju strojeve i radnike dok su aktivnosti radni nalozi u proizvodnom sustavu, odnosno tehnološke operacije ukoliko se izrađuje jedan proizvod.

Problem raspoređivanja tehnoloških operacija po radnim mjestima u procesu proizvodnje odjeće spada u problem raspoređivanja s ograničenim sredstvima (engl. *Resource Constrained Project Scheduling Problem*, RCPSP). Problem raspoređivanja s ograničenim sredstvima obuhvaća skup J koji se sastoji od n poslova, $J_1, J_2, J_3, \dots, J_n$. Skup poslova J treba pridružiti skupu strojeva M i skupa radnika K u vremenskom periodu $T = 0, \dots, t_{max}$ [2]. Pritom svaki posao oznake j mora biti izveden na stroju i koji pripada podskupu strojeva M_j skupa M koji su potrebni za posao j i izveden od strane radnika k koji pripada podskupu K_j skupa K , podskupu radnika koji svojim vještinama mogu obaviti posao j na stroju i [2].

Dodatno, svaki se posao J_j sastoji od m_j operacija $O_{j1}, O_{j2}, O_{j3}, \dots, O_{jm_j}$ koje se moraju izvesti po unaprijed određenom redoslijedu izvođenja, poštujući tzv. uvjete prednosti (engl. *precedence constraints*) i na pripadajućem stroju [1]. Svaku operaciju O_{jk} karakterizira vrijeme izvođenja p_{jk} (engl. *processing time*).

Cilj dokorskog rada jest izrada modela raspoređivanja tehnoloških operacija po radnim mjestima u procesu proizvodnje odjeće kojim će se minimizirati ciklus proizvodnje (engl. *makespan*) uz istovremeno postizanje najboljeg mogućeg stupnja proizvodnosti po radnim mjestima (engl. *productivity rate*).

2. Eksperimentalni dio

Prvi dio eksperimentalnog dijela dokorskog rada provest će se u poduzeću za proizvodnju odjeće. Na temelju ulaznih podataka dobivenih iz proizvodnje definiraju se tipovi korištenih strojeva te svojstva posla i ograničenja unutar sustava, tab. 1.

Tablica 2: Okolina strojeva, svojstva posla i ograničenja unutar pogona za proizvodnju odjeće [2, 3]

Tip stroja	Opis
Paralelni identični strojevi (Pm)	Postoji m identičnih strojeva u pogonu poduzeća koji rade paralelno (npr. univerzalni šivaći strojevi u više proizvodnih linija).
Karakteristika posla i ograničenja sustava	
Ograničenje redoslijeda (engl. <i>precedence constraints</i>)	Tehnološka operacija ne može započeti dok ona koja joj prethodi nije završena.
Ograničenje kapaciteta (engl. <i>capacity constraints</i>)	Na svakom stroju može se istovremeno obavljati samo jedna tehnološka operacija.
Prekidivost radnog naloga (engl. <i>pre-emption</i>)	Radni nalog se smije prekidati tijekom svoga izvođenja te ponovno nastaviti nakon određenog vremenskog perioda ili izrađene količine odjevnih predmeta.
Vještina radnika (engl. <i>workers' skill requirement</i>)	Tehnološke operacije izrade odjevnog predmeta imaju definiranu kategoriju rada, tj. složenost izvođenja. Definiran je podskup radnika koji imaju vještine za izvođenje tehnoloških operacija po kategoriji izrade. Dodatno, radnici mogu raditi na podskupu strojeva za koje su obučeni.
Ograničenje dnevnog radnog vremena (engl. <i>shift and workday constraints</i>)	Svaki stroj i radnik dnevno rade isključivo u jednoj smjeni (450 minuta).

3. Rezultati i rasprava

Vrednovanje razvijenog modela raspoređivanja tehnoloških operacija po radnim mjestima u procesu proizvodnje odjeće temeljit će se na kriterijima vremena trajanja ciklusa proizvodnje te stupnja proizvodnosti. Evaluacija razvijenog modela za raspoređivanje u proizvodnji bit će provedena na temelju rezultata rada u realnom sektoru.

4. Zaključci

Problem raspoređivanja u proizvodnim sustavima obuhvaća pronalazak najboljeg mogućeg rasporeda izvođenja tehnoloških operacija po radnim mjestima. Njegovim rješavanjem teži se optimizirati jedan ili više kriterija samog raspoređivanja. U doktorskom radu određeno je kako će se optimizirati ciklus trajanja proizvodnog procesa izrade odjeće te stupanj proizvodnosti po radnim mjestima. Time bi se postiglo zadovoljstvo kako poslodavca tako i radnika u proizvodnji.

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**Josip Jelić****Životopis**

Josip Jelić rođen je 26.6.1980. godine u Zagrebu. Osnovnu i srednju školu završio je u Zagrebu. Tekstilno-tehnološki fakultet Sveučilišta u Zagrebu završio je 2015 godine. Na Tekstilno-tehnološkom fakultetu Sveučilišta u Zagrebu upisao je poslijediplomski sveučilišni studij Tekstilna znanost i tehnologija 2017 godine.

Naslov teme doktorskog rada

Ciljana izrada vlaknastog nosača za uzgoj tkivnih stanica kombiniranim elektroispredanjem

Studijski savjetnik

Prof. dr. sc. Budimir Mijović

Datum obrane doktorskog rada

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MEHANKA KOMPOZITNIH MATERIJALA

Josip JELIĆ

Carwizz, Slavonska avenija 26/9, Zagreb, josipjelic2004@gmail.com

Sažetak: Kompozit ili kompozitni materijal građen je od međusobno čvrsto spojenih različitih materijala radi dobivanja novog, drugačijeg materijala, s fizikalnim ili kemijskim svojstvima koja nadmašuju svojstva pojedinačnih dijelova ili sa svojstvima koje ti pojedinačni dijelovi nemaju. Većina kompozita sadrži jedan materijal kao kontinuiranu fazu (matricu), a u nju su uklopljeni odvojeni dijelovi druge faze, koja najčešće ima funkciju ojačala. Mehanička svojstva kompozitnih materijala poput: vlačnih, tlačnih, savitljivosti, čvrstoće i krutosti ovise o različitim čimbenicima, a neki od njih su: sastav materijala, njihovi volumni udjeli i korišteni proizvodni procesi. Istraživanje različitih tehnika proizvodnje kompozitnih materijala je veoma bitno. To može uključivati proučavanje procesa poput ručnog postavljanja, namotavanja filamena, kompresijskog kalupljenja i još mnogo toga kako bi se optimizirala mehanička svojstva konačnog proizvoda.

1. Uvod

Tekstilni kompozitni materijali napredni su materijali koji kombiniraju tekstil (kao što je tkani ili netkani tekstil) s drugim materijalima, često polimerima ili vlaknima za ojačavanje, kako bi se stvorili materijali s poboljšanim svojstvima i učinkom [1]. Ovi se kompoziti materijali koriste u širokom rasponu primjena u raznim industrijama zbog svoje jedinstvene kombinacije karakteristika, koje mogu uključivati čvrstoću, izdržljivost, laganu težinu, fleksibilnost i toplinsku ili električnu vodljivost [2]. Neki od ključnih aspekata i primjena tekstilnih kompozitnih materijala su: Materijali za ojačanje: Tekstilni kompoziti često koriste vlakna kao što su karbonska vlakna, staklena vlakna, aramidna vlakna (npr. Kevlar) ili prirodna vlakna (npr. lan ili juta) kao ojačanje. Ova vlakna daju čvrstoću i krutost kompozitu dok istovremeno održavaju fleksibilnost i svojstva lagane tkanine. Matrični materijali: Matrični materijal, obično polimerna smola, koja okružuje i povezuje ojačavajuća vlakna zajedno, osiguravajući koheziju i prijenos opterećenja između vlakana. Uobičajeni matrični materijali uključuju epoksid, poliestar i termoplastične polimere. Tehnike laminiranja: Tekstilni kompozitni materijali često se proizvode pomoću različitih tehnika laminiranja, kao što su ručno polaganje, vakuumsko pakiranje u vrećice, infuzija smole ili stvrdnjavanje u autoklavu, ovisno o specifičnoj primjeni i potrebnim karakteristikama izvedbe.

2. Materijal i metode rada

U radu je korišten Shieldex Bonn koji je visoko vodljivi termički vezan netkani materijal izrađen od 100% poliamida (Nylon 6.6) sa sadržajem srebra od cca. 17%. Zbog sadržaja srebra ovaj netkani materijal djeluje antimikrobno, električki je i toplinski vodljiv te štiti od elektromagnetskog zračenja. Unatoč svojim antimikrobnim svojstvima, Shieldex Bonn se također koristi za tehničke svrhe u industriji. Osim elektromagnetske zaštite, ovaj tehnički materijal osigurava antistatičku disipaciju i vrlo dobru električnu vodljivost do $< 0,5 \Omega$. Shieldex Bonn je posebno prikladan za senzore u medicinskoj tehnologiji, zaštitne tapete u zaštiti prostorija ili antistatičko pražnjenje u elektroničkim komponentama. Također materijal je usklađen s OEKO-TEX® STANDARD 100, REACH i RoHS. Učinkovitost zaštite (0,2–2 GHz) Prosječno < 63 dB od 0,2 GHz – 2 GHz. Učinkovitost zaštite (2–5 GHz) Prosječno < 70 dB od 2 GHz – 5 GHz. Učinkovitost zaštite (5–14 GHz) Prosječno < 78 dB od 5 GHz – 14 GHz. Težina $56 \text{ g/m}^2 \pm 15 \%$. Debljina $0,35 \text{ mm} \pm 30 \%$.

2.1. Mjerna oprema i uzorci

Norma ISO 9073-3, koju je razvila Međunarodna organizacija za standarde (ISO), opisuje metodu ispitivanja za određivanje vlačnih svojstava netkanih tkanina metodom posmične trake. Za mjerenje se koristi dinamometar Statimat M tvrtke Textechno. Točnost ovog aparata odgovara klasi 1, s pogreškom zabilježene maksimalne sile $\pm 1\%$. Sila pri lomljenju materijala općenito je poznata kao vlačna čvrstoća ili krajnja vlačna čvrstoća, što se odnosi na napetost. Produljenje se mjeri primjenom vlačne sile ili rastezanjem materijala na isti način kao što je prethodno opisano i određivanjem promjene duljine u odnosu na izvornu. produljenje se mjeri primjenom vlačne sile ili rastezanjem materijala na isti način kao što je prethodno opisano i određivanjem promjene duljine u odnosu na izvornu. Produljenje se izražava kao postotak izvorne duljine. Krajnje produljenje je postotak promjene duljine od izvorne do prekida. Za mjerenje se pripremaju uzorci u obliku traka dimenzija

$50 \pm 0,5$ mm x $200 \pm 0,5$ mm. Izrezano je po 10 uzoraka u 3 smjera po šablonu sa slike 3, sa sljedećim oznakama: X smjer 0° , Y smjer 90° , Z smjer 45° .

3. Rezultati vlačne sile na suhim uzorcima

U radu je izmjereno i prikazano ponašanje materijala pri vlačnom naprezanju na dinamometru. Testirano je 20 uzoraka u suhom stanju i 20 uzoraka u mokrom stanju u 3 različita smjera. Tijekom mjerenja, mjerna duljina uređaja za ispitivanje rastezanja postavljena je na 100 ± 1 mm. Ispitna brzina postavljena je na 100 mm min⁻¹, te maksimalna sila 1000 N. Atmosfera osigurana za predkondicioniranje i kondicioniranje uzoraka odgovarala je preporukama iz EN 20139.

Prema rezultatima može se vidjeti da najveću čvrstoću u X smjeru u suhom stanju ima uzorak 4 i ona iznosi 172,51 cN/mm. Najmanju čvrstoću ima uzorak 2 i ona iznosi 135,21 cN/mm. Uzorak 4 također ima i najveće prekidno istezanje koje iznosi 61,40 %, dok najmanje prekidno istezanje ima uzorak 2 i ono iznosi 42,30 %. Najveću čvrstoću u Y smjeru u suhom stanju ima uzorak 4 i ona iznosi 82,21 cN/mm. Najmanju čvrstoću ima uzorak 2 i ona iznosi 65,41 cN/mm. Prema izmjerenim podacima u suhom stanju najveću čvrstoću materijal ima u X smjeru.

4. Zaključak

Mehanička svojstva kompozitnih materijala poput: vlačnih, tlačnih, savitljivosti, čvrstoće i krutosti ovise o različitim čimbenicima, a neki od njih su: sastav materijala, njihovi volumni udjeli i korišteni proizvodni procesi. Istraživanje različitih tehnika proizvodnje kompozitnih materijala je veoma bitno. To može uključivati proučavanje procesa poput ručnog postavljanja, namotavanja filamena, kompresijskog kalupljenja i još mnogo toga kako bi se optimizirala mehanička svojstva konačnog proizvoda.

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**Ana Kalazić****Životopis**

Rođena 1993. godine u Zagrebu. Nakon završetka Opće gimnazije Tituša Brezovačkog u Zagrebu, akademske godine 2012./2013. upisuje studij na Ekonomskom fakultetu u Zagrebu, gdje stječe zvanje stručne prvostupnice poslovne ekonomije. Godine 2015./2016. upisuje Tekstilno-tehnološki fakultet u Zagrebu, gdje diplomira u akademskoj godini 2019./2020. i stječe zvanje magistre inženjerke tekstilne tehnologije i inženjerstva. U akademskoj godini 2020./2021. upisuje poslijediplomski doktorski studij Tekstilna znanost i tehnologija na Tekstilno-tehnološkom fakultetu u Zagrebu. Od 2020. do 2023. godine radi na istom fakultetu kao stručni suradnik na projektu IRI II „Razvoj multifunkcionalne negorive tkanine za dualnu namjenu“, financiranom iz Europskog fonda za regionalni razvoj. Od 2024. godine nastavlja rad na Tekstilno-tehnološkom fakultetu u Zagrebu na mjestu asistenta.

Naslov teme doktorskog rada

Razvoj metode za objektivno vrednovanje taktilnih karakteristika tkanina

Studijski savjetnik

Doc. dr. sc. Snježana Brnada

Datum obrane doktorskog rada

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ISPITIVANJE POVRŠINSKE HRPAVOSTI TKANINE U RAZLIČITIM SMJEROVIMA OPTIČKOM METODOM

Ana KALAZIĆ

Sveučilište u Zagrebu, Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, ana.kalazic@ttf.unizg.hr

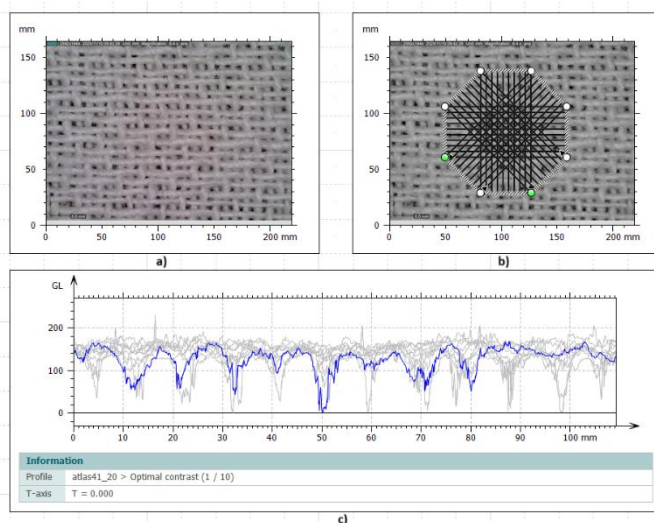
Sažetak: U radu je analizirana površinska hrapavost tkanina primjenom optičke metode uz pomoć softvera. Digitalne mikroskopske slike površine tkanine u atlas vezu korištene su za generiranje primarnih profila hrapavosti u različitim smjerovima mjerenja. Posebna pozornost posvećena je utjecaju smjera mjerenja, a rezultati potvrđuju visoku osjetljivost optičke metode na lokalne mikrostrukturne razlike i ortotropnu prirodu tekstilnih površina.

1. Uvod

Optička analiza površine tkanine omogućuje beskontaktno ispitivanje mikoreljefa tkanina. Hrapavost tkanine je uvjetovana vrstom veza, gustoćom niti i smjerom mjerenja, zbog čega je nužna analiza profila hrapavosti u više smjerova. U radu je provedena analiza površinske hrapavosti s ciljem ispitivanja utjecaja položaja i orijentacije mjernih linija na dobivene vrijednosti parametra hrapavosti. Poseban naglasak stavljen je na tkaninu u atlas vezu zbog njenih specifičnih topografskih obilježja.

2. Eksperimentalni dio

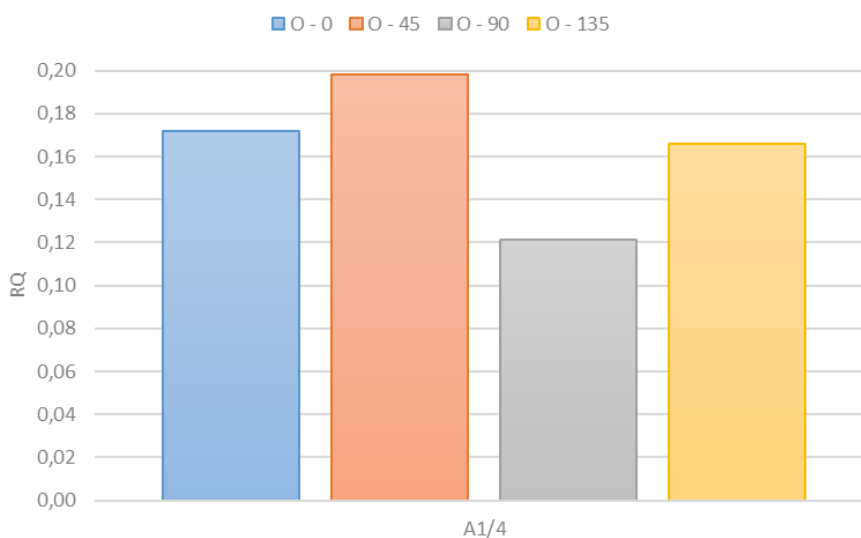
Površina tkanine snimljena je Dino-Lite digitalnim mikroskopom, a dobivene slike analizirane su u softveru MountainsLab. Radi naglašavanja topografskih razlika, slike su pretvorene u monokromatski prikaz. Analiza je provedena u četiri smjera mjerenja: dva glavna smjera (smjer osnove i smjer potke) te dva dijagonalna (pod kutem od 45° i 135°). Za svaki smjer definirano je deset mjernih linija po kojima su generirani profili hrapavosti. Položaj linija u odnosu na niti pređe pokazao se ključnim čimbenikom jer linije položene duž niti daju glađe profile, dok linije u međuprostoru između niti bilježe veću lokalnu hrapavost. Parametar hrapavosti R_q izračunan je iz primarnih profila, a konačna vrijednost za pojedini smjer određena je kao aritmetička sredina svih mjerenja.



Slika 1: Sučelje MountainsLab softvera – a) monokromatska slika tkanine, b) odabrane linije za generiranje profila hrapavosti svakog pojedinog kuta mjerenja, c) skup profila hrapavosti jednog od ispitanih smjerova

3. Rezultati i rasprava

Rezultati optičke analize pokazali su izraženu smjernu ovisnost Rq parametra hrapavosti površine tkanine u atlas vezu, dobivenu optičkom metodom mjerenja, što upućuje na anizotropni karakter površinske topografije. U smjeru osnove zabilježena je najmanja vrijednost parametra Rq, što upućuje na najizraženiju glatkoću u tom smjeru i predstavlja tipično obilježje atlas veza, pri čemu gušći i napetiji raspored osnovnih niti dovodi do manje izraženih prijelaza odnosno flotacija te ujednačenije površinske topografije tkanine. Nasuprot tome, više vrijednosti parametra hrapavosti u smjeru potke i dijagonalnim smjerovima odražavaju složeniji utjecaj rasporeda niti i njihovih međusobnih interakcija na optički registriranu morfologiju površine tkanine, čime se potvrđuje visoka osjetljivost optičke metode na lokalne strukturne značajke i smjernu nehomogenost same tkanine.



Slika 2: Vrijednost parametra hrapavosti Rq u različitim smjerovima (0°, 45°, 90° i 135°) mjerenim na tkanini u atlas vezu

4. Zaključci

Optička metoda analize površinske hrapavosti u softveru MountainsLab omogućuje detaljnu karakterizaciju mikroreljefa tkanina. Dobiveni rezultati potvrđuju izraženu ovisnost parametra hrapavosti o smjeru mjerenja i položaju mjernih linija, koja proizlazi iz ortotropne prirode tkanih struktura te je posebno naglašena kod tkanina u atlas vezu uslijed karakterističnih flotiranja. Optička metoda stoga predstavlja vrijedan alat za analizu finih površinskih razlika, uz nužnost pažljivog definiranja mjernog postupka.

5. Literatura

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**Ivan Kraljević****Životopis**

Ivan Kraljević je rođen 1991. Upisuje studij na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu 2010. Uspješno završava prijediplomski sveučilišni studij Tekstilna tehnologija i inženjerstvo, smjer Projektiranje i menadžment tekstila 2013., a dvije godine poslije diplomski sveučilišni studij pod mentorstvom prof. dr. sc. Antonete Tomljenović. U studenom 2016. upisuje poslijediplomski sveučilišni studij Tekstilna znanost i tehnologija. Od veljače 2016. je zaposlen u Jadran Tvornici čarapa d.d. kao voditelj pletione i šivaone. Kao doktorand suradnik je bio uključen u HRZZ projekt IP-2016-06-5278. U koautorstvu je publicirao više znanstvenih radova i jedan stručni rad, a područje znanstvenog interesa vezuje uz kvalitetu i ispitivanje inovativnih materijala za izradu čarapa i kože.

Naslov teme doktorskog rada

/

Studijska savjetnica

Prof. dr. sc. Antoneta Tomljenović

Datum obrane doktorskog rada

/

VRJEDNOVANJE UDOBNOSTI PAMUČNIH KRATKIH ČARAPA

Ivan KRALJEVIĆ

Jadran Tvornica čarapa d.d., Vinka Žganeca 2, HR - 10000 Zagreb,
ivan.kraljevic@ttf.unizg.hr

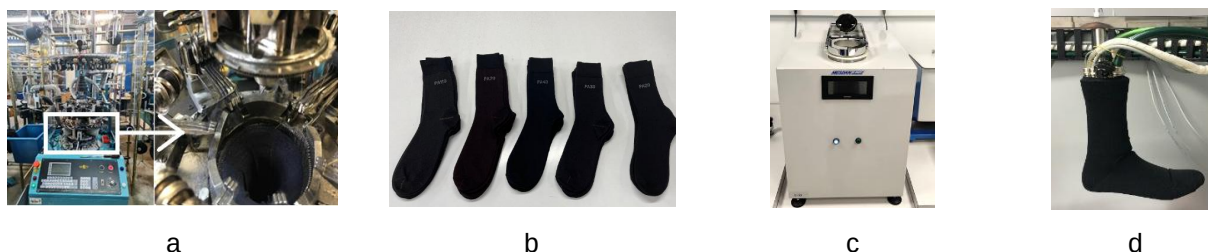
Sažetak: Vrijednovana je udobnost finih muških kratkih čarapa, izrađenih s najvećim udjelom pamuka u potpunom platiranju s teksturiranom multifilamentnom poliamidnom pređom različite duljinske mase. Pritom je ispitana dišljivost pletiva čarapa ispitivanjem propustljivosti zraka, hidrofilnost pletiva čarapa ispitivanjem apsorptivnosti vlage te toplinska svojstva čarapa ispitivanjem otpornosti prolazu topline na toplinskom stopalu.

1. Uvod

Kratke čarape su pleteni odjevni predmeti koji se nalaze u izravnom dodiru s kožom korisnika, prekrivajući pritom stopalo, petu i dio potkoljenice [1]. Tijekom uporabe trebaju ispunjavati visoke zahtjeve na uporabnu kvalitetu, a posebice udobnost. Pritom su propustljivost zraka, vlage i topline pletene strukture čimbenici koji izravno utječu na udobnost čarapa. Kako udobnost značajno ovisi o konstrukciji čarapa i sirovinskom sastavu, veoma je značajno odabrati odgovarajuće pređe za njihovu izradu [2]. Muške kratke čarape se najčešće izrađuju s visokim udjelom pamuka koji osigurava mekoću i udobnost odijevanja, a u mješavini s poliamidnom pređom poradi poboljšanja pristalosti i trajnosti čarapa. Stoga je u okviru istraživanja vrijednovana udobnost muških kratkih čarapa izrađenih s najvećim udjelom pamuka u potpunom platiranju s pređom iz poliamida 6.6 različite duljinske mase. Ispitana je dišljivost pletiva čarapa ispitivanjem propustljivosti zraka, hidrofilnost pletiva čarapa ispitivanjem apsorptivnosti vlage te toplinska svojstva čarapa ispitivanjem otpornosti prolazu topline na toplinskom stopalu [3].

2. Eksperimentalni dio

Istraživanje je provedeno na pet skupina finih muških kratkih čarapa crne boje (Slika 1b) izrađenih u veličini 42 s najvećim udjelom pamuka (primjenom jednonitne prstenasto predene pređe finoće 29.4 tex) u potpunom platiranju s teksturiranom multifilamentnom pređom iz poliamida 6.6 različite duljinske mase, označenih: PA1 (49 dtex); PA2 (70 dtex); PA3 (93 dtex); PA4 (166 dtex); PA5 (237 dtex). Čarape su izrađene u jednostavnom desno-lijevom prepletu, uz izuzetak okrajka koji je izrađen u desno-desnom rebrastom prepletu 1×1. Pletene su u Jadran Tvornici čarapa d.d. na čaraparskom automatu finoće E14 tt. Lonati promjera cilindra 95 mm, (3 3/4") koji je pleo sa 168 igala (Slika 1a) te izglacane pri temperaturi od 120 °C na stroju tt. Cortese [3].



Slika 1: Kratke čarape: a) izrada ispitivanih čarapa primjenom čaraparskog automata, b) prikaz izrađenih čarapa, c) ispitivanje propustljivosti zraka (tt. Mesdan-Lab), d) ispitivanje toplinske udobnosti čarapa na toplinskom stopalu

Temeljna svojstva muških kratkih čarapa, označenih (CO/PA1 – CO/PA5), prikazana su u tablici 1, a uključuju vrijednosti mase jedne čarape te plošne mase, debljine i gustoće pletiva čarapa.

Tablica 1: Temeljna svojstva pamučnih kratkih čarapa [3]

Uzorak čarapa	Masa čarape, g	Plošna masa pletiva, g/m ²	Debljina pletiva, mm	Br. nizova/cm	Br. redova/cm
CO/PA1	15,5	178	0,90	11	12

CO/PA2	16,5	190	0,93	11	12
CO/PA3	17,9	203	1,00	10	11
CO/PA4	21,8	224	1,13	10	11
CO/PA5	25,2	263	1,25	9	10

Prije ispitivanja uzorci čarapa su kondicionirani položeni na ravnu površinu u trajanju od najmanje 24 sata u uvjetima referentne atmosfere, temperature 20 ± 2 °C i relativne vlažnosti 65 ± 4 %. Propustljivost zraka pletiva čarapa (Slika 1c) je ispitana prema normi EN ISO 9237:1995 (uz površinu 5 cm^2 i podtlak 100 Pa), apsorpcija vlage pletiva vlage metodom sušenja prema ASTM D2654-22, a otpornost prolazu topline na toplinskom stopalu (Slika 1d, *Thermal foot manikin system UCS*, uz strujanje zraka 1 m/s).

3. Rezultati i rasprava

Povećanjem duljinske mase poliamidne pređe primijenjene za platiranje pletiva čarapa povećava se masa čarape te debljina i plošna masa pletiva čarapa, dok se broj nizova i redova očica u pletenoj strukturi smanjuje (Tablica 1). S povećanjem duljinske mase platirne pređe također se povećava otpor prolazu topline čarapa, a smanjuje propustljivost zraka i apsorpcija vlage pletiva čarapa (Tablica 2). Proizlazi da se u debljih, gušćih i težih struktura pletiva čarapa smanjuje dišljivost, apsorpcija vlage i propustljivost topline čarapa.

Tablica 2: Svojstva udobnosti pamučnih kratkih čarapa [3]

Uzorak čarapa	Apsorpcija vlage, %	Propusnost zraka, mm/s	Otpor prolazu topline, $\text{m}^2 \text{ }^\circ\text{C/W}$
CO/PA1	7,0	912,85	0,021451
CO/PA2	6,4	738,94	0,025756
CO/PA3	6,0	722,13	0,034049
CO/PA4	5,7	584,48	0,040618
CO/PA5	5,6	477,04	0,042103

4. Zaključak

Kako se muške kratke čarape uz pamuk najčešće izrađuju u mješavini s poliamidom, utvrđeno je da je odgovarajućim odabirom duljinske mase platirne teksturirane multifilamentne pređe iz poliamida 6.6 moguće utjecati na udobnost kratkih čarapa.

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**Robert Matašić****Životopis**

Robert Matašić rođen je 1999. godine u Zagrebu. Na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu 2020. godine završio je prijediplomski, a 2022. diplomski studij Tekstilna tehnologija i inženjerstvo, smjer Projektiranje i menadžment tekstila. U akademskoj godini 2020./2021. dobitnik je Rektorove nagrade za društveno koristan rad te Dekanove nagrade za aktivno sudjelovanje u promociji Fakulteta. U akademskoj godini 2021./2022. dobitnik je Dekanove nagrade za postignut izvrstan uspjeh tijekom studija. Dobitnik je pet zlatnih i jedne srebrne medalje za inovacije na domaćim i svjetskim izložbama inovacija. Nakon završetka studija radi dvije godine u struci. U akademskoj godini 2024./2025. upisuje doktorski sveučilišni studij Tekstilna znanost i tehnologija na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu, a krajem 2024. godine zapošljava se kao asistent na Tekstilno-tehnološkom fakultetu. Sudjeluje na projektu IP.1.1.03.0143 *Multifunkcionalna povezanost osobne zaštitne opreme u svrhu zaštite zdravlja i povećane funkcionalnosti*.

Naslov teme doktorskog rada

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Studijska savjetnica

Prof. dr. sc. Snježana Firšt Rogale

Datum obrane doktorskog rada

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PROGRAM ZA PROJEKTIRANJE PLETENIH UZORAKA

Robert MATAŠIĆ

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, Zagreb, robert.matasic@tff.unizg.hr

Sažetak: Tema doktorskog rada obuhvaća ispitivanje toplinskih svojstava 48 pletenih pulovera izrađenih iz kulirnih desno-lijevih pletiva. Za izradu pulovera koristit će se 100% pamuk, 100% akril, 50/50% vuna/akril i 50/50% pamuk/akril končana pređa finoće 36 tex x 2. Mjerni uzorci će biti izrađeni na ravnopletaćem dvoigleničnom stroju tvrtke STOLL finoće E5, E7 i E10. Koristit će se program M1Plus za projektiranje pletenih mjernih uzoraka. Navedenim programom se projektirana struktura pletiva i kraj odjevnog predmeta prenose u datoteku spremnu za strojnu uporabu.

1. Uvod

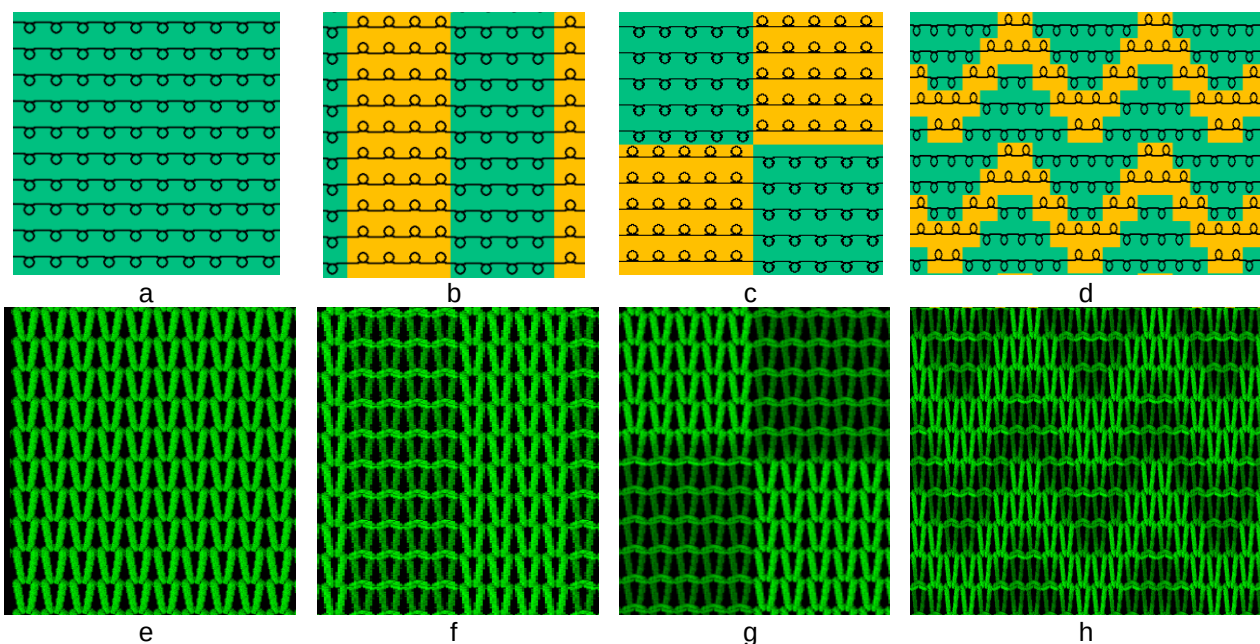
Interes za tehnologiju pletenja leži u mogućnosti širokog područja primjene. Računalno vođeno pletenje na ravnopletaćim strojevima jedno je od tehnologija izrade kulirnih pletiva. Raznolikost pletenih proizvoda opravdava korištenje u modne, medicinske i tehničke svrhe. Primjena ravnopletaćih strojeva uz uporabu programa M1Plus uključuje razne mogućnosti kao što su dizajniranje i izrada urbanih ženskih pletenih kolekcija s uzorcima optičkih iluzija [1], izrada bešavnih rukavica s pet prstiju s predviđenom vrijednošću jedinične kompresije i odgovarajućom uzdužnom krutošću ovisno o anatomiji ruke [2], izrada tradicionalnih vjenčanica s kineskim motivima pletenih tehnikom platiranja [3], izrada pletenih pametnih uložaka za obuću integriranih s piezoelektričnim nanogeneratorima za istovremeno prikupljanje energije iz ljudskog kretanja i praćenje signala ljudskog hoda [4] te izrada 3D pletiva kao što su pleteni džepovi, srčani zalisci, medicinske čarape i pleteni gornji dijelovi obuće [5].

2. Eksperimentalni dio

M1plus je profesionalni CAD/CAM program za dizajniranje, programiranje i pripremu uzoraka za proizvodnju na STOLL ravnopletaćim strojevima. Omogućuje dizajnerima i tehnolozima izradu struktura krojeva, uzoraka boja i potpuno oblikovanih odjevnih predmeta za različite finoće strojeva. Program nudi uređivanje očicu po očicu, širok izbor elemenata za pletenje (rupice, pletenice, romboide), opcije platiranja te vizualne preglede pletiva za provjeru izvedivosti prije proizvodnje. Vizualni pregled uključuje prikaz simbola očica i same strukture pletiva što pomaže u procesu pletenja kompleksnih prepleta. Program dolazi s mogućnošću provjere napisane programske datoteke što pomaže u identificiranju problema kao što su sintaktičke pogreške, ograničenja prijenosa očica s jedne iglenice na drugu ili sudaranje nosača pređe, smanjujući pogreške na stroju, a time i na pletivu [6].

3. Rezultati i rasprava

Primjenom navedene strojne opreme i prikladnog računalnog programa izrađeni su mjerni uzorci kulirnih desno-lijevih pletenih pulovera koji se razlikuju po prepletu i sirovinskom sastavu. Realizirana su 4 različita prepleta, sl. 1. Na sl. 1a vidljiv je prikaz simbola očica, a na sl. 1e prikaz strukture pletiva za strukturu koja se sastoji samo od desnih očica. Na sl. 1b prikazan je izgled simbola očica, a na sl. 1f prikaz rebraste strukture pletiva s 4 desne i 4 lijeve očice. Na sl. 1c prikazan je izgled simbola očica, a na sl. 1g prikaz kvadratičaste strukture koja se sastoji od kvadrata 5x5 desnih i kvadrata 5x5 lijevih očica. Na sl. 1d prikazan je izgled simbola očica, a na sl. 1h prikaz strukture s uzorkom vodoravnih valova.



Slika 1: Programski prikaz mjernih pletenih uzoraka: a, b, c i d prikaz simbola očica; e, f, g i h prikaz strukture pletiva

4. Zaključak

Za potrebe doktorskog rada izrađeno je 48 mjernih uzoraka pletenih pulovera iste odjevne veličine s različitim prepletima i sirovinskim sastavima. Za njihovo projektiranje i dizajn korišten je program M1Plus. Na izrađenim mjernim uzorcima provest će se ispitivanje toplinskih svojstava odjeće.

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**Petra Mihovilović****Životopis**

Petra Mihovilović diplomirala je na Kemijskom odsjeku Prirodoslovno-matematičkog fakulteta Sveučilišta u Zagrebu, gdje je nagrađena Medaljom Kemijskog odsjeka za izvrstan uspjeh. Od 2022. zaposlena je kao asistentica na Zavodu za primijenjenu kemiju Tekstilno-tehnološkog fakulteta Sveučilišta u Zagrebu, gdje upisuje doktorski studij Tekstilna znanost i tehnologija. Njezin znanstveni interes usmjeren je na razvoj metodologije uzorkovanja i separacije čestica mikroplastike iz otpadnih voda, te njihovom fizikalno-kemijskom karakterizacijom spektroskopskim i kromatografskim tehnikama. Dobitnica je Nagrade za najuspješniji znanstveno-istraživački rad u području tekstila 2023. godine. Sudjelovala je kao suradnica na znanstveno-istraživačkom projektu HrZZ-IP-2020-02-7575. Objavila je 20 publikacija uključujući znanstvene radove, sudjelovanja na konferencijama posterskim i usmenim priopćenjem.

Naslov teme doktorskog rada

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Studijski savjetnik

Prof. dr. sc. Branka Vojnović

Datum obrane doktorskog rada

/

ČESTICE MIKROPLASTIKE KAO VEKTORI ZA PRIJENOS BOJILA: MEHANIZMI VEZANJA I TRANSPORTA U VODENIM SUSTAVIMA

Petra MIHOVILOVIĆ

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, Zagreb, petra.mihovilovic@tff.unizg.hr

Sažetak: Tekstilni sektor značajno doprinosi globalnom onečišćenju okoliša mikroplastikom, za koji se procjenjuje u ukupnoj emisiji čestica sudjeluje s udjelom većim od trećine. Čestice mikroplastike fibrilarnog oblika (MPF) uglavnom se oslobađaju tijekom pranja tekstilnih materijala, kada putem otpadnih voda dospijevaju u okoliš. Otpuštene čestice, zbog male veličine, velike specifične površine, poroznosti, amorfne strukture, izražene hidrofobnosti te prisutnosti različitih funkcionalnih skupina, predstavljaju učinkovit medij za vezanje drugih zagađivala, poput bojila, koja su često prisutna u otpadnim vodama tekstilne industrije. U okviru ovog doktorskog rada istražit će se kako kontrolni čimbenici (kontaktno vrijeme, početna koncentracije bojila i MPF, pH te ionska jakost otopine) utječu na adsorpciju odabranog bojila na čestice MPF-a, pri čemu će se analizom čestica prije i nakon adsorpcije razjasniti mogući mehanizmi vezanja i prijenosa zagađivala kroz vodeni ekosustav.

1. Uvod

Otpadne vode tekstilne industrije složenog su kemijskog sastava jer, osim otopljenih organskih tvari (površinski aktivnih tvari, kelati, soli, kiselina, lužina, enzima, itd.), sadrže i velik udio čestičnih tvari. Često pokazuju povišene vrijednosti parametara poput temperature, mutnoće, pH, elektrovodljivosti, sadržaja suspendiranih tvari te kemijske (KPK) i biokemijske potrošnje kisika (BPK) [1]. MPF, zbog svoje fibrilarne strukture, ima veću specifičnu površinu u odnosu na čestice mikroplastike drugačijih oblika, što joj omogućuje učinkovitiju adsorpciju drugih zagađivala prisutnih u otpadnim vodama tekstilne industrije. Osim toga, tekstilna vlakna često sadrže dodatne toksične komponente, uključujući sredstva za završnu obradu, koje dodatno povećavaju njihovu toksičnost. Zbog specifične morfologije i male gustoće, fibrilarna mikroplastika dulje se zadržava u zraku i vodenim sustavima, što povećava mogućnost akumulacije u okolišu te prijenosa u organizme putem vode, zraka i hrane [2].

2. Eksperimentalni dio

Tekstilna industrija značajno doprinosi onečišćenju voda uporabom organskih i anorganskih bojila. U procesima bojadisanja i tiska zaostaju značajne količine neiskorištenih bojila (do 20%), koji se potom ispuštaju u otpadne vode. Bojila čak i pri vrlo niskim koncentracijama ($< 1 \text{ mg dm}^{-3}$) veoma toksična, zbog čega predstavljaju ozbiljan ekološki problem [3,4]. Istraživanja pokazuju da čestice mikroplastike učinkovito vežu bojila prisutna u otpadnim vodama. Čestice promijenjena sastava mogu pokazivati pojačane toksične učinke i djeluju kao izvor sekundarnih onečišćenja kada promjena okolišnih uvjeta dovede do otpuštanja prethodno vezanih bojila. Stoga je razumijevanje mehanizama adsorpcije i desorpcije bojila na čestice MPF u vodenim sustavima ključno za procjenu potencijalnih ekoloških rizika [5].

Plan istraživanja sastoji se od 3 faze:

- (1) Priprava internog standarda usitnjavanjem standardnih materijala pomoću krio mlina (Slika 1. a) i b)). Čestice će se fizikalno-kemijski okarakterizirati uporabom različitih analitičkih tehnika (SEM, FTIR, BET, zeta potencijal, itd.)
- (2) Provođenje i optimiranje eksperimenata adsorpcije pri različitim kontrolnim uvjetima (kontaktno vrijeme, početna koncentracije bojila i MPF, pH te ionska jakost otopine)
- (3) Fizikalno-kemijska karakterizacija čestica nakon procesa adsorpcije/desorpcije



Slika 2: Prikaz a) krio mlina korištenog za pripremu PET internog standarda i b) pripremljenih čestica standarda

3. Rezultati i rasprava

Pripravljene čestice zbog izraženog statičkog elektriciteta i sklonosti agregaciji potrebno je pripremiti u obliku suspenzija. U dosadašnjim istraživanjima kao optimalno sredstvo pokazao se etanol, koji smanjuje efekt samoudruživanja i omogućuje ravnomjernu disperziju hidrofobnih čestica. Čestice je nakon provedenih eksperimenata adsorpcije potrebno izolirati iz uzoraka modelnih otpadnih voda kako bi se u sljedećem koraku pristupilo analizi. Stoga je razvijena metodologija separacije MPF-a iz otpadnih voda tekstilne industrije. Izabrana metoda separacije u gradijentu pokazala se zadovoljavajućom, s učinkovitošću većom od 90 %. Kao reagens koristi se zasićena otopina NaBr koja je kompatibilna sa sastavom matrice i ne uzrokuje fizikalno-kemijske promjene MPF-a.

4. Zaključci

Onečišćenje okoliša MPF-om predstavlja jedno od važnijih ekoloških pitanja današnjice. Znanstveni doprinos ove doktorske disertacije ogledat će se kroz nekoliko aspekata. Razvijena metodologija izolacije i karakterizacije MPF-a iz složenih uzoraka otpadnih voda pruža osnovu za provođenje daljnjih istraživanja. Očekuje se da će rad značajno doprinijeti razumijevanju uloge MPF-a kao vektora za prijenos bojila u vodenim sustavima, uključujući identifikaciju ključnih kontrolnih čimbenika koji utječu na adsorpciju/desorpciju. Dobiveni rezultati omogućiti će bolje tumačenje migracije ovih zagađivala kroz okoliš, njihovog utjecaja na organizme te razvoj strategija za njihovu buduću prevenciju.

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**Eanamul Haque Nizam****Životopis**

Eanamul Haque Nizam je docent na Odjelu za tekstilno inženjerstvo Sveučilišta Jugoistok u Bangladešu, gdje radi od kolovoza 2022. Magisterije znanosti iz modnog dizajna i inženjerstva stekao je na Tekstilnom sveučilištu Wuhan u Kini, a iz tekstilnog inženjerstva na Znanstveno-tehnološkom sveučilištu Mawlana Bhashani u Bangladešu. Stručno se usavršavao u području lanaca prodaje odjeće, industrijskog inženjerstva, proizvodnje i kontrole kvalitete u proizvodnji odjeće. Radio je kao asistent u nastavi na Tekstilnom sveučilištu Wuhan te kao predavač na BUFT-u, Gradskom sveučilištu i Međunarodnom sveučilištu Fareast. Počasni je recenzent časopisa Global Journal of Researches in Engineering i urednički asistent časopisa Journal of Textile Engineering (IEB). Njegovi istraživački interesi uključuju antropometriju, razvoj azijskih tablica veličina, morfologiju tijela, prilagodbu krojeva i razvoj odjevnih proizvoda.

Naslov teme doktorskog rada

Studija o antropometrijskim proporcijama i preporučenim veličinama odjeće muške populacije u dobi između dvadeset i dvadeset pet godina u Bangladešu

Mentori

Prof. emer. dr. sc. Darko Ujević

Prof. dr. sc. Ayub Nabi Khan

Datum obrane doktorskog rada /

ANTROPOMETRIJSKA ERGONOMSKA PROCJENA PRILAGOĐENOSTI I UDOBNOSTI UNIFORME MEĐU MLADIM MUŠKARCIMA U BANGLADEŠU

Eanamul Haque NIZAM

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Hrvatska,
eanamul.nizam@seu.edu.bd

Sažetak: U radu su istražene uniforme škola i radnih mjesta u smislu ergonomske udobnosti s obzirom na antropometrijske mjere za mlade muškarce iz Bangladeša (20-25 godina). Antropometrijska mjerenja i procjene udobnosti nošenja ukazali su na značajnu varijabilnost u dimenzijama tijela koju postojeći sustavi veličina uniformi ne mogu udovoljiti. Problemi s pristajanjem u ramenima bili su najčešći s 42%, zatim s duljinom rukava s 47%, a s pristajanjem u struku s 38%. Prosječne ocjene udobnosti ukazivale su na općenito umjerenu ukupnu udobnost, iako je najniži rezultat vezan uz lakoću kretanja bio 2,9 na ljestvici od pet stupnjeva. Ovi nalazi ukazuju na funkcionalna ograničenja u svakodnevnim aktivnostima. Ovi rezultati pokazuju izrazitu neusklađenost između standardiziranih veličina uniformi i antropometrijskih mjera među ciljanom populacijom. Ovaj rad identificira potrebu za sustavima veličina specifičnim za populaciju, zajedno s ergonomske podržanim prilagodbama dizajna, uključujući poboljšano ocjenjivanje temeljeno na proporcijama i dopštene količine za lakoću kreta

1. Uvod

Ergonomska udobna odjeća važan je čimbenik fizičkog blagostanja, osiguravanja radne učinkovitosti i održavanja općeg zadovoljstva korisnika u okruženjima s dugim razdobljima nošenja uniformi. Uniforme koje se koriste u obrazovnim ustanovama i na radnim mjestima trebale bi pružati uvjete za slobodno kretanje, ispravno držanje te toplinsku i mehaničku udobnost. Međutim, kad god dimenzije odjeće ne odgovaraju dimenzijama tijela nositelja, to može uzrokovati nelagodu, ograničenje kretanja i dugoročne probleme s mišićno-koštanim sustavom. Antropometrija, kao znanstvena metoda mjerenja morfoloških dimenzija ljudskog tijela, ima važnu ulogu u dizajniranju odjeće i uniformi. Ispravan prikaz antropometrijskih proporcija u sustavima veličine odjeće osigurava bolje pristajanje, udobnost i funkcionalne performanse. Iz prethodnih istraživanja poznato je da su primjena standardiziranih ili stranih sustava veličina na lokalnom stanovništvu bez odgovarajuće prilagodbe, često bile uzrok neusklađenosti između tjelesnih dimenzija i veličina odjeće. Nedostatak razmatranja stvarnih antropometrijskih mjera posebno je izražen u zemljama u razvoju, gdje se uniforme proizvode prema općim tablicama veličina umjesto antropometrijskim podacima reprezentativnim za stanovništvo. U Bangladešu su školske i radne uniforme uobičajene među mladom odraslom muškom populacijom, posebno onima u dobi između 20 i 25 godina, koji čine vrlo aktivnu kategoriju stanovništva. Iako Bangladeš ima jednu od najvećih odjevnih industrija na svijetu, provedeno je malo istraživanja kako bi se utvrdilo koliko učinkovito trenutno korištene veličine školskih i radnih uniformi odgovaraju antropometrijskim karakteristikama mlade muške populacije u Bangladešu. Većina postojećih istraživanja opisuje određivanje osnovnih veličina školskih i radnih uniformi, ali procjeni ergonomske udobnosti pri nošenju ove odjeće posvećeno je malo pažnje. Ergonomska udobnost ima različite modalitete, uključujući udobnost fizičkog pristajanja, kretanja, raspodjele pritiska i udobnost koju percipira nositelj. Ako školske i radne uniforme ne odgovaraju proporcijama širine ramena, opsega prsa, opsega struka i duljine rukava, razina ergonomske udobnosti se smanjuje, što rezultira poteškoćama za mladu odraslu populaciju, koja značajan dio dana provodi u školi i na poslu. Ovo istraživanje usmjereno je na ergonomska udobnost pri nošenju školskih i radnih uniformi i antropometrijske proporcije mlade muške populacije u Bangladešu. Korištenjem objektivnih antropometrijskih podataka u kombinaciji sa subjektivnim procjenama udobnosti, istraživanje ima za cilj identificirati područja percipirane neusklađenosti veličina i nelagode s ciljem razvoja preporuka za dizajn i određivanje veličine poboljšanih uniformi za stanovnike Bangladeša.

2. Eksperimentalni dio

Plan istraživanja: Za mjerenje ergonomske udobnosti školske/radne uniforme u odnosu na antropometrijske proporcije muške mladeži u Bangladešu usvojen je presječni deskriptivni plan istraživanja. U ovoj studiji provedena su kvantitativna antropometrijska mjerenja.



Odabir mjerne populacije: Uzorak su činili mladi muški sudionici bangladeškog podrijetla, u dobi između 20 i 25 godina. Sudionici su odabrani sa sveučilišta, tehničkih instituta i radnih mjesta gdje su ljudi prvi put nosili uniforme. Ukupno je 120 sudionika odabrano iz populacije korisnika uniformi. Sudionici su bili zdravi pojedinci koji su dali informirani pristanak prije studij

Antropometrijska mjerenja: Standardni antropometrijski podaci, koji su relevantni za dizajn odjeće za gornji i donji dio tijela, prikupljeni su na temelju međunarodno prihvaćenih smjernica za mjerenje.

Relevantne mjerne varijable bile su:

- Visina
- Opseg prsarsa
- Opseg struka
- Opseg bokova
- Širina ramena
- Duljina rukava
- Duljina unutarnjeg šava

Podaci su prikupljeni pomoću antropometrijske trake, kliznog kalipera i visinomjera. Sudionici su stajali u opuštenom položaju.

Karakteristike uniforme: U studiji su ispitane i korištene široko korištene školske i radne uniforme, uglavnom košulja i hlače izrađene od tkanog pamuka ili mješavine pamuka. Uniforme su izrađene u veličinama spremnim za nošenje S, M, L i XL, koje se široko koriste u lokalnoj modi, bez ikakvih prilagodbi po mjeri.

Procjena ergonomske udobnosti: Ocjena ergonomske udobnosti provedena je pomoću strukturiranog upitnika na Likertovoj ljestvici od pet stupnjeva, koja predstavlja 1 = vrlo neugodno i 5 = vrlo udobno.

Sudionici su ocijenili udobnost u odnosu na:

- Prianjanje uz ramena
- Prianjanje uz prsa
- Prianjanje u struku
- Duljinu rukava
- Lakoću kretanja
- Ukupnu udobnost tijekom dugotrajnog nošenja

Analiza podataka: Analize podataka provedene su korištenjem deskriptivne statistike, kao što su srednja vrijednost, standardna devijacija i postotna raspodjela. Usporedbe su napravljene kako bi se povezale antropometrijske dimenzije i prijavljena nelagoda. Podaci su analizirani korištenjem standardnog softvera za analizu podataka.

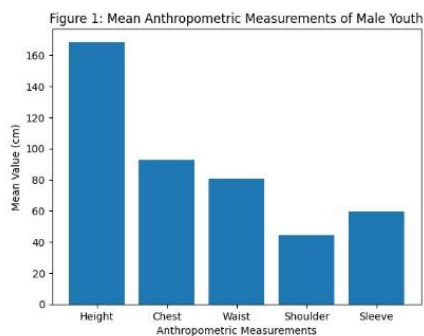
3. Rezultati i rasprava

3.1. Antropometrijski profil sudionika

Tablica 1: Deskriptivna statistika ključnih antropometrijskih mjerenja (n = 120)

Mjerna varijabla	Srednja vrijednost(cm)	Standardna devijacija
Visina	168.4	5.9
Opseg prsa	92.6	6.4
Opseg struka	80.8	7.1
Širina ramena	44.2	2.8
Duljina rukava	59.5	3.2

Rezultati ukazuju na umjerenu varijabilnost u dimenzijama tijela, što naglašava ograničenje korištenja kategorija fiksnih veličina za ujednačenu proizvodnju.



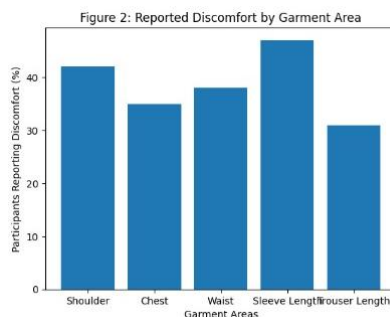
Slika 1: Srednje vrijednosti antropometrijskih mjera muške mladeži

3.2. Prijavljena područja nelagode

Tablica 2: Postotak sudionika koji prijavljuju nelagodu prema području

Područje	Postotak ispitanika koji prijavljuju nelagodu prema području odjeće (%)
Ramena	42
Prsa	35
Struk	38
Duljina rukava	47
Duljina hlača	31

Duljina rukava i pristajanje ramenima pojavili su se kao najproblematičnija područja, što sugerira neusklađenost između duljine ruku i širine ramena te postojećih veličina uniforme.

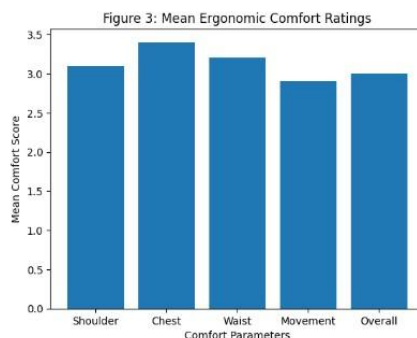


Slika 2: Prijavljena nelagoda prema području odjeće

3.3. Ocjene ergonomske udobnosti

Tablica 3: Prosječne ocjene udobnosti (5-stupanjska Likertova skala)

Parametar udobnosti	Prosječni rezultat
Udobnost u ramenima	3.1
Udobnost u prsima	3.4
Udobnost u struku	3.2
Mogućnost kretanja	2.9
Ukupna udobnost	3.0



Slika 3: Prosječne ocjene ergonomske udobnosti

Niži rezultati za lakoću kretanja ukazuju na to da uniforme mogu ograničavati funkcionalne aktivnosti poput savijanja, dosezanja i hodanja, što je u skladu s nalazima u prethodnim studijama ergonomske odjeće. Sveukupno, može se vidjeti da postoji jaka povezanost između antropometrijskih varijacija i ergonomske nelagode. Podaci također pokazuju da nije moguće da uniforme dizajnirane korištenjem standardnih ili generičkih sustava veličina uzmu u obzir proporcionalne varijacije u širini ramena, duljini rukava i dimenzijama struka koje mogu biti prisutne kod mladića iz Bangladeša. Slični trendovi već su uočeni u drugim antropometrijskim studijama provedenim u različitim južnoazijskim populacijama.

4. Zaključak

Rezultati ove studije pokazali su kako postojeće uniforme koje nose mladi muškarci u bangladeškim školama i radnim ustanovama, među populacijom u dobi od 20 do 25 godina, nisu ispunile antropometrijske zahtjeve, istovremeno uzrokujući nelagodu onima koji ih nose. Najproblematičnija područja identificirana su kao širina ramena, duljina rukava i udobnost kretanja, što ukazuje na potrebu za razvojem antropometrijskih sustava za određivanje veličina i ergonomske smjernice za dizajn uniformi.

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**Ante Osmak****Životopis**

Ante Osmak, rođen je 26.01.1999. godine u Zagrebu. Srednjoškolsko obrazovanje završava u EEB4 u Bruxellesu. Sveučilište u Zagrebu Tekstilno Tehnološki Fakultet, studij Tekstilnog inženjerstva i Tehnologije upisuje 2019. te brani završni rad 2022. godine. Po završetku preddiplomskog studija upisuje diplomski studij na istoimenom fakultetu. Diplomski rad na temu sinteze i karakterizacije novih disperznih azo bojila i njihovih bojadisarskih svojstva pod mentorstvom prof. dr. sc. Livia Racanéa obranio je 2024. godine. Također je dobitnik Rektorove nagrade u akademskoj godini 2023./2024. za znanstveni rad pod mentorstvom dr. sc. Anje Beč. Po završetku diplomskog studija započinje rad na Tekstilno-tehnološkom fakultetu Sveučilišta u Zagrebu kao stručni suradnik na zavodu za primijenjenu kemiju te upisuje doktorski studij tekstilna znanost i tehnologija na istom fakultetu 2025. godine.

Naslov teme doktorskog rada

/

Studijski savjetnik

Prof. dr. sc Livio Racané

Datum obrane doktorskog rada

/

SINTEZA, STRUKTURNA KARAKTERIZACIJA I BOJADISARSKA SVOJSTVA NOVIH 6-AZOBENZOTIAZOLNIH BOJILA

Ante OSMAK

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, aosmak@tff.hr

Sažetak: Cilj ovoga rada je održivim sintetskim procedurama, upotrebom zelenih otapala i odabirom netoksičnih prekursora, prirediti nove 6-azobenzotiazolne derivate i njihove komplekse s cinkom. Svim bojilima odredit će se bojadisarska svojstva, a optimirat će se i proces bojadisanja upotrebom ultrazvuka što je u skladu s načelima održivog razvoja.

1. Uvod

Azo bojila predstavljaju najvažniju i najzastupljeniju skupinu sintetskih bojila, s ključnom ulogom u tekstilnoj, farmaceutskoj i kemijskoj industriji [1-3]. Aromatske diazo komponente, u sintezi azo bojila, sve češće se zamjenjuju heteroaromatskim diazo komponentama jer priređena heterociklička azo bojila pokazuju bolja bojadisarska svojstva kao što su ton boje i svjetlina, te bolju postojanost na svjetlo u usporedbi s odgovarajućim karbocikličkim azo bojilima [4-6]. S druge strane derivati benzotiazola predmet su stalnog znanstvenog interesa zbog širokog spektra biološke aktivnosti od kojih su najznačajnije antitumorska i antibakterijska aktivnost [7-8]. Nadalje, koriste se kao komponente u tradicionalnim tekstilnim bojilima i optičkim bjelilima. Zahvaljujući konjugiranoj elektronskoj strukturi azo benzotiazolni derivati učinkovito tvore stabilne, obojene komplekse s metalnim ionima, što ih čini pogodnima za primjenu u kemijskim senzorima, analitičkim uređajima i sustavima za detekciju metala [9-11]. Azo bojila koji sadrže benzotiazolnu jezgru poznata su po stvaranju intenzivnih i postojanih tonova, u rasponu od žute do plave, ovisno o prirodi i položaju supstituenata. Osim navedenih spektroskopskih karakteristika, ovi spojevi pokazuju i odlična bojadisarska svojstva.

2. Hipoteza i ciljevi

Sintezom azo bojila koja sadrže benzotiazol kao heterocikličku jezgru mogu se prirediti nova bojila koja imaju intenzivne i raznolike tonove, te imaju bolja bojadisarska svojstva kao što su ton boje, svjetlina te postojanost u usporedbi s karbocikličkim analozima. Upotrebom zelenih sintetskih metoda za sintezu benzotiazolskih spojeva omogućiti će dobivanje novih sintetskih bojila na održiv način. Stoga je cilj održivim sintetskim procedurama, upotrebom zelenih otapala i odabirom netoksičnih prekursora, prirediti nove 6-azobenzotiazolne derivate i njihove komplekse s cinkom. Svim bojilima odredit će se bojadisarska svojstva, a optimirat će se i proces bojadisanja upotrebom ultrazvuka što je u skladu s načelima održivog razvoja. Ova istraživanja provodit će se u okviru institucijskog projekta: Održiva sinteza i ispitivanje bojadisarskih svojstava novih 6-azobenzotiazolnih derivata i njihovih kompleksa s cinkom (SIMBA-6) a time će se provesti i eksperimentalna istraživanja u okviru doktorske disertacije.

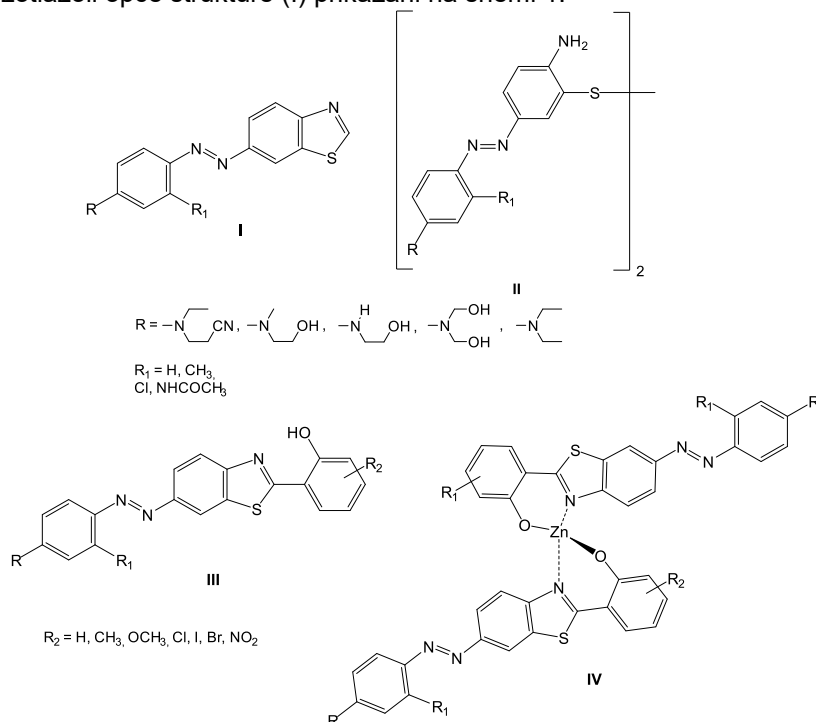
3. Radni plan

3.1. Sinteza

Osnovna strategija za sintezu ciljanih bojila bila je priprava 6-azobenzotiazolnog derivata temeljena na reakciji diazotacije 6-aminobenzotiazola i kopulacije sa odabranim anilinom. Pomoću 6-azobenzotiazolnog derivata bio bi pripremljen ključni disulfidni prekursor koji može poslužiti za reakcije sa različitim salicilaldehidima u svrhu dodavanja različito supstituiranih fenilnih jezgri 6-azobenzotiazolnom derivatu koji će poslužiti kao ligand za reakcije kompleksiranja sa cinkom. Alternativno, disulfidni prekursor se može kondenzirati i sa 2,5-supstituiranim furfuralima koji predstavlja ekološki povoljniji supstrat za daljnje proširenje kromofornog sustava.

Prethodno je u okviru laboratorija za organsku kemiju TTF-a razvijena metoda sinteze 6-azobenzotiazolnih derivata [12-14]. Stoga je prvi korak sinteze reakcija diazotacije 6-aminobenzotiazola i kopulacije s okolišno

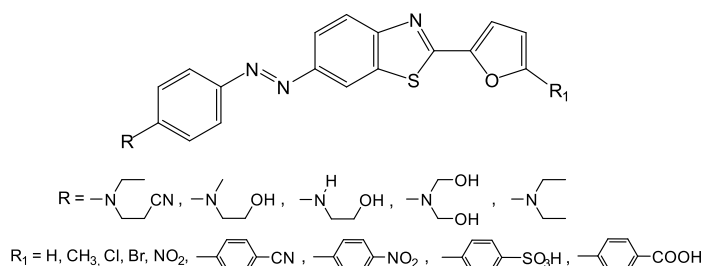
prihvatljivim i komercijalno dostupnim supstituiranim aminima kako bi se priredili novi 6-azosupstituiranibenzotiazoli opće strukture (I) prikazani na shemi 1.



Shema 1: Opće strukturne formule ciljanih bojila i njihovih prekursora

Nadalje, otvaranjem benzotiazolnog prstena sa 1,3-propilendiaminom u glicerolu se može prirediti odgovarajući bis(2-amino-5-azofenilni)-disulfidni intermedijeri opće strukture (II) koji će poslužiti kao ključni prekursori za kondenzacijske reakcije u glicerolu sa supstituiranim salicilaldehidima pri čemu će se prirediti mala biblioteka novih bojila. Dobiveni novi 6-azo-2-(2-hidroksifenilni)benzotiazolni derivati opće strukture (III), poslužit će kao ligandi za reakcije kompleksiranja s cinkom upotrebom sintetskih metoda koje su opisane u literaturi za druge 2-(2-hidroksifenilne)benzotiazolne derivate. Ova reakcija će se optimirati s ciljem pronalaženja zelenije sinteze cinkovih kompleksa 6-azo-2-(2-hidroksifenil)benzotiazola opće strukture (IV)

U skladu s aktualnim konceptima održivog razvoja, u posljednje vrijeme raste zanimanje za sintezu novih spojeva s kemikalijama iz bioloških izvora što bi smanjilo upotrebu kemikalija dobivenih iz nafte. Taj kriterij zadovoljavaju derivati furana koji se mogu dobiti iz poljoprivrednog otpada. Razvojem bojila izvedenih iz furanskih derivata [15] razvija se koncept polusintetskih bojila koja bi bila između sintetskih i prirodnih. Obzirom na ranija iskustva u sintezi furanskih derivata, u okviru ove klase spojeva, uvela bi se furanska jezgra u kromoforni sustav te dobila nova polusintetska bojila za čiju sintezu bi se koristile kemikalije dobivene iz biootpada. Stoga bi prethodno navedeni disulfidni prekursori (II) poslužili kao supstrati za kondenzacijske reakcije 2,5-supstituiranih furfurala pri čemu bi se dobila mala biblioteka novih 6-azo-2-furilnilbenzotiazolnih derivata. Osim komercijalno dostupnih 2,5-supstituiranih furfurala, sam 2-furfural bi se Meerweinovom reakcijom ariliranja supstituirao s različitim p-supstituiranim anilinima čime bi se priredili 5-(4-supstituiranifenil)-2-furankarbaldehidi kao ključni intermedijeri za daljnje povećavanje kromofornog sustava koji uključuje i furansku jezgru opće strukture prikazane na shemi 2.



Shema 2: Opća strukturna formula 6-azobenzotiazolnih derivata sa furanskom jezgrom

3.2. Strukturna karakterizacija

Strukturna karakterizacija sintetiziranih spojeva bit će provedena primjenom nekoliko komplementarnih spektroskopskih metoda: NMR, UV/Vis i IR spektroskopije, kao i pomoću spektrometrije masa. Termička svojstva cinkovih kompleksa kao i udio metala u kompleksu odredit će se termalnim analitičkim tehnikama TGA i DSC. Na svim spojevima provest će se elementna analiza.

Kristalizacijskim tehnikama pokušat će se azo-bojila dobiti u kristalnom obliku pogodnim za određivanje njihove strukture primjenom rendgenske strukturne analize u jediničnom kristalu.

3.3. Ispitivanje bojadisarskih svojstava

Svim novopripređenim bojilima ispitat će se bojadisarska svojstva i postojanost obojenja na pranje. Bojadisarska svojstva bojila topljivih u vodi ispitat će se na vunenom i poliamidnom vlaknu, a bojila netopljiva u vodi ispitat će se kao disperzna bojila za bojadisanje poliesterskog i poliamidnog vlakna.

Bojila koja neće pokazati afinitet prema vlaknu (pigmentna bojila) nanijet će se na tekstilni materijal mehaničkim putem i fiksirati pomoću vezivnih sredstava. Dodatno, optimirat će se proces bojadisanja upotrebom ultrazvuka što je u skladu s načelima održivog razvoja, a s ciljem poboljšanja učinkovitosti procesa, održivosti i kvalitete bojadisanj. Dodatno, optimirat će se proces bojadisanja upotrebom ultrazvuka što je u skladu s načelima održivog razvoja, a s ciljem poboljšanja učinkovitosti procesa, održivosti i kvalitete bojadisanja [16].

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**Ana Palčić****Životopis**

Ana Palčić rođena je u Zagrebu 1993. godine. Diplomirala je 2019. godine na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu (TTF) gdje je zaposlena kao asistent od 2022. godine te iste godine upisuje doktorski studij Tekstilna znanost i tehnologija. Radno iskustvo stekla je kao tehnolog procesa kemijskog čišćenja i pranja rublja u Lemia d.o.o. ekološkim kemijskim čistionicama. Bila je članica na uspostavnom istraživačkom projektu HRZZ-UIP-05-2017-8780 „Bolničke zaštitne tekstilije“. Trenutno je članica institucionalnih istraživačkih projekata ZORA (TTF) i DOBRA (Sveučilište u Dubrovniku) te projekta u suradnji s Drugom ekonomskom srednjom školom Zagreb „Igla šiva svoju priču“. Znanstveni interes veže uz područje oplemenjivanja tekstila s ciljem postizanja višefunkcionalne zaštitne obrade s naglaskom na uporabu ekološki povoljnijih sredstva te termičke i fizikalno-kemijske karakterizacije tekstilnih materijala.

Naslov teme doktorskog rada

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Studijska savjetnica

Prof. dr. sc. Sandra Flinčec Grgac

Datum obrane doktorskog rada

/

MODIFIKACIJA PAMUK/POLIESTERSKIH TKANINA S INKLUZIJSKIM KOMPLEKSOM β -CIKLODEKSTRIN-ETERIČNO ULJE

Ana PALČIĆ

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, 10000 Zagreb, ana.palcic@tff.unizg.hr

Sažetak: Zahvaljujući svojoj sposobnosti stvaranja inkluzijskih kompleksa s različitim molekulama, svojstvima netoksičnosti i biorazgradivosti, β -ciklodekstrini mogu značajno doprinijeti funkcionalnosti tekstilnih materijala. Često se koriste na tekstilijama za kontrolirano oslobađanje aktivnih tvari i mirisa, ali istovremeno i postizanje antimikrobnih ili UV zaštitnih svojstava koji tako oplemenjenoj tkanini omogućuju ciljanu primjenu.

1. Uvod

Ubrzani napredak tehnologije dovodi do razvoja novih tekstilnih materijala koji svoju primjenu mogu pronaći u različitim područjima interesa, a što uvelike može unaprijediti i poboljšati način života. Kako bi se zadovoljili svi zahtjevi potrošača i tržišta proizašla je ideja o aplikaciji aktivnih tvari na tekstil pri čemu je glavni izazov postizanje njihovog učinkovitog i kontrolirano otpuštanja uz istovremeno očuvanje zadovoljavajuće postojanosti na pranje. Ciklodekstrini su ciklički oligosaharidi sposobni stvarati inkluzijske komplekse s različitim molekulama što značajno unapređuje funkcionalna svojstva tekstilnih materijala. Zbog svoje netoksičnosti i biorazgradivosti uvelike se primjenjuju u tekstilnoj industriji za kontrolirano i selektivno upravljanje funkcionalnim svojstvima. Odlikuje ih mogućnost tvorbe inkluzijskih kompleksa s raznim aktivnim tvarima kao što su eterična ulja koja pružaju povoljne učinke na zdravlje ljudi [1-2]. U ovom istraživanju poseban je naglasak stavljen na primjenu eteričnog ulja čajevca koje ima izražena antimikrobna i antiseptička svojstva. Kompleksiranjem eteričnog ulja čajevca u šupljinu β -ciklodekstrina postiže se njegova stabilizacija dok se vezivanjem inkluzijskog kompleksa na CO/PES tkaninu nastoji osigurati njihova funkcionalna primjena u svrhu višekratne upotrebe tako obrađenih tekstilnih materijala.

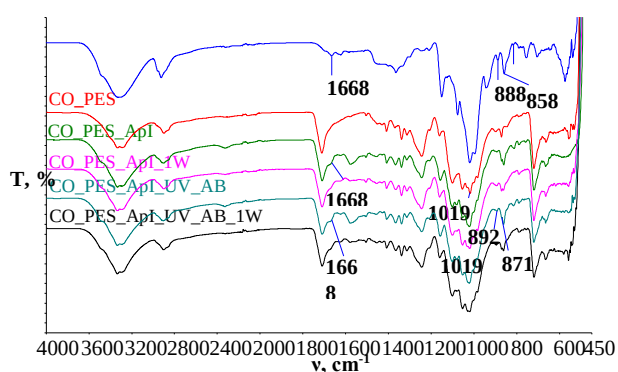
2. Eksperimentalni dio

U ovom istraživanju za postupak modifikacije CO/PES tkanine u atlas vezu provedeno je inkluzijsko kompleksiranje visokoenergetskim vibracijskim mikromlinom (RESTCH[®]-MM 400) pri frekvenciji 25,0 Hz tijekom 20 min. U tu svrhu korišten je β -ciklodekstrin (Tokyo Chemical Industry Co., Ltd) i 30 % eteričnog ulja čajevca (Aromara, Australija) na masu β -ciklodekstrina. Pripremljeni kompleks (CD_CAJEVAC) osušen je u autoklavu u sušioniku na 80 °C u tijekom 6 h. Uzorci su predobrađeni s 8 % NaOH uz dodatak Subitola (CHT Bezema, Švicarska) u napetom stanju, a potom su obrađeni u kupelji (Apl) koja je sadržavala: 35 g/l maleinske kiseline (Sigma-Aldrich, Njemačka), 32,5 g/l Na-hipofosfit hidrata (SHP) kao umreživača (Sigma-Aldrich, Njemačka), 1 g/l Felosan RG-N kao sredstva za kvašenje (CHT Bezema, Švicarska) te 30 % pripremljenog kompleksa na masu materijala. Impregnacija uzoraka provedena je na fularu (Benz, Švicarska) uz efekt cijedenja 100 % te su uzorci zajedno s kupelji, podvrgnuti djelovanju mikrovalne energije (SHARP, YC-GG252A, Japan) u vremenu od 5 min uz snagu od 80 %, a potom su stavljeni na odležavanje 24 h. Nakon odležavanja uzorci su ocijedeni na fularu te su osušeni na rasteznom sušioniku (Benz, Švicarska) 5 min na temperaturi od 80 °C. Kondenzacija obrađenih uzoraka provedena je u UV komori (Solarscreen Test Chamber STC 01) s UV-A i UV-B žaruljom snage 11 W, napona 37 V te struje žarulje od 0,33 A u trajanju od 30 min. Nakon obrade uzorci su podvrgnuti jednom ciklusu pranja (1W) u uređaju Wascator FOM71 CLS (Electrolux, Švedska) prema standardu EN ISO 15797:2017 na sniženoj temperaturi pranja na 50 °C uz standardni deterdžent s optičkim bjelilima bez fosfata (WFK 88060) i ekološki povoljnim sredstvom ϵ -(ftalimido) peroksi heksanske kiseline (PAP). Uzorci su osušeni u sušilici Electrolux T5130-LAB prema programu NORMAL LAB u trajanju od 30 minuta.

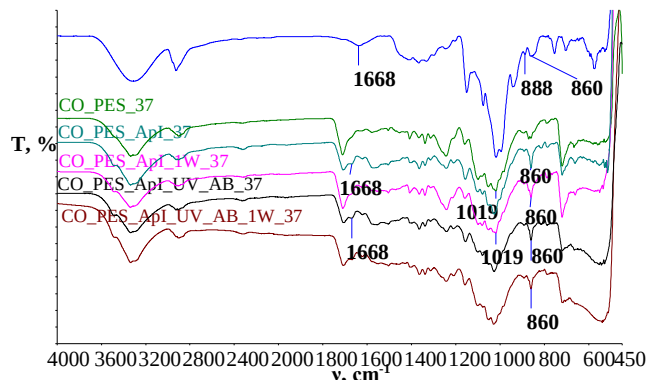
3. Rezultati i rasprava

Metodom infracrvene spektroskopije s Fourierovom transformacijom u tehnici prigušene ukupne refleksije (FTIR-ATR Golden Gate) ispitana je učinkovitost funkcionalizacije CO/PES tkanine pomoću kompleksa

CD_CAJEVAC te su analizirane fizikalno-kemijske promjene do kojih dolazi tijekom toplinske razgradnje prije i nakon procesa pranja.



Slika 1: Spektralne krivulje inkluzijskog kompleksa, neobrađene i obrađeneh CO/PES tkanina prije i nakon ciklusa pranja snimljene na temperaturi od 25 °C



Slika 2: Spektralne krivulje inkluzijskog kompleksa, neobrađene i obrađeneh CO/PES tkanina prije i nakon ciklusa pranja snimljene na temperaturi od 37 °C

Obrađeni uzorci pokazuju karakteristične pikove za kompleks CD_CAJEVAC pri čemu je izražen pik na 1019 cm^{-1} (C-O-C rastezanje). Prisutnost pikova na valnim brojevima 892 i 871 cm^{-1} ukazuje na kompleksiranje ciklodeksrina i eteričnog ulja. Nakon pranja intenzitet pikova se blago smanjuje što je posljedica uklanjanja površinski nataloženih kompleksa. Usporedbom krivulja snimljenih na 25 °C i 37 °C uočavaju se blagi pomaci i smanjenje intenziteta pikova za pojedine funkcionalne skupine što ukazuje na moguće oslobađanje hlapivih komponenti eteričnog ulja. Navedeno ukazuje na to da inkluzija eteričnog ulja u šupljinu β -ciklodeksrina uspješno osigurava veću stabilnost na blago povišenim temperaturama. Pik na valnom broju 1668 cm^{-1} (C=O rastezanje) izraženiji je u uzorcima podvrgnutim UV_AB zračenju jer dolazi do oksidacije pojedinih komponenti te on zaostaje i nakon pranja što može ukazivati na povoljan utjecaj kondenzacije UV-AB zrakama te trajnije zadržavanje kompleksa na tkaninama [3-4].

4. Zaključak

Dobiveni rezultati jasno potvrđuju uspješno formiranje inkluzijskog kompleksa i njihovo stabilno vezivanje na tekstilni materijal. Ovakav pristup funkcionalizacije i praćenja otpuštanja aktivne tvari još je u istraživačkoj fazi no ukazuje na mogućnost primjene za stvaranje i vrednovanje ekološki povoljnih funkcionaliziranih tekstilija.

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**Željka Pavlović****Životopis**

Željka Pavlović je rođena 4. veljače 1987. godine u Zaboku. Nakon završene osnovne škole u Samoboru, upisuje Ekonomsku, trgovačku i ugostiteljsku školu te je završava 2005. godine. U periodu od 2005. do 2012. godine studira na Sveučilištu u Zagrebu Tekstilno-tehnološki fakultet, gdje je diplomirala s temom „Upotrebna svojstva kratkih čarapa“, mentor prof. dr. sc. Zlatko Vrljić. Nakon završenog studija zapošljava se u Tvornici čarapa Jadran d.d., gdje je 3,5 godine radila kao tehnolog u proizvodnji. U 2015. godini zaposlena je kao asistent na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu, na Zavodu za projektiranje i menadžment tekstila. U 2016. godini upisuje poslijediplomski sveučilišni studij „Tekstilna znanost i tehnologija“ na Tekstilno-tehnološkom fakultetu. Područja od posebnog interesa su joj projektiranje i proizvodnja čarapa te analiza rada pletaćih strojeva.

Naslov teme doktorskog
rada

Termofiziološka svojstva pletiva uvjetovana procesom
pletanja i strukturom pletiva

Mentorica

Prof. dr. sc. Vesna Marija Potočić Matković

Datum obrane doktorskog
rada

/

TERMOFIZIOLOŠKA SVOJSTVA PLETIVA UVJETOVANA PROCESOM PLETENJA I STRUKTUROM PLETIVA

Željka PAVLOVIĆ

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, zeljka.pavlovic@ttf.unizg.hr

Sažetak: Propusnost zraka jedno je od ključnih svojstava pletiva koje izravno utječe na udobnost nošenja i termoregulaciju odjeće. U ovom radu analiziran je utjecaj sirovinskog sastava, konstrukcijskih parametara i procesa dorade na propusnost zraka različitih tipova pletiva. Ispitivanja su provedena na sirovim i dorađenim uzorcima pletiva, a rezultati su analizirani deskriptivnom statistikom, t-testom i korelacijskom analizom. Dobiveni rezultati pokazuju da dorada u većini slučajeva značajno smanjuje propusnost zraka, pri čemu konstrukcijski parametri poput gustoće, debljine i površinske mase imaju dominantan utjecaj na prozračnost pletiva.

1. Uvod

Propusnost zraka tekstilnih materijala predstavlja važno termofiziološko svojstvo koje utječe na prijenos topline i vlage između tijela i okoline, a time i na udobnost nošenja odjeće [1]. Ona je u velikoj mjeri određena strukturom materijala, odnosno veličinom, brojem i raspodjelom očica unutar pletene strukture [2]. Zbog strukture, pletiva u pravilu imaju veću propusnost zraka u odnosu na tkanine iste površinske mase. Na prozračnost pletiva utječu sirovinski sastav, način predenja pređe, konstrukcijski parametri te procesi dorade, koji mogu značajno promijeniti poroznost i zbijenost strukture [3]. Cilj ovog rada je analizirati utjecaj navedenih čimbenika na propusnost zraka pletiva.

2. Eksperimentalni dio

Ispitivanje propusnosti zraka provedeno je na različitim tipovima pletiva izrađenih od različitih sirovina i tehnologija predenja, u sirovom i dorađenom stanju. Propusnost zraka mjerena je kao protok zraka po jedinici površine materijala pri konstantnoj razlici tlakova, a rezultati su izraženi u $\text{cm}^3/\text{cm}^2/\text{s}$. Za analizu dobivenih podataka korištene su metode deskriptivne statistike, t-test za usporedbu sirovih i dorađenih uzoraka te Pearsonova korelacijska analiza za ispitivanje povezanosti propusnosti zraka s osnovnim konstrukcijskim parametrima pletiva.

3. Rezultati i rasprava

Rezultati ispitivanja pokazuju izrazite razlike u propusnosti zraka između pojedinih uzoraka pletiva. Kod sirovih uzoraka, propusnost zraka kretala se od $34,54 \text{ cm}^3/\text{cm}^2/\text{s}$ (puno platirno pletivo) do $420,29 \text{ cm}^3/\text{cm}^2/\text{s}$ (pletivo od liocelnog vlakna). Najveće vrijednosti zabilježene su kod pletiva izrađenih rotorskim postupkom predenja od liocelnih, viskoznih, mikromodalnih vlakana što upućuje na otvoreniju strukturu i veću poroznost pletiva u sirovom stanju.

Kod dorađenih uzoraka, propusnost zraka bila je značajno niža te se kretala od $17,56 \text{ cm}^3/\text{cm}^2/\text{s}$ (pamuk, interlok struktura) do $211,99 \text{ cm}^3/\text{cm}^2/\text{s}$ (modal, desno-desna struktura). Usporedbom sirovih i dorađenih uzoraka uočeno je da dorada u većini slučajeva dovodi do smanjenja propusnosti zraka. Najizraženije smanjenje zabilježeno je kod uzoraka ispletenih pređom od viskoznih vlakana izrađenom rotorskim postupkom predenja (s $416,52$ na $158,37 \text{ cm}^3/\text{cm}^2/\text{s}$), pređom od liocelnih vlakana izrađenom rotorskim postupkom predenja (s $420,29$ na $194,36 \text{ cm}^3/\text{cm}^2/\text{s}$) i uzorka ispletenog pređom od poliesterskih vlakana izrađenom prstenastim postupkom predenja (s $317,29$ na $138,42 \text{ cm}^3/\text{cm}^2/\text{s}$). Pojedini uzorci (ispleteni pređom od liocelnih i modalnih vlakana prstenastim postupkom predenja) pokazali su povećanje propusnosti nakon dorade, što se može povezati s promjenama u strukturi pletiva uzrokovanim završnom obradom.

Tablica 1: Rezultati t-testa za usporedbu propusnosti zraka sirovih i dorađenih pletiva

	sirovo	dorađeno
Srednja vrijednost	221,39	137,16
Varijanca	17438,13	4129,63
Broj uzoraka	18	18
Pearsonova korelacija	0,726	
Hipotetska razlika srednjih vrijednosti	0	
df	17	
t Stat	3,717	

Tablica 2: Korelacijska veza između propusnosti zraka i osnovnih parametara sirovih i dorađenih uzoraka pletiva

Propusnost zraka	Horiz. gustoća	Vert. gustoća	Utrošak niti	Debljina pletiva	Plošna masa	Zapreminska masa
Sirovi	-0,6947	-0,5425	0,2607	-0,5771	-0,7769	-0,3578
Dorađeni	-0,7275	-0,6898	0,0905	-0,7957	-0,6651	0,7285

Rezultati t-testa, tablica 1., potvrđuju statistički značajnu razliku između sirovih i dorađenih pletiva ($p < 0,01$). Prosječna propusnost zraka smanjila se s 221,39 $\text{cm}^3/\text{cm}^2/\text{s}$ kod sirovih na 137,16 $\text{cm}^3/\text{cm}^2/\text{s}$ kod dorađenih pletiva, što jasno potvrđuje značajan utjecaj procesa dorade. Visoka Pearsonova korelacija ($r = 0,726$) dodatno ukazuje na konzistentan učinak dorade na iste uzorke.

Korelacijska analiza, tablica 2., pokazala je da je kod sirovih pletiva propusnost zraka snažno negativno povezana s plošnom masom ($r = -0,7769$), horizontalnom gustoćom ($r = -0,6947$) i debljinom pletiva ($r = -0,5771$). Kod dorađenih pletiva najjači negativni utjecaj na propusnost zraka imaju debljina pletiva ($r = -0,7957$) te horizontalna i vertikalna gustoća, dok zapreminska masa pokazuje pozitivnu korelaciju ($r = 0,7285$), što upućuje na složeniji utjecaj strukture nakon dorade.

4. Zaključci

Rezultati istraživanja potvrđuju da propusnost zraka pletiva u velikoj mjeri ovisi o konstrukcijskim parametrima i procesu dorade. Dorada u većini slučajeva značajno smanjuje prozračnost pletiva zbog zbijanja strukture i smanjenja poroznosti. Plošna masa, gustoća i debljina pletiva identificirani su kao ključni čimbenici koji negativno utječu na propusnost zraka, pri čemu je njihov utjecaj izraženiji kod dorađenih uzoraka. Dobiveni rezultati potvrđuju važnost odabira strukture pletiva u svrhu postizanja željene razine udobnosti i funkcionalnosti tekstilnih proizvoda.

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**Marijana Pavunc Samaržija****Životopis**

Marijana Pavunc Samaržija 2012. godine završila je diplomski sveučilišni studij Tekstilna tehnologija i inženjerstvo, modul Tekstilna kemija, materijali i ekologija na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu. Od 2013. do 2020. radila je na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu na Zavodu za materijale, vlakna i ispitivanje tekstila kao asistent, a od 2021. zaposlena je kao predavač. Od početka znanstvenog rada njezin znanstveni interes usmjeren je na tekstilna vlakna, vlaknima ojačane kompozite te recikliranje tekstilnih materijala i konzervaciju i restauraciju tekstila.

Naslov teme doktorskog
rada

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Studijska savjetnica

Prof. dr. sc. Edita Vujasinović

Datum obrane doktorskog
rada

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ISTRAŽIVANJE CJELOŽIVOTNOG CIKLUSA VLAKNIMA OJAČANIH KOMPOZITA – MEHANIČKA SVOJSTVA RECIKLIRANIH VLAKANA

Marijana PAVUNC SAMARŽIJA

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, Zagreb, marijana.pavunc@tff.unizg.hr

Sažetak: Recikliranje i ponovna uporaba materijala dobivaju sve veći značaj zbog rastućih potreba za sirovinama kao i zahtjeva za održivim gospodarenjem. Recikliranje vlaknima ojačanih kompozita je posebno izazovno često zbog njihove složene strukture i sastava, ali i činjenice da oporabljena vlakna često nemaju svoju ishodišnu kvalitetu. U ovom radu istražen potencijal oporabljenih vlakana iz biokompozita (prirodnim vlaknima ojačani kompozit) nakon kemijskog recikliranja.

1. Uvod

Održivo upravljanje resursima i smanjenje otpada predstavljaju ključne izazove suvremenog društva, osobito u kontekstu vlaknima ojačanih kompozita koji se sve više primjenjuju u brojnim industrijskim sektorima. Njihova rastuća uporaba neizbježno dovodi ili će dovesti do povećanja količine otpada, čije zbrinjavanje predstavlja ekološki i tehnološki izazov [1, 2]. Kako bi se smanjio negativan utjecaj ovih materijala na okoliš, pažnja se posvećuje razvoju i primjeni biokompozita, odnosno kompozitima temeljenih na biorazgradivim polimernim matricama ojačanim prirodnim, također biorazgradivim biljnim vlaknima [3]. Iako se biokompoziti često ističu kao održiva alternativa konvencionalnim kompozitima zbog manjeg ugljičnog otiska i upotrebe obnovljivih vlaknatih sirovina za njihovu proizvodnju, njihovo zbrinjavanje i recikliranje na kraju životnog ciklusa još uvijek predstavlja izazov [3, 4]. Razlog tomu je njihova heterogena struktura te sklonost degradaciji prirodnih vlakana tijekom postupka recikliranja čime se ograničava njihova ponovna primjena u istovrijednim kompozitnim materijalima [5].

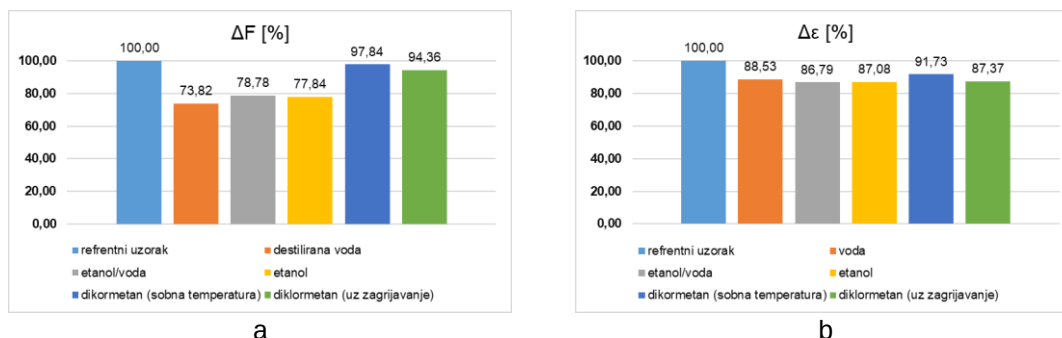
Kompozite je moguće reciklirati mehaničkim, termičkim i kemijskim postupcima [6], gdje mehaničko recikliranje u osnovi dovodi do skraćivanja vlakana i značajnog gubitka njihovih mehaničkih svojstava (prvenstveno čvrstoće) [5], što su pojave koje se događaju i kod termičkih postupaka [3]. Nasuprot tome, kemijsko recikliranje se često ističe kao metoda kojom je moguće razdvajanje matrice i vlakana uz potencijalno očuvanje kako morfoloških tako i mehaničkih svojstava vlakana, čime se povećava mogućnost njihove ponovne uporabe u vlaknima ojačanim kompozitnim strukturama. Razumljiva je stoga potreba za detaljnijim istraživanjem kvalitete recikliranih vlakana iz vlaknima ojačanih kompozita (biokompozita) nakon kemijskih postupaka recikliranja [6].

2. Eksperimentalni dio

Kod kemijskog recikliranja posebno je važno utvrditi u kojoj mjeri korištena otapala i pritom odabrani postupci omogućuju očuvanje ishodišnih svojstava vlakana. U tom kontekstu, cilj ovog rada bio je odrediti promjenu prekidne sile i prekidnog istezanja vlakana brnistre (*Spartium junceum* L.) izdvojenih nakon procesa kemijskog recikliranja biokompozita. Tretirani biokompozit izrađen je od polilaktidne kiseline (PLA) kao matrice, ojačane s 20 % po masi vlakana brnistre (*Spartium junceum* L.) pri čemu su vlakna brnistre usmjerena u jednom smjeru, a sam kompozit je izrađen na vakuumskoj laboratorijskoj preši LAB 100 C (Pinette PEI) uz pritisak od 20 kN i na temperaturi od 190°C. Kemijsko recikliranje ovih biokompozita provedeno je upotrebom četiri različita otapala i to destilirane vode, 96% etanola, mješavine 96% etanola i destilirane vode u omjeru 50:50 te diklormetana, pri čemu su tijekom postupka varirani uvjeti obrade poput temperature, vremena i mehaničkog pokretanja uzorka biokompozita u otapalu. Prekidna sila i prekidno istezanje oporabljenih vlakana određena su prema normi HRN EN ISO 5079:2020 [7], koristeći dinamometar Vibrodyn 400 (Lenzing).

3. Rezultati i rasprava

Na slici 1 prikazani su rezultati ispitivanja promjene prekidne sile i prekidnog istezanja oporabljenih vlakana dobivenih različitim postupcima kemijskog recikliranja.



Slika 1: Kvaliteta recikliranih vlakana iskazana kroz: a) promjenu prekidne sile; b) promjenu prekidnog istežanja

Iz rezultata prikazanih na slici 1 vidljivo je da su prekidna sila i prekidno istežanje oporabljenih vlakana brnistre (*Spartium junceum* L.) najbolje očuvana pri kemijskom recikliranju gdje se PLA matrica otapa u diklormetanu, pri čemu prednjači postupak sa hladnim diklormetanom što je i energetski povoljnije. Značajnije smanjenje prekidne sile uočeno je kod vlakana oporabljenih nakon izlaganja ostalim otapalima budući da u predviđenom vremenu kod njih ne dolazi do potpunog otapanja matrice već samo omekšavanja što značajno utječe na mogućnost izdvajanja vlakana iz matrice i njihove primjerenosti za određivanje prekidne sile. S Obzirom na dobivene rezultate može se zaključiti da i nakon kemijskog recikliranja dolazi do pada svojstava oporabljenih vlakana čime je onemogućena njihova upotreba za istovrijedni kompozit, ali se mogu ponovno upotrijebiti u manje zahtjevnim kompozitnim strukturama.

4. Zaključak

Provedeno istraživanje pokazalo je da očuvanje istraživanih svojstava oporabljenih vlakana brnistre nakon kemijskog recikliranja jednosmjernog biokompozita uvelike ovisi o odabiru odgovarajućeg otapala. U ovom slučaju to je diklormetan, no unatoč njegovoj visokoj učinkovitosti, njegova toksičnost može predstavljati problem ukoliko se postupak ne provodi uz sve sigurnosne mjere.

Zahvala

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- [7] HRN EN ISO 5079:2020 Tekstilna vlakna -- Određivanje prekidne sile i prekidnog istežanja pojedinačnih vlakana

**Antonija Petrov****Životopis**

Antonija Petrov rođena je 1993. godine u Zagrebu. Na Tekstilno-tehnološkom fakultetu Sveučilišta u Zagrebu 2017. godine završila je prijediplomski, a 2019. godine diplomski studij Tekstilne tehnologije i inženjerstva, smjer Projektiranje i menadžment tekstila, stekavši naziv magistre inženjerke tekstilne tehnologije i inženjerstva. Od 2021. godine pohađa poslijediplomski doktorski studij Tekstilna znanost i gospodarstvo u okviru projekta „Aspekti primjene termografije u evaluaciji termofiziološke udobnosti sportske odjeće – ATLETO (DOK-2021-02-4746)“, pod mentorstvom prof. dr. sc. Gorana Čubrića. Od 2025. godine zaposlena je kao asistentica u Zavodu za odjevnju tehnologiju. Sudjeluje u više znanstveno-istraživačkih projekata, a njezin znanstveni interes usmjeren je na primjenu infracrvene termografije u vrednovanju udobnosti sportske odjeće.

Naslov teme doktorskog rada

Primjena termografije u vrjednovanju udobnosti pletenih struktura za izradu sportske odjeće

Mentor

Prof. dr. sc. Goran Čubrić

Datum obrane doktorskog rada

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ANALIZA TERMOFIZIOLOŠKE UDOBNOСТИ SPORTSKE ODJEĆE PRIMJENOM INFRACRVENE TERMOGRAFIJE

Antonija PETROV

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28 a, Zagreb, antonija.petrov@tff.unizg.hr

Sažetak: *Udobnost sportske odjeće ima ključnu ulogu u očuvanju termalne ravnoteže i sportske izvedbe tijekom tjelesne aktivnosti. Pravilno oblikovana sportska odjeća treba omogućiti učinkovito upravljanje toplinom i vlagom, osobito u uvjetima povećanog metaboličkog opterećenja. Infracrvena termografija predstavlja neinvazivnu metodu za praćenje dinamičkih promjena temperature kože sportaša tijekom aktivnosti i faze oporavka. U radu je prikazana primjena infracrvene termografije u procjeni udobnosti sportske odjeće analizom temperaturnih promjena na tijelu sportaša tijekom definirane fizičke aktivnosti. Dobiveni rezultati ukazuju na povezanost između temperaturnih odgovora tijela, intenziteta aktivnosti i sposobnosti sportske odjeće da učinkovito regulira toplinu i vlagu. Ovakav pristup omogućuje objektivnije vrednovanje udobnosti sportske odjeće te doprinosi razvoju funkcionalnih materijala prilagođenih zahtjevima sportaša.*

1. Uvod

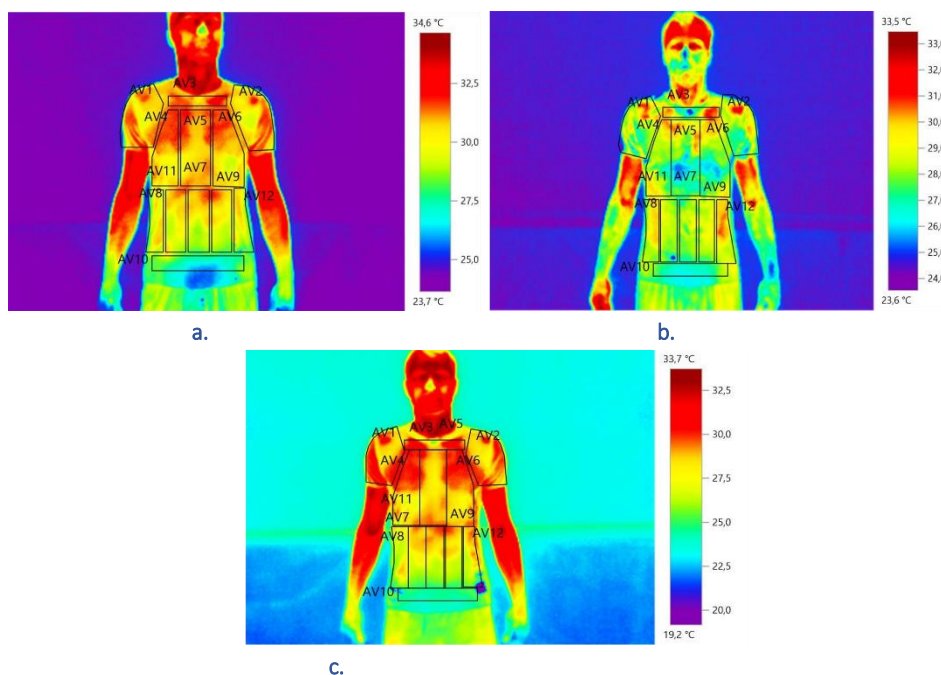
Udobnost odjeće smatra se jednim od ključnih zahtjeva kod sportske odjeće te proizlazi iz složenih procesa prijenosa topline i vlage između tijela i okoline kroz slojeve materijala. Ovaj pojam obuhvaća više aspekata, uključujući termofiziološke, senzorne i fiziološke, pri čemu su svojstva materijala vezana uz prijenos vodene pare, upijanje znoja i brzinu sušenja presudna za održavanje stabilne tjelesne temperature i osjećaja ugođe tijekom nošenja [1–3]. Tijekom tjelesnih aktivnosti umjerenog do visokog intenziteta, percipirana udobnost sportaša dodatno ovisi o fiziološkom odgovoru organizma i uvjetima izvođenja aktivnosti, uključujući razinu metaboličkog opterećenja, intenzitet znojenja, interakciju kože i odjeće te okolišne uvjete. U takvim uvjetima, sportska odjeća treba omogućiti neutralan toplinski osjet i učinkovitu regulaciju topline i vlage kako bi se nakon znojenja osigurala suha površina kože i očuvao osjećaj udobnosti [4]. Infracrvena termografija je beskontaktna metoda određivanja površinske temperature i njezine raspodjele temeljem detekcije infracrvenog zračenja, koja omogućuje vizualizaciju temperaturnih razlika u obliku termograma bez fizikalnog kontakta s mjerenim objektom. Takav način snimanja omogućuje praćenje dinamičkih promjena temperature kože i odjeće tijekom i nakon tjelesne aktivnosti te vizualnu identifikaciju zona znojenja, hlađenja i povratka tijela u toplinsku ravnotežu [5, 6]. U primjeni na tekstilne materijale infracrvena termografija se koristi kao objektivna metoda za analizu termofizioloških odgovora odjevnih sustava, čime doprinosi razumijevanju utjecaja materijala na regulaciju topline i vlage te optimizaciji dizajna sportske odjeće za veću udobnost korisnika [7].

2. Eksperimentalni dio

Za potrebe istraživanja korištene su različite pletene strukture izrađene od 100 % poliestera, koje se uobičajeno primjenjuju u izradi sportske odjeće. Uzorci se razlikuju prema osnovnim strukturnim i fizikalno-mehaničkim karakteristikama, uključujući plošnu masu, debljinu, finoću i gustoću pletiva, a u rezultatima je prikazan primjer jednog od tih ispitanih dresova kako bi se ilustrirala termofiziološka udobnost tijekom nošenja. Ispitivanje je provedeno primjenom infracrvene termografije, pri čemu je za snimanje korištena infracrvena termografska kamera Testo 872. Termografsko mjerenje provedeno je u tri definirane faze: prije početka tjelesne aktivnosti, neposredno nakon završetka aktivnosti te nakon desetominutne faze odmora. Ovakav pristup omogućuje praćenje temperaturnih promjena kože, procesa hlađenja tijela, isparavanja znoja i povratka organizma u stanje toplinske ravnoteže nakon fizičkog opterećenja. Prije početka tjelesne aktivnosti provedena je faza aklimatizacije u trajanju od 10 minuta, tijekom koje su se ispitanici prilagodili uvjetima okoline. Nakon aklimatizacije proveden je protokol strukturirane tjelesne aktivnosti u trajanju od 25 minuta, koji se sastojao od niza klasičnih sportskih vježbi zagrijavanja. Između pojedinih vježbi predviđen je kratki odmor u trajanju od 10 sekundi. Po završetku aktivnosti uslijedila je faza odmora u trajanju od 10 minuta. Termografska analiza provedena je na prednjoj strani tijela sportaša, pri čemu je promatrano područje podijeljeno u dvanaest unaprijed definiranih anatomskih zona. Takav zonalni pristup omogućuje sustavnu i usporedivu analizu temperaturnih promjena u različitim fazama tjelesne aktivnosti te objektivnu procjenu termofiziološke udobnosti sportske odjeće u realnim uvjetima korištenja.

3. Rezultati i rasprava

Na Slikama 1a – 1c prikazani su termogrami snimljeni tijekom tri faze mjerenja: prije početka tjelesne aktivnosti (Slika 1a), neposredno nakon završetka aktivnosti (Slika 1b) te deset minuta nakon završetka aktivnosti tijekom faze odmora (Slika 1c). Termogram snimljen prije tjelesne aktivnosti predstavlja početno, odnosno referentno stanje. U ovoj fazi tijelo još nije zagrijano, a raspodjela temperature na površini majice je relativno ujednačena. Nisu uočljive izražene zone povišene ili snižene temperature niti područja intenzivnog znojenja, što odgovara očekivanom stanju organizma prije fizičkog opterećenja. Na termogramu snimljenom neposredno nakon završetka tjelesne aktivnosti, jasno su vidljive promjene u raspodjeli temperature. Uočava se pojava zona intenzivnog znojenja, koje se na termogramu očituju kao područja niže temperature, prikazana hladnijim nijansama boje. Iako je u ovoj fazi metabolička proizvodnja topline povećana, isparavanje znoja s površine kože i sportske odjeće uzrokuje lokalno sniženje temperature. Ovakav temperaturni odgovor omogućuje jasnu identifikaciju područja najintenzivnijeg znojenja. Termogram snimljen deset minuta nakon završetka tjelesne aktivnosti prikazuje fazu oporavka organizma. U ovoj fazi većina znoja je isparila, a sportska odjeća započinje proces sušenja. Uočava se postupni porast temperature kože i povratak prema vrijednostima zabilježenima prije početka aktivnosti, što upućuje na uspostavljanje toplinske ravnoteže. Ova faza jasno ilustrira ulogu materijala u upravljanju vlagom, pri čemu brže sušenje materijala omogućuje učinkovitiju stabilizaciju tjelesne temperature i raniji osjećaj udobnosti.



Slika 1: Primjer termograma: a) prije početka tjelesne aktivnosti b) neposredno nakon završetka tjelesne aktivnosti c) deset minuta nakon završetka tjelesne aktivnosti

4. Zaključak

Infracrvena termografija predstavlja učinkovitu i neinvazivnu metodu za procjenu termofiziološke udobnosti sportske odjeće. Omogućuje vizualizaciju zona znojenja, hlađenja i povratka tijela u toplinsku ravnotežu, čime doprinosi razumijevanju utjecaja materijala na regulaciju topline i upravljanje vlagom. Takva saznanja ključna su za razvoj funkcionalne, prozračne i brzo sušeće sportske odjeće koja osigurava veću udobnost sportaša tijekom aktivnosti.

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**Luka Savić****Životopis**

Luka Savić doktorand je na Doktorskom studiju Tekstilna znanost i tehnologija na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu, gdje je zaposlen kao asistent. Sudjeluje u nastavi i laboratorijskim aktivnostima vezanim uz kemijsko ispredanje filamenata iz polimera i ispitivanje tekstila. Tijekom međunarodnog iskustva na Sveučilištu u Oxfordu radio je na temama povezanim s elektroispredanjem, optimizacijom procesnih parametara te izradom i karakterizacijom nanovlakana za primjene u području biomaterijala i medicinskog/tehničkog tekstila. Paralelno razvija i istraživanja povezana s FDM 3D ispisom – od pripreme i ispitivanja polimernih filamenata do izrade prototipova i funkcionalnih elemenata, uključujući 3D tiskane šablone i alate za laboratorijsku i nastavnu uporabu. Aktivno je volonterski uključen u rad udruge Penkala, udruge Eurodoc (član glavnog odbora) te udruge Upcikličići, s naglaskom na popularizaciju znanosti i akademska pitanja. Član je BFUG-a (Bologna Follow-Up Group) gdje sudjeluje u raspravama o razvoju bolonjskog procesa na razini EU.

Naslov teme doktorskog
rada

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Studijska savjetnica

Doc. dr. sc. Iva Brlek

Datum obrane doktorskog
rada

/

MEHANIČKO I KEMIJSKO RECIKLIRANJE PA 6: USPOREDBA SVOJSTAVA FILAMENATA ZA TEKSTILNU PRIMJENU I 3D ISPIS

Luka SAVIĆ

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, 10000 Zagreb, luka.savic@ttf.unizg.hr

Sažetak: Rad prikazuje koncept istraživanja usmjeren na usporedbu izvornog, mehanički i kemijski recikliranog poliamida 6 (PA 6) te njihovu primjenjivost u izradi filamenata za tekstilnu primjenu i FDM 3D ispis. Uspoređuju se osnovna svojstva materijala i obradivost, a emisije CO₂ tijekom termičke razgradnje mogu biti dodatni pokazatelj promjena u polimeru [1–4].

1. Uvod

Kružno gospodarstvo u području polimera sve više zahtjeva pouzdanu procjenu recikliranih materijala za tehničke i proizvodne primjene. Poliamid 6 (PA 6) relevantan je zbog široke uporabe u tekstilu i srodnim proizvodima, kod kojeg postupak recikliranja može utjecati na promjenu molekulne mase, reologije taline, kristalnosti i posljedično stabilnosti obrade tijekom kemijskog ispredanja. U praksi se najčešće analizira mehaničko recikliranje, koje je dostupnije, ali može pojačati degradaciju, te kemijsko recikliranje, koje omogućuje depolimerizaciju do monomera i potencijalno zatvaranje ciklusa materijala [3–5].

U ovom istraživanju prezentirati će se okvir za usporedbu izvornog (fosilnog), mehanički i kemijski recikliranog PA 6, s fokusom na izradu filamenata za tekstilnu primjenu i FDM 3D ispis. Usporedba uključuje procjenu obradivosti (stabilnost promjera i površine filamenata), temeljnih toplinskih i mehaničkih svojstava te praćenje emisija CO₂ tijekom termičke razgradnje kao dodatnog pokazatelja promjena u polimeru. Metodologija istraživanja postavljena je tako da se oslanja i na iskustva ranijih istraživanja unutar istraživačke grupe na TTF-u vezanih uz modifikaciju recikliranog PA 6 tijekom kemijskog ispredanja te primjene polimera u 3D ispisu na tekstilne podloge [1, 2].

2. Eksperimentalni rad

U istraživanju koristit će se originalni (fosilni) PA 6, mehanički recikliran PA 6 (definirani broj ciklusa) te kemijski recikliran PA 6. Umjetna vlakna će se kemijski ispredati iz taline polimera poliamida na laboratorijskom ekstruderu koji uključuje dio za ekstruziju filamenata, uz optimiranje i kontrolu procesnih parametara. Promjer filamenata pratiti će se mjernim uređajima (mikrometar ili laserski mjerač promjera), uz povlačnu jedinicu i namatanje na rotirajući valjak [5,6].

Karakterizacija uključuje ispitivanje dijela reoloških svojstava taline, toplinsku analizu (DSC uređaj za T_m/T_c i kristalnost; DMA za termo-mehaničku analizu), te mehanička ispitivanja filamenata i 3D ispisanih uzoraka za ispitivanje (kidalice TENSOLAB). Morfologija i kvaliteta površine procjenjuju se optičkom i pretražnom elektronskom mikroskopijom (SEM). Termička razgradnja analizirati će se (TGA–FTIR) radi praćenja plinovite faze i identifikacije/kvantifikacije CO₂. Za provjeru primjenjivosti u aditivnoj proizvodnji provesti će se FDM ispisi na standardiziranim uzorcima i analizirati dimenzijska točnost i ponovljivost procesa [1,2,5].

Uzorci izvornog PA 6, mehanički recikliranog PA 6 i kemijski recikliranog PA 6 će se usporediti i analizirati s ciljem postavljanja hipoteza i zaključaka. Materijali će se oblikovati u filamente uz kontrolu ključnih procesnih parametara, pri čemu se bilježe osnovni pokazatelji obradivosti i stabilnosti procesa [1,3–6].

3. Rezultati i rasprava

Očekuje se da će različiti postupci recikliranja pokazati razlike u stabilnosti obrade i svojstvima filamenata. Rezultati će omogućiti usporedbu trendova promjena kroz reološka i mehanička svojstva te emisije pri termičkoj razgradnji. Time se dobiva osnova za odabir postupka recikliranja i ciljane primjene materijala u tekstilnoj ili aditivnoj proizvodnji [1–4].

4. Zaključci

Predloženi pristup može dati usporedivu procjenu PA 6 dobivenog različitim postupcima recikliranja u kontekstu izrade filamenata. Uključivanje praćenja CO₂ tijekom termičke razgradnje može biti dodatni pokazatelj promjena materijala povezan s obradivošću i osnovnim svojstvima [1–4].

Zahvala

Autor zahvaljuje institucijskoj mentorici prof. dr. sc. Sanji Ercegović Ražić i studijskoj savjetnici doc. dr. sc. Iva Brlek te suradnicima na stručnoj podršci pri definiranju istraživačkog okvira te na podršci u laboratorijskim aktivnostima na Fakultetu.

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**Vanja Šantak****Životopis**

Nakon diplomiranja na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu, kao diplomirani inženjer tekstilne tehnologije, započeo je svoj profesionalni put 2003. godine kao uredski administrator u tvrtki Birokorekt d.o.o. Njegova sposobnost prilagođavanja raznim poslovima došla je do izražaja dok je radio u Orka Zagreb d.o.o., Esotehna d.o.o., Color Trade d.o.o. i Orka Lab d.o.o. Karijerni razvoj veže se u Interallis Chemicals d.o.o. gdje je radio kao voditelj prodaje od 2011. do 2013. te stekao značajno iskustvo u prodaji i tehnologiji. Danas je prodajni inženjer specijaliziran za vodne tehnologije u tvrtki NTI d.o.o. i službeni distributer Solenis kemikalija.

Naslov teme doktorskog rada

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Studijska savjetnica

Prof. dr. sc. Tanja Pušić

Datum obrane doktorskog rada

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OZONOM POTPOMOĞNUTI PROCESI PRANJA TEKSTILIJA

Vanja ŠANTAK

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, Zagreb, vsantak@ttf.hr

Sažetak: Ozon zbog visokog oksidacijskog potencijala u pranju tekstilija može predstavljati dopunu postojećim procesima radi doprinosa higijeni, učinkovitosti i održivosti. U radu će se analizirati učinak različitih koncentracija ozona uz deterdžent u procesu pranja taninskog zaprljanja kako bi se vrednovala njegova prilagodljivost, fleksibilnost i održivost. Cilj je utvrditi prednosti i nedostatke ozonom potpomognutog procesa pranja u odnosu na deterdžent pri temperaturama 30 °C, 40 °C, 60 °C, 75 °C i 90 °C.

1. Uvod

Ozon (O₃) kao snažno oksidacijsko sredstvo prepoznat je u tehnologiji pranja tekstilija jer ima određene prednosti u odnosu na učinak postojećih sredstava, a koje se primarno očituju u higijeni i ekološkoj održivosti. Ozonski proces je zbog učinkovitosti uklanjanja mikroorganizama, te ostalih održivih benefita smanjenja upotrebe vode i energije prihvaćen i kao jedan od ključnih tehnologija (KET-Key Enabling Technologies). U posljednje vrijeme dobiva na značenju radi učinka dezinfekcije i sprečavanja križne kontaminacije kod pranja bolničkih tekstilija, te drugih tekstilija gdje je potrebno zadovoljiti visoke higijenske kriterije. Recentna istraživanja ističu kako pranje ozonom osigurava dubinsko čišćenje i dezinfekciju, smanjuje potrošnju energije i vode, čime doprinosi ekološkoj održivosti i smanjenju ugljičnog otiska tehnologije pranja [1-3]. U kontekstu sve veće globalne skrbi za okoliš i promicanju načela održivosti, pranje ozonom može predstavljati ključnu tehnologiju u nastojanju za zelenijim i održivijim pristupima u procesnom inženjerstvu [4,5]. Osim toga, ozon se pokazao iznimno učinkovitim u uklanjanju različitih vrsta nečistoća i patogena, uključujući viruse i bakterije, što ga čini idealnim rješenjem u kontekstu trenutnih i budućih javnozdravstvenih izazova. Njegova sposobnost prilagođavanja različitim vrstama tkanina, primjerice od pamuka, poliestera i njihovih mješavina, dodatno potvrđuje njegovu primjenjivost i fleksibilnost. Tema doktorske disertacije obuhvatiti će ozonom potpomognuti proces pranja tekstilija s posebnim fokusom na njegove ekološke prednosti, učinkovitost i prilagodljivost u uklanjanju mrlja s različitih vrsta tkanina uz varijaciju čimbenika Sinnerovog kruga.

2. Eksperimentalni dio

Proces pranja standardnog test monitora zaprljanog crvenim vinom (WFK 90 LI, EMPA, Eidgenössische Materialprüfungs und Forschungsanstalt, St. Gallen, Švicarska) zajedno sa šest kg pamučnog balasta proveden je u stroju za pranje Giant-C MAX, LG, Južna Koreja, opremljenim generatorom ozona, uz varijaciju vremena, temperature, koncentracije deterdženta, bjelila i ozona. Generator ozona, BWO3, korišten je za doziranje ozona u koncentracijskom rasponu, 0.5 do 1.0 mg/L i 0.5 do 2.0 mg/L u pretpranje i ispiranju, prilikom dovoda vode temperature do 20 °C. Pokusi su provedeni tekućim deterdžentom u dvije koncentracije (D-1 i D-2) uz praškasto bjelilo (B), oba proizvoda od belgijske tvrtke Christeyns. Sastav deterdženta prema EC Direktivi sadržavao je anionske i amfoterne tenzide (<5 %), sapun i neionske tenzide (5–15 %), polimere, optička bjelila i mirise. Budući da uklanjanje specifičnih obojenih mrlja tekućim deterdžentima nije učinkovito, upotrijebljeno je sredstvo za kemijsko bijeljenje ili obezbojavanje (B) formulirano u skladu s EC direktivom, a koje sadrži neionski tenzid (<5 %), natrijev perkarbonat (>30 %), kompleksante i mirise. Oznake procesa i doziranja tekućeg deterdženta (D), bjelila (B) i ozona (O) prikazana su u tablici 1, a vrijeme provedbe procesa pranja pri odabranim temperaturama u tablici 2.

Tablica 1. Oznake i doziranje

Proces pranja	Doziranje		
	D (mL/kg)	B (g/kg)	O ₃ (mg/L)
D-1	8.3	6.7	-
D-1-O-1	8.3	6.7	≤1
D-1-O-2	8.3	6.7	≤2
D-2	15.0	10.0	-

D-2-O-1	15.0	10.0	≤1
D-2-O-2	15.0	10.0	≤2

Tablica 2. Temperature i vrijeme procesa pranja

T (°C)	30	40	60	75	90
t (min)	51	61	69	84	99

Učinak uklanjanja mrlje od vina praćen je analizom spektralnih svojstava standardnog monitora prije i nakon procesa pranja pomoću remisijskog spektrofotometra Spectraflash SF300, DataColor, Rotkreutz, Švicarska, sa standardnim izvorom svjetlosti D65 koji imitira dnevno svjetlo i geometrijom d/8° (difuzno osvjetljenje pod kutom promatranja od 8°). Za analizu uklanjanja mrlje, vrijednost remisije na valnoj duljini od 460 nm (R460) mjerena je na četiri nasumično odabrana mjesta, pri čemu viša vrijednost ukazuje na bolje performanse procesa pranja standardnog monitora.

3. Rezultati i rasprava

Standardni pamučni monitor obojen crvenim vinom, WFK 90 LI obiluje piranoantocijaninima, gdje piranski prsten stabilizira strukturu i intenzivira ton dobiven od antocijaninskog bojila [6].

Tablica 3. WFK 90 LI—standardni monitor kupan crvenim vinom prije (U) i nakon procesa pranja pri odabranim temperaturama

T (°C)	D-1	D-1-O-1	D-1-O-2	D-2	D-2-O-1	D-2-O-2
30	45.37	32.45	56.89	49.07	49.53	54.35
40	48.82	46.21	51.33	53.34	52.28	56.39
60	53.54	51.33	57.75	60.48	61.69	57.46
75	70.99	56.23	65.61	74.99	74.09	68.32
90	66.31	66.80	72.78	84.38	82.45	78.96
U	32.45	32.45	32.45	32.45	32.45	32.45

Primarni učinak u procesu pranja standardnog monitora kupanog crvenim vinom poboljšava se povećanjem temperature u gotovo svim analiziranim uvjetima procesa pranja (D-1, D-2, D-1-O-1, D-1-O-2, D-2-O-1, D-2-O-2). Malo smanjenje vrijednosti remisije zabilježeno je samo za monitor WFK 90 LI opran manjom koncentracijom deterdženta i izbjeljivača na 90 °C (D-1). Utjecaj niže koncentracije ozona (O-1) s visokom koncentracijom deterdženta (D-2) i bjelila (B) je neznatan. Utjecaj više koncentracije ozona (O-2) s većom koncentracijom deterdženta i bjelila u usporedbi s D-2 i D-2-O-1 povoljan je samo na 30 °C i 40 °C. Niže koncentracije deterdženta (D-1) i bjelila (B) uz potporu veće koncentracije ozona (O-2) poboljšavaju vrijednosti remisije oprane WFK LI tkanine na svim analiziranim temperaturama, Tablica 3.

4. Zaključak

Rezultati su potvrdili utjecaj koncentracije ozona na učinak uklanjanja mrlje od crvenog vina. Proces pranja s većom koncentracijom deterdženta i izbjeljivača i nižom koncentracijom ozona (D-2-O-1) u usporedbi s procesom pranja bez ozona ne pogoduje učinku uklanjanja mrlja od vina na analiziranim temperaturama, dok veća koncentracija ozona (D-2-O-2) pogoduje učinku na 30 °C i 40 °C.

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**Irena Topić****Životopis**

Irena Topić rođena je 1983. u Zagrebu i radi kao profesorica likovnog. 2011. diplomirala je sveučilišni diplomski studij kostimografije na Sveučilištu u Zagrebu Tekstilno- tehnološkom fakultetu (TTF), a 2013. sveučilišni diplomski studij nastavniki, smjer slikarstvo na Akademiji likovnih umjetnosti. Od 2004. do 2006. radila je kao terenski mjeritelj na projektu Hrvatski antropometrijski sustav (HAS) voditelja prof. emeritusa dr.sc. D. Ujevića. Na TTFu prvo je radila kao asistent (2011. - 2017.), a kasnije kao vanjski suradnik (2018. - 2021.). Tijekom karijere ostvarila je brojna stručna usavršavanja: u CFPIC Institutu, Felgueiras, Portugal (projekt Tied Shoe, voditeljice prof. emerite dr.sc. A. M. Grancarić), na Fakultetu Tekstila, kože i industrijskog menadžmenta, "Gheorghe Asachi", Iași, Rumunjska te u Cité des Arts, Pariz. Sudjelovala je na projektu Knowledge for footwear (K4F).

Naslov teme doktorskog rada

Utjecaj tjelesnih proporcija u postupcima konstruiranja odjeće za osobe s pretilošću

Studijski savjetnik

Prof. emer. dr. sc. Darko Ujević

Datum obrane doktorskog rada

/

UTJECAJ TJELESNIH PROPORCIJA U POSTUPCIMA KONSTRUIRANJA ODJEĆE ZA OSOBE S PRETILOŠĆU

Irena TOPIĆ

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, irena.topic@ttf.hr

Sažetak: Istraživanja tjelesnih proporcija mogu doprinijeti novim kvalitetnijim postupcima konstruiranja i modeliranja odjeće za muške i ženske osobe s pretilošću. U okviru doktorskog rada cilj je utvrditi trend u pretilosti odraslih žena i muškaraca u Gradu Zagrebu, koji će poslužiti za unapređenje postupaka konstruiranja i dizajniranja svakodnevne odjeće. Također će se ustanoviti odstupanja od Hrvatskog tehničkog izvještaja od 2012. godine o porastu pretilosti kod odraslih muškaraca i žena, provedenog u okviru projekta STIRP HAS. Na osnovu rezultata provedenih antropometrijskih mjerenja odabrane populacije cilj doktorskoga rada je utvrditi relevantne kriterije za navedenu populaciju i omogućiti prijedlog novih tipova tijela te unapređenje postupaka konstruiranja i dizajniranja odjeće.

1. Uvod

Antropometrijska mjerenja provode se već od 1900. godine s ciljem unapređenja i razvoja sustava veličina i tipova tijela. pristupi istraživača i načini mjerenja mijenjali su se i unapređivali razvojem antropometrijskih instrumenata. Tjelesnim proporcijama određuje se sukladnost i međusobni odnos pojedini tjelesnih mjera. Istraživanja u okviru doktorskoga rada temeljiti će se na utvrđivanju antropometrijskih izmjera kod muškaraca i žena s pretilošću te odstupanja od prosječne građe. Novim kvalitetnijim postupcima konstruiranja i modeliranja odjeće za osobe s pretilošću moguće je pristupiti istraživanjima njihovih tjelesnih proporcija. Navedenim istraživanjima želi se postići povećanje kvalitete života i zaštite zdravlja osoba s pretilošću. Tjelesne proporcije osoba s pretilošću određuju se sustavnim antropometrijskim mjerenjima.

2. Eksperimentalni dio

Mjerenje za potrebe doktorskoga rada provoditi će se u KBC Zagreb, nasumičnim odabirom (kriterij dolaska) ispitanika koji odgovaraju kriterijima određivanja pretilosti muške i ženske populacije. U istraživanje će biti uključeni ispitanici u dobi od 18 do 65 godina, koje imaju indeks tjelesne mase (u daljnjem tekstu ITM) $>30 \text{ kg/m}^2$, opseg struka veći od 88 cm za žene i opseg struka veći od 102 cm za muškarce. Istraživanje će obuhvatiti dvije skupine: 50 žena i 50 muškaraca. Za ispitanike isključni kriteriji su uzimanje kortikosteroidne terapije ili Cushingovo oboljenje ili Cushingovog sindroma. Prilikom ispunjavanja anketnih upitnika i njihovom statističkom obradom utvrditi će se podaci osobnim preferencijama ispitanika, osjećaju udobnosti prilikom odijevanja i poteškoćama u pronalaženju prikladne odjeće. Antropometrijska mjerenja u okviru doktorskog rada provodit će se s pomoću kompleta antropometrijskih instrumenata: antropometrom s jednim i /ili dva kraka, mjerne vrpce, jednostranog i/ili obostranog kutomjera, kljunastog kliznog antropometra, mjerne trake za određivanje opsega vrata i digitalne vage.

Istraživanje se provodi u četiri faze i to:

1. faza: priprema plana istraživanja, pregled publicirane literature, razvoj suradnje s drugi znanstvenim i istraživačkim institucijama i proizvođačkim tvrtkama.
2. faza: umjeravanje istraživačke opreme, izrada anketnih upitnika i obrazaca te antropometrijski mjerenja za ispitanike: 57 izmjera za žene i 54 za muškarce.
3. faza: provedba ispitivanja i antropometrijskih mjerenja tijekom ambulantnog endokrinološkog pregleda (KBC Zagreb).
4. faza: matematičko-statistička obrada podataka antropometrijskih izmjera, definiranje novih tipova tijela, dopuna postojećih razmjernika odjevnih veličina i potencijalna primjena pri konstruiranju i dizajniranju odjeće.

3. Rezultati i rasprava

Rezultati antropometrijskih mjerenja koja će se provesti ovim istraživanjem imat će tendenciju utvrđivanja trenda promjene tjelesnih proporcija u osobama s pretilošću (ženama s opsegom struka većim od 80 cm i

muškarcima s opsegom struka većim od 102 cm), čime će se omogućiti utvrđivanje novih tipova tijela. Ovim radom dat će se doprinos razvoju i utvrđivanju smjernica ka stvaranju novih normi i razmjernika odjevnih veličina u zemljama članicama Europske unije. Tjelesnim proporcijama se određuje sukladnost i međusobni odnos pojedinih tjelesni mjera, u konkretnom slučaju pretilost kod žena i muškaraca i/ili odstupanja od prosječne građe, čime se može egzaktno utvrditi postojanje nesukladnosti pri dizajniranju i konstruiranju odjeće za dnevnu uporabu.

4. Zaključci

Na temelju provedenih istraživanja i dobivenih rezultata utvrdit će se relevantni kriteriji za populaciju s problemom pretilosti kod žena i muškaraca u Republici Hrvatskoj što će omogućiti prijedlog novih tipova tijela sukladno utvrđenim odstupanjima od prosječne građe tijela. Time će se omogućiti objektivna znanstvena usporedba, kao i usporedba s populacijom drugih država, zemalja članica EU i šire. Također se planira uspostava suradnje s europskim institutima, koji također prate trendove povećanja pretilosti kod žena i muškaraca. Time će se stvoriti osnova za izradu muške i ženske dnevne odjeće te zaštita zdravlja u području stražnjeg dijela tijela. Primjenom rezultata istraživanja doprinijet će se daljnjoj dopuni razmjernika odjevnih veličina, izradi novog tehničkog izvještaja za populaciju s pretilosti u muškaraca i žena, a time i cjelovito unaprjeđenje konstruiranja i dizajniranja te izrade odjeće za dnevnu uporabu.

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**Gabriela Vanja****Životopis**

Gabriela Vanja rođena je 1995. god. u Zagrebu. 2022. god. diplomirala je na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu, smjer: Tekstilna kemija, materijali i ekologija. Nakon završetka diplomskog studija zapošljava se u Eurofins Ireland kao laboratorijski asistent. Od 01.07.2024. god. zaposlena je u Zavodu za projektiranje i menadžment tekstila Sveučilišta u Zagrebu Tekstilno-tehnološkog fakulteta na radnom mjestu asistenta. U akad. god. 2024./2025. upisuje poslijediplomski doktorski studij Tekstilna znanost i tehnologija na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu.

Naslov teme doktorskog rada

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Studijska savjetnica

Prof. dr. sc. Vesna Marija Potočić Matković

Datum obrane doktorskog rada

/

DIZAJN I KARAKTERIZACIJA TERMOKROMNIH PLETIVA ZA ADAPTIVNU SPORTSKU ODJEĆU

Gabriela VANJA

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Prilaz baruna Filipovića
28a, Zagreb, gabriela.vanja@tff.unizg.hr

Sažetak: Pametna vlakna i tekstili posljednjih su godina privukli sve veću pozornost, potaknuti brzim razvojem nosive elektronike i pojavom koncepta pametne odjeće. Doktorski rad temeljit će se na termokromnim materijalima u tekstilnoj i tiskarskoj tehnologiji, s naglaskom na leuko bojila i sustave tekućih kristala integrirane u pametni tekstil. Njihova primjena u sportskoj odjeći omogućuje vizualno prikazivanje topline i praćenje promjena tjelesne temperature u stvarnom vremenu, podržavajući procjenu performansi, toplinsku udobnost i svijest korisnika.

1. Uvod

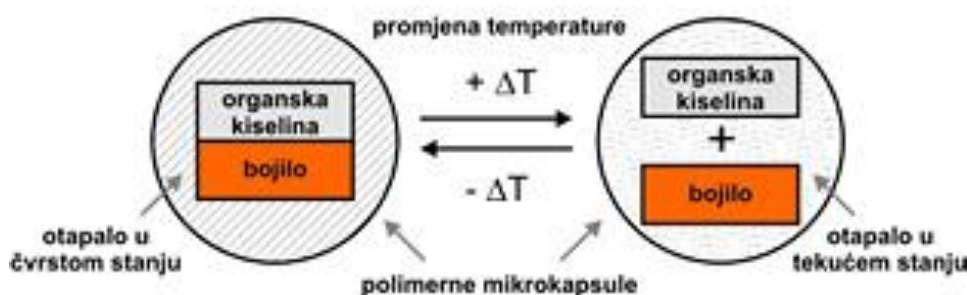
U posljednjih nekoliko godina, pametne pređe i tekstili privlače veliku pozornost zbog rastuće popularnosti nosive elektronike i koncepta pametne odjeće. Razvoj inteligentnih tekstilnih materijala predstavlja značajan inženjerski izazov i važan cilj industrijskih inovacija. Broj objavljenih radova o pametnim tekstilima kontinuirano raste unazad 10 godina. Pametni tekstili mogu se podijeliti u tri kategorije: pasivni, aktivni i ultra-pametni. Pasivni tekstil – poput kromatskih materijala – mogu detektirati promjene u okolini, ali na njih ne mogu reagirati. Aktivni tekstili, osim što osjete podražaj, mogu i na njega odgovoriti, dok ultra-pametni tekstili imaju napredne funkcionalnosti koje im omogućuju prilagodbu, promjenu oblika kao odgovor na vanjske uvjete [1]. Napredak u ovom području zahtijeva usku suradnju inženjera i dizajnera kako bi se kromatski tekstili razvili u pametne materijale koji su tehnološki napredni, ali i ekonomski isplativi.

Kromizam označava promjenu boje, a materijali koji pokazuju tu sposobnost nazivaju se kromogeni materijali. Termokromizam se odnosi na promjenu boje uzrokovanu temperaturnim promjenama [2]. Ta je promjena najčešće reverzibilna, što znači da se materijal vraća u prvotno stanje nakon što se temperatura normalizira [3]. Sustavi temeljeni na leuko bojilima najčešće se primjenjuju; mogu se mikrokapsulirati unutar polimernih matriksa i koristiti kao pigment ili se izravno ugrađivati u vlakna namijenjena tekstilnim primjenama [4].

Termokromna bojila omogućuju izradu funkcionalne sportske odjeće bez vanjske elektronike, jer se promjena boje pokreće vlastitim fiziološkim signalima nositelja. Time predstavlja znatno pristupačniji oblik praćenja tijela u odnosu na elektroničke sustave. Omogućuje procjenu intenziteta vježbanja i mogu signalizirati tjelesni umor temeljen na promjenama boje tkanine [5].

2. Eksperimentalni dio

Eksperimentalni dio dokorskog rada obuhvatit će primjenu komercijalnog mikrokapsuliranog termokromnog bojila na ispletenom uzorku pletiva. Tisak na uzorak pletiva će se zatim provesti ručnim sito-tiskom. Termokromni sustav se sastoji od tri osnovne komponente: organskog tvorca boje (leuko bojila), proton – donatorskog razvijaa (organska kiselina) te hidrofobnog otapala niste točke tališta koje određuje temperaturu pri kojoj dolazi do promjene boje. Mikrokapsulacija osigurava stabilnost i kontrolirano aktiviranje. Reakcija bojila i razvijaa odvija se pri niskim temperaturama dok je otapalo u krutom stanju. Povećanjem temperature otapalo prelazi u tekuće stanje, kompleks bojila i razvijaa se raspada, a sustav postaje bezbojan. Nakon hlađenja otapalo opet očvrstne, bojilo i razvijaa se ponovno spajaju i vraća se prvobitna boja (slika 1) [6].



Slika 1: Shematski prikaz strukturnih promjena molekula termokromnih mikrokapsuliranih bojila tijekom zagrijavanja i hlađenja [6].

Na tiskanim uzorcima pletiva će se zatim provesti sljedeće analize: mikroskopska analiza, spektrofotometrijska analiza, analiza primjene FTIR spektrometra te će se ispitivati postojanosti bojila, osobito na pranje i trenje.

3. Rezultati i rasprava

Rezultati ispitivanja obojadisnog pletenog uzorka imaju cilj utvrditi jednoličnost obojenja uzorka prije i nakon podvrgnutog zagrijavanja te stabilnost otisnutog uzorka pri višekratnoj uporabi. Spektrofotometrijskom analizom ispitati će se raspon promjene obojenja u određenom broju ciklusa zagrijavanja i hlađenja te odrediti remisijska krivulja. Pletiva će se analizirati na FTIR spektrofotometru te odrediti spektralne krivulje.

4. Zaključci

Termokromni materijali predstavljaju inovativnu klasu funkcionalnih tekstilnih materijala, sposobnih vizualno reagirati na toplinu. Najčešće se koriste sustavi temeljeni na leuko bojilima zbog reverzibilnosti, raspona boja i ekonomičnosti. Unatoč izazovima poput ograničene postojanosti i osjetljivosti na okolišne uvjete, recentna istraživanja pokazuju napredak u performansama i metodama integracije, otvarajući mogućnosti za primjenu u sportu, modi, medicini i zaštitnoj odjeći.

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**Franka Žuvela Bošnjak****Životopis**

Franka Žuvela Bošnjak rođena je 22. veljače 1978. godine u Splitu. Zvanje dipl. ing. stječe 2003. godine na Sveučilištu u Zagrebu Tekstilno-tehnološkom fakultetu (SuZg TTF). 1999. godine proglašena je najboljom studenticom kemijskog smjera a 2000. godine dobiva Rektorovu nagradu za znanstveni rad. Nakon 13 godina rada u industriji, 2016. godine zapošljava se na radnom mjestu asistenta na SuZg TTF-u u području tehničkih znanosti, znanstveno polje tekstilna tehnologija, znanstvena grana tekstilna kemija, a danas radi kao predavač na istom Fakultetu. Nakon zaposlenja upisala je poslijediplomski sveučilišni studij Tekstilna znanost i tehnologija. Područja znanstvenog interesa su istraživanje struktura i svojstava različitih vrsta koža te priprema i obrada koža.

Naslov teme doktorskog rada

Utjecaj sintetskih zeolita i β -ciklodekstrina na svojstva goveđe kože

Mentor

Prof. dr. sc. Sandra Flinčec Grgac

Datum obrane doktorskog rada

/

FIZIKALNO-KEMIJSKE PROMJENE U STRUKTURI GOVEĐE KOŽE

Franka ŽUVELA BOŠNJAK

Sveučilište u Zagrebu Tekstilno-tehnološki fakultet, Hallerova aleja 6a,
Varaždin, franka.zuvela.bosnjak@tff.unizg.hr

Sažetak: Zbog široke primjene goveđe kože u industriji i sve strožih ekoloških zahtjeva, istražuje se mogućnost zamjene tradicionalnih fungicida ekološki prihvatljivijim sredstvima. U ovom radu ispitana je primjena zeolita kao alternative konvencionalnim fungicidima u procesu štavljenja goveđe kože. Sirova goveđa koža prošla je kroz pripremne radove u tvorničkim uvjetima, a zatim kromno štavljena u dvije varijante: s dodatkom fungicida i sa zeolitom umjesto fungicida. Nakon štavljenja, uzorci su analizirani FT-IR ATR spektroskopijom radi procjene utjecaja zeolita na fizikalno-kemijska svojstva kože. Dobiveni rezultati omogućuju uvid u strukturne promjene uzorka obrađenog zeolitom u odnosu na uzorak s fungicidom.

1. Uvod

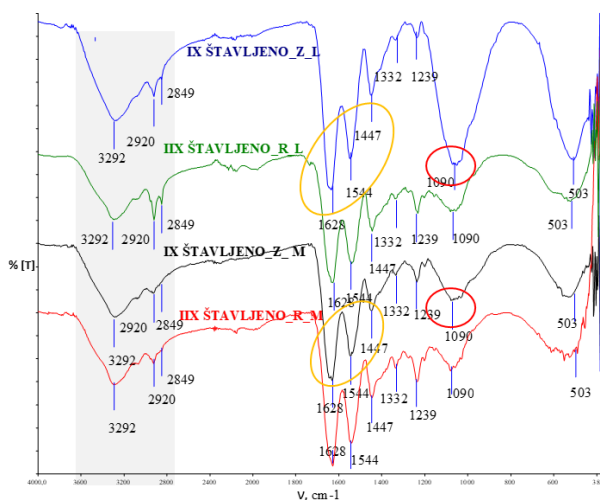
Zbog široke primjene goveđe kože u industriji, stalno se traže ekološki prihvatljiviji načini obrade. Strogi propisi zahtijevaju primjenu postupaka koji štite okoliš, pa se u ovom radu istražuje mogućnost zamjene štetnih fungicida zeolitom. Mikroorganizmi koriste hranjive tvari iz kože, što može dovesti do njenog propadanja tijekom obrade, osobito u vlažnim i kiselim uvjetima. Gljivice uzrokuju oštećenja poput degradacije kolagena i pojave mrlja, što smanjuje vrijednost proizvoda i povećava troškove. Zbog štetnosti tradicionalnih sredstava, industrija prelazi na prirodnije alternative poput eteričnih ulja i kitozana. Europska unija i druge zemlje uvode stroge regulative, pa se sve više primjenjuju manje štetne metode zaštite kože. [1-2].

2. Eksperimentalni dio

U tvorničkim uvjetima, sirova goveđa koža najprije je podvrgnuta pripremnim radovima koji uključuju močenje, luženje, odvapnjivanje i piklanje prema redovnim recepturama. Proces štavljenja proveden je u bačvama za obradu uzoraka (FER-TI, Italija). Provedena su dva različita postupka: u prvom je korišteno kromno štavno sredstvo uz dodatak fungicida, dok je u drugom procesu fungicid zamijenjen zeolitom. Prema uobičajenoj recepturi, fungicid se dozira u dva navrata: 0,20 % pet sati od početka procesa te dodatnih 0,10 % sedam sati nakon početka štavljenja. Na tako uštavljenim uzorcima provedena je analiza fizikalno kemijskih svojstava uzoraka primjenom infracrvene Fourierove transformacije spektra (FT-IR) u tehnici smanjene ukupne refleksije (ATR) (Perkin Elmer, softver Spectrum 100). Učinjena su 4 skeniranja za svaki uzorak pri rezoluciji od 4 cm^{-1} između 4000 cm^{-1} i 380 cm^{-1} . Uzorak označen IX_ŠTAVLJENO_Z_L predstavlja kožu štavljenu zeolitom, strana lica. Uzorak IX_ŠTAVLJENO_Z_M označava kožu štavljenu zeolitom, mesna strana. Uzorak IX_ŠTAVLJENO_R_L označava kožu kromno štavljenu po redovnoj recepturi, strana lica, dok IX_ŠTAVLJENO_R_M označava kožu kromno štavljenu po redovnoj recepturi, mesna strana.

3. Rezultati i rasprava

Na uzorcima sa zeolitom pojavljuje se intenzivan pik na 1090 cm^{-1} koji upućuje na vibracije nastale unutar tetraedarske TO_4 strukture mikroporoznog zeolita (obilježeno crveno). Poznato je da apsorpcijski pikovi koji se pojavljuju u rasponu od 1090 cm^{-1} do 1020 cm^{-1} nastaju uslijed vibracija unutar C-N veza primarnih amino skupina kolagena. Iz navedenog može se zaključiti da je promjena intenziteta pika pri valnom broju 1090 cm^{-1} nastala uslijed prisutnosti zeolita u kolagenu. Pikovi karakteristični za amid I (1650 cm^{-1}), amid II (1550 cm^{-1}) i amid III (1235 cm^{-1}) kod uzorka sa zeolitom (obilježeno žuto) ostaju u istom valnom području kao kod redovnog uzorka ali pojačanog intenziteta[3]. Kod svih uzoraka vidljivi su i pikovi u području $3000 - 3600\text{ cm}^{-1}$ koji upućuju na vibracije unutar O-H i N-H veze (3292 cm^{-1}) kao i pikovi u području $2800 - 3100\text{ cm}^{-1}$ koji upućuju na vibracije unutar C-H veze (2849 cm^{-1}).



Slika 1: Spektralne krivulje uzoraka kože nakon provedenog štavljenja snimljene na strani lica i mesnoj strani

4. Zaključak

Rezultati FTIR analize pokazuju da primjena zeolita u procesu obrade kože uzrokuje specifične promjene u spektralnom području od 1100 do 900 cm^{-1} , pri čemu se javlja intenzivan pik na 1090 cm^{-1} karakterističan za strukturu zeolita. Također, promjene u intenzitetu pikova u ovom području upućuju na interakciju zeolita s kolagenom, posebno s primarnim amino skupinama. Pikovi karakteristični za amid I, II i III ostaju u istom valnom području kao kod redovno štavljenog uzorka, ali su pojačanog intenziteta, što sugerira da prisutnost zeolita utječe na strukturu i svojstva kolagena. Dobiveni rezultati ukazuju da već manje količine primjene zeolita u procesu štavljenja kože, imaju pozitivan učinak na kožu koja zadržava osnovne strukturne karakteristika kolagena s vidljivim pikovima karakterističnim za zeolite.

5. Zahvala

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Prof. Sanja Ercegović Ražić, Ph. D., head of the doctoral study

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Introduction

The Doctoral Study Programme in Textile Science and Technology is a continuation of the university graduate study programme, combining theoretical knowledge, research work and problem-solving experience based on an understanding of modern production systems. The programme is offered by the Faculty of Textile Technology at the University of Zagreb within the scientific field of Textile Technology (part of the broader area of Technical Sciences).

The Doctoral Study Programme in Textile Science and Technology (<https://www.ttf.unizg.hr/tekstilna-znanost-i-tehnologija/226>) is the only doctoral programme in this field in the Republic of Croatia and the most significant in the region.

The primary goal of the programme is to equip doctoral candidates for independent scientific research, foster innovation and enable the transfer of research findings to improve modern production processes in the textile and clothing industries. Advancements in technical sciences focus particularly on material research and characterisation, with an emphasis on the application of biotechnology and nanotechnology. Key developments in this area include advanced materials and composites, as well as multifunctional protective and smart clothing and footwear. The International Council of Academies of Engineering and Technological Sciences (CAETS) has designated materials research – including research into textile materials – as a priority area.

The Doctoral Study Programme in Textile Science and Technology enables doctoral candidates to pursue careers in research institutions, organisations with a significant research component, the public and private sectors and the broader economy. Upon completion of the programme, graduates are qualified for teamwork and for independently leading national, bilateral and European scientific and professional projects within the scope of the programme's research areas. The knowledge they acquire and their research potential enable them to continue their scientific work through further doctoral-level professional development..

Head of the doctoral study

Dean of the University of Zagreb
Faculty of Textile Technology

Prof. Sanja Ercegović Ražić, Ph. D.

Prof. Anica Hursa Šajatović, Ph. D.

Foreword

The University of Zagreb Faculty of Textile Technology, as the organiser of the doctoral study programme Textile Science and Technology, is holding the PhD Students' Day scientific conference for the fourth time. This scientific event proudly presents the research work of its doctoral candidates under the guidance of their esteemed mentors.

In the Proceedings of the PhD Students' Day 2026, 20 extended abstracts of papers on PhD research topics, written in Croatian and English, have been published. In addition to the extended abstracts of papers on PhD research topics, full papers by eight (8) Doctors of Science have been included; they completed their doctorates at the University of Zagreb Faculty of Textile Technology since the previous PhD Students' Day in 2026.

This collection of papers provides insight into the diversity and quality of scientific research topics and the involvement of our doctoral students in the development of new, innovative methods, materials and technologies through the application of new ideas and engineering solutions.

Head of the doctoral study

prof. Sanja Ercegović Ražić, Ph. D.



Ivana ČORAK RIBIĆ

Biography

She graduated from the University of Zagreb, Faculty of Textile Technology (TTF) in 2015. At TTF, she worked as an assistant on the project HRZZ-DOK-2018-09-4254 Bio-innovated polyester material aimed for use in the hospital environment. She was a researcher on HRZZ UIP-05-2019-8780 HPROTEX, the bilateral Croatia and Serbia scientific project Bio-innovated polyesters, and Erasmus+ projects Sustainable Design and Process in Textiles for Higher Education (GreenTEX) and AEQUALIS4TCLF Blueprint project. She received the Interim Deans Award for Excellence at Postgraduate Doctoral Study TST in 2019/2020, TSRC Award 2021 for the scientific research work in the field of textiles in category I: young researchers at the TSRC Day 2021, and the Young Scientist Award "Vera Johanides" for 2024. Since 2025, she has been employed as a senior assistant at TTF in the field of printing and color theory.

Title of Ph. D. thesis

Bio-innovated polyester material aimed for use in a hospital environment

Mentor

Prof. Anita Tarbuk, Ph. D.

Date of dissertation defense

November 22nd, 2024

BIO-INNOVATED POLYESTER MATERIAL AIMED FOR USE IN A HOSPITAL ENVIRONMENT

Ivana ČORAK RIBIĆ

University of Zagreb Faculty of Textile Technology, Prilaz baruna Filipovića 28a, Zagreb,
ivana.corak@tft.unizg.hr

Abstract: The research within the scope of the dissertation includes the development of bio-innovated polyester materials aimed for use in a hospital environment. The activation of the surface of the polyester fabric was carried out by alkaline hydrolysis at a reduced temperature with the addition of accelerators and environmentally friendly enzymes, amano lipase. Functionalization was carried out with chitosan homogenized in an aqueous solution of acetic acid using the pad-dry-cure method. The comfort of the fabric after processing as well as the persistence of processing was confirmed by measuring total comfort after 10 cycles of adapted washing process.

1. Introduction

Polyester accounts for almost 80% of the total production of synthetic fibers, of which poly(ethylene terephthalate), PET, is the most common, and is characterized by a hydrophobic surface due to high crystallinity. Because of that, surface modifications such as hydrolysis are carried out, which causes cleavage at the ester bonds and results in an increased number of hydroxyl and carboxyl groups, whereby the fabrics have better adsorptivity. Compared to the environmentally unfavorable alkaline hydrolysis, which can permanently damage the fibers, enzymatic hydrolysis enables hydrolysis of the material at a low temperature. Due to their size, enzymes act exclusively on the surface of the fiber, so they do not cause damage. Various enzymes are used for enzymatic hydrolysis of PET, but the best effects are achieved with lipase and cutinase [1, 2]. Chitosan is a natural biopolymer consisted mainly of 2-amino-2-deoxy-D-glucopyranose units linked by β -1,4-linkages. Despite the numerous existing antimicrobial agents, public awareness and EU policy have highlighted the need for new bio-agents in the development of hospital materials. The great interest in the application of chitosan in the hospital environment is because of its favourable properties: biocompatibility, biodegradability, non-toxicity, antimicrobial, hemostatic and moisturizing efficacy [3]. The development of bio-innovated polyester materials aimed for use in a hospital environment has been researched using amano lipase and chitosan. Activated fabric surface was functionalized with a homogenized solution of chitosan in acetic acid by the pad-dry-cure method, Figure 1.

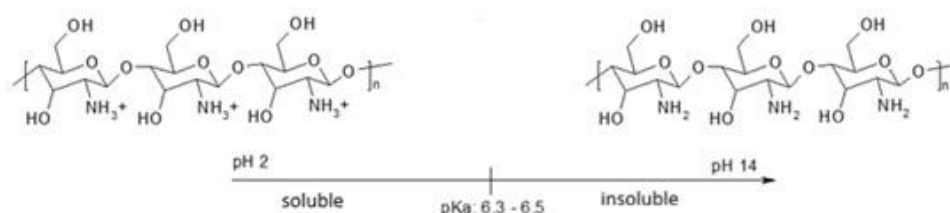


Figure 1: Schematic representation of chitosan in aqueous solution depending on pH value

2. Experimental

A commercial polyester fabric made of 100% poly(ethylene terephthalate) with a surface mass of 60 g/m² (Belira) was used for the research. Hydrolysis was carried out in 1.5 M NaOH at 80 °C for 10 min with the addition of 2 g/l accelerator, cationic surfactant hexadecyltrimethyl ammonium chloride (HDTMAC, 25% aqueous solution, Fluka). Enzymatic hydrolysis was performed with 0.2 g/l Amano Lipase A (*Aspergillus niger*) from Sigma-Aldrich at pH 9 at 60 °C for 60 min. For functionalization, chitosan obtained from oyster mushroom mycelium from Chibio BioTECH was used. The fabrics were impregnated in a homogenized solution of chitosan in acetic acid (3 g/l), dried at 110 °C for 2 min and thermocondensed at a temperature of 170 °C for 90 seconds. The labels and their interpretation used in the research are shown in Table 1.

Table 1: Labels and their interpretation used in the research

Label	Interpretation
PET	Commercial PET fabric
H	Alkaline hydrolyzed fabric with the addition of HDTMAC
ALA	Enzymatically hydrolyzed fabric using Amano Lipase A from <i>A. niger</i>
K	3 g/l of homogenized chitosan
1W or 10W	1 st or 10 th wash cycle

In order to determine the comfort of the fabrics, as well as the persistence of the processing, the following measurements were carried out. The zeta potential was measured on a SurPASS electrokinetic analyzer (Anton Paar GmbH) using the flow potential method. The electrokinetic potential (zeta, ζ) was measured as a function of the pH value of 1 mmol/l KCl using a cell with an adjustable gap and the isoelectric point (IEP) was determined [4]. The moisture management ability test was performed according to AATCC TM 195-2021 Liquid Moisture Management Properties of Textile Fabrics on a Moisture Management Tester (MMT), M290 MMT, by SDL Atlas. Before the measurements, the samples were conditioned in a stability climate chamber, model KBF-S 240 E6, 9020-0366, Binder GmbH at 21 ± 2 °C and relative air humidity $65 \pm 5\%$ [5, 6]. The comfort of the fabric was determined by measuring the physical properties of fabrics related to the sense of touch on the SDL Atlas Fabric Touch Tester (FTT M293). The measured properties provide 13 different FTT indices of the flat textile material, and then the FTT software calculates the modulus (smooth, soft, warm) and the overall comfort of the flat textile material. The samples were conditioned under standard conditions before the measurement procedure [7, 8]. The tests were carried out after the 1st and 10th cycles of adapted washing in a Wascator FOM71 CLS (Electrolux) washing machine. Washing was carried out in soft water with the addition of detergent with optical brightener (ISO 15797:2002) with the subsequent addition of PAP, ϵ -(phthalimido) peroxyhexanoic acid, at 50 °C according to a specially designed program. Drying was carried out in a T5130-LAB – Type A1 (Electrolux) dryer for 30 min in the NORMAL LAB program.

3. Results and Discussion

The values of the zeta potential and the isoelectric point of the measured samples are shown in Table 2. The low values of the zeta potential of PET fabric in an alkaline medium are the result of its hydrophobic surface caused by the high crystallinity of the fiber and the small number of active groups. By functionalization with chitosan, the zeta potential has higher values in alkaline and neutral media due to the presence of amino groups of chitosan [3]. Alkaline hydrolysis of polyester led to the creation of a larger number of active groups and an increase in the adsorption surface on which homogenized chitosan was adsorbed, which led to a more positive zeta potential in alkaline medium and a shift of the IEP towards higher pH values compared to unhydrolyzed polyester. It can be seen that the zeta potential decreases with each washing cycle, which indicates that the adsorbed homogenized chitosan is removed from the surface. Enzymatic hydrolysis leads to peeling of the surface, which is not visible in the change of IEP. However, chitosan functionalization indicates that the enzymatic hydrolysis was successful as the zeta potential values are higher compared to non-hydrolyzed PET. Enzymatically hydrolyzed PET fabric with ALA enzyme has better wash fastness compared to alkaline hydrolyzed and untreated PET fabric as indicated by IEP.

Table 2: Zeta potential (ζ) and isoelectric point (IEP) of the samples

Sample	PET			PET-H			PET-ALA		
	$\zeta_{\text{pH } 4}$ [mV]	$\zeta_{\text{pH } 8}$ [mV]	IEP	$\zeta_{\text{pH } 4}$ [mV]	$\zeta_{\text{pH } 8}$ [mV]	IEP	$\zeta_{\text{pH } 4}$ [mV]	$\zeta_{\text{pH } 8}$ [mV]	IEP
	-44.24	-69.46	< 2	-23.78	-61.15	2.62	-54.40	-71.11	< 2
K	26.65	-50.82	4.97	36.33	-37.67	5.40	32.35	-43.57	5.59
K 1W	25.21	-50.18	4.96	33.25	-40.70	4.81	29.77	-50.51	4.88
K 10W	-15.68	-30.12	2.59	-25.50	-60.49	2.70	-35.05	-62.86	3.15

The fabric type of the tested samples determined by testing the liquid moisture management ability is shown in Table 3. The types of textile materials and the description of their properties [5, 6] shown in the table are as follows: Water Penetration Fabric (WPF) – small spreading area, excellent one-way transport; Moisture Management Fabric (MMF) – medium to fast wetting, medium to fast absorption, large spread area at bottom surface, fast spreading at bottom surface, good to excellent one-way transport; Fast Absorbing and Quick Drying Fabric (FAQDF) – medium to fast wetting, medium to fast absorption, large spreading area, fast spreading, poor one-way transport. Alkaline hydrolyzed samples with chitosan show the best moisture management ability and are characterized as fast-absorbing and fast-drying textile materials.

Table 3: Fabric type of measured samples determined by MMT

Sample	Fabric type		
	PET	PET-H	PET-ALA
	MMF	WPF	MMF
K	WPF	MMF	WPF
K_1W	MMF	FAQDF	MMF
K_10W	MMF	FAQDF	MMF

The tactile sensation obtained based on the indices determined in the FTT is shown in Figure 2. The tactile sensation can have values between 0 and 1, with the value 0 indicating the roughest, hardest or coldest fabric, and 1 indicating the smoothest, softest or warmest fabric [9].

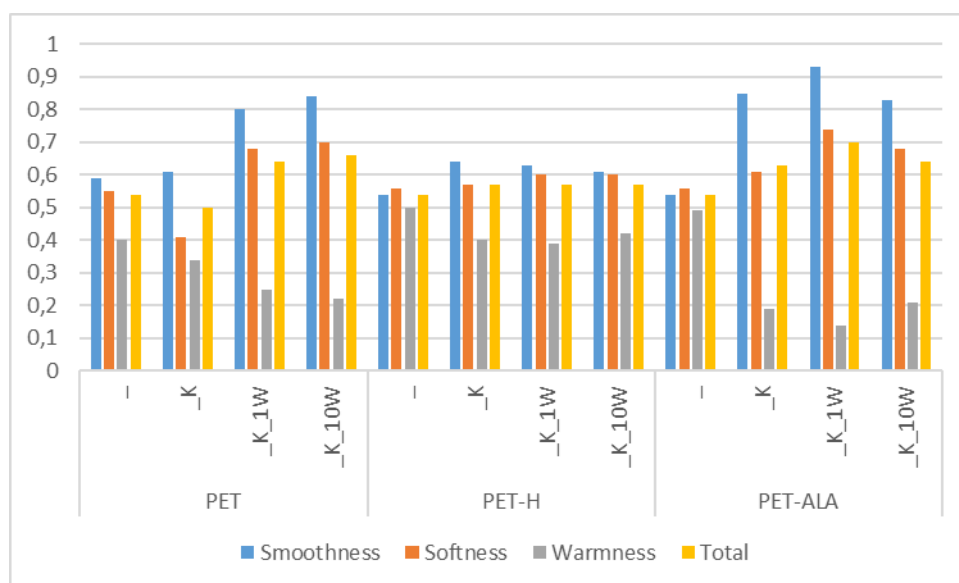


Figure 2: Tactile sensation obtained based on indices determined at the FTT

It is visible that PET fabric before and after chitosan functionalization has the lowest total comfort. The washing process of chitosan functionalized samples results in an increase in smoothness and softness, which also increases the total comfort of the fabric itself. Alkaline hydrolyzed fabric has greater comfort compared to non-hydrolyzed fabric, however, with chitosan functionalization the total comfort remains almost the same. Enzymatic hydrolysis also does not increase the comfort, however, with chitosan functionalization the sample becomes smoother, especially after the first wash cycle. After the 10th wash cycle, there is a decrease in smoothness and softness, the fabric retains a cool feel, but the total comfort is still above 0.6, which is higher compared to the non-hydrolyzed sample.

4. Conclusion

With the right selection of process parameters, hydrolysis of the surface of commercial polyester fabric can be carried out in an ecologically, energetically and economically acceptable way. The pad-dry-cure method with a homogenized solution of chitosan in acetic acid is stable even after multiple washing cycles. Hydrogen and ionic bonds are formed between protonated chitosan (NH₃⁺) and carboxyl and hydroxyl groups of PET fiber.

The overall comfort of the enzymatically hydrolyzed sample is satisfactory even after 10 washing cycles, which is important if the apparels are to be worn multiple times. Considering all the obtained results, the bio-innovated process of activating the surface of PET fabrics by enzymatic hydrolysis with amanolipase A from *Aspergillus niger* (ALA) functionalized with homogenized chitosan by pad-dry-cure method proved to be more acceptable.

Acknowledgment



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Franka KARIN

Biography

Franka Karin, Ph.D., was born in Zagreb. At the University of Zagreb, Faculty of Textile Technology, she completed her undergraduate study in Textile and Fashion Design in 2009, and her graduate study in Textile Technology and Engineering in 2012. She completed her postgraduate doctoral study in Textile Science and Technology in 2025 when she defended her doctoral thesis entitled Development of basic silhouettes of women's clothing adapted to the fundamental principles of sustainability in fashion. Since 2017, she has been employed at the Faculty of Textile Technology as an associate assistant at the Department of Textile and Clothing Design. Scientific research work is related to the concept of zero waste and its application in fashion design for the purpose of sustainable development and defining new methods of construction, modelling and clothing production that reduce intercutting loss during production.

Title of Ph. D. thesis

The development of basic silhouettes of women's clothing adapted to the fundamental principles of sustainability in fashion

Mentor

Associate prof. Blaženka Brlobašić Šajatović, Ph. D.

Date or dissertation defense

January 29th, 2025

THE TAXI METHOD AS A SUSTAINABLE SOLUTION TO REDUCE INTERCUT LOSS OF THE BASIC "X" SILHOUETTE OF WOMEN'S CLOTHING

Franka KARIN

University of Zagreb Faculty of Textile Technology, Prilaz baruna Filipovića
28 a, franka.karin@ttf.unizg.hr

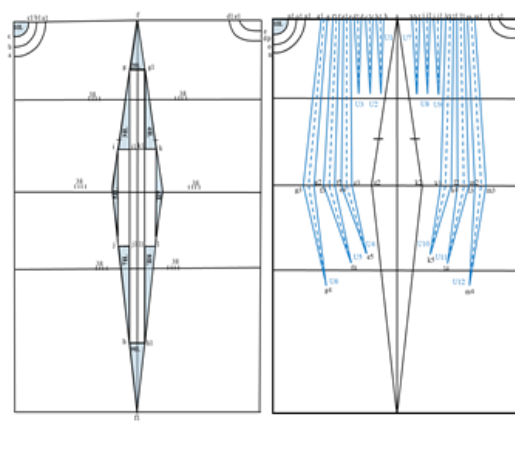
Abstract: *Inter-pattern waste generated in garment production processes represents a growing challenge for the apparel industry, which is why new approaches to clothing design based on sustainable development and the zero-waste concept are being developed. This paper presents the development of a women's dress with a basic "X" silhouette using the innovative TAXI method. The basic pattern based on the fundamental garment construction was compared with the basic pattern and the pattern developed according to the TAXI method design proposal. Fabric utilization was analyzed for both methods. The results show that the basic "X" silhouette designed using the TAXI method achieves 99.8% fabric utilization, which is 32.5% higher compared to the basic pattern. The proposed TAXI method enables the maximum possible use of fabric without compromising the aesthetic component. It provides a good fit to the body and achieves recognizable garment silhouettes.*

1. Introduction

Sustainable development in clothing design and the application of the zero-waste concept play a key role in reducing inter-pattern waste and protecting natural resources. The fashion industry is one of the largest contributors to textile waste due to inter-pattern waste generated during garment production processes. The goal of the zero-waste concept in clothing design is focused on the rational use of fabric and the extension of the life cycle of garments, with designers playing a significant role in both the design and production processes. Previous research on zero-waste concept methods has shown significant progress in reducing inter-pattern waste; however, limitations related to garment fit according to the basic silhouettes of women's clothing have also been identified. The silhouette of a garment is important in clothing design because it defines the shape and the way the garment fits the body. This paper presents a comparison of inter-pattern waste between the basic pattern and the pattern developed according to the design proposal based on the fundamental garment construction and the developed TAXI method for a women's dress with a basic "X" silhouette. The TAXI method is focused on preserving the shape of the basic silhouettes of women's garments while reducing inter-pattern waste. The research results in the definition of the basic pattern-making procedure and the design-based pattern-making procedure for the "X" basic silhouette of a women's dress according to the developed TAXI method, thereby contributing to the advancement of sustainable development in garment production and the development of innovative methods in the field of design [1–5].

2. Experimental part

Within the scope of the research, existing clothing design methods based on the zero-waste concept were analysed, on the basis of which a new TAXI method in the field of clothing design and construction was developed. The proposed method enables the creation of a basic pattern and its adaptation to the basic silhouettes of women's clothing while fulfilling five fundamental criteria of sustainable development: aesthetics, fit, cost, reduction of inter-pattern waste, and manufacturability. The new method is based on the basic silhouettes of women's clothing ("T," "A," "X," and "I"). The paper presents the development of a basic pattern and a design-based pattern for the basic "X" silhouette of a women's dress using the new method, which has clearly defined rules and procedures for creating basic patterns (Figures 1a and 1b). The procedure starts from a grid defined by the fabric width of 70 cm, a garment length of 100 cm, and the main vertical body measurements. Mathematical expressions of construction body measurements were adopted from the fundamental construction and modified, while certain measurements were defined according to the TAXI method [6].



a

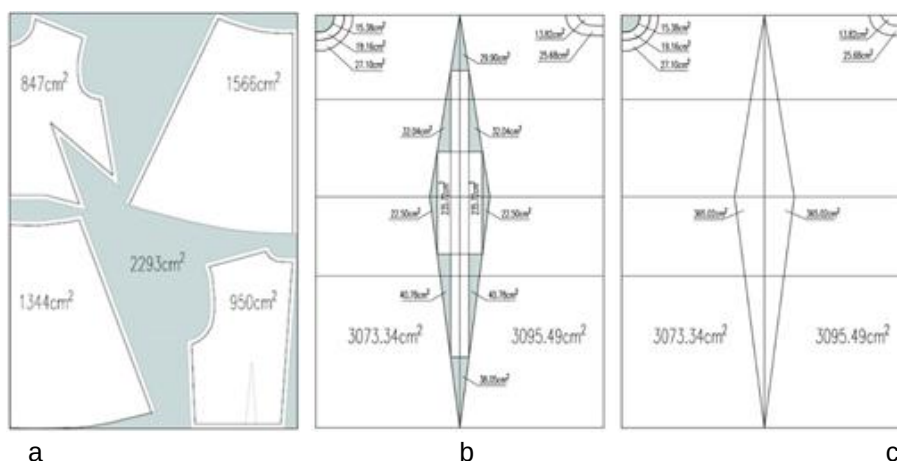
b

Figure 1: Construction of a women's dress according to the TAXI method: a) basic dress cut of the basic "X" silhouette, b) cut according to the design proposal of a women's dress of the basic "X" silhouette [6].

The patterns were created using the AutoCAD computer program, in which the areas of the pattern pieces and the inter-pattern waste were precisely defined. By modeling the basic patterns according to the TAXI method, a design-based procedure was developed that enables the adaptation of basic silhouettes with maximum fabric utilization through the application of construction elements in the waist, hip, shoulder, and garment length areas. Inter-pattern waste was compared for both methods in order to determine whether the proposed zero-waste concept method can reduce inter-pattern waste in comparison with the fundamental garment construction. The fit of the basic "X" silhouette was tested using the Clo 3D computer program [6].

3. Results and discussion

The paper presents the results of the analysis of inter-pattern waste areas for the basic "X" silhouette of a women's dress, modeled according to the fundamental garment construction shown in Figure 2a, according to the TAXI method proposal shown in Figure 2b, and according to the TAXI method design proposal shown in Figure 2c. The fundamental construction of the women's dress was created for ready-to-wear size 38 and was modeled with the aim of achieving the basic "X" silhouette [6].



a

b

c

Figure 2: Surfaces of intercut losses: a) surface of intercut loss of a women's dress "X" of the basic silhouette according to the basic garment construction, b) surface of intercut loss of a women's dress "X" of the basic silhouette of the basic cut according to the TAXI method, c) surface of intercut loss of a women's dress "X" of the basic silhouette of the design proposal according to the TAXI method [6].

The total area of the pattern layout according to the fundamental garment construction is 7000 cm². For the basic "X" silhouette of a women's dress, the area of the front and back pattern pieces is 4707 cm², while the inter-pattern waste amounts to 2293 cm². In the basic pattern of the "X" silhouette women's dress developed according to the TAXI method, the area of the front and back pattern pieces is 6168.83 cm², the area of the facings for the front and back neckline, armholes, and dress length is 557.2 cm², and the inter-pattern waste

amounts to 341.93 cm². According to the TAXI method design proposal, the area of the front and back pattern pieces is 6168.83 cm², while the inter-pattern waste area is 15.38 cm². Fabric utilization for the basic "X" silhouette of a women's dress according to the fundamental construction is 67.3%, while according to the TAXI method it increases to 96%, and according to the TAXI method design proposal it reaches 99.8%, representing a 32.5% improvement in utilization. Inter-pattern waste was reduced from 32.7% to 0.2%. These results confirm that the TAXI method significantly reduces textile waste. A simulation of women's dresses with a basic "X" silhouette was carried out in the Clo 3D computer program to compare the fit according to the fundamental garment construction and the TAXI method (Figures 3a and 3b). Based on the simulation, it can be concluded that the fit achieved by the proposed TAXI method is equally good as that achieved by the fundamental garment construction [6].



Figure 3: "X" basic silhouette of a women's dress in the Clo 3d computer program: a) simulation of the "X" basic silhouette of a women's dress according to the basic construction of the garment, b) simulation of the "X" basic silhouette of a women's dress according to the TAXI method design proposal [6].

4. Conclusion

The analysis of existing zero-waste concept methods showed that garments lack recognizable basic silhouettes, even though they achieve the maximum possible fabric utilization. The proposed TAXI method achieves fabric utilization of 99.8% and meets the fundamental criteria of sustainable development. The inter-pattern waste defined in the basic pattern, which arises as the difference between the silhouette shape and the sum of the main body measurements in the bust, waist, and hip areas, was used for construction elements in the design proposal in order to further emphasize the "X" silhouette and its fit to the body. The basic "X" silhouette developed according to the TAXI method achieves very high fabric utilization with minimal inter-pattern waste, significantly better than silhouettes based on the fundamental garment construction. The results confirm that the TAXI method offers a sustainable and practical solution for the production of women's garments, reducing textile waste and enabling application in mass production.

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Mateo Miguel Kodrič Kesovia

Biography

Born in 1987 in Dubrovnik. He graduated in textile conservation and restoration at the University of Dubrovnik, where he has been employed and became Assistant Professor in 2021. He teaches several courses at the Department of Art and Restoration, University of Dubrovnik, and is a visiting lecturer at the University of Montenegro. In 2025 he finished his Ph. D. in Textile Science and Technology at the University of Zagreb. He has specialized his skills and knowledge at institutions in Italy, Austria, and Switzerland. Collaborated on numerous domestic and international conservation-restoration projects. Author of several scientific and professional papers. He actively participates in domestic and international expert committees and organizations (HRD, ECCO, ENCoRE). His scientific interests include the history of textile technology, and cultural heritage digitization.

Title of Ph. D. thesis

Method of analysis and digitalization of technical documentation of historical damask fabrics in Dubrovnik region

Mentors

Prof. Željko Penava, Ph. D.

Prof. Katarina Nina Simončič, Ph. D.

Date of dissertation defense

July 21st, 2025

METHOD OF ANALYSIS AND DIGITALISATION OF TECHNOLOGICAL DOCUMENTATION OF HISTORICAL DAMASK FABRICS FROM THE DUBROVNIK AREA

Mateo Miguel KODRIČ KESOVIA

University of Dubrovnik, Branitelja Dubrovnika 41, mmkesov@unidu.hr

Abstract: This dissertation presents an innovative approach to researching and documenting historical fabrics in a digital environment. Through an interdisciplinary approach, it links different scientific fields to ensure a comprehensive analysis and interpretation of historical textile materials.

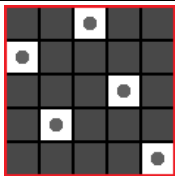
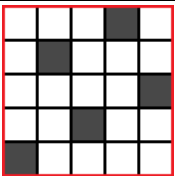
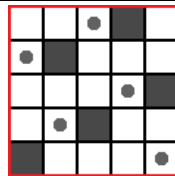
1. Introduction

Patterned fabrics, as a form of expression of human creativity, are created through an interesting interaction between the designer and the weaver in all stages of their realization and represent a complex but perfect symbiosis of textile art and technology. Among historical patterned fabrics, damask stands out in particular, in which artistic and ornamental solutions are realized exclusively through the construction of the fabric, which, due to its constructional logic and visual possibilities, has been used continuously from the early Middle Ages to the present day.

The fundamental characteristic of damask derives from the alternation of face and reverse sides of the fabric, whereby the pattern is formed through changes in weave structures, most commonly within the same weave type. This technique enables the creation of rich decorative compositions without additional materials, which had significant technological and economic advantages in historical production [1].

The analysis of historical damask fabrics conducted within this research encompassed an exceptionally representative sample size, in which almost all known damask typologies were identified. The only exception comprises early Chinese damasks, which were not found due to their rarity as well as specific historical, cultural and geographic context. Such representation enabled a comprehensive insight into the diversity of construction solutions and their influence on the final appearance of the damask. Within this research, a systematic classification of damask typologies was carried out for the first time, with graphic representations and compatibility of all structures of ground weaves and pattern weaves. Such an approach has not previously been established in the relevant scientific literature and represents a significant contribution to the understanding of the constructional principles and recognizing the diversity of damask typologies.

Table 3: Graphic representation of the weave structures in a classic 5-end damask

Ground weave	Pattern weave	Weave compatibility
 5-end warp satin, interruption 3	 5-end weft satin, interruption 2	

Historical damasks form an important segment of museum and ecclesiastical textile heritage in the Dubrovnik area, where they are preserved as part of liturgical and representative collections. However, a large proportion of these artefacts has been preserved without original technical documentation or weaving drafts, which complicates their attribution, dating and interpretation.

Research into historical damasks is further complicated by their fragility and material sensitivity, which precludes the use of invasive analytical methods. Consequently, the need for precise yet non-invasive approaches to technological analysis and documentation has become a key requirement in contemporary textile heritage research [2].

An additional challenge concerns the lack of standardised professional terminology in the Croatian language, particularly in the description of weave structures and design. In this research, existing terms were applied and clearly defined in accordance with internationally accepted CIETA standards. Although systematic terminological standardisation exceeds the scope of this paper, it is recognised as an important contextual aspect of the research [3].

The aim of this paper is to present an overview of a doctoral research project focused on the development of a methodology for the analysis and digitalisation of technological documentation of historical damask fabrics and to highlight the possibilities of applying the collected data in scientific and professional contexts.

2. Experimental part

The experimental part of the research was conducted on historical damask fabrics from museum and ecclesiastical collections in the Dubrovnik area and its surroundings. A total of 53 historical damasks were analysed, differing in period of origin, state of preservation and constructional characteristics. Given that these are unique and fragile textile artefacts, all analytical procedures were carried out with particular care and in accordance with conservation-restoration guidelines. The applied methods were selected to minimise physical contact with the original objects, with emphasis on visual analysis and digital data recording [4].

2.1. Technical analysis and documentation of historical damasks

A workflow methodology adapted to the analysis of historical damask fabrics was developed within the research, integrating a sequence of steps from initial visual inspection to the creation of digital documentation. The technical analysis included visual examination, analysis of the weave structure, and identification of ground and pattern weaves. The workflow was designed to ensure repeatability of procedures and consistency of collected data. The data obtained is systematically recorded and structured, ensuring a consistent basis for the creation of technological documentation and its further digital processing.

2.2. Digital documentation model and database prototype

Inovative digital form and database prototype were developed exclusively for the purposes of this research, in collaboration with an interdisciplinary team of experts in the fields of textile technology, art history, conservation-restoration, and digital technologies. The interdisciplinary approach enabled the integration of different scientific and professional perspectives into a unified documentation system, structured into four sections: General data of fabric, art-historical and stylistic analysis of the pattern, technical parameters and notes. Such a structure supports application in scientific, museum and conservation contexts.

The digital model of the technical documentation form was designed as a standardized tool for recording data on historical sampled fabrics. Special attention was paid to adapting the form to work with historical fabrics, avoiding the introduction of parameters that would require invasive procedures. This ensured the applicability of the form for scientific purposes, but also in museum and conservation-restoration practice. The model was applied to the analyzed historical damask fabrics, confirming its applicability and flexibility.

2.3. Methods of data application

The developed system has proven to be applicable in various scientific fields, including textile technology, art history and digital humanities, but also in an industrial context, especially in the field of reconstruction of historical patterns and contemporary textile (re)production.

The collected and digitally processed data were applied in comparative analysis, attribution and dating of historical damask fabrics. The relationships between pattern and constructive parameters were analyzed, as well as variations in the application of the weave structure. The analysis additionally included a comparison of variability within the same typological groups, which identified differences in execution that were not visible exclusively at the level of ornamentation. Such an approach enabled a deeper understanding of technological decisions in historical production. Graphic visualisation methods enabled the identification of groups of samples with a high degree of mutual similarity (Diagram 1).

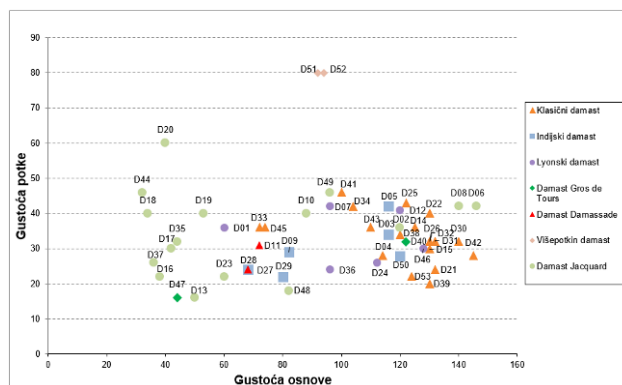


Diagram 1: Scatter plot of analysed damask samples, based on warp and weft density

The results obtained showed that the combination of quantitative and qualitative parameters significantly increases the reliability of the comparative analysis. Data visualization additionally facilitated the interdisciplinary interpretation of the relationships between the analyzed damask fabrics [5].

Furthermore, the documented data served as a basis for the reconstruction of weaving drafts using reverse engineering methods, which enabled the production of contemporary reproductions of damask fabrics and verification of the applied methodology.



Figure 1: Experimental reproduction: a) Classical silk damask, Italy, 16th-17th century. inv.no. DUM KPM T-40
b) reconstructed pattern sample and rewoven replica of the historical damask

2.4. Survey research

The developed digital documentation model was evaluated through a survey conducted among 32 experts who are involved in some form of study and/or preservation of historical fabrics. All survey respondents (100%) agreed that the model encompasses all essential parameters required for documenting historical textiles. A large or very large probability that the model would facilitate the study and documentation of historical textiles was indicated by 96.9% of respondents.

3. Conclusions

Textile heritage represents an inexhaustible reservoir of human artistic creativity and technological achievements that, unfortunately, is still not sufficiently explored. The main reason for this lies in the lack of standardized methods for the analysis and documentation of such a complex and sensitive material.

The scientific contribution of the doctoral thesis was achieved through the systematic processing of relevant professional and scientific literature, the analysis of existing documentation models, surveying domestic experts, and based on personal experience, with the aim of developing an innovative form of digital documentation of historical patterned fabrics. The hypotheses set were confirmed within the framework of the work, and the defined goals were achieved. The interdisciplinary nature of the research enabled the connection of theoretical and applied knowledge and opens up possibilities for applying the results in various fields of science, culture, and creative industries - especially in the context of museum documentation and conservation and restoration practice.

The developed methodology for the analysis and digitization of historical fabrics has proven to be effective in the research of historical damasks. The digital model of technical documentation enables the systematic recording and application of data and represents a valuable contribution to the preservation and interpretation of textile heritage. The analyses conducted, the development of the digital technical documentation model, and its practical application demonstrate the effectiveness of an integrated technological and digital approach. The standardized digital form enables the reproducibility and comparability of results, which is an important step towards the systematic research of historical patterned fabrics. Further development of the system may include expanding the database and integrating with international digital platforms.

Acknowledgements

I would express my sincere gratitude to both my mentors for their professional guidance, support and valuable advice during the doctoral research. Appreciation is also extended to all the institutions and experts who kindly enabled access to historical textile collections and contributed to the realisation of this study.

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Mislav Majdak

Biography

Mislav Majdak was born on June 4th, 1995 in Zagreb. In 2020 he graduated from the university module Textile chemistry, material and ecology University of Zagreb, Faculty of Textile Technology. In 2021 he enrolls a doctoral study Textile Science and Technology University of Zagreb, Faculty of Textile Technology. The same year he was employed on a project *Antimicrobial coating for biodegradable medicine materials*, led by Prof. Iva Rezić Meštrović, Ph. D. On September 12th 2025 he has successfully presented his Ph. D. thesis under title *Antimicrobial coatings with nanoparticles for biodegradable polymers and textile materials*.

Title of Ph. D. thesis

Antimicrobial coatings with nanoparticles for biodegradable polymers and textile materials

Mentor

Prof. Iva Rezić Meštrović, Ph. D.

Date of dissertation defense

September 12th, 2025

ANTIMICROBIAL COATINGS WITH NANOPARTICLES FOR BIODEGRADABLE POLYMERS AND TEXTILE MATERIALS

Mislav MAJDAK

University of Zagreb Faculty of Textile Technology, Prilaz baruna Filipovića
28 a, majdak.mislav@tff.unizg.hr

Abstract: As part of this doctoral thesis, new advanced antimicrobial formulations were developed using innovative technologies. Treating conventional medical textiles – such as bandages and gauze – as well as non-textile materials (e.g. plastic medical devices) with these formulations enables the production of functional antimicrobial medical materials. The results demonstrated that antimicrobial coatings containing encapsulated silver nanoparticles effectively inhibit harmful micro-organisms..

1. Introduction

Inappropriate and frequent use of antimicrobial medication has led to an increase in the number of antibiotic-resistant bacterial strains, as well as antifungal-resistant fungi, which represents a significant burden on healthcare systems worldwide. By 2050, the number of deaths caused by resistant bacteria is predicted to surpass the number of deaths caused by AIDS and tuberculosis, while the current number of deaths caused by resistant fungi is comparable to the number of deaths caused by tuberculosis [1]. In order to effectively combat the growing threat of microorganisms, especially bacteria and fungi, the scientific community has focused significant efforts on the development of textiles and biodegradable polymers functionalized with nanoparticles of metals and metal oxides, such as silver (Ag), zinc oxide (ZnO), titanium dioxide (TiO₂), magnetite (Fe₃O₄) and copper (Cu) [2]. Metal and metal oxide nanoparticles, especially silver, have excellent antimicrobial properties, due to their extremely small dimensions, high surface area to volume ratio, and specific particle morphology with sharp edges [3]. Moreover, textile medical materials with antimicrobial formulations based on silver (nanoparticles or silver nitrate) have been used for some time to treat chronic wounds and to inhibit harmful microorganisms [4, 5]. In order to achieve a controlled, targeted and gradual release of antimicrobial nanoparticles, it is necessary to use methods such as encapsulation [6]. Encapsulation using ionic gelation and polyelectrolyte complexation enables the production of microcapsules whose outer shell enables improved release control [7, 8]. The successful development of antimicrobial medical materials requires detailed characterization of antimicrobial coatings using ultraviolet and visible spectroscopy (UV-VIS) and scanning electron microscopy with X-ray dispersive spectroscopy (SEM-EDS), as well as biological tests of the antimicrobial effect. The application of the mentioned methods confirms the success of the functionalization, as well as the effectiveness of the inhibition of microorganisms [9, 10].

2. Experimental

Ag nanoparticles and silver nitrate (Gram-mol) were encapsulated using ionic gelation and polyelectrolyte complexation with a Büchi B-390 encapsulator (BÜCHI Labortechnik AG) using sodium alginate (Sigma-Aldrich), zinc sulfate heptahydrate (Gram-mol) and chitosan (Sigma-Aldrich). Antimicrobial formulations were encapsulated using ionic gelation inside the shell created by the complexation of sodium alginate and zinc sulfate heptahydrate. By applying polyelectrolyte complexation with chitosan, an additional shell was created on the surface of the microcapsules, the purpose of which is to slow down the release. The microcapsules were characterized using SEM-EDS SEM TESCAN VEGA TS5136LS SEM-EDS (Tescan Vega Co.). The release of the microcapsule contents was monitored using UV-VIS spectroscopy with Lambda 20 (Perkin Elmer). As part of the doctoral thesis, for the successful suppression of Methicillin-resistant *Staphylococcus aureus* (MFBF 10679) and Methicillin-susceptible *Staphylococcus aureus* (ATCC 29213) strains, metal and metal oxide nanoparticles of various sizes listed in Table 1 were used.

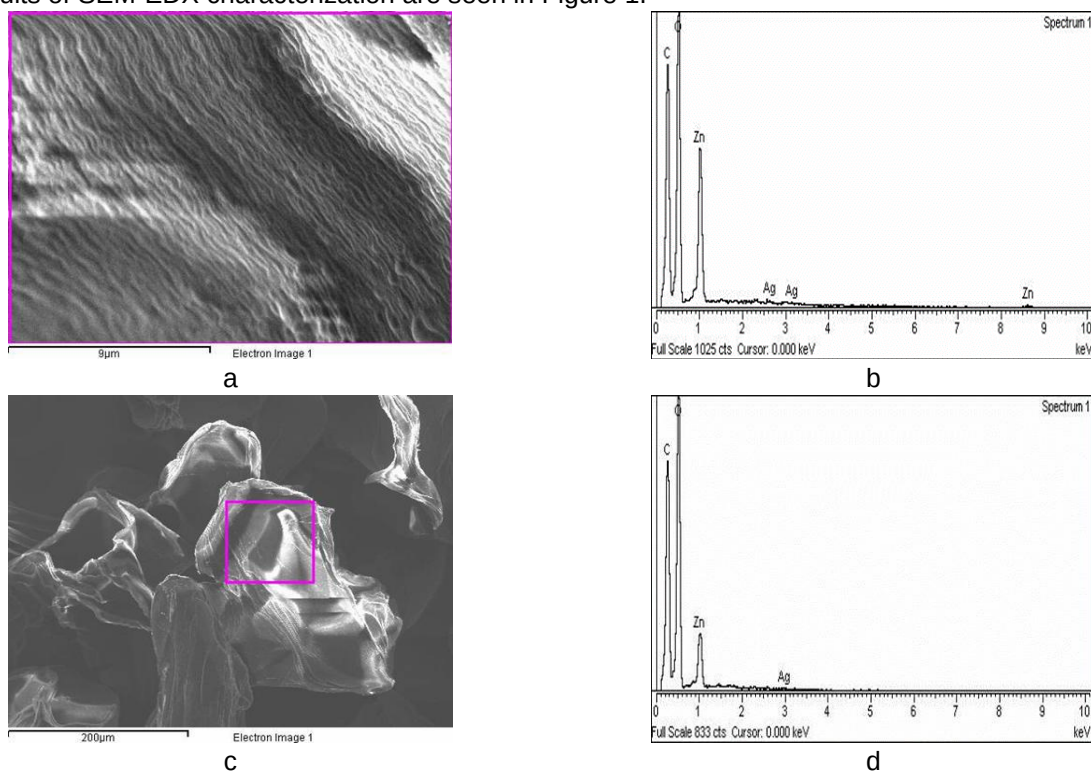
Table 1. Metal and metal oxide nanoparticles used in investigation

Nanoparticles	Size [nm]	Nanoparticles	Size [nm]	Company
Silver (Ag)	10; 40	Zirconium dioxide (ZrO ₂)	100	Sigma-Aldrich
Titanium dioxide (TiO ₂)	100	Platinum (Pt)	4	
Zinc oxide (ZnO)	40; 100	Yttrium(III) oxide (Y ₂ O ₃)	100	

The antimicrobial effect of antimicrobial nanoparticles was investigated using the broth dilution method, a method that provides insight into the interaction of microorganisms with antimicrobial formulations under more realistic conditions. For the purpose of the investigation, in addition to the nanoparticles listed in Table 1, Gentamicin sulfate (Sigma Aldrich) was used as a positive control.

3. Results and discussion

The results of SEM-EDX characterization are seen in Figure 1.


Figure 1: Results of SEM-EDX analysis: a) microcapsule without a chitosan shell, b) EDX spectra of microcapsule without a chitosan shell, c) microcapsule with a chitosan shell, d) EDX spectra of microcapsule with a chitosan shell

The investigation results show that the microcapsules, after lyophilization, do not have a damaged structure, i.e. the microcapsules are suitable for long-term preservation of antimicrobial formulations. The use of EDX characterization shows the presence of silver in the core of the microcapsules, which is an evidence of the effectiveness of the encapsulation process. Furthermore, the results of monitoring the release of the microcapsule contents are shown in Figure 2.

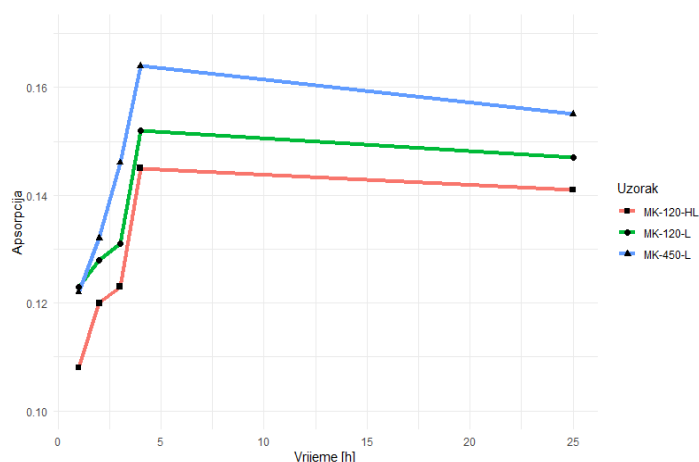


Figure 2: Lines representing silver release from lyophilized samples obtained with the use of 120 and 450 μm nozzles

By monitoring the release of silver ions from microcapsules in water over a period of 25 hours, as shown in Figure 3, it is clearly seen that within the first five hours of measurement there is a sudden increase in release. After this period, a period with a slower meta-stable release rate followed. At the same time, it is clearly visible in Figure 3 that with the addition of a chitosan shell, the measured silver concentrations in water are lower than the measured silver concentrations in samples without a chitosan shell, which is of great importance for achieving high efficiency during real-world application.

In the final step, the antimicrobial efficacy of the tested nanoparticles was tested against model organisms. The test results are listed in Tables 2 and 3.

Table 2. Investigation results of the antimicrobial efficacy of metal and metal oxide nanoparticles against model organisms *S. aureus* ATCC 29213 (MSSA) using the broth dilution method

Nanoparticles	Minimal inhibition concentration [$\mu\text{g}/\text{cm}^3$]	Minimal bactericidal concentration [$\mu\text{g}/\text{cm}^3$]
Pt (4 nm)	$0,06 \pm 0,04$	$0,20 \pm 0,17$
Ag (10 nm)	$0,09 \pm 0,07$	$0,31 \pm 0,27$
Ag (40 nm)	$0,02 \pm 0,02$	$1,04 \pm 1,26$
ZnO (100 nm)	$0,03 \pm 0,00$	$0,14 \pm 0,06$
TiO ₂ (100 nm)	$40,28 \pm 0,00$	$80,57 \pm 0,0$
Y ₂ O ₃ (100 nm)	$<12,21$	$12,21 \pm 0,00$
ZrO ₂ (100 nm)	$<0,06$	$>12,500,00$
Gentamicin sulphate		$0,63 \pm 0,00$

Table 3. Investigation results of the antimicrobial efficacy of metal and metal oxide nanoparticles against model organisms *S. aureus* MFBF 10679 (MRSA) using the broth dilution method

Nanoparticles	Minimal inhibition concentration [$\mu\text{g}/\text{cm}^3$]	Minimal bactericidal concentration [$\mu\text{g}/\text{cm}^3$]
Ag (10 nm)	$0,47 \pm 0,27$	$2,50 \pm 0,00$
ZnO (100 nm)	$3,28 \pm 0,55$	$3,28 \pm 0,00$
TiO ₂ (100 nm)	$20,14 \pm 0,00$	$93,00 \pm 61,53$
Gentamicin sulphate		$1,00 \pm 0,40$

The results clearly show that metal and metal oxide nanoparticles are excellent antimicrobial agents, with Ag nanoparticles showing the best antimicrobial effect. Moreover, the results show that, in addition to material composition, the antimicrobial effect of nanoparticles also depends largely on their size, i.e., smaller nanoparticles have greater inhibitory and bactericidal efficacy compared to larger nanoparticles.

4. Conclusion

The rising problem of resistant microorganisms is a global problem that requires innovative solutions. Therefore, it is necessary to develop and research new and advanced antimicrobial formulations using innovative technologies. Such formulations were developed as part of this doctoral thesis. With a further coating of conventional textile medical materials, such as bandages and gauzes, as well as non-textile materials such as plastic medical devices with the aforementioned formulations, enables the production of functional antimicrobial medical materials, but also opens up the possibility of expanding its application for the production of special protective equipment and food packaging.

Acknowledgment



This work has been made as a part of the project "Antibacterial coating for biodegradable medical materials (IP-2019-04-1381) under the leadership of Prof. Iva Rezić Meštrović, Ph.D. Ph.D.", with the support of the Career Development Project for Young Researchers - Education of New Doctors of Science (DOK-01-2020-111), under the leadership of Prof. Iva Rezić Meštrović, Ph.D. Ph.D., and the Mobility Program - Outgoing Mobility of Assistants (MOBDOK-2023-7747), under the leadership of Mislav Majdak, mag. ing. techn. text. These projects are funded by the Croatian Science Foundation.

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Maja Mahnić Naglić

Biography

Born in 1984 in Slavonski Brod. At the University of Zagreb, Faculty of Textile Technology, she completed the undergraduate study program Textile Technology and Engineering, majoring in Clothing Engineering, the graduate study program Industrial Clothing Design, and the university postgraduate doctoral study program Textile Science and Technology. Since 2015, she has been employed at the Department of Clothing Technology, teaching courses in the fields of computer-aided design, 2D/3D clothing design, CAD/CAM systems in clothing engineering, and Digital Costume Design. So far, she has published 11 scientific papers in journals indexed in WoS and Scopus, 3 scientific papers in other journals, 1 review paper, 3 chapters in scientific books, and 21 scientific papers in proceedings of international and domestic conferences.

Title of Ph. D. thesis

The Dynamic Clothing Behaviour Under the Influence of Body Biomechanics

Mentor

Prof. Slavenka Petrak, Ph. D.

Date of dissertation defense

May 28th, 2024

THE DYNAMIC CLOTHING BEHAVIOUR UNDER THE INFLUENCE OF BODY BIOMECHANICS

Maja MAHNIĆ NAGLIĆ

University of Zagreb Faculty of Textile Technology, Prilaz baruna Filipovića
28a, Zagreb, maja.mahnic@ttf.unizg.hr

Abstract: Within the framework of the doctoral dissertation, research in the field of computer-based 2D/3D garment design was conducted, proposing a novel methodology for the analysis of garment fit and dynamic behaviour under the influence of human body biomechanics. The research integrates anthropometric analysis of the female body, algorithmic classification of body shape and posture types and the analysis of body surface deformations during movement using the optical 3D measuring system Aramis, applied for the first time in the field of dynamic anthropometry. Based on the obtained results, parametric patterns were developed using 50 originally defined mathematical expressions for the automatic adjustment to individual anthropometric characteristics and functional ease allowances, grounded in the values of body surface deformations during movement. By linking 3D body scanning with the parametric SMPL (Skinned Multi-Person Linear Model) body model, animated 3D avatars were developed for garment simulation in predefined movements, enabling the analysis of dynamic fit and its evaluation in relation to the applied parameters of textile material mechanical properties. The proposed methodology for the development and analysis of dynamic fit of digital 3D prototypes was verified through comparative analysis with physically manufactured prototypes, wherein the dynamic fit of real garment prototypes was for the first time analysed using the Aramis optical 3D deformation measurement system.

1. Introduction

The human body, specifically its shape and movement kinematics, represents the foundation of research in the field of garment design and development [1]. Various measurement systems for human body analysis, such as 3D and 4D scanners, enable detailed research of anthropometric and kinematic body characteristics and the application of their parameters in pattern construction and the development of digital 3D garment prototypes [2]. Garment fit under dynamic conditions has become one of the most prominent topics in clothing technology in recent years. Dynamic fit directly affects garment functionality, which is one of the most critical elements in the apparel design process. During movement, the human body surface dimensions changes, resulting in variations in body measurements that require additional garment modifications in corresponding areas [1–3]. Computer analysis of garment fit under static or dynamic conditions relies on physical simulation and the development of 3D prototypes, in which surface geometry deformations of the garment model, determined by the physical and mechanical parameters of the target textile material, are analysed in contact with the 3D body model. In this context, the following doctoral research hypotheses were formulated:

H1: Body surface deformations during movement depend on body development and shape, and by developing and applying mathematical models for adapting kinematic points on the body and deforming surface segments according to specific body types, realistic animation of scanned body models can be achieved, suitable for computer 3D garment simulation under dynamic conditions.

H2: Through mathematical modelling of fabric mechanical behaviour during garment simulation, based on the values of specific mechanical properties, garment surface deformability will correlate with the deformability of the given body type in a predefined movement.

H3: Based on the analysis of geometric deformations of digital garment models interacting with a moving body model, garment stress under dynamic conditions can be reliably evaluated.

2. Experimental

Based on the defined hypotheses, the doctoral research methodology was structured into seven systematically related sections. The first section includes anthropometric analysis of the female body using 3D scanning and the development of an algorithm for classifying body shape and posture types based on scanned 3D models. The second section focuses on the investigation and analysis of dynamic anthropometry characteristics, wherein a methodology for applying the Aramis optical 3D deformation measurement system [4] in the field of dynamic anthropometry was defined for the first time. The study was conducted on three test subjects representing different body types, performing five movements defined by kinematic chains describing transitions from an upright standing position to five characteristic body postures relevant for garment fit analysis. Deformations were analysed in the transverse (x/weft) and longitudinal (y/warp) directions, and zones of maximum deformation were identified for each movement, Fig. 1.

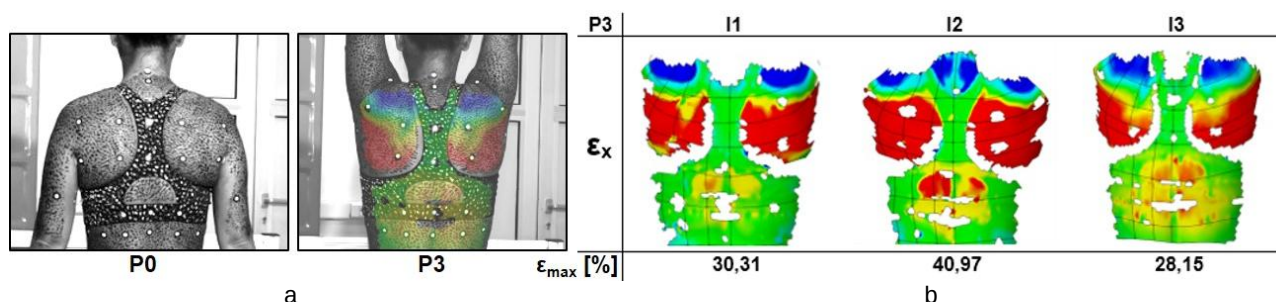
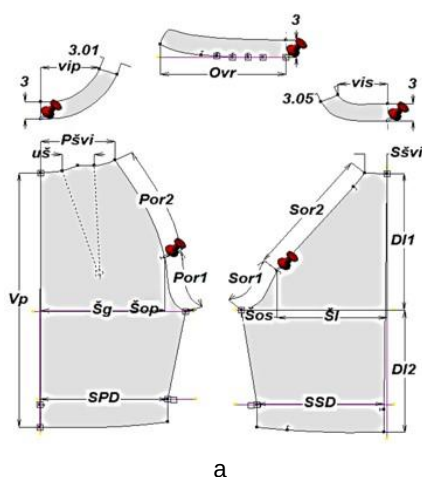


Figure 1: Analysis of body surface deformations: a) recorded data of test subject I3 in the initial position P0 and final position P3, b) maximum body surface deformation values determined in position P3 for all three participants (I1, I2, I3)

The third research section includes the development of animated 3D avatars for three test subjects with different body shape types. In Autodesk Maya 2022, a method for adjustment of the universal SMPL body model as a template [5] to a targeted anthropometric and kinematic characteristics obtained via 3D scanning was established, based on script files developed in Python v.2. The fourth section includes the analysis of physical and mechanical properties of two textile materials selected for the development of women's garment models, using four testing methods: the Kawabata Evaluation System KES-FB [6], tensile strength and elongation testing using the strip method according to HRN EN ISO 13934-1:2013, a modified method based on Fabric Kit system parameters [6], and textile material digitisation using the SEDDI Textura AI application [7]. Within the fifth section, parametric patterns for five garment models were developed in the Modulate v.15.1 CAD system Optitex: a basic blouse and trousers, a work overall, a tight-fit leotard, and a functional, work overall designed to meet dynamic anthropometry criteria. Based on anthropometric body type analysis and dynamic body surface deformation results, 50 mathematical expressions were developed to enable automatic pattern adjustment, considering segments ratios within overall body measurements depending on body type, as well as functional ease allowances to adjust target segment dimensions and provide additional comfort in identified zones of maximum body surface deformation during movement, Fig. 2. The sixth section includes the development of digital 3D garment prototypes and the evaluation of garment fit on a moving body using the CLO software. Input data for 3D simulations included adjusted parametric garment patterns and animated 3D avatars for three test subjects of different body shape types. The possibilities of defining mechanical property parameters using values obtained from real fabric testing, using various evaluation methods, were investigated, based on which reference values for evaluating the dynamic fit of digital 3D prototypes were established. During simulation, fabric stretch in the weft (x-direction) and/or warp (y-direction) was analysed depending on body posture and relevant garment zone. Stretch and deformation maps were monitored throughout the entire movement sequence, with values recorded in final characteristic postures. For verification purposes, real garment prototypes were produced and recorded using the Aramis system during predefined movements. The recorded data were processed and analysed analogously to the body deformation analysis method, and the results were used to evaluate the fit of the developed digital 3D prototypes.



a

$$Og_{kroj} = 2[(0,203 \cdot Og_{tijela} + 0,25 \cdot D_{komocija}) + (0,042 \cdot Og_{tijela}) + (0,083 \cdot Og_{tijela}) + (0,086 \cdot Og_{tijela} \cdot fd + 0,125 \cdot D_{komocija}) + (0,086 \cdot Og_{tijela} + 0,125 \cdot D_{komocija})]$$

$$Og_{kroj} = 2[0,203 \cdot 90,3 + 1,5) + (0,042 \cdot 90,3) + (0,083 \cdot 90,3) + (0,086 \cdot 90,3 \cdot 1,345 + 0,75) + (0,086 \cdot 90,3 + 0,75)] = 2(19,84 + 3,79 + 7,49 + 11,20 + 8,52) = 101,68 \text{ cm} \Rightarrow 11,38 \text{ cm ukupne komocije}$$

b

Legend: Šg – bust width, Šop – front armhole width, SPD – front waist, Vp – front height, uš – dart, Pšvi – front neckline width, Por1/Por2 – front armhole curve length, Šl – back width, Šos – back armhole width, SSD – back waist, D1/D2 – back length, Sor1/Sor2 – back armhole curve length, Sšvi – back neckline width, Ovr – collar length

Figure 2: Development of a parametric garment pattern: a) parametric upper part pattern of the work overall designed from the perspective of dynamic anthropometry, b) developed mathematical expression for bust circumference adjustment and an example calculation for test subject I1

3. Results and Discussion

The proposed methodology for recording and analysing body surface geometry deformations during motion using the Aramis optical 3D measuring system enabled continuous monitoring of body surface deformations throughout the entire movement and analysis of dimensional changes by zones and surface segments. This represents a far more comprehensive approach compared to analysing linear body measurement changes on scanned body models in characteristic postures. Data significant for garment construction and design were identified, forming the basis for the development of a garment pattern parametrisation method. The results demonstrated that the proposed mathematical expressions for adjustment of pattern segments dimensions to three different body types, including dynamic parameters, enable a substantially more complex and comprehensive adjustment in terms of garment fit and functionality. The development of animated avatars and the method for the internal kinematic skeleton adjustment via script files enabled direct integration between 3D scanning systems and the animation process, significantly accelerating the otherwise time consuming and complex development of animated models adjusted to target anthropometric characteristics. Performing 3D simulations on animated avatars enabled the analysis of digital 3D prototype deformations under dynamic conditions. The proposed approach of evaluating digital 3D prototypes using defined mechanical property parameters of target materials, represents an advancement in the field of digital 3D garment design, as previous studies limitations on explicitly defined methodology for fit evaluation, relying primarily on expert subjective assessment. Fit analysis results confirm good garment pattern adjustment achieved through the developed parametrisation method and defined mathematical expressions, which incorporate additional ease allowances based on dynamic body deformations. Analysis of dynamic fit of real garment prototypes using the Aramis system enabled verification of digital prototypes development and fit analysis results through objectively measurable indicators. The obtained deformation value deviations between digital and real prototypes, ranging from 0.4 to 3%, depending on the garment model and analysed deformation zone, indicate a high level of predictive capability for garment behaviour under dynamic conditions based on digital prototypes developed using the proposed methodology. This represents a significant contribution to the field of clothing technology and the development of garments with high functional requirements, Fig. 3.

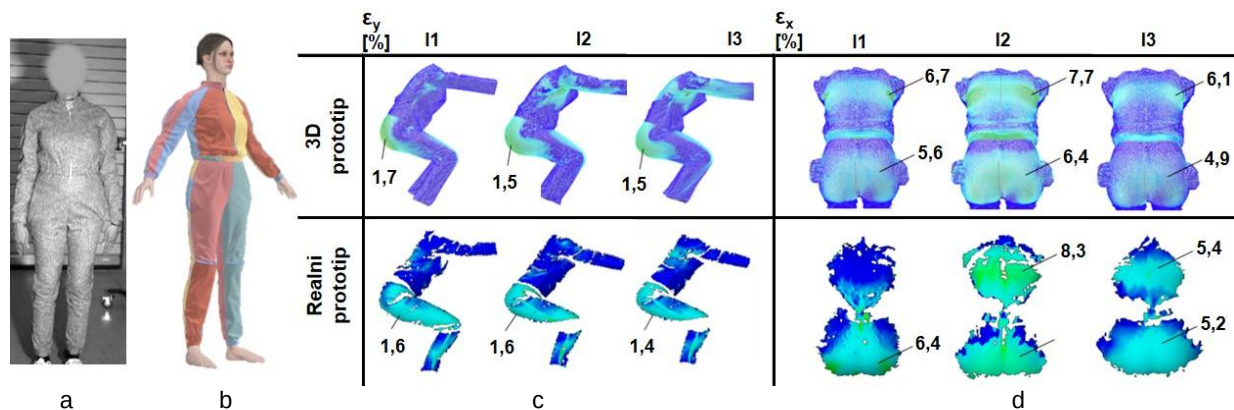


Figure 3: Results of dynamic fit analysis of digital and real prototypes of a functional work overall in squatting position (P5): a) real prototype – test subject I1, b) digital 3D prototype – test subject I1, c) determined maximum longitudinal surface deformation values – warp direction (ϵ_y) for three test subjects I1, I2 i I3, d) determined maximum transversal surface deformation values – weft direction (ϵ_x) for three test subjects I1, I2 i I3

4. Conclusions

Through analysis of kinematic parameters of scanned 3D body models in the Anthroscan software, data on the hierarchical structure and joint coordinate positions were identified, applicable to adjustment of the internal kinematic skeleton to the shape and dimensions of the surface model. The developed method for automatic adjustment of internal kinematic skeleton joint positions to scanned 3D body models via script files confirmed hypothesis H1. Simulations of digital 3D garment prototypes developed using the proposed methodology and performed on avatars adjusted to the test subjects of different body types, revealed differences in zones of maximum deformation values and the shapes of garment surface segments affected by deformation, further confirming hypothesis H1. By performing 3D garment simulations based on defined material property parameters obtained through testing of real textile samples, realistic surface deformations of digital 3D prototypes were achieved, relative to the dimensions and deformations of 3D body models of different types under dynamic conditions, confirming hypothesis H2. Analysis of digital 3D prototypes provided very good results and a satisfactory level of realism in surface deformations compared to results of real prototypes analysis, thereby confirming hypothesis H3 and demonstrating the applicability of the methodology for the development and analysis of digital 3D prototypes under dynamic conditions proposed within doctoral research.

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**Paula Štampalija****Biography**

Paula Štampalija (née Marasović), born on October 24, 1994, in Šibenik, earned her Master's degree in Textile Technology and Engineering within the TEngineering Design and Management of Textiles program and a Ph. D. in the Textile Science and Technology doctoral program at the University of Zagreb. She served as a student assistant in the courses Nonwoven and Technical Textiles, and Spinning. She worked as a Production Planner at Kelteks Ltd. from 2018 to 2019. Since 2021, she has been a doctoral researcher on the project "Development of biodegradable nonwoven agrotexiles from natural and renewable sources,". From 2024, she has been employed as an Assistant at the Faculty of Textile Technology, Department of Textile Design and Management. She completed an ERASMUS+ professional traineeship at Lodz University of Technology in 2023. She published 11 WoS- and Scopus-indexed scientific papers and has presented 16 papers at international scientific conferences. She received the Young Researcher Award for Scientific Excellence in the 2023/2024 academic year

Title of Ph. D. thesis

Development of nonwoven agrotexile from natural and renewable sources for mulching application

Mentor

Prof. Dragana Kopitar, Ph. D.

Date of dissertation defense

June 2nd, 2025



DEVELOPMENT OF NONWOVEN AGROTEXTILE FROM NATURAL AND RENEWABLE SOURCES FOR MULCHING APPLICATION

Paula ŠTAMPALIJA

University of Zagreb Faculty of Textile Technology, Prilaz baruna Filipovića
28a, Zagreb, paula.stampalija@ttf.unizg.hr

Abstract: The doctoral dissertation investigates the development of biodegradable nonwoven mulches made from natural and renewable fibres as a sustainable alternative to conventional polyethylene agrofoil. Two field experiments were conducted to evaluate mulch biodegradation, weed suppression, and soil quality, as well as their effects on lettuce growth, yield, and nutrient content. Nonwoven mulches produced from viscose, jute, hemp, and polylactic acid (PLA) fibres, and their blends, exhibited controlled biodegradation and significant structural changes under field conditions, as confirmed by SEM, FTIR, and WAXD analyses. Compared to PE agrofoil and bare soil, biodegradable mulches improved soil temperature and moisture regulation, increased organic carbon content and enhanced microbial activity. PLA-based mulches and cellulose/PLA blends maintained effective weed suppression over longer exposure periods. The results demonstrate that biodegradable nonwoven mulches can replace fossil-based agrofoils, thereby improving soil quality and increasing lettuce yield, thereby supporting sustainable agricultural practices.

1. Introduction

The extensive use of fossil-based agrotexiles, particularly polyethylene (PE) mulch films, has raised serious environmental concerns related to waste accumulation, soil contamination and microplastic formation [1–3]. Mulching is a key agricultural practice used to suppress weeds, regulate soil temperature and moisture, improve crop yield and reduce the need for chemical herbicides [2,4]. However, conventional plastic mulches are non-biodegradable, and their removal, recycling, and disposal remain complex and economically unfavourable [5,6].

Recent studies report that plastic mulches contribute significantly to agricultural plastic waste and soil microplastic pollution, negatively affecting soil structure, microbial activity and plant growth [5–7]. In line with the principles of sustainable agriculture and the circular economy, increasing attention is being directed toward biodegradable alternatives produced from natural and renewable sources [8–10].

Nonwoven agrotexiles produced from cellulose-based fibres and biopolymers represent a promising solution due to their biodegradability, soil compatibility and favourable physical properties. Nevertheless, comprehensive long-term field studies evaluating their biodegradation behaviour, weed-suppression efficiency, and impacts on soil quality and crop yield remain limited, particularly for mechanically produced needlepunched nonwoven fabrics on cards.

This doctoral dissertation addresses this gap by developing and evaluating nonwoven mulches produced from natural and renewable fibres as a sustainable alternative to conventional PE agrofoil, with special emphasis on their behaviour under field conditions.

2. Experimental

The research was structured into two complementary field experiments carried out under open-field conditions using a randomised complete block design (RCBD). Nonwoven mulches were produced at the Renotex Ltd. factory on cards bonded by needle-punching, using the same technological parameters to ensure comparability of results. The investigated materials included viscose (CV), jute, hemp and polylactic acid (PLA) fibres, as well as blends of cellulose-based fibres (CV, jute, hemp) with PLA fibres in an 80:20 ratio. Mulches were produced with mass per unit area of 200 g m⁻² and 400 g m⁻², depending on fibre type and their processability.

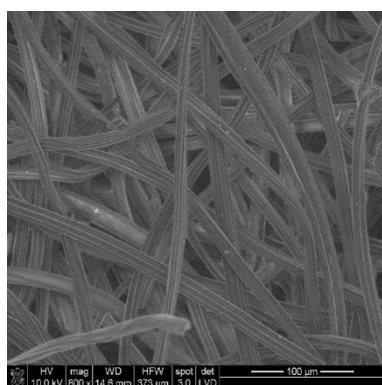
The first experiment evaluated the biodegradation behaviour, weed-suppression efficiency, and soil-quality impacts of nonwoven mulches during exposure periods of 300 and 380 days. The performance of biodegradable mulches was compared with conventional PE agrofoil and bare soil (control field). Mulch degradation and performance were monitored using visual inspection, dimensional changes, mass per unit area (HRN EN ISO 9073-1:2023), thickness (HRN EN ISO 9073-2:2021), density, tensile properties (HRN EN ISO 9073-3:2023) and air permeability (HRN EN ISO 9073-15:2007). Structural and molecular changes were

analysed by SEM, FTIR, WAXD and DSC. Soil temperature, moisture, and weed suppression were continuously monitored, and at the end of the experiments, soil chemical properties and microbial activity were analysed.

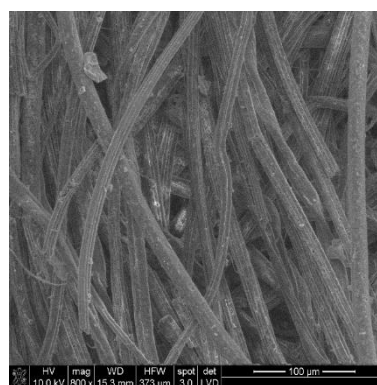
3. Results and discussion

Field exposure induced significant physical, mechanical and structural changes in all biodegradable nonwoven mulches. Cellulose-based mulches exhibited progressive degradation, as evidenced by mass loss, reduced tensile strength, increased air permeability, and visible fibre damage, as confirmed by SEM analysis. FTIR and WAXD analyses confirmed molecular degradation of cellulose fibres, evidenced by reduced hydrogen bonding, changes in crystallinity, and a decreased degree of polymerisation.

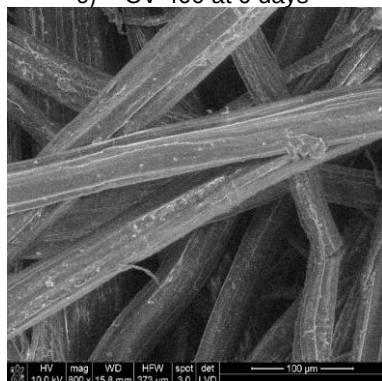
PLA mulches exhibited the highest resistance to environmental exposure, with slower degradation rates and better retention of mechanical properties, whereas blends of cellulose fibres with PLA demonstrated controlled degradation behaviour and improved structural stability compared with cellulose nonwovens at a 100% fibre ratio.



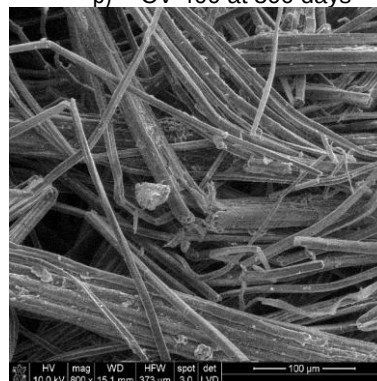
o) CV 400 at 0 days



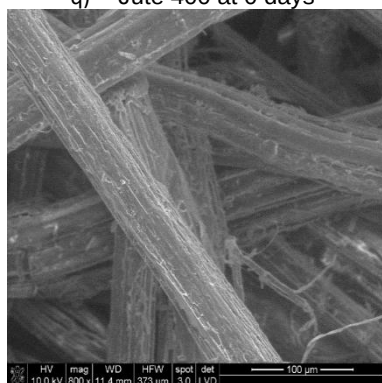
p) CV 400 at 300 days



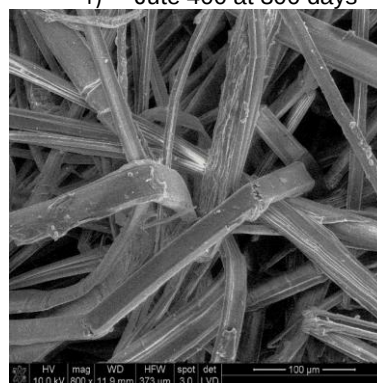
q) Jute 400 at 0 days



r) Jute 400 at 300 days



s) Hemp 400 at 0 days



t) Hemp 400 at 300 days

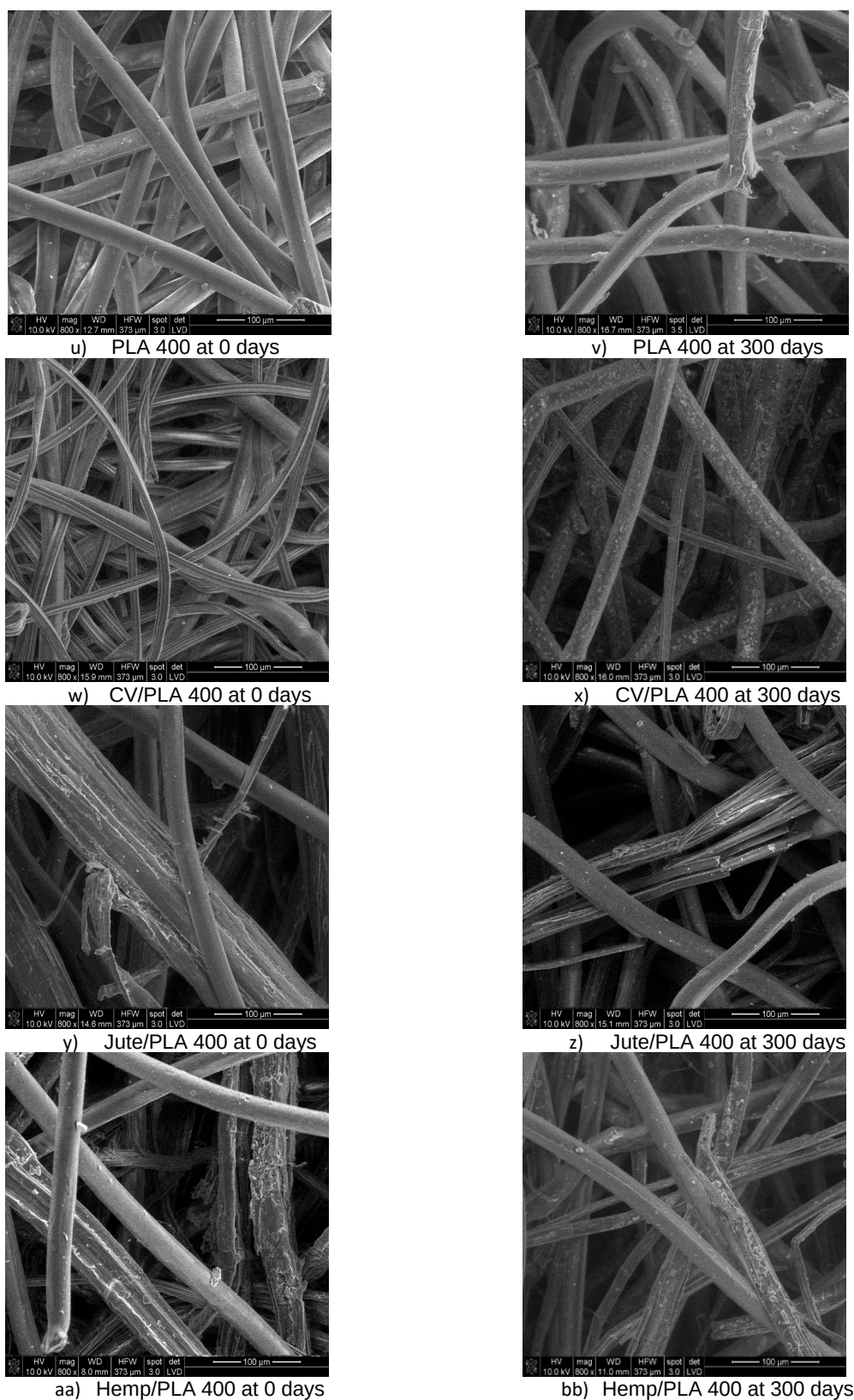


Figure 1: SEM images of nonwoven mulches with a mass per unit area of 400 g m^{-2} at $800\times$ magnification

Nonwoven mulches effectively stabilised soil temperature and moisture compared with the control field (bare soil) and often performed PE agrofoil. Soil quality analysis showed increased total organic carbon content and enhanced microbial activity beneath biodegradable mulches, indicating positive interactions with soil



ecosystems. Weed suppression efficiency was confirmed for all mulches during the early exposure phase. However, cellulose-based mulches gradually lost weed-suppression efficacy due to structural degradation, whereas PLA-based mulches and blends maintained effective suppression for a longer period.

In lettuce cultivation, biodegradable nonwoven mulches improved lettuce growth and yield compared to the control field. Blends of CV/PLA and jute/PLA outperformed conventional PE agrofoil in terms of lettuce biomass, yield and nutrient content, while also improving soil quality indicators. These results confirm the agronomic and environmental advantages of biodegradable nonwoven mulches over fossil-based materials.

4. Conclusion

The research confirms that nonwoven mulches produced from natural and renewable fibres represent a viable and sustainable alternative to conventional PE agrofoil. The results of Experiment 1 demonstrate that biodegradable nonwoven mulches effectively suppress weeds, enhance soil microbial activity and degrade under field conditions, positively impacting soil quality. Experiment 2 confirms their positive influence on lettuce growth, yield and nutrient uptake. Mulches containing PLA, particularly in blends with cellulose fibres, provide an optimal balance between durability during use and biodegradability after application. Their implementation reduces agricultural plastic waste, eliminates the need for mulch removal and contributes to improved soil health and sustainable crop production.

Acknowledgment

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**Anja Ludaš Dujmić****Biography**

Anja Ludaš Dujmić (Zagreb, 1993) received her PhD in 2025 from the University of Zagreb, Faculty of Textile Technology, and has been employed as an assistant since 2019. Her scientific and teaching work focused on the extrusion of fibres from recycled polymers, textile testing, surface modifications of textile materials using environmentally friendly cold plasma and the use of natural extracts for processing textile materials. She teaches Erasmus+ courses in English. She is immediate supervisor of 8 final and diploma theses. She collaborates on projects, scientific societies, science popularization, and faculty bodies. She is a member of the editorial board of the journal Inženjerski glasnik. She is the author of 11 scientific, 2 professional and 16 conference papers. She has received of the University of Zagreb, Faculty of Textile Technology Dean's two Awards.

Title of Ph. D. thesis

Modification of the properties of melt-spun recycled PA 6 polymer filaments by addition of bioactive substances and non-thermal plasma post-treatment

Mentor

Prof. Sanja Ercegović Ražić, Ph. D.

Date or dissertation defense

October 16th, 2025

MODIFICATION OF THE PROPERTIES OF MELT-SPUN RECYCLED PA 6 POLYMER FILAMENTS BY ADDITION OF BIOACTIVE SUBSTANCES AND NON-THERMAL PLASMA POST-TREATMENT

Anja LUDAŠ DUJMIĆ

University of Zagreb Faculty of Textile Technology, Prilaz baruna Filipovića
28a, 10000 Zagreb, Croatia, anja.ludas@ttf.unizg.hr

Abstract: The possibility of producing modified filaments from recycled PA 6 polymer by chemical melt spinning was investigated. By optimising the extrusion parameters, homogeneous filaments were produced with the addition of ZnO, ZnO obtained by green synthesis, TiO₂, and chitosan. The use of ZnO obtained by green synthesis further enhanced the environmental acceptability of the process and the thermal stability of the material. Genotoxicity tests indicated low toxicity, although antimicrobial activity was not observed, in contrast to samples with commercial ZnO, which were effective against *Klebsiella pneumoniae*. Subsequent treatment with cold low-pressure plasma altered the surface morphology and chemical composition, enabling increased and controlled release of bioactive metals, as confirmed by ICP analysis.

1. Introduction

Chemical melt spinning is one of the most commonly used production processes due to its simplicity, absence of solvents, and favourable environmental impact, with increasing emphasis on the use of recycled polymers. Among the most common polymers, polyamide 6 (PA 6) stands out for its good mechanical, thermal, and chemical properties, wide application in the textile and technical industries, and recyclability [1-3]. However, the production and use of synthetic fibres contribute to environmental pollution with microfragments, which encourages the development of more environmentally friendly technologies, including reduced use of additives and the application of green synthesis methods. In this context, nanotechnology enables the development of textile materials with improved functional properties, such as antimicrobial resistance, UV protection, and self-cleaning. Zinc oxide and titanium dioxide nanoparticles, as well as the biopolymer chitosan, are often used as functional additives due to their efficiency and biocompatibility [4, 5]. Further improvement of properties is achieved by environmentally friendly surface treatments, such as cold plasma, which modify only the surface layer of the material without altering its basic properties. Such processes have significant applications in medical, protective, and technical textiles and contribute to the development of sustainable and highly functional textile materials [6, 7].

2. Experimental

The research was conducted in three phases:

- (1) The parameters of the chemical spinning process for synthetic fibres from the melt on a spinning device were optimised according to the thermal characteristics of the PA 6 polymer. Subsequently, the extrusion of the modified recycled PA 6 polymer with bioactive agents was performed on a twin-screw extruder (Bench Top 21 mm), tt. Rondol Technology (France).
- (2) The concentrations of conventional ZnO and TiO₂ nanoparticles, chitosan biopolymers, and ZnO nanoparticles obtained by green synthesis from neem plant leaves were optimised per mass of PA 6 polymer to produce a filament with targeted modifications (antimicrobial and UV protective properties).
- (3) The resulting filaments were modified by low-pressure plasma (LP-Nano LF-40kHz), tt. Diener Electronic GmbH (Germany) under optimised conditions, which could enhance the release of the active substance and the achievement of the desired properties, as its action is manifested by physicochemical changes in the surface layer of the substrate and by modification of the surface properties depending on the nature of the gas and the mode of action of the active plasma particles in interaction with the material surface.

Filaments, with and without the addition of bioactive substances, were analysed to assess modification and uniformity of the applied treatment using modern analytical methods. The characterisation included thermal (DSC), spectrophotometric, morphological (SEM), chemical analysis (SEM-EDS, FTIR, ICP-OES), evaluation of antimicrobial and genotoxic properties, and colour fastness to artificial light of the modified filaments.

3. Results and Discussion

In this paper some part of the results will be presented. After optimising the extruder operating parameters, filaments were produced from recycled PA 6 modified with different concentrations of additives: zinc oxide, titanium dioxide, zinc oxide obtained by green synthesis, and chitosan (Figure 1). Each additive was incorporated in defined, adjusted proportions to achieve optimal particle dispersion within the polymer matrix. Figure 2 shows SEM analysis of PA 6 polymers with different additive concentrations at a magnification of 5000x, where the presence of additives on the surface of the modified filaments is visible.

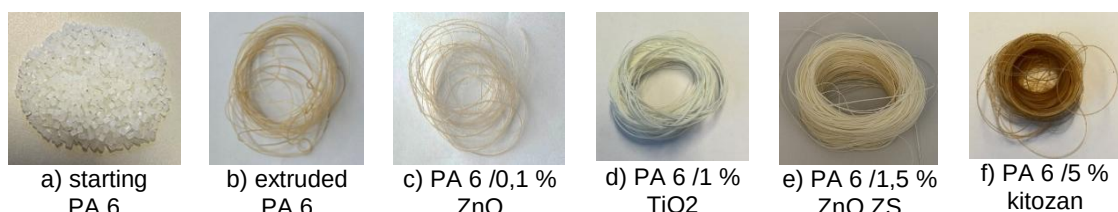


Figure 1: a) starting PA 6, b) extruded PA 6, c)–f) PA 6 filaments obtained with different additive concentrations

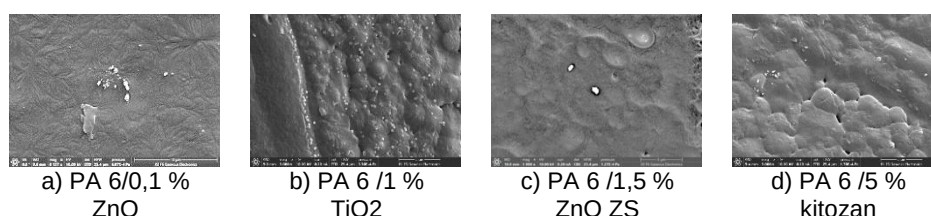
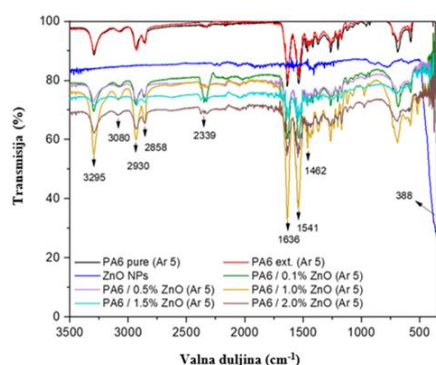
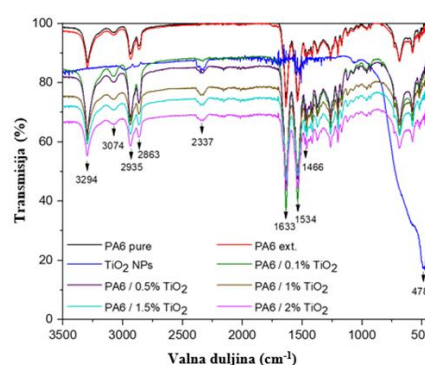


Figure 2: SEM analysis of PA 6 polymer with various additive concentrations at 5000× magnification

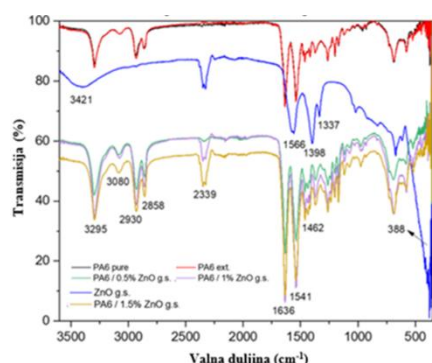
Figure 3 presents the FTIR spectra with peaks corresponding to the added additives, confirming their successful incorporation into the PA 6 polymer: 388 cm^{-1} for Zn–O stretching (3.a), 478 cm^{-1} for Ti–O bending (3.b), 388 cm^{-1} for Zn–O stretching and 3421 cm^{-1} for O–H stretching of the amide group from plant extracts used in green synthesis (e.g. alkaloids or phenols) (3.c), and 1022 cm^{-1} characteristic of P=O stretching from phosphate groups, as well as COH and C–N stretching vibrations specific to chitosan (3.d).



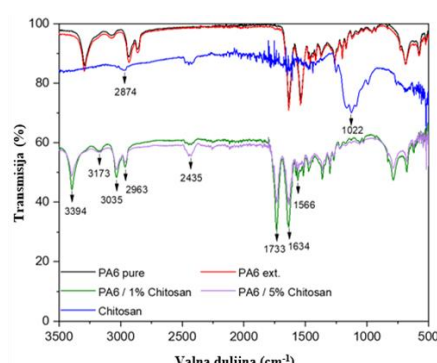
a) FTIR PA 6 with varying concentrations of ZnO



b) FTIR PA 6 with varying concentrations of TiO2



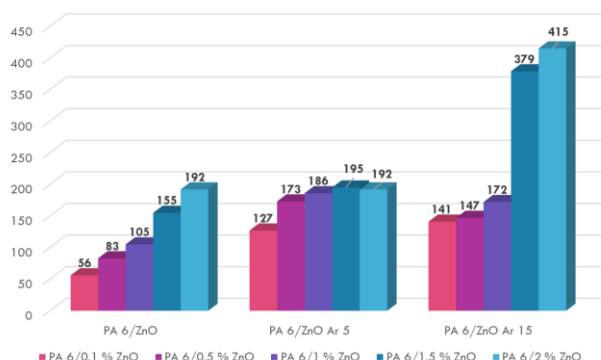
c) FTIR of PA 6 with varying concentrations of ZnO ZS



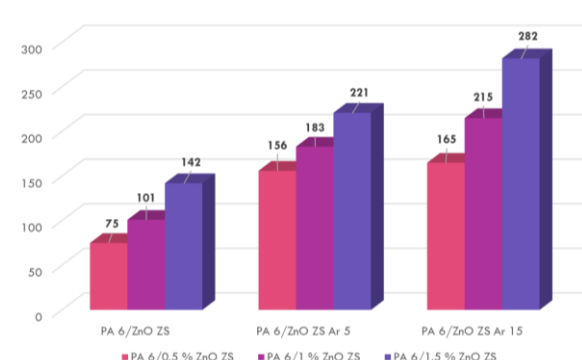
d) FTIR PA 6 with varying concentrations of chitosan

Figure 3: FTIR spectra at different additive concentrations

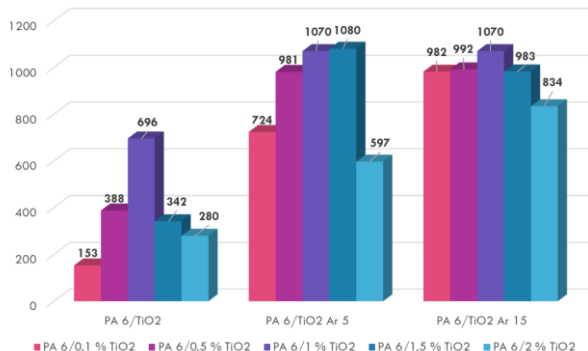
Figure 4 presents the results of inductively coupled plasma mass spectrometry (ICP) leaching. Samples without plasma treatment show an increase in the concentration of released zinc with increasing ZnO. Argon plasma treatment increases zinc release, particularly at higher ZnO contents. A similar trend is observed for samples with ZnO ZS. Samples with TiO₂ without plasma treatment show limited titanium release, with a maximum at 1% TiO₂, which may indicate agglomeration of nanoparticles at higher concentrations. Plasma treatment significantly increases titanium release compared to untreated samples, with the most pronounced effect recorded after 5 minutes of treatment. Longer treatment results in more stable, but somewhat lower concentrations, suggesting saturation and changes in the distribution of nanoparticles.



a) Measured concentrations (µg/L) of zinc released from PA 6 filaments into water



b) Measured concentrations (µg/L) of zinc released from PA 6 filaments into water



c) Measured concentrations (µg/L) of titanium released from PA 6 filaments into water

Figure 4: Measured concentrations (µg/L) of zinc and titanium released from PA 6 filaments into water

4. Conclusion

The research contributed scientifically to the development and optimisation of an environmentally friendly process for the chemical spinning of filaments from recycled PA 6. By optimising the extrusion parameters,

homogeneous filaments were produced with the addition of ZnO, ZnO obtained by green synthesis, TiO₂, and chitosan. DSC analysis revealed changes in thermal properties, including increased crystallisation and melting temperatures and higher crystallinity, particularly in filaments containing ZnO synthesised by green methods. The incorporation of bioactive components was confirmed by FTIR, SEM, and SEM-EDS analyses, along with improved optical properties of the filaments. The use of ZnO obtained by green synthesis further enhanced the environmental acceptability of the process and the thermal stability of the material. Genotoxicity tests indicated low toxicity, although antimicrobial activity was not observed, in contrast to samples with commercial ZnO, which were effective against *Klebsiella pneumoniae*. Subsequent treatment with cold low-pressure plasma altered the surface morphology and chemical composition, enabling increased and controlled release of bioactive metals, as confirmed by ICP analysis. The results demonstrate the potential for developing sustainable and functional textile materials from recycled polymers for technical, protective, and medical applications.

Acknowledgment



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**Juro Živičnjak****Biography**

Juro Živičnjak was born on February 28, 1995, in Zagreb. He earned his Ph.D. in 2025 at the University of Zagreb Faculty of Textile Technology, under the mentorship of professor Antoneta Tomljenović. Since July 1, 2019, he is employed as an assistant at the Department of Materials, Fibers and Textile Testing, where he conducts laboratory exercises in Textile Materials, Testing of Textiles and Clothing, Quality of Textiles and Clothing, and Quality Management. With Professor Dubravka Rogale, he developed an award-winning device for measuring and generating electric charge. His research focuses on the quality, comfort, and durability of textiles, with an emphasis on electrostatic properties. He has published several scientific and professional papers and participated in HRZZ and RAST projects.

Title of Ph. D. thesis

Evaluation of the wear-related unevenness of woven fabric surfaces using an improved method for visual assessment and the analysis of electrostatic properties

Mentor

Prof. Antoneta Tomljenović, Ph. D.

Date of dissertation defense

October 17th, 2025

EVALUATION OF PILLING OCCURRENCE ON WOVEN FABRICS BY IMPROVED VISUAL ASSESSMENT METHODOLOGY

Juro ŽIVIČNJAK

University of Zagreb Faculty of Textile Technology, Prilaz baruna Filipovića
28a, Zagreb, juro.zivicnjak@tff.unizg.hr

Abstract: During use, textile materials are prone to wear, which leads to occurrence of surface unevenness such as pilling. The assessment of pilling is carried out in accordance with the standardized visual method, with the possibility of applying instrumental methods. In the doctoral thesis, the visual assessment procedure was improved by developing innovative apparatus that enables the creation of digital images of the entire surface of woven fabric specimens in accordance with the conditions of the standardized visual method. By computer analysis of these digital images a series of numerical parameters related to the occurrence of pilling, and a parameter that objectively describes its appearance was selected. The research results indicate improved grading ability while maintaining a high level of correlation between the ratings assigned by visual assessment and the improved instrumental method.

1. Introduction

The surface appearance of a textile material changes over time, with the abrasion being one of the most common causes, due to direct physical contact between the textile surface and other objects from the environment. Abrasion causes wear of the material, but also the appearance of various surface unevenness, of which the most noticeable is the occurrence of pilling. Pilling describes the occurrence of smaller or larger clusters (pills) of entangled protruding fibers, that are slightly raised above the fabric surface and of such density that, during visual inspection, light does not pass through their structure, thereby creating a shadow. The propensity to pilling is a frequently tested property, assessed according to the standardized visual assessment method EN ISO 12945-4:2020, and expressed as a grade ranging from 5 (no change in surface appearance) to 1 (very pronounced change in surface appearance). Recent studies have shown growing use of instrumental methods, which are allowed by standard EN ISO 12945-4:2020. However, the standard does not fully specify the conditions under which these methods should be carried out.

The pilling grade assigned by the instrumental assessment method is based on computer analysis of the digital image of the fabric specimen surface. Digital imaging is the first and key step of the instrumental method, as the quality of the images directly affects the resolution and representativeness of data on the occurrence of pilling [1]. A review of previous research has shown that various devices are being used in digital imaging process (cameras, scanners, microscopes), that is often carried out under non-standardized conditions (observer distance and angle, specimen positioning, type of illumination, and size of the analyzed surface). Therefore, as part of this doctoral research, an innovative apparatus was developed to ensure the acquisition of digital images of the entire specimen surface under standardized conditions, utilizing a Dino-Lite AM-413ZT digital microscope camera.

2. Experimental

This research was conducted on six standard single-component woven fabrics in plain weave, made of 100 % cotton, wool, staple viscose, polyamide, polyester, and acrylic fibers, purchased from the authorized manufacturer of standard materials for textile testing, SDC Enterprises Limited, UK. Pilling on fabric specimens was induced using a modified Martindale method (EN ISO 12945-2:2020), in which the abrasion procedure involved rubbing the specimen against the same fabric in a room with standard atmospheric conditions (temperature 20 ± 2 °C and relative humidity 65 ± 4 %, according to EN ISO 139:2005/A1:2011). For this research, 12 control points, i.e., rubbing passes, were defined (from 125, 500, 1000, 2000, 5000, 7000, 10000, 14000, 18000, 22000, 26000, to 30000), and for each control point, one specimen was prepared. Pilling assessment was conducted using both the visual assessment method (figure 1) and the improved instrumental assessment method (figure 2 and 3).

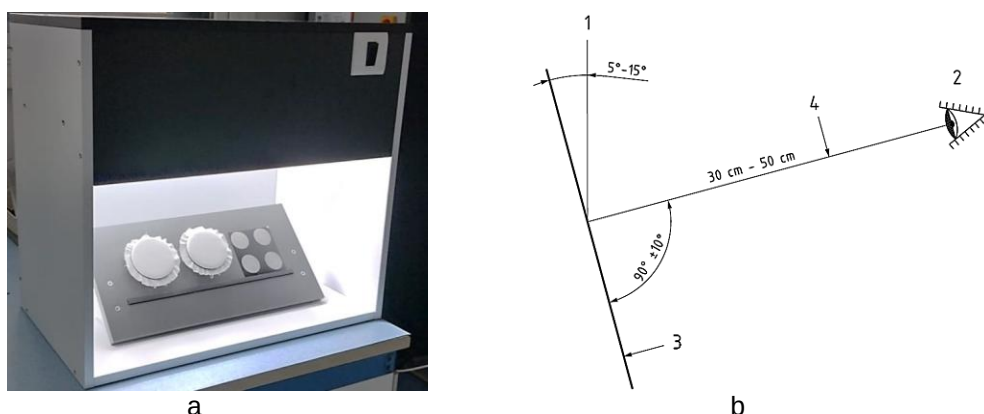


Figure 1: Visual assessment method: a) custom-designed apparatus for illumination and assessment of specimen surface area, b) standard assessment conditions: 1 – illumination angle, 2 – observer, 3 – fabric specimen surface, 4 – distance from the observer to specimen surface

To improve the instrumental assessment method, an innovative apparatus was designed and constructed (figure 2a), that ensured digital imaging of the entire fabric specimen surface area (figure 2c) under standard conditions (figure 2b). Computer analysis of digital images was conducted in Fiji, software that allowed segregation of pilling occurrence, by the use of Fast Fourier transform (figure 3a) and threshold adjustment (figure 3b) as well as the analysis and display of the following parameters: the number of individual pills, density of pills on analyzed surface area, surface area of each individual pill and their average area, the sum of all pill surface areas, the total percentage of the fabric specimen surface area covered with pills.

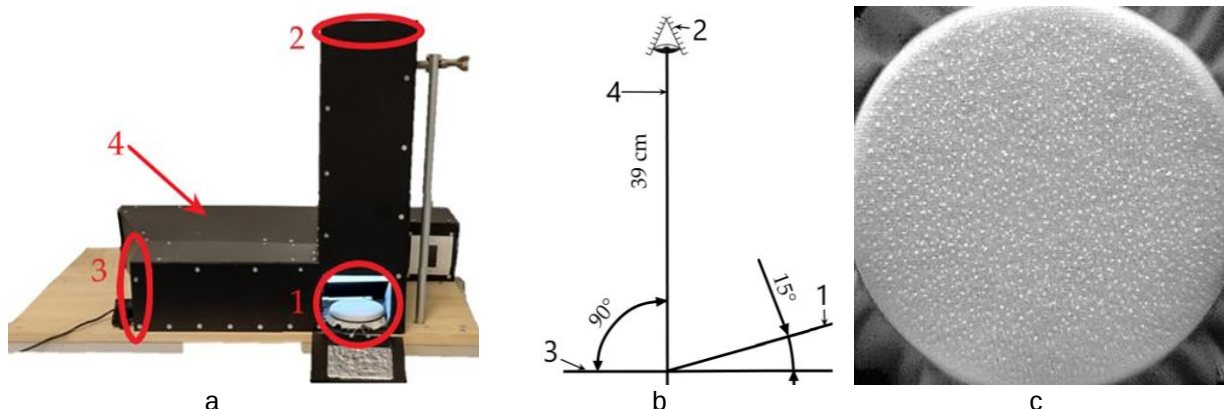


Figure 2: Improved instrumental assessment method – digital imaging process: a) innovative apparatus: 1 – position for fabric specimen placement, 2 – first camera position, 3 – second camera position, 4 – position of the illumination source, b) first camera position: 1 – illumination angle, 2 – first camera position, 3 – fabric specimen surface, 4 – distance from first camera position to specimen surface, c) digital image of polyester fabric specimen rubbed against the same fabric after 30000 pilling rubs

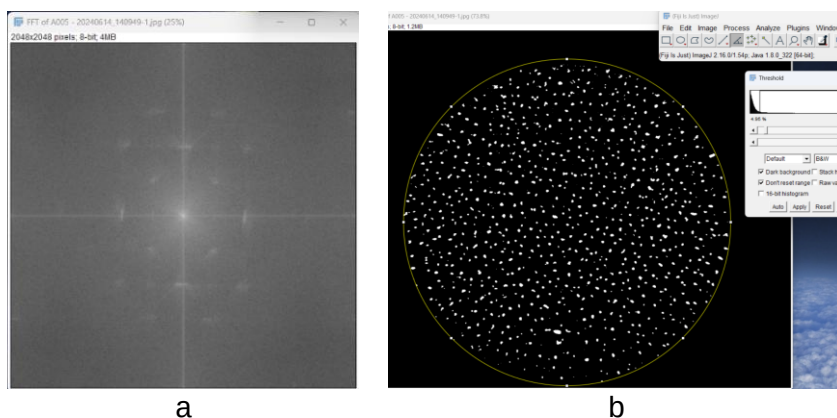


Figure 3: Improved instrumental assessment method – computer analysis of digital images a) spectrum of frequencies obtained through the Fast Fourier transform, b) digital image after the Fast Fourier transform with adjusted threshold value

3. Results and Discussion

The total percentage of the fabric specimen surface area covered with pills is a pilling parameter obtained through computational analysis, which was determined to most objectively represent pilling occurrence and intensity. Therefore, it was used to form nine grading classes (table 1), based on which the improved grading method was performed.

Table 1: Nine grading classes defined based on the value of the total percentage of the fabric specimen surface area covered with pills

Grade	Grading classes					
	Cotton	Wool	Viscose	Polyamide 6.6	Polyester	Acrylic
1.0	≥ 1.409	≥ 0.433	≥ 1.662	≥ 1.518	≥ 2.051	≥ 2.213
1.5	1.234–1.408	0.379–0.432	1.456–1.661	1.330–1.517	1.795–2.050	1.938–2.212
2.0	1.059–1.233	0.325–0.378	1.251–1.455	1.142–1.329	1.538–1.794	1.664–1.937
2.5	0.884–1.058	0.271–0.324	1.045–1.250	0.954–1.141	1.282–1.537	1.389–1.663
3.0	0.709–0.883	0.217–0.270	0.84–1.0440	0.766–0.953	1.026–1.281	1.114–1.388
3.5	0.534–0.708	0.162–0.216	0.634–0.839	0.578–0.765	0.769–1.025	0.839–1.113
4.0	0.359–0.533	0.108–0.161	0.428–0.633	0.390–0.577	0.513–0.768	0.565–0.838
4.5	0.184–0.358	0.054–0.107	0.223–0.427	0.202–0.389	0.256–0.512	0.290–0.564
5.0	≤ 0.183	≤ 0.053	≤ 0.222	≤ 0.201	≤ 0.255	≤ 0.289

The grading classes were defined using linear interpolation, with boundary values corresponding to the pilling appearance grades assigned by the visual assessment method: the fabric specimen rated with the highest grade (5.0, representing the initial fabric specimen) and the lowest grade (after the abrasion process). The relationship between the pilling occurrence grades determined by the visual assessment method and the improved instrumental assessment method was established using Pearson's correlation coefficient (figure 4) and the coefficient of determination (figure 5), both with a 95% confidence interval. The correlation analysis revealed a high to very high level of association between the pilling occurrence grades obtained through visual assessment and those obtained using the improved instrumental method.

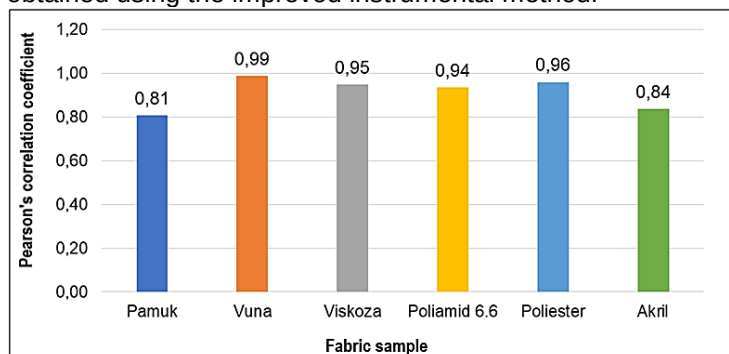


Figure 4: Display of Pearson's correlation coefficient values that indicate the strength of the relationship between the grades assigned by visual assessment method and improved instrumental assessment method

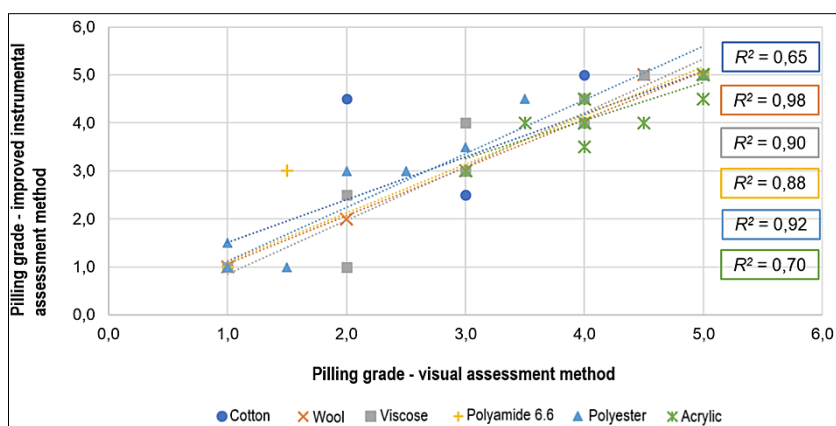


Figure 5: Correlation diagram of pilling grades assigned by the visual assessment method and improved instrumental assessment method

4. Conclusion

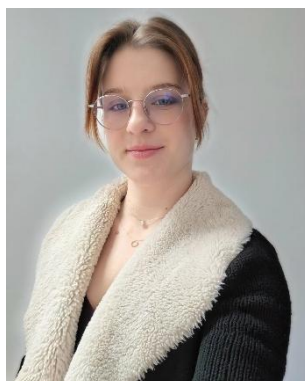
The use of the improved instrumental assessment method and the developed apparatus enabled uniform digital imaging of the entire fabric specimen surface under standard visual assessment conditions and achieved high visual similarity between the digital images and the specimen surface as perceived by the observer. The total percentage of the specimen surface area covered with pills proved to be the most reliable and objective pilling parameter, as it significantly reduces the influence of individual pill size variability and allows for objective pilling assessment without the need for a pre-established computer dataset.

Acknowledgment

Part of this research was financed under the project „ Comfort and antimicrobial properties of textiles and footwear “of the Croatian Science foundation (HRZZ IP-2016-06-5278), led by prof. Zenun Skenderi, Ph. D..

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**Stefana Begović****Biography**

Stefana Begović was born in Zagreb in 1995. She graduated in 2022 from the University of Zagreb Faculty of Textile Technology (UniZG TTF). Since March 2025, she has been employed at the UniZG TTF as teaching assistant/young researcher. In the academic year 2025/2026, she enrolled in the doctoral study programme "Textile Science and Technology" at the UniZG TTF. To date, she has co-authored two scientific papers published in journals, one full paper in the proceedings of an international conference, one book chapter and two abstracts. She held oral presentation of two scientific papers at international conferences, and participated in science popularisation events. She is a collaborator in the institutional research project of the University of Zagreb Faculty of Textile Technology "Green Technologies in Ecological Design and Development of Sustainable Materials - ZORA" funded by the European Union – NextGenerationEU.

Title of Ph. D. thesis

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Study advisor

Professor Anita Tarbuk, Ph. D.

Date of dissertation
defense

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ENZYMATIC PRE-TREATMENT OF COTTON/POLYESTER BLEND FABRIC

Stefana BEGOVIĆ

University of Zagreb, Faculty of Textile Technology, Prilaz baruna Filipovića
28a, Zagreb, stefana.begovic@ttf.unizg.hr

Abstract. In this study, enzymatic pre-treatment of a cotton/polyester blend fabric was performed to activate the surface and improve the hydrophilicity of the polyester component, which can negatively affect garment comfort. Commercially available enzymes were used for pre-treatment: pectinases for the cotton component and lipases for the polyester component, with an emphasis on minimal changes on mechanical properties. The effects were evaluated by measuring changes in mass, breaking force, wetting time, and zeta potential. Enzymatic pre-treatment was found to improve fabric properties.

1. Introduction

Textiles made from polyester and raw cotton initially exhibit hydrophobic properties; therefore, increasing hydrophilicity is an important step in their pre-treatment. Impurities in raw cotton act as a hydrophobic barrier and must be removed during the scouring process [1, 2]. Polyester, primarily poly(ethylene terephthalate) (PET), contains a small number of polar functional groups (hydroxyl and carboxyl groups) responsible for forming hydrogen bonds with water molecules [3, 4]. As a result, polyester/cotton blends are commonly used, with the cotton component providing comfort and antistatic properties, while the polyester component ensures mechanical strength and plays a primary role in moisture management [5, 6]. Using conventional methods, the hydrophilicity of cotton and polyester is achieved by alkaline treatments (cotton scouring, alkaline hydrolysis of polyester), most often using NaOH at elevated temperatures [1, 4–6]. These treatments have a significant environmental impact due to energy and water consumption and the generation of potentially toxic compounds. Enzymatic treatment offers an environmentally friendly alternative to alkaline treatments, as enzymes act on specific substances at moderate temperatures and neutral pH, contributing to process sustainability. Pectinases enhance the removal of cotton impurities by exposing cellulose hydroxyl groups, while enzymatic hydrolysis of polyester fiber surfaces with lipases increases the number of polar groups [1–5]. Therefore, in this study, lipase and pectinase enzymes were used on cotton/polyester blend fabric to improve hydrophilic properties while inducing minimal changes in the mechanical properties of the fabric.

2. Experimental

A cotton/polyester blend fabric (50/50) in panama weave (N) was used for the research. The fabric was pre-treated with 2% enzyme for 60 minutes at 60 °C in a Polycolor drum (Mathis): lipase Texazym PES, Inotex (2%, T); pectinase Biosol PRO, CHT-Bezema (2%, BP); and their combination (1% + 1%, BPT). The mass per unit area (m) was measured according to ISO 3801; tensile properties - force (F) and elongation (ε) according to ISO 13934-1; wetting time (WT) according to AATCC TM 195 using MMT M290 (SDL Atlas); and zeta potential (ζ) using Surpass (Anton Paar) were determined before and after enzymatic pre-treatment.

3. Results and Discussion

The results for areal mass, breaking force, elongation, and fabric wetting time before and after enzymatic pre-treatment are presented in Table 1, while the zeta potential results are shown in Figure 1.

Table 1: The mass per unit area (m), tensile properties: force (F) and elongation (ϵ), and wetting time (WT) of fabrics before and after enzymatic pre-treatment

Sample	m [g/m ²]	F [N]	ϵ [%]	WT [s]
N	169,81	1096,0 $\pm$ 2,5	11,55 $\pm$ 1,84	5,35
T	171,38	1016,5 $\pm$ 1,2	12,60 $\pm$ 3,37	2,39
BP	173,06	1031,0 $\pm$ 2,0	14,25 $\pm$ 1,49	2,44
BPT	176,43	1068,3 $\pm$ 0,4	14,33 $\pm$ 1,86	2,46

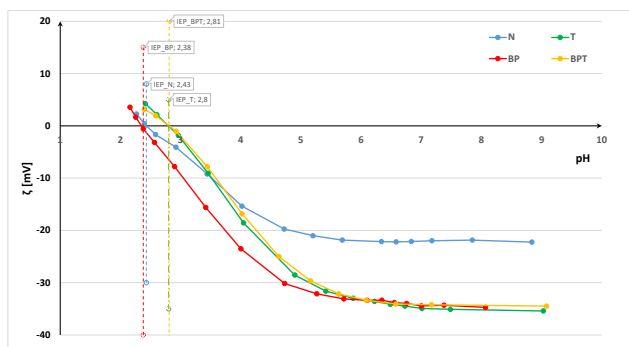


Figure 1: Zeta potential of fabrics before and after enzymatic pre-treatment

The mass per unit area increased due to swelling of the cotton component and shrinkage after drying. The removal of cotton impurities and hydrolysis of polyester lead to a lower tensile properties i.e. force; however, hydroxyl and carboxyl groups are simultaneously formed or become available, increasing fabric hydrophilicity. The wetting time and zeta potential results further confirm this: wetting time is shorter, and the zeta potential becomes more negative due to a greater number of electronegative groups.

4. Conclusion

Enzymatic pre-treatment with pectinase and lipase increases hydrophilicity with minimal reduction in mechanical properties. The lipase enzyme (Texazym PES) has a greater effect on mechanical properties because it hydrolyzes polyester. The bath containing both enzymes is the most effective pre-treatment, achieving optimal results by improving hydrophilicity while maintaining mechanical properties.

Acknowledgement



This research was co-financed by the Croatian Science Foundation (HRZZ) project UIP-2017-05-8780 "Hospital Protective Textiles" and short-term financial support from the University of Zagreb TP/2-2025 "Non-conventional Scouring Processes of Cotton". It is part of the institutional research project of the University of Zagreb Faculty of Textile Technology "Green Technologies in Ecological Design and Development of Sustainable Materials - ZORA" funded by the European Union - NextGenerationEU.

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**Darinka Cvetković****Biography**

Born in Zagreb on July 22nd, 1962. In 1981 employed in Radio Industry in Zagreb at IETA (Electrical and Telecommunication Research). Worked in the lab for the recording and production of technical films (photographic, dry film, chemical copper double plates, galvanic baths and their analyses) and administrative work. In 1984 enrolled the Faculty of Chemical Engineering and Labour. In 1991 enrolled the Faculty of Chemistry and Technology, graduating in Footwear technology. In 2009, she enrolled a Distinctive Study at the Faculty of Textile Technology, and in 2011 graduated from the Textile Chemistry, majoring in textile chemistry, materials and ecology. She enrolled doctoral studies at the Faculty of Textile Technology in 2016, with the aim of improving research.

Title of Ph. D. thesis

Development and characterization of coatings with propolis and biopolymers on textiles for topical application

Mentor

Prof. Maja Somogyi Škoc, Ph. D.

Date or dissertation defense

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DEVELOPMENT AND CHARACTERIZATION OF COATINGS WITH PROPOLIS AND BIOPOLYMERS ON TEXTILES FOR TOPICAL APPLICATION

Darinka CVETKOVIĆ

Gračansko Dolje 44, Zagreb, cvetkovicdarinka@gmail.com

Summary: The research will focus on developing coatings for textiles intended for topical application on the skin or mucosa. Bioactive coatings based on natural polysaccharides (chitosan, sodium carboxymethyl cellulose, alginate), with added propolis, will be developed and characterised to achieve a synergistic effect for use on cellulose fibre fabric and non-woven textiles. Process parameters will be varied, and the optimal coating formulations will be selected using experimental design. The aim is to contribute to the development of innovative, natural, and sustainable textile coatings for local application that can promote targeted stimulation of healthy granulation and epithelisation in topical cosmetics.

1. Introduction

The growing demand for sustainable, functional, and safe textile materials is driving the development of innovative solutions in technical textiles, particularly medical textiles. In this context, ecological processes are increasingly being explored, with greater attention given to the use of natural substances such as medicinal plants and biopolymers derived from natural sources, including polysaccharides such as chitosan, cyclodextrins, dextrans, and alginates (e.g. bioactive dressings for chronic wounds). These polysaccharides have attracted significant interest due to their biomedical and physicochemical properties, such as biodegradability, non-immunogenicity, potential for functionalisation, hygroscopicity, and anti-inflammatory and antioxidant properties. As a result, they are generally regarded as safe (GRAS) and are widely used in the food industry [1]. Given the safety of these substances, they provide an excellent basis for developing new biomaterials and coatings in medical and cosmetic textiles.

Polysaccharides contain numerous hydroxyl groups or other hydrophilic groups, such as carboxyl groups in alginate and amino groups in chitosan, which enhance water solubility and improve bioadhesion and biorecognition properties through non-covalent (electrostatic) bonding [2]. Chitosan is the only naturally charged polysaccharide and can bind to negatively charged mucosal layers via electrostatic interactions. Due to their biochemical compatibility with human extracellular matrices, polysaccharides are readily recognised and metabolised in the body [3], and they have been found to participate in various biological processes, including immune recognition and cell signalling [4], which are responsible for activating antimicrobial and anti-inflammatory responses [5]. Additionally, these polysaccharides undergo enzymatic and/or hydrolytic degradation in vivo, producing harmless degradation products that can be reused in biological systems and cleared by the immune system. When extracts of medicinal plants or, for example, propolis are added to coatings based on these polysaccharides, a synergistic effect can be achieved, offering a high level of safety for human health without burdening the environment.

Propolis, a bee product rich in flavonoids and phenols, is known for its strong antimicrobial and antioxidant properties. However, its application to textiles is challenging due to its hydrophobic nature and poor adhesion to fibres. In combination with biopolymers such as chitosan, alginate, gelatine, or zein, it is possible to achieve more stable coatings and enable controlled release of active substances, thereby improving the efficiency and functionality of the treated materials. Numerous studies confirm the potential of the propolis–biopolymer system in the functionalisation of textiles.

2. Experimental

In planning and conducting the research, general knowledge of scientific work methodology is applied, including the preparation of research materials, implementation of research, and processing of results. Methods and procedures that ensure the reproducibility of modifications and morphological characteristics of research materials are employed, using modern and reliable measurement techniques to evaluate the effectiveness of individual effects. In processing, analysing, and evaluating the obtained results, appropriate mathematical and statistical methods are applied to ensure a certain degree of reliability in drawing conclusions. To ensure the reproducibility of the modifications, cotton reference fabric and non-woven textiles

will be used for the research. For preparing functional coatings, propolis available in pharmacies and native propolis from local bee sources will be used, ensuring the freshness and authenticity of the samples. In addition to propolis, biopolymer materials, primarily of polysaccharide character (sodium carboxymethylcellulose, chitosan, and alginate), will also be used in the research. Their application will improve the mechanical and biological properties of the coatings, providing additional antimicrobial and dermally stimulating functionality. The research will focus on determining the optimal conditions for the modification of textile materials by varying the type and concentration of selected polysaccharides and propolis. Optimisation of the formulations will be carried out using Design of Experiments (DOE), with special emphasis on preserving the original textile properties of the modified materials. The research methodology is designed to enable systematic testing of all relevant factors affecting the quality and effectiveness of the modified materials. The first step involves characterising raw propolis, primarily its phenolic compounds and flavonoids (thin layer chromatography (TLC), UV-VIS spectroscopy). After preparation, the propolis-enriched biopolymer coatings will undergo multiple characterisations to assess their morphological and functional characteristics. All experiments will be carefully designed and conducted to enable a comprehensive understanding of the relationship between the chemical composition, structural characteristics, and biological activity of the developed bioactive systems on textiles. This approach will enable systematic evaluation of their effectiveness and stability under conditions that simulate real topical application.

3. Conclusion

The scientific contribution of the proposed research is demonstrated in the systematic development and optimisation of biopolymer and propolis formulations using experimental design, as well as in the functional modification of textile materials to achieve coatings with antimicrobial properties suitable for topical application. An additional contribution is expected through the analysis and understanding of the bioadhesive properties of the developed formulations on textiles. The advantage of these formulations lies in the use of ingredients of natural origin that are safe for oral administration, making them particularly suitable for external, that is, topical use.

4. References

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**Jasna Dročić****Biography**

Born on 8 January 1979 in Slavonski Brod, Croatia. She graduated in 2009 from the University of Zagreb, Faculty of Textile Technology (Textile Technology programme; Process Engineering track). From March 2004 to August 2007, she worked at the International Centre for Cultural Services, branch: Collection and Workshop of Traditional Folk Costumes, in the position of Folk Costume and Costume Preparator. She participated in numerous projects related to traditional heritage and culture through various gallery and stage programmes and museum exhibitions. From April 2008 to April 2018, she worked at the fashion house *Nebo* as a garment constructor. Since April 2018, she has been employed by the Croatian National Folk Dance and Song Ensemble Lado as Head of the Collection and Workshop of Traditional Folk Costumes. She works on projects involving educational workshops on traditional embroidery techniques and costume-making methods. She is a co-author of the exhibition "*The Beauty of the Bebrina Costume*", held at the Museum of Prigorje in Sesvete from 3 June to 25 July 2016 (the exhibition presented a family collection of garments and household textiles from the early 20th century to the present day).

Title of Ph. D. thesis

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Study advisor

Prof. Sanja Ercegović Ražić, Ph. D.

Date or dissertation
defense

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RESEARCH INTO THE REPLACEMENT OF SILK FIBRE IN TRADITIONAL WOVEN FABRIC OF SLAVONIA WITH THE AIM OF INCREASING COSTUME STRENGTH AND DURABILITY

JASNA DROČIĆ

University of Zagreb, Faculty of Textile Technology, Prilaz baruna Filipovića
28a, Zagreb, jasna.drocic1@gmail.com

Abstract: *The aim of this doctoral dissertation is to investigate and define the optimal replacement for silk fibre in the weft of traditional woven fabric, which would improve the mechanical properties of the fabric—particularly strength and durability—while preserving the aesthetic and tactile characteristics of original silk. Special emphasis is placed on the similarity of the replacement fibre in terms of appearance, colour, thickness, fineness, and material behaviour during gold embroidery (zlatovez), in order to preserve the authenticity of the visual identity of the Slavonian folk costume.*

1. Introduction

The traditional costume of Slavonia, particularly that of the Slavonski Brod region, represents an exceptionally valuable segment of Croatian cultural and textile heritage. The most ceremonial parts of women's folk costumes were made from domestically woven fabric, with a cotton warp and a silk weft. This combination of materials enabled the production of fine and aesthetically highly valuable textiles, especially suitable for hand embroidery—*zlatovez*—with which the costume was additionally decorated. This type of folk costume was highly valued at the beginning of the 20th century and, due to its beauty and awareness of its value, was not worn frequently. Women wore it only three times a year, primarily for Sunday church attendance.

Although silk fibre is visually and tactually highly attractive, it shows certain limitations in terms of mechanical strength, resistance to abrasion, and long-term durability, which poses challenges in contemporary production, reconstruction, and stage use of traditional costumes. This issue is particularly pronounced in costumes that are intensively used under performance conditions.

I am employed by the Croatian National Folk Dance and Song Ensemble Lado as Head of the Collection and Workshop of Traditional Folk Costumes, where I am directly involved in the collection, preservation, maintenance, and production of traditional garments. One of the key projects within this work concerns the creation of new types of costumes based on original examples owned and used by the Lado Ensemble, which, due to their age, material sensitivity, and degree of wear, are no longer suitable for stage use. It is precisely this long-term practical experience of working with original materials and costume constructions that served as the impetus for the scientific research presented in this doctoral dissertation.

I would particularly like to emphasize the insight into the durability of hand-made *zlatovez*, the significant effort invested, and the high cost of gold and silver threads and metal sequins, which further increases the importance of the research task and the desire for the long-term preservation of such garments [1-5].

2. Experimental Part

The research includes an analysis of potential natural and regenerated fibres as replacements for silk, experimental production of fabrics with a cotton warp and alternative fibres in the weft, and testing of their mechanical, physical, and aesthetic properties. The obtained results will have the potential for direct application in the production of new functional stage costumes for the needs of the Lado Ensemble, while simultaneously respecting traditional techniques and the visual characteristics of the original garments.

3. Results and Discussion

The test results are expected to show significant differences between fabrics produced with different types of weft fibres. Certain alternative raw materials are anticipated to demonstrate improved mechanical properties compared to silk fibre, particularly in terms of strength and abrasion resistance.



Analysis of textile and tactile characteristics is expected to show that some replacements largely retain the appearance and feel of silk fibre, while exhibiting better performance under conditions of increased mechanical stress. The results will be interpreted in the context of stage-use requirements, with particular emphasis on the importance of balancing authenticity and functionality.

4. Conclusion

Based on the conducted research, it will be possible to conclude that silk fibre in the weft of traditional woven fabric can be replaced with appropriate alternative fibres, achieving improved mechanical properties while maintaining the aesthetic value of the fabric. The obtained results will confirm that a scientifically grounded approach to materials can significantly contribute to the preservation and contemporary application of traditional folk costumes.

This work provides a foundation for further research and practical application in the production of new types of costumes, particularly for stage use, thereby ensuring the long-term preservation of cultural heritage.

Acknowledgements

I would like to thank my supervisor and the members of the committee for the professional guidance, advice, and support they provide during the preparation of this doctoral dissertation. I also thank the Lado Ensemble for their trust and for providing the opportunity to initiate this major undertaking, as well as all collaborators whose knowledge and experience will contribute to the successful realization of this project.

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Selma Imamagić

Biography

Selma Imamagić was born in 1998 in Zagreb. In 2022, she graduated on the University of Zagreb Faculty of Textile Technology, study: Clothing Engineering. After graduating, she enrolled in the doctoral programme Textile Science and Technology at the University of Zagreb Faculty of Textile Technology in the same year. She currently works as an assistant at the Department of Clothing Technology, University of Zagreb Faculty of Textile Technology. She has published four co-authored original scientific papers, one review, and two professional papers. Her areas of scientific interest are time study, protective clothing, and the organisation of production process in garment industry.

Title of Ph. D. thesis

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Study advisor

Prof. Anica Hursa Šajatović, Ph. D.

Date of dissertation
defense

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MODEL OF SCHEDULING TECHNOLOGICAL OPERATIONS TO WORKPLACES IN THE GARMENT PRODUCTION PROCESS

Selma IMAMAGIĆ

University of Zagreb Faculty of Textile Technology, Prilaz baruna Filipovića
28 a, selma.imamagic@tff.unizg.hr

Abstract: Scheduling is the process of allocating scarce resources to a specific set of activities to optimise one or more scheduling criteria. In the garment industry, scarce resources include machines and workforce, while activities refer to production orders. This doctoral thesis is based on creating a model for scheduling technological operations by workplaces in the garment production process. The aim is to define an objective function that will minimise the makespan and increase the productivity rate in the garment manufacturing system.

1. Introduction

Scheduling involves allocating scarce resources to activities with the aim of optimising an objective function, that is, one or more scheduling criteria. Depending on the context, resources and activities can take different forms [1]. In the garment industry, scarce resources are machines and workforce, while activities are production orders or, more specifically, technological operations required to manufacture a product.

The scheduling problem of assigning technological operations to workstations in the garment production process is an example of a *Resource Constrained Project Scheduling Problem* (RCPSP). The *Resource Constrained Project Scheduling Problem* includes a set J consisting of n jobs, $J_1, J_2, J_3, \dots, J_n$. The set of J jobs must be scheduled on a set M of machines by a set K of workers within the time period $T = 0, \dots, t_{max}$ [2]. Thus, each job j must be executed on a machine i that belongs to the subset M_j of machines from the set M used for processing job j , and performed by a worker k belonging to the subset K_{ij} of workers from the set K [2]. This subset K_{ij} comprises workers who have the skills to perform job j on machine i [2].

Furthermore, each job j consists of m_j operations $O_{j1}, O_{j2}, O_{j3}, \dots, O_{jm_j}$ that must be processed in a predetermined order, respecting precedence constraints and on the specified machine [1, 3]. Each operation O_{jk} is characterised by its processing time p_{jk} .

The aim of this doctoral thesis is to create a model for scheduling technological operations to workplaces in the garment production process that will minimise the makespan and increase the productivity rate in the garment manufacturing system.

2. Experimental

The early stage of the experimental part of the doctoral thesis will be conducted in the garment factory. Based on the input data obtained from the factory, type of used machines, job characteristics, and scheduling constraints are defined, as shown in Tab. 1.

Table 4: Machine environment, job characteristics and scheduling constraints in garment factory [2-4]

Type of machine	Description
Parallel and identical machines (Pm)	There are m identical machines in the factory that operate in parallel (e.g. single-needle lockstitch machines in production lines).
Job characteristics and scheduling constraints	
Precedence constraints	A technological operation cannot start before its predecessor is completed.
Capacity constraints	Each machine and worker can perform only one technological operation at a time.



Pre-emption	A production order can be pre-empted and resumed after reaching a defined time period or specified quantity of products.
Workers' skill requirement	The technological operations required to produce a certain garment have defined the complexity of performance. The complexity of performance is linked to the skills required of workers to carry out such operations. Therefore, a subset of workers with the necessary skills to perform technological operations according to complexity is defined. Additionally, workers can operate only a subset of machines for which they are trained.
Shift and workday constraints	Each machine and worker is available for only one shift per day (450 minutes).

3. Results and discussion

The developed model for scheduling technological operations by workplaces in the garment production process will be analysed according to the scheduling objectives of makespan and productivity rate. The evaluation of the model for production scheduling will be based on the results of real-time tests.

4. Conclusion

The scheduling problem in manufacturing systems involves finding the optimal sequence for processing technological operations at workplaces. The aim is to optimise one or more scheduling objectives. In the doctoral thesis, the decision is made to optimise makespan and productivity rate by workplaces. This would achieve satisfaction for both the employer and the workers in production.

5. References

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Josip Jelić

Biography

Josip Jelić was born on June 26, 1980 in Zagreb. He completed primary and secondary school in Zagreb. He graduated from the Faculty of Textile Technology, University of Zagreb, in 2015. He enrolled in the postgraduate university study program Textile Science and Technology at the Faculty of Textile Technology, University of Zagreb, in 2017.

Title of Ph. D. thesis

Targeted fabrication of fibrous scaffolds for tissue cell cultivation by combined electrospinning

Study advisor

Prof. Budimir Mijović, Ph. D.

Date of dissertation defense

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COMPOSITE MATERIALS' MECHANICS

Josip JELIĆ

Carwizz, Slavenska avenija 26/9, Zagreb, josipjelic2004@gmail.com

Abstract: A composite or composite material is made up of different materials that are firmly bonded together to produce a new, different material with physical or chemical properties that exceed those of the individual parts or that are not possessed by the individual parts. Most composites contain one material as a continuous phase (matrix), and separate parts of a second phase are embedded in it, which usually acts as a reinforcement. The mechanical properties of composite materials such as tensile, compressive, flexibility, strength and stiffness depend on various factors, some of which are: the composition of the materials, their volume fractions and the manufacturing processes used. Research into different techniques for manufacturing composite materials is very important. This may include studying processes such as hand-laying, filament winding, compression molding and many more in order to optimize the mechanical properties of the final product.

1. Introduction

Textile composites are advanced materials that combine textiles (such as woven or nonwoven textiles) with other materials, often polymers or reinforcing fibres, to create materials with enhanced properties and performance [1]. These composite materials are used in a wide range of applications in various industries due to their unique combination of characteristics, which may include strength, durability, light weight, flexibility, and thermal or electrical conductivity [2]. Some of the key aspects and applications of textile composites are: Reinforcing materials: Textile composites often use fibres such as carbon fibres, glass fibres, aramid fibres (e.g., Kevlar), or natural fibres (e.g., flax or jute) as reinforcement. These fibres provide strength and stiffness to the composite while maintaining the flexibility and properties of a lightweight fabric. Matrix materials: A matrix material, usually a polymer resin, that surrounds and binds the reinforcing fibres together, providing cohesion and load transfer between the fibres. Common matrix materials include epoxy, polyester, and thermoplastic polymers. Lamination techniques: Textile composite materials are often produced using various lamination techniques, such as hand-laying, vacuum bagging, resin infusion, or autoclave curing, depending on the specific application and required performance characteristics.

2. Materials and methods

The work used Shieldex Bonn, which is a highly conductive thermally bonded nonwoven made of 100% polyamide (Nylon 6.6) with a silver content of approx. 17%. Due to the silver content, this nonwoven material has an antimicrobial effect, is electrically and thermally conductive and protects against electromagnetic radiation. Despite its antimicrobial properties, Shieldex Bonn is also used for technical purposes in industry. In addition to electromagnetic protection, this technical material provides antistatic dissipation and very good electrical conductivity up to $< 0.5 \Omega$. Shieldex Bonn is particularly suitable for sensors in medical technology, protective wallpapers in room protection or antistatic discharge in electronic components. The material is also compliant with OEKO-TEX® STANDARD 100, REACH and RoHS. Shielding efficiency (0.2–2 GHz) Average < 63 dB from 0.2 GHz – 2 GHz. Shielding efficiency (2–5 GHz) Average < 70 dB from 2 GHz – 5 GHz. Shielding efficiency (5–14 GHz) Average < 78 dB from 5 GHz – 14 GHz. Weight $56 \text{ g/m}^2 \pm 15 \%$. Thickness $0.35\text{mm} \pm 30 \%$.

2.1. Measuring equipment and samples

The ISO 9073-3 standard, developed by the International Standards Organization (ISO), describes a test method for determining the tensile properties of nonwoven fabrics by the shear band method. The Statimat M dynamometer from Textechno is used for the measurement. The accuracy of this apparatus corresponds to class 1, with an error of the maximum force recorded $\pm 1\%$. The force at break of a material is generally known as the tensile strength or ultimate tensile strength, which refers to tension. Elongation is measured by applying a tensile force or stretching the material in the same way as previously described and determining the change in length compared to the original. Elongation is measured by applying a tensile force or stretching the material in the same way as previously described and determining the change in length compared to the original.



Elongation is expressed as a percentage of the original length. Ultimate elongation is the percentage change in length from the original to the break. Samples are prepared for measurement in the form of strips measuring 50 ± 0.5 mm x 200 ± 0.5 mm. 10 samples were cut in 3 directions according to the template in Figure 3, with the following markings: X direction 0° , Y direction 90° , Z direction 45° .

3. Tensile force results on dry samples

The paper presents the results and measured values of the material under tensile stress on a dynamometer. 20 samples in a dry state and 20 samples in a wet state were tested in 3 different directions. During the measurement, the measuring length of the tensile testing device was set to 100 ± 1 mm. The test speed was set to 100 mm min⁻¹, and the maximum force was 1000 N. The atmosphere provided for preconditioning and conditioning of the samples corresponded to the recommendations of EN 20139.

According to the results, it can be seen that the highest strength in the X direction in the dry state is sample 4 and it is 172.51 cN/mm. The lowest strength is sample 2 and it is 135.21 cN/mm. Sample 4 also has the highest breaking elongation which is 61.40 %, while sample 2 has the lowest breaking elongation which is 42.30 %. The highest strength in the Y direction in the dry state is found in sample 4, which is 82.21 cN/mm. The lowest strength is found in sample 2, which is 65.41 cN/mm. According to the measured data in the dry state, the material has the highest strength in the X direction.

4. Conclusion

The mechanical properties of composite materials such as tensile, compressive, flexural, strength and stiffness depend on various factors, some of which are: the composition of the materials, their volume fractions and the manufacturing processes used. Research into different techniques for manufacturing composite materials is very important. This may include studying processes such as hand-laying, filament winding, compression molding and many more to optimize the mechanical properties of the final product.

5. References

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**Ana Kalazić****Biography**

Born in 1993 in Zagreb. After completing the Tituš Brezovački Gymnasium in Zagreb, she enrolled in the academic year 2012/2013 at the Faculty of Economics and Business, University of Zagreb, where she obtained the degree of Bachelor of Professional Studies in Business Economics. In the academic year 2015/2016, she enrolled at the Faculty of Textile Technology, University of Zagreb, where she graduated in the academic year 2019/2020 and obtained the degree of Master of Engineering in Textile Technology and Engineering. In the academic year 2020/2021, she enrolled in the postgraduate doctoral study program in Textile Science and Technology at the Faculty of Textile Technology, University of Zagreb. From 2020 to 2023, she worked at the same faculty as a project associate on the IRI II project "*Development of multifunctional non-flammable fabric for dual use*", funded by the European Regional Development Fund. Since 2024, she has continued her work at the Faculty of Textile Technology, University of Zagreb, in the position of assistant.

Title of Ph. D. thesis

Development of a method for the objective evaluation of the tactile characteristics of fabrics

Study advisor

Assist. prof. Snježana Brnada, Ph. D.

Date of dissertation defense

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ANALYSIS OF FABRIC SURFACE ROUGHNESS IN DIFFERENT DIRECTIONS USING AN OPTICAL METHOD

Ana KALAZIĆ

University of Zagreb, Faculty of Textile Technology, Prilaz baruna Filipovića
28a, 10000 Zagreb, Hrvatska, ana.kalazic@tff.unizg.hr

Abstract: In this study, the surface roughness of fabrics was investigated using an optical measurement method supported by dedicated software. Digital microscopic images of the fabric surface in **satin weave** were employed to generate primary roughness profiles in multiple measurement directions. Particular emphasis was placed on the influence of measurement direction, and the results demonstrate the high sensitivity of the optical method to local microstructural variations and to the orthotropic nature of textile surfaces.

1. Introduction

Optical analysis of the fabric surface enables non-contact examination of the microrelief of fabrics. Fabric roughness is governed by the type of weave, yarn density, and measurement direction, which necessitates the analysis of roughness profiles in multiple directions. In this study, surface roughness analysis was conducted with the aim of investigating the influence of the position and orientation of measurement lines on the obtained roughness parameter values. Particular emphasis was placed on satin weave fabrics due to their specific topographical characteristics.

2. Experimental

The fabric surface was captured using a Dino-Lite digital microscope, and the acquired images were analyzed using MountainsLab software. To enhance the visibility of topographical differences, the images were converted into a monochromatic representation. The analysis was performed in four measurement directions: two principal directions (warp and weft) and two diagonal directions (at angles of 45° and 135°). For each direction, ten measurement lines were defined along which roughness profiles were generated. The position of the measurement lines relative to the yarns proved to be a critical factor, as lines aligned along the yarns yielded smoother profiles, whereas lines located in the inter-yarn spaces recorded higher local roughness. The roughness parameter R_q was calculated from the primary profiles, and the final value for each direction was determined as the arithmetic mean of all measurements.

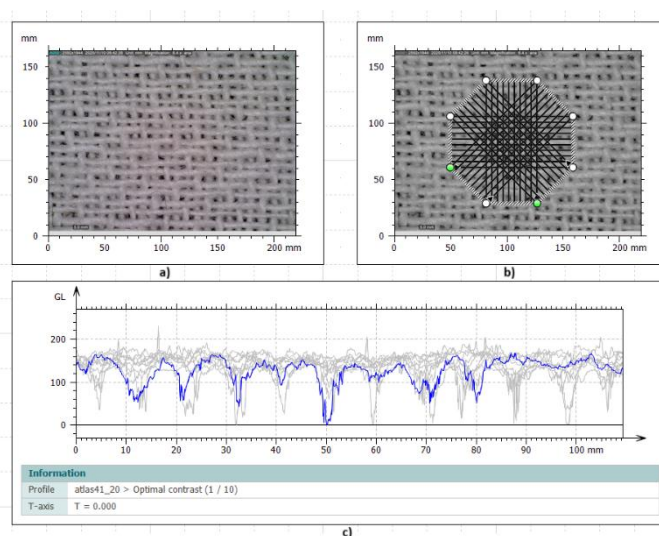


Figure 1: Interface of the MountainsLab software – a) monochromatic image of the fabric, b) selected lines for generating roughness profiles for each measurement angle, c) a set of roughness profiles for one of the investigated directions.

3. Results and Discussion

The results of the optical analysis revealed a pronounced directional dependence of the surface roughness parameter R_q for satin weave fabrics, as obtained by the optical measurement method, indicating the anisotropic nature of the surface topography. The lowest R_q value was recorded in the warp direction, indicating the highest smoothness in this direction, which is a typical characteristic of satin weaves. This is due to the denser and more tensioned arrangement of warp yarns, resulting in less pronounced transitions, or floats, and a more uniform fabric surface topography. In contrast, higher roughness values in the weft and diagonal directions reflect the more complex influence of yarn arrangement and their mutual interactions on the optically registered surface morphology, confirming the high sensitivity of the optical method to local structural features and the directional inhomogeneity of the fabric.

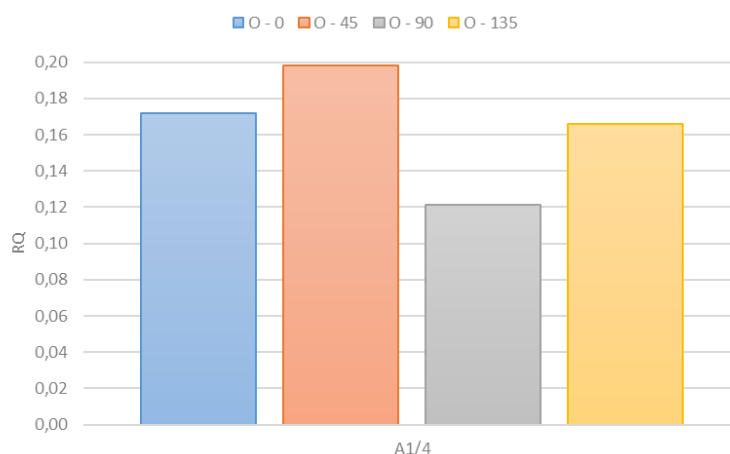


Figure 2: R_q roughness parameter values in different directions (0° , 45° , 90° , and 135°) measured on fabric in satin weave.

4. Conclusion

The optical method for analyzing fabric surface roughness using MountainsLab software enables detailed characterization of fabric microrelief. The results confirm the pronounced dependence of the roughness parameter on measurement direction and the position of measurement lines, which arises from the orthotropic nature of woven structures and is particularly emphasized in satin weave fabrics due to characteristic floats. Therefore, the optical method represents a valuable tool for analyzing fine surface variations, provided that the measurement procedure is carefully defined.

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**Ivan Kraljević****Biography**

Ivan Kraljević, born in 1991, enrolled in the Faculty of Textile Technology at the University of Zagreb in 2010. He successfully completed his undergraduate studies in TTE, specializing in Engineering Design and Management of Textiles, with the thesis "Quality evaluation of leather for suitcases." Two years later, he completed his graduate study with the thesis "Testing the prints durability on semi processed bovine leather," under the mentorship of Prof. Antoneta Tomljenović. In November 2016, he enrolled in the doctoral program in Textile Science and Technology. Since February 2016, he has been employed at Jadran Hosiery as head of the knitting and sewing department. He has contributed to the research project HRZZ IP-2016-06-5278 and has published several co-authored scientific and professional papers. His research interests include testing and quality control of new materials for the sock industry and leather.

Title of PhD thesis

Socks with advanced functionality and options for objective evaluation

Study advisor

Prof. Antoneta Tomljenović, PhD

Date of dissertation defense

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EVALUATION OF COMFORT OF COTTON SOCKS

Ivan KRALJEVIĆ

Jadran Hosiery, Vinka Žganeca 2, HR - 10000 Zagreb,
ivan.kraljevic@ttf.unizg.hr

Abstract: The comfort of high-quality men's socks, made with a high proportion of cotton and fully plated with textured multifilament polyamide yarns of varying linear densities, was evaluated. The breathability of the knitted socks was assessed by measuring air permeability, hydrophilicity was evaluated by measuring moisture absorbency, and thermal properties were tested by measuring thermal resistance using a thermal foot.

1. Introduction

Socks are knitted, next-to-skin garments worn on the feet that cover the ankle and part of the calf [1]. During use, they must meet high standards of usability, particularly comfort. The air, moisture, and heat permeability of the knitted structure directly affect sock comfort. Because comfort largely depends on sock construction and the fibers used, selecting appropriate yarns for their manufacture is very important [2]. Men's socks are most often made with a high proportion of cotton, which ensures softness and comfort, blended with polyamide yarn to improve fit and durability. Therefore, this research evaluated the comfort of men's socks made with the highest proportion of cotton, fully plated with polyamide 6.6 yarns of different linear densities. The breathability of the sock knits was assessed by testing air permeability, hydrophilicity by testing moisture absorptivity, and thermal properties by testing thermal resistance on a thermal foot [3].

2. Experimental

The investigation was conducted on five groups of calf-length, fine, casual, black men's socks (Figure 1b) in size EU 42, made of high cotton content (using single ring-spun cotton yarn with a linear density of 29.4 tex) fully plated with texturized polyamide 6.6 multifilament yarns of different linear densities, designated as PA1 (49 dtex), PA2 (70 dtex), PA3 (93 dtex), PA4 (166 dtex), and PA5 (237 dtex). A plain single jersey pattern was used for the foot and leg parts, and a 1×1 rib structure was used for the cuff. The socks were produced at Jadran Hosiery using a Lonati E14 sock knitting machine with a cylinder diameter of 88.9 mm ($3 \frac{1}{2}$ ") and 168 needles (Figure 1a), and were ironed at 110 °C using a Cortese machine [3].

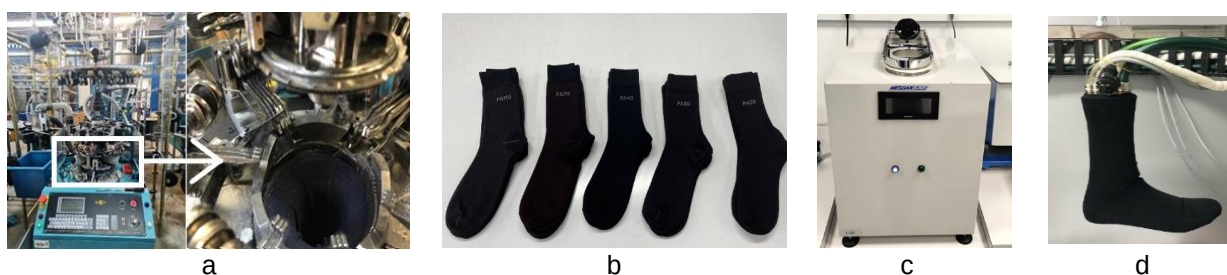


Figure 1: Socks: a) production of tested socks using a knitting machine, b) display of produced socks, c) testing air permeability (Mesdan-Lab), d) testing thermal comfort of socks on a thermal foot

The basic properties of men's socks, designated as CO/PA1 to CO/PA5, are shown in Table 1, including values for sock weight, mass per unit area, thickness, and density parameters of the sock plain knits.

Table 1: Basic properties of cotton socks [3]

Sock sample	Weight of sock, g	Mass per unit area, g/m ²	Thickness, mm	Wales/cm	Courses/cm
CO/PA1	15.5	178	0.90	11	12
CO/PA2	16.5	190	0.93	11	12
CO/PA3	17.9	203	1.00	10	11
CO/PA4	21.8	224	1.13	10	11
CO/PA5	25.2	263	1.25	9	10

Prior to measurement, the sock samples were conditioned on a flat surface for at least 24 hours in a standard atmosphere with a temperature of 20 ± 2 °C and a relative humidity of $65 \pm 4\%$. The air permeability of knitted socks (Figure 1c) was tested according to EN ISO 9237:1995, using a surface area of 5 cm² and a pressure drop of 100 Pa. The moisture regain of the knitted socks was measured by the drying method according to ASTM D2654-22. The thermal resistance was tested on a thermal foot (Figure 1d, Thermal Foot Manikin System UCS) with an airflow of 1 m/s.

3. Results and Discussion

Increasing the linear density of polyamide 6.6. yarns used for plating of socks increases the weight of the socks as well as the thickness and mass per unit area of the sock plain knits, while the density of the knitted structure (number of wales and courses per centimetre) slowly decreases (Table 1). Increasing the linear density of the plating yarn increases the resistance to heat transfer of the socks and reduces the air permeability and moisture absorption of the sock knit (Table 2). Therefore, in thicker, denser, and heavier sock knit structures, breathability, moisture absorption, and heat transmission of the socks decrease.

Table 2: Comfort properties of cotton socks [3]

Sock sample	Moisture regain, %	Air permeability, mm/s	Thermal resistance, m ² °C/W
CO/PA1	7.0	912.85	0.021451
CO/PA2	6.4	738.94	0.025756
CO/PA3	6.0	722.13	0.034049
CO/PA4	5.7	584.48	0.040618
CO/PA5	5.6	477.04	0.042103

4. Conclusion

Since men's socks are most often made from a blend of cotton and polyamide, it has been found that by appropriately selecting the linear density of the plaited textured multifilament yarn made of polyamide 6.6, it is possible to influence the comfort of the socks.

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**Robert Matašić****Biography**

Robert Matašić was born in 1999 in Zagreb. He completed undergraduate studies in Textile Technology and Engineering in 2020 and graduate studies in 2022, majoring in Engineering Design and Management of Textiles, at the University of Zagreb Faculty of Textile Technology. In the academic year 2020/2021, he received the Rector's Award for socially useful work and Dean's Award for active participation in the promotion of the Faculty. In the academic year 2021/2022, he received the Dean's Award for outstanding achievement during his studies. He has won five gold and one silver medal for innovations at domestic and international innovation exhibitions. After completing his studies, he worked in the profession for two years. In the academic year 2024/2025, he enrolled in the doctoral university study programme in Textile Science and Technology at the University of Zagreb Faculty of Textile Technology. At the end of 2024, he was appointed as an assistant at the Faculty of Textile Technology and currently participates in the project IP.1.1.03.0143 *Multifunctional integration of personal protective equipment for the purpose of health protection and enhanced functionality*.

Title of Ph. D. thesis

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Study advisor

Prof. Snježana Firšt Rogale, Ph. D.

Date or dissertation
defense

/

SOFTWARE FOR DESIGNING KNITTED SAMPLES

Robert MATAŠIĆ

University of Zagreb Faculty of Textile Technology, Prilaz baruna Filipovića
28a, 10000 Zagreb, robert.matasic@ttf.unizg.hr

Abstract: The topic of the Ph. D. thesis involves testing the thermal properties of 48 weft knitted single jersey pullovers made from 100% cotton, 100% acrylic, 50/50% wool/acrylic and 50/50% cotton/acrylic yarns of 36 tex x 2 fineness. The samples will be produced on a STOLL flat knitting two-needlebed machine of E5, E7 and E10 gauges. M1Plus software will be used for the design of the samples. The mentioned software is used to transfer the designed knit structure and garment shape into a file ready for machine use.

1. Introduction

Interest in knitting technology stems from its wide range of applications. Numerical control knitting on flat knitting machines is one of the technologies for producing weft knitwear. The diversity of knitted products justifies their use in fashion, medical and technical fields. The use of flat knitting machines with M1Plus software includes various possibilities such as the designing and producing of urban women's knitted collections with optical illusion patterns [1], producing seamless five-finger gloves with a predicted unit compression value and appropriate longitudinal stiffness depending on the anatomy of the hand [2], creating traditional wedding dresses with Chinese motifs knitted using the plating technique [3], producing knitted smart shoe insoles integrated with piezoelectric nanogenerators for simultaneous energy harvesting from human movement and tracking of human gait signals [4], and manufacturing 3D knitwear such as knitted pockets, heart valves, medical socks, and knitted shoe uppers [5].

2. Experimental

M1plus is a professional CAD/CAM software for designing, programming and preparing patterns for production on STOLL flat knitting machines. It allows designers and technologists to create garment shapes, color samples and complete garments for different machine gauges. The software offers loop-by-loop editing, a wide selection of knitting elements (pointelle, cable, aran), plating options and visual preview of knits to check feasibility before production. Visual preview includes symbol view and technical view, which help in the process of knitting complex knits. Software comes with the ability to check the written software file, which helps in identifying problems such as syntax errors, restrictions on the transfer of loops from one needlebed to another or collision of yarn carriers, reducing error on the machine and therefore on the knit [6].

3. Results and discussion

Using the specified machinery and appropriate software, samples of weft knitted single jersey pullovers were produced, differing in knitting structure and composition. Four different knitting structures were created, as shown in Fig. 1. Fig. 1a shows the display of a symbol view, and Fig. 1e shows the technical view of a structure consisting only of right loops. Fig. 1b shows the symbol view, and Fig. 1f shows the technical view of a rib knit structure with 4 right and 4 left loops. Fig. 1c shows the symbol view, and Fig. 1g shows the technical view of a square structure consisting of a 5x5 square of right and a 5x5 square of left loops. Fig. 1d shows the symbol view, and Fig. 1h shows the technical view of a structure with a horizontal wave pattern.



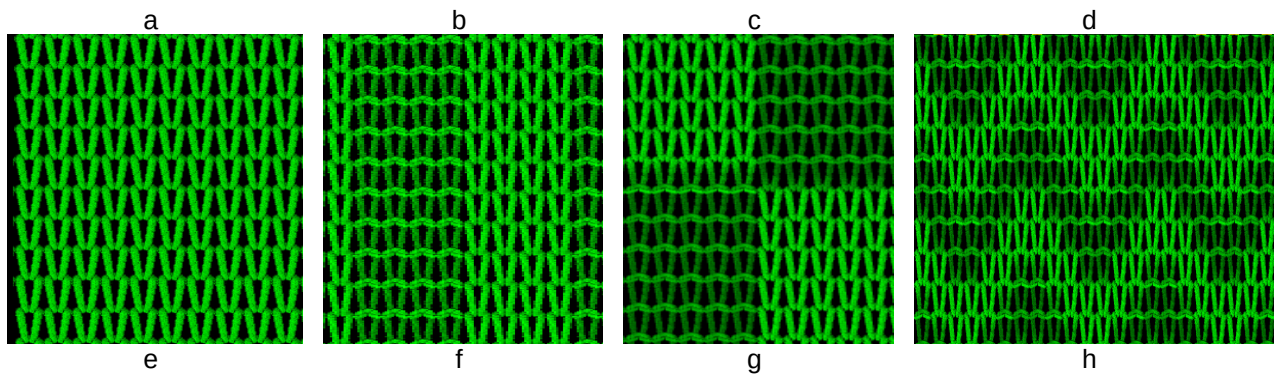


Figure 1: Software view of knitted samples: a, b, c and d represent the symbol view; e, f, g and h represent the technical view of the knitting structure

4. Conclusion

For the purposes of the Ph. D. thesis, 48 single jersey weft knitted pullovers of the same clothing size with different knitting structures and compositions were produced. M1Plus software was used for their planning and design. The thermal properties of the clothing will be tested on the produced samples.

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**Petra Mihovilović****Biography**

Petra Mihovilović graduated from the Department of Chemistry, University of Zagreb Faculty of Science, where she received the Department of Chemistry Medal for Outstanding Achievement. Since 2022, she has been employed as an Assistant at the Department of Applied Chemistry, University of Zagreb Faculty of Textile Technology, where she is also enrolled in the doctoral program in Textile Science and Technology. Her scientific interests focus on the development of methodologies for the sampling and separation of microplastic particles from wastewater, as well as their physicochemical characterization using spectroscopic and chromatographic techniques. She is the recipient of the Award for the Most Successful Scientific Research Work in the Field of Textiles (2023). She has participated as a collaborator in the scientific research project HrZZ-IP-2020-02-7575. To date, she has published 20 works, including scientific articles and conference contributions in the form of poster and oral presentations.

Title of Ph. D. thesis

Microplastic Particles as Vectors for Dye Transport:
Binding and Transport Mechanisms in Aquatic
Systems

Study advisor

Prof. Branka Vojnović, Ph. D.

Date of dissertation
defense

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MICROPLASTIC PARTICLES AS VECTORS FOR DYE TRANSPORT: BINDING AND TRANSPORT MECHANISMS IN AQUATIC SYSTEMS

Petra MIHOVILOVIĆ

University of Zagreb Faculty of Textile Technology, Prilaz baruna Filipovića
28a, Zagreb, petra.mihovilovic@tff.unizg.hr

Abstract: The textile sector is a one of the major contributors to global microplastic pollution, responsible for over one third of total particle emissions. Fibrous microplastic particles (MPFs) are predominantly released during the washing of textile materials, subsequently entering the environment through wastewater. These particles are characterized by their small size, large specific surface area, porosity, amorphous structure, pronounced hydrophobicity, and diverse functional groups. Such properties make them an efficient medium for the adsorption of other pollutants, including dyes commonly present in textile wastewater. Within the framework of this doctoral research, the effects of key controlling factors (contact time, initial dye and MPFs concentrations, pH, and solution ionic strength) on the adsorption of a selected dye onto MPF particles will be investigated. In addition, particle characterization before and after adsorption will be performed to elucidate the underlying binding mechanisms and the potential transport of pollutants within aquatic ecosystems.

1. Introduction

Textile wastewater has a complex chemical composition, as it contains not only dissolved organic substances (such as surfactants, chelating agents, salts, acids, alkalis, and enzymes), but also a high proportion of particulate matter. These wastewaters often exhibit elevated values of parameters such as temperature, turbidity, pH, conductivity, suspended solids content, as well as chemical oxygen demand (COD) and biochemical oxygen demand (BOD) [1]. Owing to their fibrous structure, MPFs exhibit a larger specific surface area than microplastic particles of other morphologies, which leads to more efficient adsorption of pollutants present in textile wastewater. Moreover, textile fibres often contain additional toxic components, including finishing agents, which further increase their overall toxicity. Because of their distinctive morphology and low density, fibrous microplastics exhibit prolonged persistence in air and aquatic environments, thereby increasing their potential for environmental accumulation and transfer via water, air, and food chains [2].

2. Experimental

The textile industry significantly contributes to water pollution through the use of organic and inorganic dyes. During dyeing and printing processes, substantial amounts of unused dyes (up to 20%) remain, and are subsequently discharged into wastewater streams. Even at very low concentrations ($< 1 \text{ mg dm}^{-3}$), these dyes are highly toxic, representing a serious environmental concern [3,4]. Studies have shown that MPFs can effectively adsorb dyes present in wastewater. Particles with altered chemical composition may exhibit enhanced toxicity and act as sources of secondary pollution when environmental changes trigger the release of previously adsorbed dyes. Therefore, a comprehensive understanding of the dyes adsorption and desorption mechanisms onto MPFs in aquatic systems is essential for the assessment of potential environmental risks. [5].

The research plan consists of three phases:

- (1) Preparation of an internal standard by cryogenic milling of standard materials (Figure 1a and b). The particles will be physicochemically characterized using various analytical techniques (SEM, FTIR, BET, zeta potential, etc.).
- (2) Performing and optimization of adsorption experiments under different controlled conditions, including contact time, initial dye and MPF concentrations, pH, and solution ionic strength.
- (3) Physicochemical characterization of particles after the adsorption/desorption processes.



Figure 3: a) Cryogenic mill used for the preparation of the PET internal standard and b) prepared standard particles

3. Results and Discussion

Due to their pronounced electrostatic charge and tendency to aggregate, the prepared particles must be dispersed as suspensions. Previous studies have identified ethanol as the optimal dispersing medium, as it reduces self-aggregation and ensures uniform dispersion of hydrophobic particles. After the adsorption experiments, the particles must be isolated from model textile wastewater samples to allow subsequent analyses. To this end, a methodology for the separation of MPFs from textile wastewater was developed. The chosen density gradient separation method demonstrated satisfactory performance, achieving an efficiency exceeding 90%. A saturated NaBr solution is used as the separation reagent because it is compatible with the matrix composition and does not cause physicochemical alterations to the MPFs.

4. Conclusion

Environmental pollution by MPFs represents one of the major ecological challenges of our time. The scientific contributions of this doctoral dissertation are manifested through several key aspects. The developed methodology for the isolation and characterization of MPFs from complex wastewater samples provides a solid foundation for further research in this field. This dissertation is expected to significantly advance the understanding of the role of MPFs as vectors for dye transport in aquatic systems, including the identification of key factors controlling adsorption and desorption processes. The results obtained will allow a more comprehensive interpretation of the migration of these pollutants through the environment, their impact on living organisms, and the development of strategies for their future mitigation and prevention.

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Eanamul Haque Nizam

Biography

Eanamul Haque Nizam is an Assistant Professor in the Department of Textile Engineering at Southeast University, where he has been serving since August 2022. He is currently pursuing his Ph. D. at the University of Zagreb, Croatia. He obtained his second M. Sc. in Fashion Design and Engineering from Wuhan Textile University, China, and his first M. Sc. and B. Sc. in Textile Engineering from Mawlana Bhashani Science and Technology University, Bangladesh. He has received professional training in apparel merchandising, industrial engineering and lean manufacturing, time study, and quality control in garment manufacturing from reputed national institutions. Previously, he served as a Teaching Assistant at Wuhan Textile University and as a lecturer at BUFT, City University, and Fareast International University. He is an honorary peer reviewer for the Global Journal of Researches in Engineering and an editorial assistant of the Journal of Textile Engineering (IEB). His research interests include anthropometry, Asian size chart development, body morphology, pattern adaptation, and apparel product development. He has over 14 years of teaching experience, one year of industrial experience, and has published more than 62 research articles and two books.

Title of Ph. D. thesis

Study on the anthropometric proportions and recommended clothing sizes of the male population aged between twenty and twenty-five years in Bangladesh

Study advisors

Prof. Emer. Darko Ujević, Ph. D. Prof. Ayub Nabi Khan, Ph. D.

Date or dissertation
defense

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ANTHROPOMETRY-BASED ERGONOMICS ASSESSMENT OF UNIFORM FIT AND COMFORT AMONG YOUNG MEN IN BANGLADESH

Eanamul Haque NIZAM

University of Zagreb, Faculty of Textile Technology, Croatia,
eanamul.nizam@seu.edu.bd

Abstract: The research investigated the uniform of schools and workplaces in terms of ergonomic comfort with respect to anthropometric measures for Bangladeshi young males (20-25 years). Anthropometric measurement and wearer comfort assessments indicated significant variability in body dimensions that existing uniform sizing systems do not accommodate. Shoulder fit issues were most prevalent at 42%, followed by sleeve length at 47%, and waist fit at 38%. Mean comfort ratings indicated a generally moderate overall comfort, though the lowest score related to ease of movement was 2.9 on a five-point scale. These findings suggest functional constraints in everyday activities. These results demonstrate a distinct mismatch between standardized uniform sizes and anthropometric measures among the target population. This paper identifies the necessity for population-specific sizing systems along with ergonomically supported design adjustments, including enhanced proportion-based grading and ease allowances.

1. Introduction

Ergonomically comfortable garments are an important factor in physical well-being, ensuring work efficiency, and maintaining overall satisfaction among users in environments with long spans of uniform wear. Uniforms used in educational institutions and workplaces should provide conditions for free movement, correct posture, and thermal and mechanical comfort. However, whenever the dimensions of garments do not correspond to the dimensions of the wearer's body, it can bring about discomfort, restriction of movement, and long-term musculoskeletal problems. Anthropometry, as the scientific measurement of the human body, has an important role in designing clothes and uniforms. Correct representation of anthropometric proportions in garment sizing systems secures better fitting, comfort, and functional performance. From previous research, one knows that when standardized or imported sizing systems were applied to the local population without proper adaptation, mismatches between body dimensions and garment sizes were frequent. A lack of consideration of real anthropometric measures is especially marked in developing countries, where uniforms are produced according to general size charts instead of anthropometric data representative of the population. In Bangladesh, school and work uniforms are common among the young adult male population, notably those between the ages of 20 and 25, who comprise the highly active category of the population. Though Bangladesh has one of the largest garment industries in the world, little research works have been conducted to find out how effectively the currently used sizes in school and work uniforms match the anthropometric characteristics of the young adult male population in Bangladesh. Most existing research works describe the determination of the basic sizes for school and work uniforms, but the assessment of the ergonomical comfort while wearing these garments has received little attention. Ergonomical comfort has various shades, including the comfort of physical fit, movement, pressure distribution, and the comfort perceived by the wearer. If the school and work uniforms do not match the proportions of the shoulder width, chest girth, waist circumference, and sleeve length, the ergonomical comfort level decreases, resulting in difficulties for the young adult population, who spend a significant portion of the day in school and work. This research focuses on the ergonomical comfort while wearing school and work uniforms and the anthropometric proportions of the young adult male population in Bangladesh. By using objective anthropometric data in combination with subjective comfort judgments, the research aims at identifying areas of perceived size mismatch and discomfort with the objective of developing recommendations for the design and sizing of improved uniforms for the Bangladeshi people.

2. Experimental

Study Design: A cross-sectional descriptive study design has been adopted to measure the ergonomic comfort of the school/work uniform in relation to the anthropometric proportions of male youths in Bangladesh. Quantitative anthropometric measures and ego measurements were conducted in the present study.

Sample Selection: Young male participants from Bangladeshi origin, aged between 20 and 25 years, comprised the sample. Participants were drawn from universities, technical institutes, and workplaces where



people wore their uniforms for the first time. In total, 120 participants were selected through purposive sampling from the population of uniform users. The participants were healthy individuals who provided informed consent before the study.

Anthropometric Measurements: Standard anthropometric data, which is pertinent to upper and lower body garment design, was collected based on internationally accepted measurement guidelines. The relevant measurement variables were:

- Stature
- Chest
- Waist circumference
- Hip circumference
- Shoulder breadth
- Sleeve length
- Inseam Length

The data was taken using an anthropometric tape, a sliding caliper, and a stadiometer. The participants stood in a relaxed position.

Uniform Characteristics: The study examined and used widely applied school and work uniforms, generally a shirt and trousers made of woven cotton or cotton-blend fabric. The uniforms were made using ready-to-wear sizes S, M, L, and XL as widely applied in local fashion, without any custom-fitting adjustments.

Ergonomic Comfort Assessment: The rating of ergonomic comfort was made by means of a structured questionnaire on a five-point Likert scale representing 1 = very uncomfortable and 5 = very comfortable. The participants rated comfort in relation to:

- Shoulder fit
- Chest fit
- Waist fit
- Sleeve length
- Motion easiness
- Overall comfort during long wear

Data Analysis: Data analyses were performed using descriptive statistics, such as the mean, standard deviation, and percentage distribution. Comparisons were made to relate anthropometric dimensions and reported discomfort. The data were analyzed with the use of standard data analysis software.

3. Results and Discussion

3.1. Anthropometric Profile of Participants

Table 1: Descriptive Statistics of Key Anthropometric Measurements (n = 120)

Measurement	Mean (cm)	Standard Deviation
Height	168.4	5.9
Chest Circumference	92.6	6.4
Waist Circumference	80.8	7.1
Shoulder Breadth	44.2	2.8
Sleeve Length	59.5	3.2

The results indicate moderate variability in body dimensions, highlighting the limitation of using fixed-size categories for uniform production.

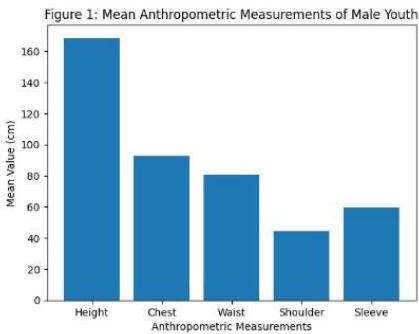


Figure 1: Mean anthropometric measurements of male youth

3.2. Reported Areas of Discomfort

Table 2: Percentage of Participants Reporting Discomfort by Garment Area

Garment Area	Percentage Reporting Discomfort (%)
Shoulder	42
Chest	35
Waist	38
Sleeve Length	47
Trouser Length	31

Sleeve length and shoulder fit emerged as the most problematic areas, suggesting a mismatch between arm length and shoulder breadth proportions and the existing uniform sizes.

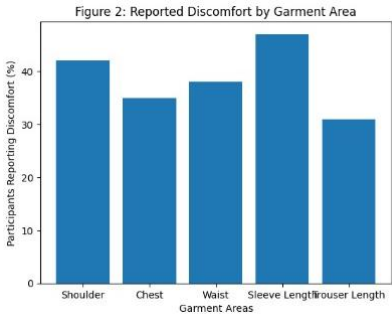


Figure 2: Reported discomfort by garment area

3.3. Ergonomic Comfort Ratings

Table 3: Mean Comfort Ratings (5-point Likert Scale)

Comfort Parameter	Mean Score
Shoulder Comfort	3.1
Chest Comfort	3.4
Waist Comfort	3.2
Ease of Movement	2.9
Overall Comfort	3.0

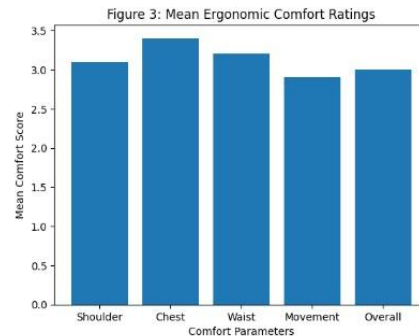


Figure 3: Mean ergonomic comfort ratings

Lower scores for ease of movement indicate that uniforms may restrict functional activities such as bending, reaching, and walking, which is consistent with findings in previous ergonomic clothing studies.

Overall, it may be seen that there is a strong association between anthropometric variation and ergonomic discomfort. The data also indicate that it is not possible for uniforms designed using standard or generic sizing systems to take into consideration the proportional variations in shoulder breadth, sleeve length, and waist dimensions that may be present in Bangladeshi male youths. Similar trends have already been observed in other anthropometric studies conducted in different South Asian populations.

4. Conclusion

The findings of this study have shown how existing uniforms being followed by male youth in Bangladeshi schools and working institutions, among the population group aged 20 to 25 years, have failed to meet anthropometric requirements and caused discomfort to the wearers. The most troublesome areas were identified as shoulder width, sleeve length, and movement comfort, indicating a requirement for developing anthropometry-based sizing systems and ergonomic design guidelines for uniforms.

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Ante Osmak

Biography

Ante Osmak, born on January 26st, 1999. in Zagreb finished his high school education in EEB4, Brussels. He enrolled in the University of Zagreb, Faculty of Textile Technology in 2019 and acquired his bachelor's degree in 2022. He enrolled in Textile engineering graduate course at the same university. He defended his master's thesis on the subject of synthesis and characterisation of new disperse azo dyes and their dyeing properties under the mentorship of prof. dr. sc. Livio Racané. He was also rewarded the rectors award in 2024 for a research paper under the mentorship of Anja Beč, Ph. D. After acquiring his master's degree, he starts his employment at the University of Zagreb, Faculty of Textile Technology as a junior associate. He enrolled in the post graduate doctoral program at the same university in 2025.

Title of Ph. D. thesis

Synthesis, structural characterisation and dyeing properties of new 6-azobenzothiazole dyes

Study advisor

Prof. Livio Racané, Ph. D.

Date of dissertation defense

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SYNTHESIS, STRUCTURAL CHARACTERISATION AND DYEING PROPERTIES OF NEW 6-AZOBENZOTHIAZOLE DYES

Ante OSMAK

University of Zagreb, Faculty of Textile Technology, Prilaz baruna Filipovića
28a, aosmak@ttf.hr

Abstract: Using green synthetic methods in the making of benzothiazole dyes will allow the acquirement of new synthetic dyes in a sustainable way. Therefore, the goal is to make new 6-azobenzothiazole derivatives and their complexes with zinc by using sustainable synthetic methods, using green solvents and choosing non-toxic precursors. The dyeing properties of all the dyes will be determined, and the process of dyeing will be optimized using ultrasound which adheres to the principles of sustainable development.

1. Introduction

Azo dyes represent the most important and most significant group of synthetic dyes with a key role in textile, pharmaceutical and chemical industries [1-3]. Aromatic diazo compounds are increasingly more often replaced with heterocyclic diazo components because the prepared heterocyclic azo dyes show better dyeing properties like colour tone and lightness as well as a better lightfastness compared to analogue carbocyclic azo dyes [4-6]. On the other hand, benzothiazole derivatives are a subject of constant interest due to a wide spectrum of biological activity, anticancer and antibacterial properties being the most notable [7-8]. Furthermore, they are used as components in traditional textile dyes and optical brighteners. Thanks to their conjugated electron structure azobenzothiazole derivatives effectively form stable, coloured complexes with metal ions making them a viable choice for application in chemical sensors, analytical devices and systems for metal detection [9-11]. Azo dyes containing a benzothiazole core are also known for creating vibrant, colourfast colours ranging from yellow to blue depending on the nature and position of substituents in the compound. Aside from the aforementioned spectroscopic characteristics, these types of compounds also exhibit great dyeing properties.

2. Hypothesis and goals

By synthesising azo dyes containing benzothiazole as a heterocyclic core, new dyes with vibrant and diverse colours can be acquired. These dyes would have superior dyeing properties such as colour tone, lightness and colourfastness compared to their carbocyclic analogues. Using green synthetic methods in the making of benzothiazole dyes will allow the acquirement of new synthetic dyes in a sustainable way. Therefore, the goal is to make new 6-azobenzothiazole derivatives and their complexes with zinc by using sustainable synthetic methods, using green solvents and choosing non-toxic precursors. The dyeing properties of all the dyes will be determined, and the process of dyeing will be optimized using ultrasound which adheres to the principles of sustainable development. This research will be carried out within the institutional project: Sustainable synthesis and testing of dyeing properties of new 6-azobenzothiazole derivatives and their complexes with zinc (SIMBA-6) and the experimental research will contribute to the doctoral thesis.

3. Research plan

Synthesis

The basic strategy for the synthesis of the desired dyes is the preparation of a 6-azobenzothiazole derivative based on the diazotization reaction of 6-aminobenzothiazole and copulation with a desired aniline. The 6-azobenzothiazole derivative would be used to prepare a key disulfide precursor which can be reacted to various salicylaldehydes with the purpose of introducing a variety of phenyl groups into the structure of the 6-azobenzothiazole derivative which will further be used as a ligand for complexation reactions with zinc. Alternatively, the disulfide precursor could be condensed with 2,5-substituted furfurals which represent an ecologically favourable substrate for further extension of the chromophore system. Previously, a method for the synthesis of 6-azobenzothiazole derivatives was developed at the organic chemistry laboratory at the Faculty of Textile Technology [12-14]. Following the procedure, the first step is the diazotization of 6-

aminobenzothiazole and copulation with selected commercially available substituted anilines to acquire new 6-azosubstituted benzothiazoles with a general structure (I) shown in Figure 1.

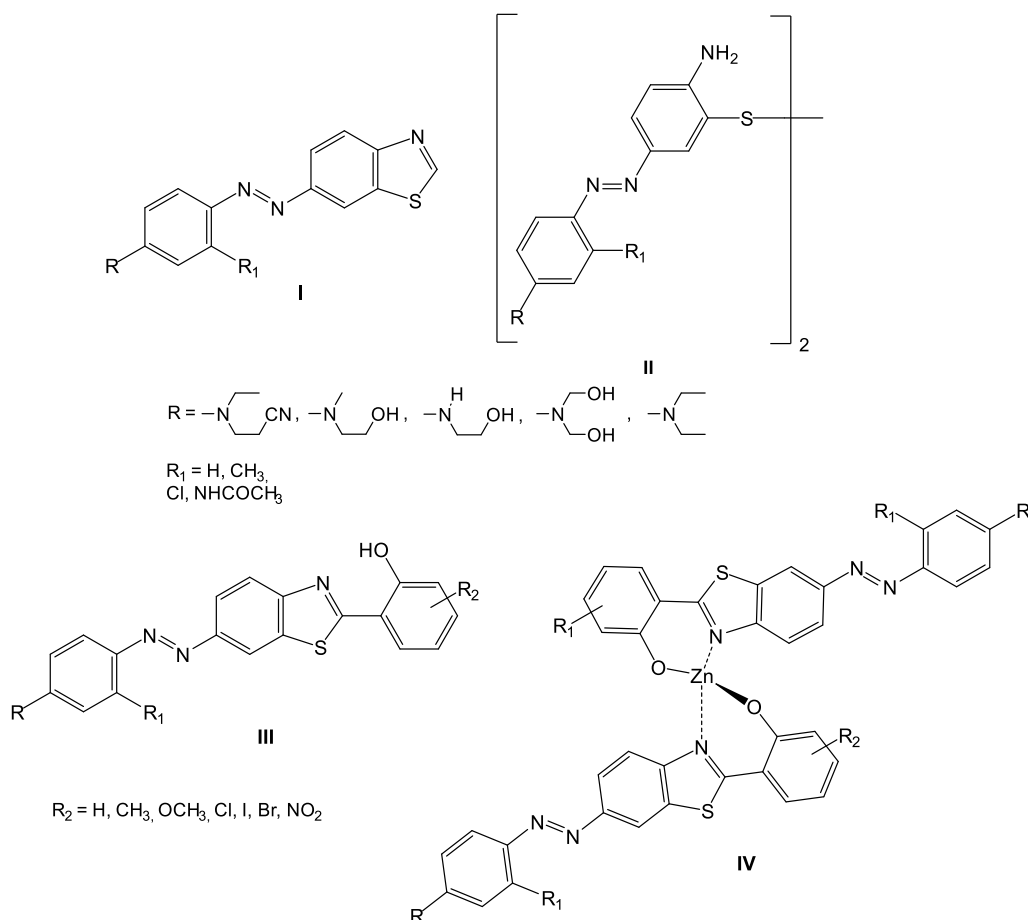


Figure 1: General structural formula of desired dyes and their precursors

Next, follows the opening of the benzothiazole ring with 1,3-propanediamine in glycerol in order to produce the corresponding bis(2-amino-5-azophenyl)-disulfide intermediaries with a general structure (II) which will be used for condensation reactions in glycerol with various salicylaldehydes to produce a small library of new dyes. The acquired new 6-azo-2-(2-hydroxyphenyl)benzothiazole derivatives with the general structure (III) will be used as ligands for complexation reactions with zinc using synthetic methods described in literature for other 2-(2-hydroxyphenyl)benzothiazole derivatives. This reaction will be further optimized with the goal of finding a greener synthesis method for zinc complexes of 6-azo-2-(2-hydroxyphenyl)benzothiazoles with a general structure (IV).

Given the current requirements for sustainable development there is a rising interest for the synthesis of new compounds with chemicals from natural sources which would decrease the usage of chemicals derived from crude oil. Dyes derived from furans meet these conditions [15], as they can be acquired from agricultural waste. Developing dyes derived from furans introduces the concept of semisynthetic dyes which, by nature, would lie somewhere between natural and synthetic dyes. Considering previous experience in the synthesis of furan derivatives as well as the type of compounds worked on, a furan ring would be introduced into the chromophore system therefore achieving new semisynthetic dyes which would utilize chemicals from agricultural waste. Therefore, the disulfide precursors (II) would be used for condensation reactions with 2,5-substituted furfurals achieving a small library of new 6-azo-2-furylbenzothiazole derivatives. Aside from the commercially available 2,5-substituted furfurals, new 5-(4-substitutedphenyl)-2-furancarbaldehydes would be prepared via Meerwein's arylation reaction with various p-substituted anilines. These would serve as key intermediaries for further extension of the chromophore system that would include a furan ring with a general structure shown in Figure 2.

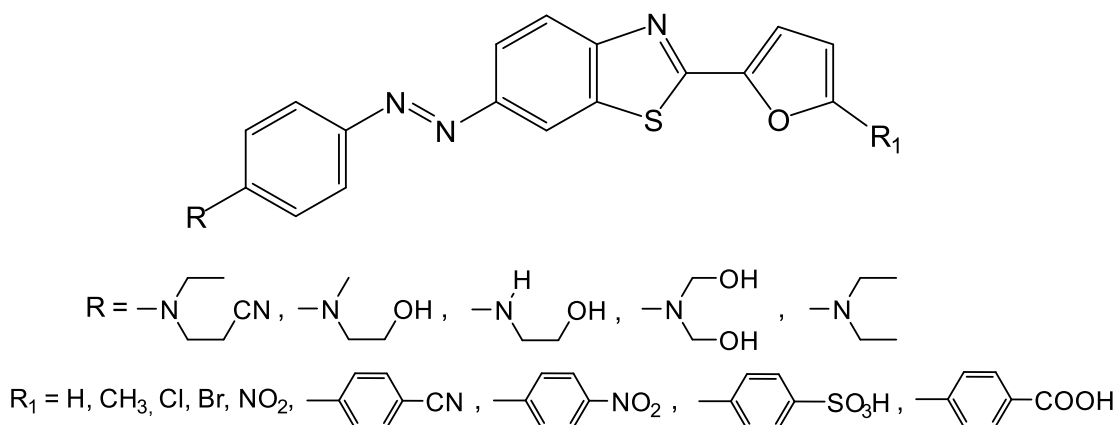


Figure 2: general structural formula of 6-azobenzothiazole derivatives with a furyl ring

Structural characterisation

The structural characterisation of the synthesized compounds will be carried out using several complementary spectroscopy methods: NMR, UV/Vis and IR spectroscopy as well as mass spectrometry. The thermal characteristics of zinc compounds as well as the content of metals in the complex will be determined with thermal analytical methods TGA and DSC. Elemental analysis will be carried out on all compounds. Crystallization techniques will be used in an attempt to acquire the azo-compounds in a crystal form suitable for determining its structure using X-ray crystallography.

Determination of dyeing properties

Dyeing properties, as well as colour fastness to washing, of all the compounds will be determined. The dyeing properties of water-soluble dyes will be tested on wool and acrylic fibres while those insoluble in water will be tested as disperse dyes for dyeing polyester and polyamide fibres.

Dyes that show no affinity for the fibre (pigments) will be applied to the textile mechanically and set using binding agents. Additionally, the process of dyeing will be optimized using ultrasound which adheres to the principles of sustainable development with the goal of increasing the effectiveness of the process, sustainability and the quality of dyeing [16].

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**Ana Palčić****Biography**

Ana Palčić was born in Zagreb in 1993. She graduated in 2019 from the University of Zagreb, Faculty of Textile Technology (TTF), where she has been employed as a research assistant since 2022, the same year she enrolled in the doctoral study programme in Textile Science and Technology. She gained professional experience as a process technologist in chemical dry-cleaning and laundry services at Lemia d.o.o. eco-friendly dry-cleaning facilities. She was a member of the Croatian Science Foundation installation research project HRZZ-UIP-05-2017-8780 "Hospital Protective Textiles". She is currently a member of the institutional research projects ZORA (TTF) and DOBRA (University of Dubrovnik), as well as a collaborative project with the Second School of Economics Zagreb entitled "The Needle Stitches Its Own Story". Her scientific interests focus on textile finishing aimed at achieving multifunctional protective treatments, with an emphasis on the use of environmentally friendly agents, as well as the thermal and physico-chemical characterisation of textile materials.

Title of Ph. D. thesis

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Study advisor

Prof. Sandra Flinčec Grgac, Ph. D.

Date of dissertation
defense

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MODIFICATION OF COTTON/POLYESTER FABRICS WITH A β -CYCLODEXTRIN–ESSENTIAL OIL INCLUSION COMPLEX

Ana PALČIĆ

University of Zagreb, Faculty of Textile Technology Prilaz baruna Filipovića
28a, 10000 Zagreb, Croatia, ana.palcic@tff.unizg.hr

Abstract: Due to their ability to form inclusion complexes with various molecules, as well as their non-toxicity and biodegradability, β -cyclodextrins can significantly enhance the functionality of textile materials. They are frequently used in textiles for the controlled release of active substances and fragrances, while also enabling antimicrobial or UV-protective properties, thereby allowing targeted applications of such functionalised fabrics.

1. Introduction

The rapid advancement of technology has led to the development of new textile materials that can be applied in various fields, significantly improving quality of life. To meet consumer and market demands, the concept of applying active substances to textiles has emerged, with the main challenge being the efficient and controlled release of these substances while maintaining satisfactory wash durability. Cyclodextrins are cyclic oligosaccharides capable of forming inclusion complexes with various molecules, which significantly enhance the functional properties of textile materials. Due to their non-toxicity and biodegradability, they are widely used in the textile industry for controlled and selective management of functional properties. They are characterised by the ability to form inclusion complexes with various active substances, such as essential oils, which provide beneficial effects on human health [1–2]. In this study, special emphasis was placed on the application of tea tree essential oil, which exhibits pronounced antimicrobial and antiseptic properties. Complexation of tea tree essential oil within the cavity of β -cyclodextrin enables its stabilisation, while binding the inclusion complex to CO/PES fabric aims to ensure its functional application for the repeated use of such treated textile materials.

2. Experimental

In this study, modification of CO/PES fabric in satin weave was carried out by inclusion complexation using a high-energy vibrational micromill (RETSCH® MM 400) at a frequency of 25.0 Hz for 20 minutes. β -cyclodextrin (Tokyo Chemical Industry Co., Ltd.) and 30% tea tree essential oil (Aromara, Australia), based on the mass of β -cyclodextrin, were used for this purpose. The prepared complex (CD_TEA TREE) was dried in an autoclave in a drying oven at 80 °C for 6 hours. The samples were pre-treated with 8% NaOH and Subitol (CHT Bezema, Switzerland) under tension, followed by treatment in a bath (Apl) containing 35 g/L maleic acid (Sigma–Aldrich, Germany), 32.5 g/L sodium hypophosphite hydrate (SHP) as a crosslinking agent (Sigma–Aldrich, Germany), 1 g/L Felosan RG-N as a wetting agent (CHT Bezema, Switzerland), and 30% of the prepared complex based on the mass of the material. Sample impregnation was carried out on a padding (Benz, Switzerland) with a wet pick-up of 100%. The samples, together with the bath, were subjected to microwave irradiation (SHARP, YC-GG252A, Japan) for 5 minutes at 80% power, followed by aging for 24 hours. After aging, the samples were padded and dried in a pad-dryer (Benz, Switzerland) for 5 minutes at 80 °C. Condensation of the treated samples was performed in a UV chamber (Solarscreen Test Chamber STC 01) with UV-A and UV-B lamps (11 W power, 37 V voltage, 0.33 A current) for 30 minutes. After treatment, the samples were washed (1W) in a Wascator FOM71 CLS device (Electrolux, Sweden) according to EN ISO 15797:2017, at a reduced washing temperature of 50 °C, using a standard detergent with optical brighteners and without phosphates (WFK 88060) and an environmentally friendly bleaching agent ϵ -(phthalimido) peroxyhexanoic acid (PAP). The samples were dried in an Electrolux T5130-LAB dryer according to the NORMAL LAB programme for 30 minutes.

3. Results and Discussion

The efficiency of CO/PES fabric functionalisation using the CD_TEA TREE complex was examined by Fourier-transform infrared spectroscopy in attenuated total reflection technique (FTIR-ATR Golden Gate), and the

physicochemical changes occurring during thermal degradation before and after the washing process were analysed.

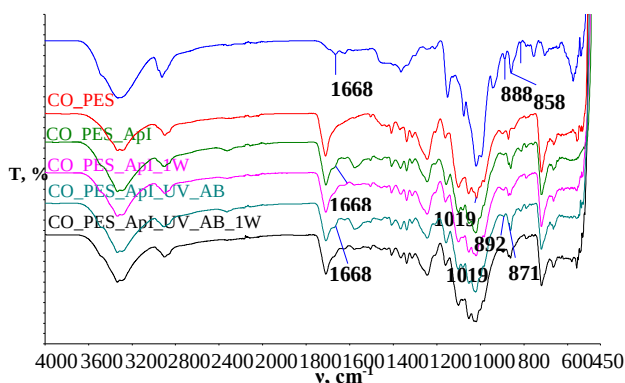


Figure 1: Spectral curves of the inclusion complex, untreated and treated CO/PES fabrics before and after the washing cycle, recorded at 25 °C.

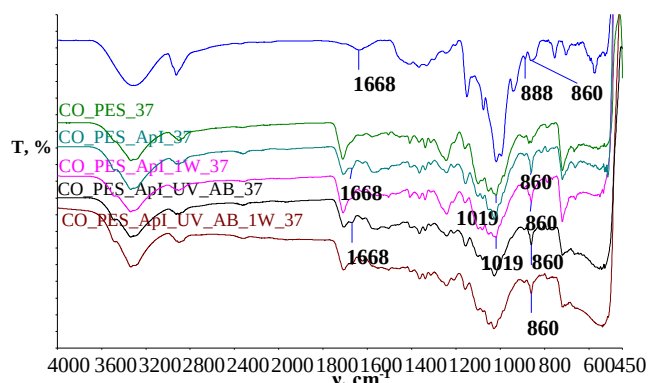


Figure 2: Spectral curves of the inclusion complex, untreated and treated CO/PES fabrics before and after the washing cycle, recorded at 37 °C.

The treated samples show characteristic peaks of the CD_TEa TREE complex, with a pronounced peak at 1019 cm^{-1} (C–O–C stretching). Peaks at 892 and 871 cm^{-1} indicate complexation between cyclodextrin and the essential oil. After washing, the peak intensities decrease slightly, reflecting the removal of surface-deposited complexes. Comparison of the spectra recorded at 25 °C and 37 °C shows slight shifts and reductions in peak intensities for certain functional groups, suggesting possible release of volatile components of the essential oil. This indicates that inclusion of the essential oil within the β -cyclodextrin cavity provides increased stability at mildly elevated temperatures. The peak at 1668 cm^{-1} (C=O stretching) is more pronounced in samples exposed to UV_AB irradiation due to oxidation of certain components, and it remains after washing, which may indicate a beneficial effect of UV-AB condensation and more durable retention of the complex on the fabrics [3–4].

4. Conclusion

The results clearly confirm the successful formation of the inclusion complex and its stable binding to the textile material. This approach to functionalisation and monitoring of active substance release remains in the research phase but indicates potential for application in the development and evaluation of environmentally friendly functionalised textiles.

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Željka Pavlović

Biography

Željka Pavlović was born on February 4th, 1987, in Zabok. After completing primary school in Samobor, she enrolled in the School of Economics, Trade, and Hospitality, graduating in 2005. From 2005 to 2012, she studied at the University of Zagreb Faculty of Textile Technology, where she graduated with a thesis on "Performance Properties of Short Socks," supervised by Prof. Dr. Zlatko Vrljićak. She worked at the Jadran Hosiery Factory for 3.5 years as a technologist. In 2015, she became an assistant at the University of Zagreb Faculty of Textile Technology, at the Department of Textile Design and Management. In 2016, she enrolled in the postgraduate university study program "Textile Science and Technology" at the Faculty of Textile Technology. Her areas of special interest include sock design and production, as well as the analysis of the operation of knitting machines.

Title of Ph. D. thesis

Thermophysiological properties of knitted fabrics as a function of the knitting process and structure

Study advisor

Prof. Vesna Marija Potočić Matković Ph. D.

Date or dissertation defense

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THERMOPHYSIOLOGICAL PROPERTIES OF KNITTED FABRICS AS A FUNCTION OF THE KNITTING PROCESS AND STRUCTURE

Željka PAVLOVIĆ

University of Zagreb Faculty of Textile technology, Prilaz baruna Filipovića
28a, zeljka.pavlovic@tff.unizg.hr

Abstract: Air permeability is one of the key properties of knitted fabrics that directly affects wearing comfort and the thermoregulation of clothing. This paper analyzes the influence of fiber composition, structural parameters, and finishing processes on the air permeability of different types of knitted fabrics. Tests were conducted on raw and finished knitted fabric samples, and the results were analyzed using descriptive statistics, t-tests, and correlation analysis. The obtained results show that finishing processes, in most cases, significantly reduce air permeability, while structural parameters such as density, thickness, and areal mass have a dominant influence on the breathability of knitted fabrics.

1. Introduction

Air permeability of textile materials is an important thermophysiological property that affects the transfer of heat and moisture between the body and the environment, and thus the wearing comfort of clothing [1]. It is largely determined by the structure of the material, specifically by the size, number, and distribution of loops within the knitted structure [2]. Due to their structure, knitted fabrics generally exhibit higher air permeability than woven fabrics of the same areal mass. The breathability of knitted fabrics is influenced by the fiber composition, yarn spinning method, structural parameters, and finishing processes, which can significantly alter the porosity and compactness of the structure [3]. The aim of this study is to analyze the influence of the mentioned factors on the air permeability of knitted fabrics.

2. Experimental

Air permeability testing was conducted on different types of knitted fabrics made from various raw materials and yarn spinning technologies, in both raw and finished states. Air permeability was measured as the airflow per unit area of the material at a constant pressure differential, and the results were expressed in $\text{cm}^3/\text{cm}^2/\text{s}$. The obtained data were analyzed using descriptive statistical methods, a t-test to compare raw and finished samples, and Pearson's correlation analysis to examine the relationship between air permeability and the basic structural parameters of knitted fabrics.

3. Results and Discussion

The test results indicate pronounced differences in air permeability among individual knitted fabric samples. For the raw samples, air permeability ranged from $34.54 \text{ cm}^3/\text{cm}^2/\text{s}$ (full plated sample) to $420.29 \text{ cm}^3/\text{cm}^2/\text{s}$ (Tencel). The highest values were recorded for knitted fabrics produced using the rotor spinning process (Tencel, viscose, micromodal), indicating a more open structure and higher porosity of these knitted fabrics in the raw state.

For the finished samples, air permeability was significantly lower, ranging from $17.56 \text{ cm}^3/\text{cm}^2/\text{s}$ (cotton, interlock structure) to $211.99 \text{ cm}^3/\text{cm}^2/\text{s}$ (modal, right-right structure). A comparison of raw and finished samples showed that finishing processes, in most cases, lead to a reduction in air permeability. The most pronounced decrease was recorded for samples knitted from viscose yarn produced by the rotor spinning process (from 416.52 to $158.37 \text{ cm}^3/\text{cm}^2/\text{s}$), Tencel yarn produced by the rotor spinning process (from 420.29 to $194.36 \text{ cm}^3/\text{cm}^2/\text{s}$), and the sample knitted from polyester yarn produced by the ring spinning process (from 317.29 to $138.42 \text{ cm}^3/\text{cm}^2/\text{s}$).

Certain samples (knitted from Tencel and modal yarns produced by the ring spinning process) exhibited an increase in air permeability after finishing, which can be associated with structural changes in the knitted fabric caused by finishing treatments.

Table 1: Results of the t-test comparing the air permeability of raw and finished knitted fabrics

	sirovo	dorađeno
Mean	221,39	137,16
Variance	17438,13	4129,63
Observations	18	18
Pearson Correlation	0,726	
Hypothesized Mean Difference	0	
df	17	
t Stat	3,717	

Table 2: Correlation between air permeability and basic structural parameters of raw and finished knitted fabrics

Air permeability	Horizontal density	Vertical density	Yarn consumption	Fabric thickness	Areal mass	Bulk density
Raw	-0,6947	-0,5425	0,2607	-0,5771	-0,7769	-0,3578
Finished	-0,7275	-0,6898	0,0905	-0,7957	-0,6651	0,7285

The results of the t-test (Table 1) confirm a statistically significant difference between raw and finished knitted fabrics ($p < 0.01$). The average air permeability decreased from 221.39 cm³/cm²/s for raw knitted fabrics to 137.16 cm³/cm²/s for finished knitted fabrics, clearly confirming the significant influence of the finishing process. A high Pearson correlation coefficient ($r = 0.726$) further indicates a consistent effect of finishing on the same samples.

Correlation analysis (Table 2) showed that, for raw knitted fabrics, air permeability is strongly negatively correlated with areal mass ($r = -0.7769$), horizontal density ($r = -0.6947$), and knitted fabric thickness ($r = -0.5771$). For finished knitted fabrics, the strongest negative influence on air permeability is exerted by fabric thickness ($r = -0.7957$) as well as horizontal and vertical density, while bulk density shows a positive correlation ($r = 0.7285$), indicating a more complex structural influence after finishing.

4. Conclusion

The results of this study confirm that the air permeability of knitted fabrics largely depends on structural parameters and the finishing process. In most cases, finishing significantly reduces the breathability of knitted fabrics due to structural compaction and reduced porosity. Areal mass, density, and fabric thickness were identified as key factors that negatively affect air permeability, with their influence being more pronounced in finished samples. The obtained results highlight the importance of selecting appropriate knitted fabric structures in order to achieve the desired level of comfort and functionality of textile products.

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Marijana Pavunc Samaržija

Biography

Marijana Pavunc Samaržija in 2012 completed graduate studies Textile Technology and Engineering (sections Textile Chemistry, Materials and Ecology) at the University of Zagreb Faculty of Textile Technology. Since 2013 till 2020 she was working at the University of Zagreb Faculty of Textile Technology (Department of Materials, Fibres and Textile Testing) as an assistant and from 2021 she was employed as a lecturer. From the beginning of her scientific work her research interests are directed to textile fibres, fibre reinforced composites, recycling of textile materials and conservation and restoration of textiles.

Title of Ph. D. thesis

Life cycle assessment of fibre reinforced composites – mechanical properties of recycled fibres

Study advisor

Prof. Edita Vujasinović, Ph. D.

Date or dissertation defense

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LIFE CYCLE ASSESSMENT OF FIBRE REINFORCED COMPOSITES – MECHANICAL PROPERTIES OF RECYCLED FIBERS

Marijana PAVUNC SAMARŽIJA

University of Zagreb Faculty of Textile Technology, Prilaz baruna Filipovića
28a, Zagreb, Croatia, marijana.pavunc@tff.unizg.hr

Abstract: Recycling and reuse of materials are gaining increasing importance due to the growing need for raw materials as well as the demand for sustainable management. Recycling fibre-reinforced composites is particularly challenging, often due to their complex structure and composition, and because the recovered fibres often do not retain their original quality. This paper investigates the potential of recovered fibres from biocomposites (natural fibre reinforced composites) after chemical recycling.

1. Introduction

Sustainable resource management and waste reduction represent key challenges of modern society, especially in the context of fibre reinforced composites that are increasingly being applied in numerous industrial sectors. Their growing use inevitably leads, or will lead, to an increase in the amount of waste, the disposal of which represents an environmental and technological challenge [1, 2]. In order to reduce the negative environmental impact of these materials, attention is being paid to the development and application of biocomposites, i.e., composites based on biodegradable polymer matrices reinforced with natural, also biodegradable, plant fibres [3]. Although biocomposites are often highlighted as a sustainable alternative to conventional composites due to their lower carbon footprint and the usage of renewable fibrous raw materials for their production, their disposal and recycling at the end of their life cycle still pose a challenge [3, 4]. The reason for this is their heterogeneous structure and the tendency of natural fibres to degrade during the recycling process, which limits their reuse in equivalent composite materials [5]. Composites can be recycled by mechanical, thermal and chemical processes [6], where mechanical recycling basically leads to fibre shortening and significant loss of their mechanical properties (primarily strength) [5], which are phenomena that also occur in thermal processes [3]. In contrast, chemical recycling is widely recognised as a method that allows separation of matrix and fibres while potentially preserving both the morphological and mechanical properties of the fibres, thereby increasing the possibility of their reuse in fiber-reinforced composite structures. It is therefore understandable that there is a need for more detailed research into the quality of recycled fibres from fibre reinforced composites (biocomposites) after chemical recycling processes [6].

2. Experimental

In chemical recycling, it is particularly important to determine to what extent the solvents used, and the processes selected enable the preservation of the original properties of the fibres. In this context, the aim of this study was to determine changes in breaking force and elongation of *Spartium junceum* L. fibres extracted after the chemical recycling process of biocomposites. The treated biocomposite was made of polylactic acid (PLA) as a matrix, reinforced with 20% by mass of *Spartium junceum* L. fibers, with the fibres oriented in one direction. The composite was made on a vacuum laboratory press LAB 100 C (Pinette PEI), at a pressure of 20 kN and a temperature of 190°C. Chemical recycling of these biocomposites was carried out using four different solvents: distilled water, 96% ethanol, a 50:50 mixture of 96% ethanol and distilled water, and dichloromethane. Processing conditions, such as temperature, time, and mechanical agitation of the biocomposite sample in the solvent, are being varied during the process. The breaking force and elongation of the recovered fibres were determined according to the HRN EN ISO 5079:2020 standard [7], using a Vibrodyn 400 dynamometer (Lenzing).

3. Results and Discussion

Figure 1 shows changes in breaking force and breaking elongation of recovered fibres obtained by different chemical recycling processes.

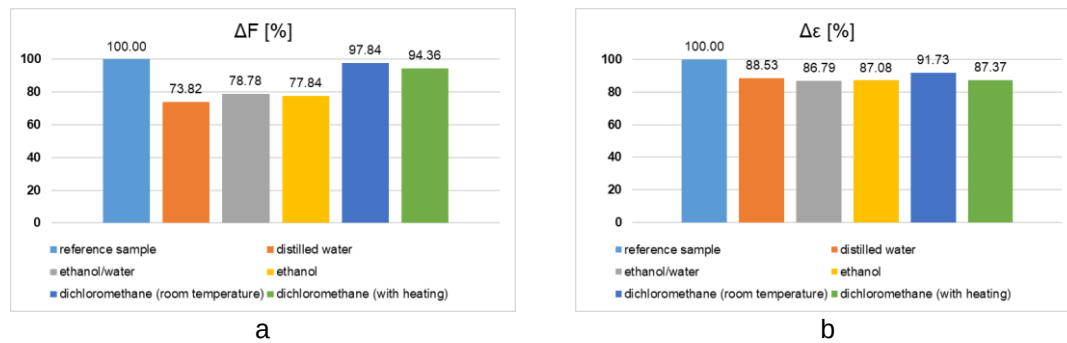


Figure 1: The quality of recycled fibres expressed through: a) change in breaking force; b) change in breaking elongation

From the results shown in Figure 1, it is evident that the breaking force and elongation of recovered *Spartium junceum* L. fibres are best preserved during chemical recycling, in which the PLA matrix is dissolved in dichloromethane. The process with cold dichloromethane is superior, as it is also more energy efficient. A more significant reduction in breaking force was observed in fibres recovered after exposure to other solvents, since the matrix didn't completely dissolve within the expected time, but only softened, which significantly affects the ability to separate the fibres from the matrix as well as their suitability for breaking force determination. Considering the obtained results, it can be concluded that even after chemical recycling, the properties of the recovered fibres decline, making their use in an equivalent composite impossible; however, they can be reused in less demanding composite structures.

4. Conclusion

The conducted research showed that the preservation of the investigated properties of recovered *Spartium junceum* L. fibres after chemical recycling of unidirectional biocomposites largely depends on the selection of an appropriate solvent. In this case, it is dichloromethane, but despite its high efficiency, its toxicity can be a problem if the process is not carried out with all safety precautions.

Acknowledgment

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- [7] HRN EN ISO 5079:2020 Textile fibres -- Determination of breaking force and elongation at break of individual fibres

**Antonija Petrov****Biography**

Antonija Petrov was born in 1993 in Zagreb. She completed her undergraduate studies in Textile Technology and Engineering at the Faculty of Textile Technology, University of Zagreb, in 2017, and her graduate studies in the same field in 2019, specialising in Engineering Design and Management of Textiles, earning the title of Master of Textile Technology and Engineering. Since 2021, she has been enrolled in the postgraduate doctoral programme Textile Science and Technology and within the project "Aspects of the Application of Thermography in the Evaluation of the Thermophysiological Comfort of Sportswear – ATLETO (DOK-2021-02-4746)", under the supervision of Prof. Goran Čubrić, Ph.D. Since 2025, she has been employed as a research assistant at the Department of Clothing Technology. She participates in several scientific research projects, and her research interests focus on the application of infrared thermography in the evaluation of sportswear comfort.

Title of Ph. D. thesis

Application of thermography in the evaluation of the comfort of knitted structures for the production of sportswear

Mentor

Prof. Goran Čubrić, Ph. D.

Date of dissertation defense

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ANALYSIS OF THERMOPHYSIOLOGICAL COMFORT OF SPORTSWEAR USING INFRARED THERMOGRAPHY

Antonija PETROV

University of Zagreb Faculty of Textile Technology, Prilaz baruna Filipovića
28 a, 10 000 Zagreb, antonija.petrov@ttf.unizg.hr

Abstract: The comfort of sportswear plays a crucial role in maintaining thermal balance and athletic performance during physical activity. Properly designed sportswear should enable effective heat and moisture management, particularly under conditions of increased metabolic load. Infrared thermography represents a non-invasive method for monitoring dynamic changes in athletes' skin temperature during physical activity and the recovery phase. This paper presents the application of infrared thermography in the assessment of sportswear comfort through the analysis of temperature changes on the athlete's body during a defined physical activity. The obtained results indicate a relationship between the body's thermal response, activity intensity, and the ability of sportswear to effectively regulate heat and moisture. Such an approach enables a more objective evaluation of sportswear comfort and contributes to the development of functional materials adapted to athletes' requirements.

1. Introduction

Clothing comfort is considered one of the key requirements of sportswear and arises from complex heat and moisture transfer processes between the body and the environment through layers of textile materials. This concept encompasses multiple aspects, including thermophysiological, sensory, and physiological factors, where material properties related to water vapour transmission, sweat absorption, and drying rate are crucial for maintaining a stable body temperature and a sense of comfort during wear [1–3]. During physical activities of moderate to high intensity, the perceived comfort of athletes further depends on the physiological response of the body and the conditions under which the activity is performed, including the level of metabolic load, sweating intensity, skin–clothing interaction, and environmental conditions. Under such circumstances, sportswear should provide a neutral thermal sensation and effective heat and moisture regulation to ensure a dry skin surface after sweating and to preserve the feeling of comfort [4]. Infrared thermography is a non-contact method for determining surface temperature and its distribution based on the detection of infrared radiation, enabling the visualization of temperature differences in the form of thermograms without physical contact with the measured object. This imaging approach allows monitoring of dynamic changes in skin and clothing temperature during and after physical activity, as well as the visual identification of sweating, cooling, and body thermal recovery zones [5, 6]. In the application to textile materials, infrared thermography is used as an objective method for analysing the thermophysiological responses of clothing systems, thereby contributing to a better understanding of the influence of materials on heat and moisture regulation and to the optimization of sportswear design for improved wearer comfort [7].

2. Experimental

For the purposes of the study, various knitted structures made of 100% polyester, commonly used in sportswear production, were employed. The samples differed in their basic structural and physical–mechanical characteristics, including areal density, thickness, yarn fineness, and knit density. In the results section, an example of one of the tested jerseys is presented to illustrate thermophysiological comfort during wear. The investigation was conducted using infrared thermography, with a Testo 872 infrared thermal imaging camera used for data acquisition. Thermographic measurements were carried out in three defined phases: before physical activity, immediately after activity, and after a ten-minute recovery period. This approach enabled monitoring of skin temperature changes, body cooling processes, sweat evaporation, and the restoration of thermal equilibrium following physical exertion. Prior to physical activity, a ten-minute acclimatization phase was conducted, during which the participants adapted to the environmental conditions. After acclimatization, a structured physical activity protocol lasting 25 minutes was performed, consisting of a series of standard sports warm-up exercises. Short rest intervals of 10 seconds were provided between individual exercises. Upon completion of the activity, a ten-minute recovery phase followed. Thermographic analysis was performed on the anterior side of the athletes' bodies, with the observed area divided into twelve predefined anatomical

zones. This zonal approach allows systematic and comparable analysis of temperature changes across different phases of physical activity and enables an objective assessment of the thermophysiological comfort of sportswear under real-use conditions.

3. Results and Discussion

Figures 1a–1c present thermograms recorded during the three measurement phases: before physical activity (Figure 1a), immediately after activity (Figure 1b), and ten minutes after the activity during the recovery phase (Figure 1c). The thermogram recorded prior to physical activity represents the initial, reference state. At this stage, the body has not yet warmed up, and the temperature distribution on the surface of the jersey is relatively uniform. No pronounced zones of elevated or reduced temperature or areas of intensive sweating are observed, which corresponds to the expected physiological condition before physical exertion. In the thermogram recorded immediately after the completion of physical activity, clear changes in temperature distribution are evident. Zones of intensive sweating can be identified, which appear on the thermogram as areas of lower temperature, represented by cooler colour shades. Although metabolic heat production is increased at this stage, the evaporation of sweat from the skin and sportswear surface leads to a local reduction in temperature. This thermal response enables clear identification of areas with the highest sweating intensity. The thermogram recorded ten minutes after the completion of physical activity illustrates the recovery phase of the body. At this stage, most of the sweat has evaporated, and the sportswear begins the drying process. A gradual increase in skin temperature and a return toward values recorded before the onset of activity can be observed, indicating the re-establishment of thermal equilibrium. This phase clearly illustrates the role of the material in moisture management, as faster drying enables more efficient stabilization of body temperature and an earlier perception of comfort.

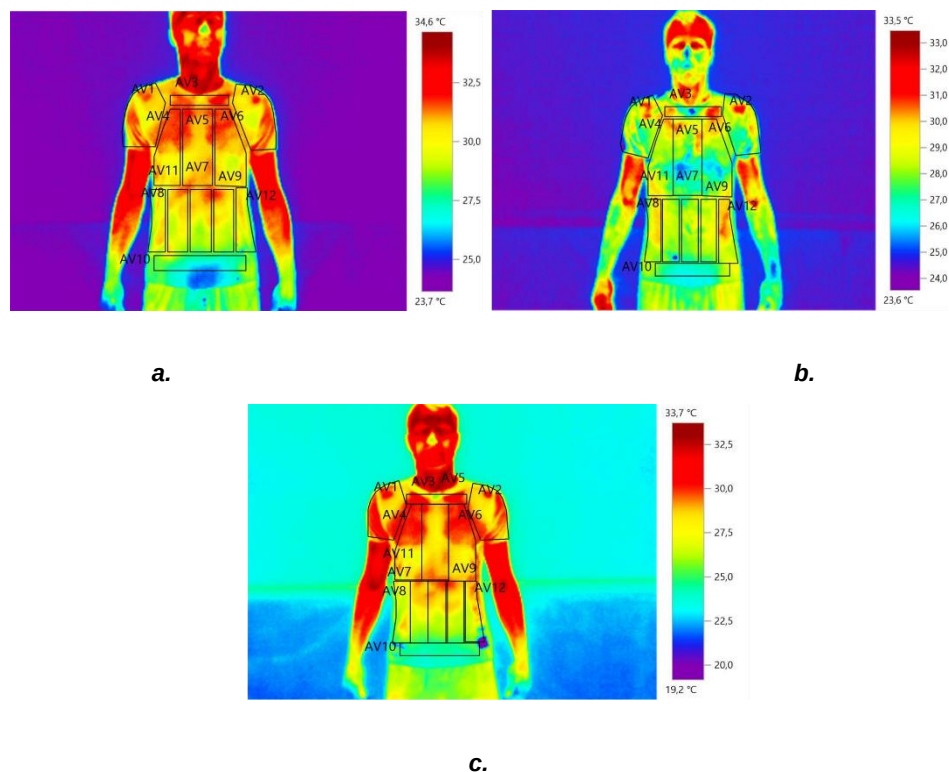


Figure 1: Example of thermograms: (a) before physical activity, (b) immediately after physical activity, (c) ten minutes after the completion of physical activity

4. Conclusion

Infrared thermography represents an effective and non-invasive method for assessing the thermophysiological comfort of sportswear. It enables visualization of sweating zones, cooling processes, and the restoration of thermal balance in the human body, thereby contributing to a better understanding of the influence of materials



on heat regulation and moisture management. Such insights are essential for the development of functional, breathable, and fast-drying sportswear that provides enhanced comfort for athletes during physical activity.

Acknowledgment



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**Luka Savić****Biography**

Luka Savić is a Ph. D. candidate in Textile Science and Technology at the University of Zagreb Faculty of Textile Technology, where he is employed as a teaching and research assistant. His academic work includes teaching activities and laboratory work related to polymers and textile technologies. During an international research experience at the University of Oxford, he worked on topics connected to electrospinning, process optimisation, and the production and characterisation of nanofibres for applications in (bio)materials and medical/technical textiles. In parallel, he develops research activities involving FDM 3D printing—from the preparation and evaluation of polymer filaments to prototyping and functional parts, including 3D-printed stencils and tools used in laboratory and teaching workflows. He is actively engaged in volunteer work through the Penkala Association, Eurodoc (member of the Governing Board), and the Upciklići Association, with a focus on science communication and academic policy. He is also a member of BFUG (Bologna Follow-Up Group), contributing to discussions on the development of the Bologna Process at EU level.

Title of Ph. D. thesis

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Study advisor

Assoc. Prof. Iva Brlek, Ph. D.

Date of dissertation
defense

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MECHANICAL AND CHEMICAL RECYCLING OF PA 6: COMPARISON OF FILAMENT PROPERTIES FOR TEXTILE APPLICATIONS AND 3D PRINTING

Luka SAVIĆ

University of Zagreb, Faculty of Textile Technology, Prilaz baruna Filipovića
28a, 10000 Zagreb, Croatia, luka.savic@tff.unizg.hr

Abstract: This paper outlines a research concept focused on comparing virgin, mechanically recycled and chemically recycled polyamide 6 (PA 6) and their suitability for producing filaments for textiles applications and FDM 3D printing. Key material properties and processability are assessed, while CO₂ emissions during thermal degradation are considered an additional indicator of polymer changes [1–4].

1. Introduction

In polymer engineering, the transition toward a circular economy increasingly requires robust assessment of recycled materials for technical and manufacturing applications. Polyamide 6 (PA6) is highly relevant due to its extensive use in textiles and related products, where recycling can alter molecular weight, melt rheology, crystallinity, and consequently the stability of melt processing during melt spinning. In practice, mechanical recycling is most commonly investigated because it is more accessible, but it may intensify degradation. Chemical recycling, in contrast, enables depolymerization to monomers and offers the potential for true material-loop closure [3–5].

This research presents a framework for comparing virgin (fossil-based) PA6 with mechanically and chemically recycled PA6, with a focus on filament production for textile applications and FDM 3D printing. The comparison includes an assessment of processability (filament diameter and surface stability), fundamental thermal and mechanical properties, and monitoring of CO₂ emissions during thermal degradation as an additional indicator of polymer changes. The methodology builds on prior work within the research group at the Faculty of Textile Technology (TTF) related to modification of recycled PA6 during melt spinning and polymer applications in 3D printing onto textile substrates [1,2].

2. Experimental

The study will use virgin (fossil-based) PA6, mechanically recycled PA6 (with a defined number of recycling cycles), and chemically recycled PA6. Man-made filaments will be produced by melt spinning from PA6 using a laboratory extruder equipped with a filament extrusion/spinning line, with optimization and control of key processing parameters. Filament diameter will be monitored using appropriate metrology (micrometer or laser diameter gauge), in combination with a take-up unit and winding onto a rotating spool [5,6].

Characterization will include selected melt rheological measurements; thermal analysis (DSC for melting/crystallization temperatures and degree of crystallinity; DMA for thermo-mechanical behaviour); and mechanical testing of filaments and 3D-printed test specimens (TENSOLAB tensile tester). Surface quality and morphology will be evaluated using optical microscopy and scanning electron microscopy (SEM). Thermal degradation will be analysed using TGA–FTIR to monitor the gas phase and to identify/quantify CO₂ evolution. To verify suitability for additive manufacturing, FDM printing will be performed on standardized specimens, and dimensional accuracy and process repeatability will be evaluated [1,2,5].

Samples of virgin PA6, mechanically recycled PA6, and chemically recycled PA6 will be compared and analysed to support hypothesis development and conclusions. Materials will be processed into filaments under controlled key parameters, while basic indicators of processability and process stability will be recorded [1,3–6].



3. Results and Discussion

Different recycling routes are expected to produce measurable differences in processing stability and filament performance. The results will enable comparison of trends across rheological and mechanical properties as well as emissions during thermal degradation. This will provide a basis for selecting an appropriate recycling pathway and aligning the material with a targeted end-use in textile manufacturing or additive production [1–4].

4. Conclusions

The proposed approach can deliver a comparable assessment of PA6 obtained via different recycling routes in the context of filament production. Incorporating CO₂ monitoring during thermal degradation may provide an additional indicator of material changes linked to processability and baseline properties [1–4].

Acknowledgements

The author thanks the institutional mentor, Prof. Sanja Ercegović Ražić, and the doctoral programme advisor, Assoc. Prof. Iva Brlek, as well as collaborators for their expert support in defining the research framework and for assistance with laboratory activities at the Faculty.

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Vanja Šantak

Biography

After graduation at University of Zagreb Faculty of Textile Technology in 2003 he began his professional career. The first job position was an office administrator in the Birokorekt d.o.o. His ability to adapt to various tasks was highlighted during his tenure at Orka Zagreb d.o.o., Esotehna d.o.o., Color Trade d.o.o., and Orka Lab d.o.o. He gained a great experience in sales and technology as the Sales Manager at Interallis Chemicals d.o.o. from 2011 to 2013. Currently, he is a Sales Engineer at NTI d.o.o., specialist in water technologies and the official distributor of Solenis chemicals.

Title of Ph. D. thesis

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Study advisor

Prof. Tanja Pušić, Ph. D.

Date of dissertation
defense

/



OZONE-ASSISTED WASHING PROCESS OF TEXTILES

Vanja ŠANTAK

University of Zagreb Faculty of Textile Technology, Prilaz baruna Filipovića
28a, Zagreb, vsantak@ttf.hr

Abstract: Due to its high oxidative potential, ozone can represent a valuable supplement to existing processes of textile washing by contributing to hygiene, efficiency, and sustainability. The paper analyzes the effect of different ozone concentrations in combination with detergent during the washing process of tannin-based stain in order to evaluate its adaptability, flexibility, and sustainability. The objective is to determine the advantages and limitations of ozone-assisted washing processes in comparison with detergent-based processes at temperatures of 30 °C, 40 °C, 60 °C, 75 °C and 90 °C.

1. Introduction

Ozone (O_3) as a powerful oxidizing agent, has been recognized in textile washing technology due to certain advantages over conventional washing agents, primarily reflected in hygiene performance and environmental sustainability. Ozone-based processes, owing to their effectiveness in microorganism removal and additional sustainability benefits such as reduced water and energy consumption, have been accepted as one of the Key Enabling Technologies (KET). In recent years, ozone washing has gained importance due to its disinfection capability and its role in preventing cross-contamination during the laundering of hospital textiles and other textiles requiring high hygienic standards.

Recent studies highlight that ozone washing provides deep cleaning and disinfection while reducing energy and water consumption, thereby contributing to environmental sustainability and lowering the carbon footprint of washing technologies [1–3]. In the context of growing global environmental awareness and the promotion of sustainability principles, ozone assisted washing can represent a key technology in the pursuit of greener and more sustainable approaches in process engineering [4,5].

Furthermore, ozone has proven to be highly effective in the removal of various types of contaminants and pathogens, including viruses and bacteria, making it an ideal solution in the context of current and future public health challenges. Its adaptability to different types of fabrics, such as cotton, polyester, and their blends, further confirms its applicability and flexibility.

The topic of the dissertation encompasses ozone-assisted textile washing processes, with a particular focus on their environmental benefits, efficiency, and adaptability in stain removal from different textile materials through variation of the Sinner cycle factors.

2. Experimental

The washing process of a standard test monitor stained with red wine (WFK 90 LI, EMPA, Eidgenössische Materialprüfungs und Forschungsanstalt, St. Gallen, Switzerland), together with six kilograms of cotton ballast, was carried out in a Giant-C MAX washing machine (LG, South Korea) equipped with an ozone generator, with variation of time, temperature, detergent concentration, bleaching agent concentration, and ozone concentration.

An ozone generator (BWO³) was used to dose ozone in concentration ranges of 0.5 to 1.0 mg/L and 0.5 to 2.0 mg/L during the pre-wash and rinsing stages, with incoming water temperatures up to 20 °C.

The experiments were performed using a liquid detergent at two concentrations (D-1 and D-2) combined with a powder bleaching agent (B), both supplied by the Belgian company Christeyns. According to the EC



Directive, the detergent composition contained anionic and amphoteric surfactants (<5%), soap and non-ionic surfactants (5–15%), polymers, optical brighteners, and fragrances.

Since the removal of specific colored stains by liquid detergents alone is insufficient, a bleach as decolorizing agent (B), formulated in accordance with the EC Directive, was applied. This agent also contained non-ionic surfactants (<5%), sodium percarbonate (>30%), complexing agents, and fragrances.

The dosages of liquid detergent (D), bleach (B), and ozone (O) are presented in Table 1, while the duration of the washing processes at selected temperatures is given in Table 2.

Table 1. Process labels and dosages

Washing process	Dosage		
	D (mL/kg)	B (g/kg)	O ₃ (mg/L)
D-1	8.3	6.7	-
D-1-O-1	8.3	6.7	≤1
D-1-O-2	8.3	6.7	≤2
D-2	15.0	10.0	-
D-2-O-1	15.0	10.0	≤1
D-2-O-2	15.0	10.0	≤2

Table 2. Washing temperatures and process duration

T (°C)	30	40	60	75	90
t (min)	51	61	69	84	99

The red wine stain removal efficiency was monitored by analyzing the spectral properties of the standard monitor before and after washing using a Spectraflash SF300 remission spectrophotometer (DataColor, Rotkreutz, Switzerland), with a standard D65 light source simulating daylight and d/8° geometry (diffuse illumination at an observation angle of 8°). Reflectance at a wavelength of 460 nm (R₄₆₀) was measured at four randomly selected positions, with higher values indicating better washing performance.

3. Results and Discussion

The standard cotton monitor stained with red wine, WFK 90 LI, contains pyranoanthocyanins, where the pyran ring stabilizes the molecular structure and intensifies the color derived from anthocyanin dyes [6].

Table 3. WFK 90 LI—standard cotton monitor stained with red wine before (U) and after washing at selected temperatures

T (°C)	D-1	D-1-O-1	D-1-O-2	D-2	D-2-O-1	D-2-O-2
30	45.37	32.45	56.89	49.07	49.53	54.35
40	48.82	46.21	51.33	53.34	52.28	56.39
60	53.54	51.33	57.75	60.48	61.69	57.46
75	70.99	56.23	65.61	74.99	74.09	68.32
90	66.31	66.80	72.78	84.38	82.45	78.96
U	32.45	32.45	32.45	32.45	32.45	32.45

The primary washing effect of the red wine–stained standard monitor improves with increasing temperature under almost all analyzed washing conditions (D-1, D-2, D-1-O-1, D-1-O-2, D-2-O-1, D-2-O-2). A slight decrease in reflectance was observed only for the WFK 90 LI monitor washed with a lower detergent and bleach concentration at 90 °C (D-1). The influence of lower ozone concentration (O-1) combined with a higher detergent (D-2) and bleach concentrations was negligible.

The effect of a higher ozone concentration (O-2) combined with higher detergent and bleach concentrations, compared to D-2 and D-2-O-1, was favorable only at 30 °C and 40 °C. Lower detergent (D-1) and bleach concentrations supported by higher ozone concentration (O-2) improved reflectance values of the washed WFK 90 LI monitor at all analyzed temperatures (Table 3).



4. Conclusion

The results confirmed the influence of ozone concentration on red wine stain removal performance. Washing processes with higher detergent and bleach concentrations combined with lower ozone concentration (D-2-O-1), compared to washing without ozone, did not enhance red wine stain removal at the analyzed temperatures, whereas higher ozone concentration (D-2-O-2) showed a favorable effect at 30 °C and 40 °C.

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Irena Topić

Biography

Irena Topić was born in 1983 in Zagreb. She works as an art teacher. In 2011 she gained a master degree in costume design at University of Zagreb Faculty of textile-technology (TTF), and in 2013 a master degree in arts education, painting orientation at the Academy of Fine Arts. From 2004 to 2006, she worked as a field measurer on the Croatian Anthropometric System (CAS) project led by prof. emeritus dr.sc. D. Ujević. At TTF she worked as an assistant (2011 to 2017) and later as an external associate (2018 to 2021). During her career, she completed numerous professional trainings: at the CFPIC Institute, Felgueiras, Portugal (Tied Shoe project, headed by prof. emeritus dr.sc. A. M. Grancarić), at the Faculty of Textiles, Leather and Industrial Management, "Gheorghe Asachi", Iași, Romania and at the Cité des Arts, Paris. She participated in the project Knowledge for footwear (K4F).

Title of Ph. D. thesis

The impact of body proportions in the process of constructing clothes for people with obesity

Study advisor

Prof. emer. Darko Ujević, Ph. D.

Date of dissertation defense

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THE IMPACT OF BODY PROPORTIONS IN THE PROCESS OF CONSTRUCTING CLOTHES FOR PEOPLE WITH OBESITY

Irena TOPIĆ

University of Zagreb, Faculty of Textile Technology, Prilaz baruna Filipovića
28a, irena.topic@tff.hr

Abstract: *Body proportions research can contribute to new better quality of clothing construction methods and modelling for men and women with obesity. Within the doctoral thesis, the goal is to determine obesity trend among adult women and men in the XXI. county City of Zagreb, which will serve for improvement of clothing construction procedures and design of everyday clothing. As well deviations in obesity among men and women from the Croatian technical report from 2012, carried out within the STIRP HAS project, will be established. Based on anthropometric measurements results carried out on the selected population, the goal is to determine the relevant criteria for the selected population and to enable the proposal of new body types, and the improvement of the construction and designing processes of clothing.*

1. Introduction

Anthropometric measurements have been carried out since 1900, with the aim of improving and development of the body sizing systems and body types. Researchers' approaches and measuring methods have changed and improved with the development of anthropometric instruments. Body proportions determine the conformity and mutual relation of individual body measurements. Research within the doctoral thesis will be based upon the determination of anthropometric measurements in men and women with obesity, and deviations from the average build. New and better methods of clothing construction and modelling for people with obesity can be used for researching of their body proportions. With stated researches the aim to increase the quality of life and health protection of people with obesity. Body proportions of people with obesity are determined by systematic anthropometric measurements.

2. Experimental

The measurement for the purposes of the doctoral thesis will be carried out at the KBC Zagreb, by random selection (arrival criterion) of participants who meet the criteria for determining obesity in the male and female population. Participants aged from 18 to 65 years, with a body mass index (hereinafter referred to as BMI) $>30\text{kg/m}^2$, with a waist circumference greater than 88 cm for women, and a waist circumference greater than 102 cm for men, will be included in the research. The research will include two groups: 50 women and 50 men. For the participants, the exclusion criteria are: taking corticosteroid therapy or Cushing's disease or Cushing's syndrome. When filling out the survey questionnaires and conducting their statistical data analysis, the data for personal preferences will be determined, as well the feeling of comfort when wearing and the difficulties in finding suitable clothes. Anthropometric measurements within the doctoral thesis will be carried out using a set of anthropometric instruments: an anthropometer with one and/or two legs, a measurement tape, a one-sided and/or two-sided goniometer, a sliding calliper, a necklace for determining the circumference of the neck and a digital scale.

The research is carried out in four phases:

1st phase: preparation of the research plan, review of published literature, development of cooperation with other scientific and research institutions and manufacturing companies.

2nd phase: calibration of the research equipment, compiling survey questionnaires and forms, and anthropometric measuring of the participants: 57 measurements for women and 54 for men.

3rd phase: conducting tests and anthropometric measurements during the ambulatory endocrinological examination (KBC Zagreb).

4th phase: mathematical-statistical anthropometric measurements data processing, defining new body types, addition of existing clothing sizes charts and potential application in clothing construction and design.



3. Results and Discussion

The results of anthropometric measurements that will be carried out by this research will tend to determine the trend of changes in body proportions in people with obesity (women with a waist circumference greater than 80 cm and men with a waist circumference greater than 102 cm), which will enable establishment of new body types. This work will contribute to the development and establishment of guidelines for making of new standards and clothing sizes charts in the countries' members of the European Union. Body proportions determine the conformity and mutual relation of individual body measures, in the specific case obesity in women and men and/or deviations from the average build, whereby the existence of non-conformity when designing and constructing clothing for daily use can be accurately determined.

4. Conclusion

Based on the conducted research and obtained results, a relevant criterion will be determined for the population with the problem of obesity in women and men in the Republic of Croatia, which will enable the proposal of new body types in accordance with established deviations from the average body build. This will enable an objective scientific comparison, as well a comparison with the population of other countries, EU member states and beyond. As well it is planned to establish a cooperation with European institutes, which also monitor the trends of increasing obesity in women and men. Thereby the basis for the production of men's and women's daily clothing will be made, as well for the health protection in the area of lower back part. Application of the research results will contribute to further addition of clothing sizes charts, the making of a new technical report for the population with obesity in men and women, and thus the overall improvement of clothing construction and designing and making clothes for daily use.

5. References

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Gabriela Vanja

Biography

Gabriela Vanja was born in 1995 in Zagreb, Croatia. In 2022, she graduated from the University of Zagreb, Faculty of Textile Technology, majoring in Textile Chemistry, Materials, and Ecology. After completing her master's degree, she was employed at Eurofins Ireland as a laboratory assistant. Since July 1, 2024, she has been employed as a research and teaching assistant at the Department of Textile Design and Management, Faculty of Textile Technology, University of Zagreb. In the academic year 2024/2025, she enrolled in the postgraduate doctoral program Textile Science and Technology at the Faculty of Textile Technology, University of Zagreb.

Title of Ph. D thesis

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Study advisor

Prof. Vesna Marija Potočić Matković, Ph. D.

Date or dissertation
defense

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DESIGN AND CHARACTERIZATION OF THERMOCHROMIC KNITTED FABRICS FOR ADAPTIVE SPORTSWEAR

Gabriela VANJA

University of Zagreb, Faculty of Textile Technology, Prilaz baruna Filipovića
28a, Zagreb, gabriela.vanja@tff.unizg.hr

Abstract: Smart fibers and textiles have attracted increasing attention in recent years, driven by the rapid development of wearable electronics and the emergence of smart clothing concepts. This doctoral research is based on thermochromic materials in textile and printing technologies, with a focus on leuco dyes and liquid crystal systems integrated into smart textiles. Their application in sportswear enables visual heat mapping and real-time monitoring of body temperature changes, supporting performance evaluation, thermal comfort, and user awareness.

1. Introduction

In recent years, smart yarns and textiles have attracted significant attention due to the growing popularity of wearable electronics and smart clothing concepts. The development of intelligent textile materials represents a major engineering challenge and an important goal of industrial innovation. The number of published studies on smart textiles has continuously increased over the past decade. Smart textiles can be divided into three categories: passive, active, and ultra-smart. Passive textiles—such as chromic materials—are capable of detecting environmental changes but cannot respond to them. Active textiles can both sense stimuli and respond accordingly, while ultra-smart textiles possess advanced functionalities that enable adaptation and shape change in response to external conditions [1]. Progress in this field requires close collaboration between engineers and designers in order to develop chromic textiles into smart materials that are both technologically advanced and economically viable.

Chromism refers to a change in color, and materials exhibiting this ability are known as chromogenic materials. Thermochromism denotes a color change induced by temperature variations [2]. This change is most often reversible, meaning that the material returns to its original state once the temperature normalizes [3]. Systems based on leuco dyes are most commonly applied; they can be microencapsulated within polymer matrices and used as pigments or directly incorporated into fibers intended for textile applications [4].

Thermochromic dyes enable the development of functional sportswear without external electronics, as the color change is triggered by the wearer's physiological signals. This represents a significantly more accessible method of body monitoring compared to electronic systems. Such textiles allow assessment of exercise intensity and can signal physical fatigue based on fabric color changes [5].

2. Experimental Section

The experimental part of the doctoral research will include the application of a commercially available microencapsulated thermochromic dye onto a knitted fabric sample. Printing on the knitted fabric will be performed using manual screen printing. The thermochromic system consists of three basic components: an organic color former (leuco dye), a proton-donating developer (organic acid), and a hydrophobic solvent with a low melting point that determines the temperature at which the color change occurs. Microencapsulation ensures system stability and controlled activation. The reaction between the dye and the developer occurs at low temperatures while the solvent is in a solid state. As the temperature increases, the solvent transitions to a liquid state, the dye-developer complex dissociates, and the system becomes colorless. Upon cooling, the solvent solidifies again, the dye and developer recombine, and the original color is restored (Figure 1) [6].

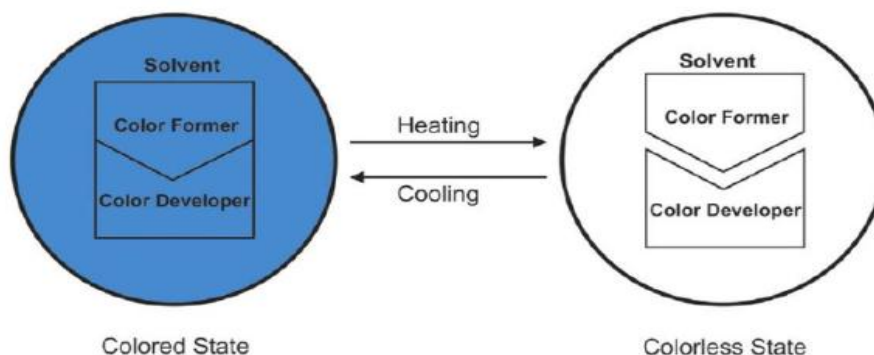


Figure 1: Schematic representation of structural changes in thermochromic microencapsulated dye molecules during heating and cooling [3].

The following analyses will be performed on the printed knitted fabric samples: microscopic analysis, spectrophotometric analysis, FTIR spectroscopic analysis, and color fastness testing, with particular emphasis on washing and rubbing fastness.

3. Results and Discussion

The aim of the tests conducted on the dyed knitted samples is to determine color uniformity before and after thermal exposure, as well as the stability of the printed pattern during repeated use. Spectrophotometric analysis will be used to examine the range of color change over a defined number of heating and cooling cycles and to determine remission curves. The knitted fabrics will also be analyzed using FTIR spectroscopy to obtain spectral curves.

4. Conclusions

Thermochromic materials represent an innovative class of functional textile materials capable of visually responding to heat. Systems based on leuco dyes are most commonly used due to their reversibility, wide color range, and cost-effectiveness. Despite challenges such as limited durability and sensitivity to environmental conditions, recent research demonstrates advances in material performance and integration methods, opening opportunities for applications in sportswear, fashion, medical textiles, and protective clothing.

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Franka Žuvela Bošnjak

Biography

Franka Žuvela Bošnjak was born on February 22, 1978, in Split. She obtained her degree in textile engineering in 2003 at the University of Zagreb, Faculty of Textile Technology (UNIZG FTT). In 1999, she was recognized as the best student in the field of chemistry, and in 2000, she received the Rector's Award for scientific work. After 13 years of working in the industry, she started working as an assistant at the UNIZG FTT in 2016, in the field of technical sciences, scientific area of textile technology, scientific branch of textile chemistry. Today, she works as a lecturer at the same Faculty. After employment, she enrolled in the postgraduate university study Textile Science and Technology. Her scientific interests include research of the structure and properties of different types of leather, as well as preparation and processing of leather.

Title of Ph. D. thesis

The Influence of Synthetic Zeolites and β -Cyclodextrins on the Properties of Bovine Leather

Study advisor

Prof. Sandra Flinčec Grgac, Ph. D.

Date or dissertation
defense

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PHYSICOCHEMICAL CHANGES IN THE STRUCTURE OF BOVINE LEATHER

Franka ŽUVELA BOŠNJAK

University of Zagreb Faculty of Textile Technology, Hallerova aleja 6a,
Varaždin, franka.zuvela.bosnjak@tff.unizg.hr

Abstract: Due to the wide application of bovine leather in industry and increasingly strict environmental requirements, the possibility of replacing traditional fungicides with more environmentally friendly agents is being explored. In this study, the use of zeolite as an alternative to conventional fungicides in the tanning process of bovine leather was examined. Raw bovine leather underwent preparatory processes under factory conditions and was then chrome tanned in two variants: with the addition of fungicide and with zeolite instead of fungicide. After tanning, the samples were analyzed by FT-IR ATR spectroscopy to assess the influence of zeolite on the physicochemical properties of the leather. The obtained results provide insight into the structural changes of the sample treated with zeolite compared to the sample with fungicide.

1. Introduction

Due to the wide application of bovine leather in industry, there is a constant search for more environmentally friendly processing methods. Strict regulations require the use of procedures that protect the environment, so this study explores the possibility of replacing harmful fungicides with zeolite. Microorganisms utilize nutrients from leather, which can lead to its deterioration during processing, especially in moist and acidic conditions. Fungi cause damage such as collagen degradation and the appearance of stains, which reduces the value of the product and increases costs. Industry is shifting to more natural alternatives such as essential oils and chitosan. The European Union and other countries are introducing strict regulations, so less harmful methods of leather protection are increasingly being applied [1-2].

2. Experimental

Under factory conditions, raw bovine leather was first subjected to preparatory processes including soaking, liming, deliming, and pickling according to standard procedures. The tanning process was carried out in sample processing drums (FER-TI, Italy). Two different procedures were performed: in the first, a chrome tanning agent with the addition of fungicide was used, while in the second process, the fungicide was replaced with zeolite. The fungicide is dosed in two steps: 0.20% five hours after the start of the tanning process and an additional 0.10% after seven hours. The physical and chemical properties of the tanned samples were analyzed using Fourier-transform infrared (FT-IR) spectroscopy with attenuated total reflectance (ATR) technique (Perkin Elmer, Spectrum 100 software). Four scans were performed for each sample at a resolution of 4 cm⁻¹ between 4000 cm⁻¹ and 380 cm⁻¹. The sample labeled IX_ŠTAVLJENO_Z_L represents leather tanned with zeolite, grain side. The sample IX_ŠTAVLJENO_Z_M refers to leather tanned with zeolite, flesh side. The sample IX_ŠTAVLJENO_R_L refers to chrome-tanned leather, grain side, while IX_ŠTAVLJENO_R_M refers to chrome-tanned leather, flesh side.

3. Results and Discussion

In the samples with zeolite, an intense peak appears at 1090 cm⁻¹, which indicates vibrations occurring within the tetrahedral TO₄ structure of the microporous zeolite (marked in red). It is known that absorption peaks appearing in the range from 1090 cm⁻¹ to 1020 cm⁻¹ are caused by vibrations within the C-N bonds of the primary amino groups of collagen. Change in the intensity of the peak at the wavenumber 1090 cm⁻¹ is due to the presence of zeolite in the collagen. Peaks characteristic for amide I (1650 cm⁻¹), amide II (1550 cm⁻¹), and amide III (1235 cm⁻¹) in the sample with zeolite (marked in yellow) remain in the same wavenumber region as in the regular sample, but with increased intensity [3]. In all samples, peaks are also visible in the region 3000 – 3600 cm⁻¹, which indicate vibrations within the O-H and N-H bonds (3292 cm⁻¹), as well as peaks in the region 2800 – 3100 cm⁻¹, which indicate vibrations within the C-H bond (2849 cm⁻¹).

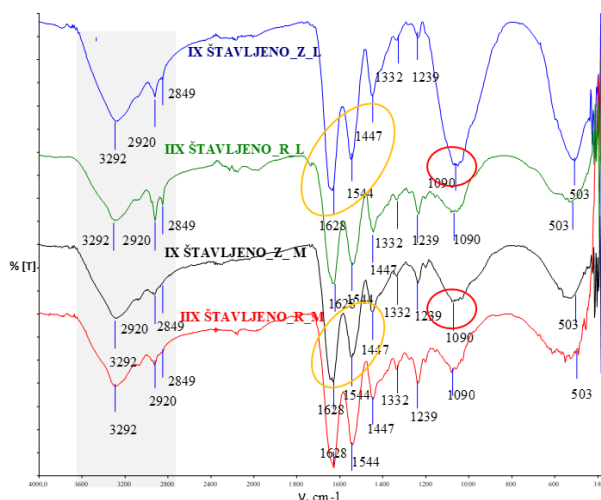


Figure 1: Spectral curves of leather samples after tanning, recorded on the grain side and flesh side

4. Conclusion

The results of the FTIR analysis show that the application of zeolite in the leather processing causes specific changes in the spectral region from 1100 to 900 cm^{-1} , with an intense peak at 1090 cm^{-1} characteristic of the zeolite structure. Changes in the intensity of peaks in this region also indicate an interaction between zeolite and collagen, especially with the primary amino groups. The peaks characteristic for amides I, II, and III remain in the same wavenumber region as in the regularly tanned sample, but with increased intensity, suggesting that the presence of zeolite affects the structure and properties of collagen. The obtained results indicate that even small amounts of zeolite used in the tanning process have a positive effect on the leather, which retains the basic structural characteristics of collagen with visible peaks characteristic of zeolites.

Acknowledgment

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