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Conductive Textiles as a Base for the Co-creation of Assistive Technology´ Clothing for Older People

Prevodne tekstilije kot osnova za soustvarjanje oblačil z vključeno podporno tehnologijo za starejše ljudi

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Abstract

The goals of this study, conducted in the scope of the MATUROLIFE project, were i) to fabricate innovative conductive fabric for the further integration of electronic items; and ii) to include a co-creation approach for the designing of two aesthetically pleasing and functional Assistive Technology (AT) clothing for older people. First, the selected fabric was electroless copper (Cu) plated to obtain a highly conductive textile. In addition, the conductive part was protected with modified acrylate resin (AR) using a spray-drying technique, washed for up to 30 washing cycles and characterised, i.e. the morphological, optical, wettability features and conductivity changes on the surfaces (Cu and Cu/AR) were analysed. Secondly, two workshops were organised taking into account the user-centred design, i.e. involving older adult participants (aged 65+), fashion designers, clothing manufacturers, psychologists and material experts. As a result, two clothing concepts were developed, which predicted the inclusion of copper metallised textile and ATs: Concept 1 – a dress included a sensor for monitoring blood sugar and a help button; and Concept 2 – a coat included a sensor for body temperature control with a heating element. The aim was to address the needs of elderly end-users.
Keywords: metallisation, smart textiles, co-creation design, clothing, assistive technology, older adults

Izvleček

Namen predstavljene raziskave, ki je bila izvedena v okviru projekta MATUROLIFE, je bil: i) izdelati inovativno prevodno tkanino za nadaljnjo integracijo elektronskih elementov in ii) vključiti koncept soustvarjanja (co-creation) za oblikovanje dveh estetskih in funkcionalnih oblačil z integrirano podporno tehnologijo (AT - Assistive Technology) za starejše ljudi. Najprej smo s selektivno metalizacijo (electroless plating) na poliestrno tkanino nanesli baker (Cu), s čimer smo dobili visokoprevodno tkanino. Prevodni del smo z uporabo tehnike pršenja zaščitili z modificirano akrilatno smolo (AR). Sledila je karakterizacija opranih vzorcev (do 30 ciklov pranja), analizirali smo morfološke, optične in prevodne spremembe na površinah vzorcev Cu in Cu/AR. V nadaljevanju sta bili organizirani dve delavnici z upoštevanjem k uporabniku usmerjenega oblikovanja, v kateri so bili vključeni starejši odrasli udeleženci (starost 65+), modni oblikovalci, izdelovalci oblačil, psihologi in strokovnjaki s področja znanosti o materialih. Kot rezultat sta bila zasnovana dva kon-

cepta oblačil, ki sta predvidela vključitev metalizirane tekstilije in podporno tehnologijo: Koncept 1 – obleka z vključenim senzorjem za spremljanje krvnega sladkorja in gumbom za pomoč, in Koncept 2 – plašč z vključenim senzorjem za spremljanje temperature telesa z ogrevalnim telesom, ki zadovoljujeta potrebe starejših končnih uporabnikov.
Ključne besede: metalizacija, pametne tekstilije, soustvarjalno oblikovanje, oblačila, podporna tehnologija, starejši ljudje

1 Introduction

The population of older people in Europe is increasing, and there is a growing trend of older people to live in urban environments. It is a key European societal challenge to ensure that they have happy, secure, independent and healthy lives. To that end, Assistive Technology (AT) plays an important role in ensuring that this is achieved, i.e. through the wearing of alarms and tracking devices around the arm or neck to alert carers to falls, or the location of elderly people if they wander, etc. [1]. Despite the availability of ATs, there are significant issues in terms of their use and acceptance due to their aesthetics and unattractive appearance [2]. Smart textiles and fabrics could revolutionise AT, enabling the production of more discreet, subtle and aesthetically pleasing AT with improved functionality, promoting the increased independence of elderly people [3].

The application of electrical conductivity on the surface of textiles leads to the production of high-added value textiles, with high capabilities to be used for conductive coverage and electronic sensors, data storage, optoelectronics, photonics and catalysts, etc. for diverse fields of applications, i.e. sport, protective, healthcare and technical purposes [4]. Wearable electronic systems typically require conductive tracks to form electrical interconnections between components [5,6]. Although copper is one of the cheapest metal options for application on flexible substrates using ink-jet printing, chemical vapour deposition or electroless plating, it is prone to oxidation and corrosion upon exposure to sweat, extreme temperatures and a water environment. Also, the poor adhesion between the coating layer and substrate limits the widespread application of wearable devices [7]. Thus, to enhance flexibility, and washing and wearing durability, diverse protective compounds can be applied using different techniques, such as coating, laminating and (screen) printing, in order to prevent the degradation of conductive tracks. These highly conductive washable textile materials will enable the embedding of 'smart' technology without a significant increase in weight.

The second part of the research outlines how smart textile solutions have been co-designed with older adults. Co-creation design is an active, creative and social process based on collaboration between producers, designers and users in order to generate value for customers [8]. It is based on the belief that users' presence is essential in the creative process. In practice, this often takes the form of a collaborative workshop in which business stakeholders, researchers, designers and end-users explore a problem and generate solutions together, taking into account their different approaches, needs and points of view to identify a solution that provides users with better experiences, and organisations with improved and innovative services [9].

2 Experimental

2.1 Preparation of conductive textiles

Experiments were carried out using an industrially dyed/finished black woven fabric composed of 55% viscose, 36% polyamide and 9% elastane (supplied by Łuksja Sp. Z.o.o., Poland) with a mass/unit area of 201.7±0.6 g/m^2 and a thickness of 0.47 mm, a warp density of 24 threads/cm and a weft density of 22 threads/cm.

The fabric was electroless copper (Cu) plated utilising a commercially available process supplied by A-Gas Electronic Materials Ltd., UK, as explained by Ojstršek et al. [10] in order to obtain highly conductive fabric, which will be used further to produce AT clothing prototypes for older adults (ongoing research). Cu conductive tracks on the fabric surface were protected against corrosion with Elpeguard SL 1307 FLZ-S (modified acrylate resin – AR) supplied by Lackwerke Peter GmbH & Co., Germany, using a spraying procedure by means of a Harder & Steenbeck Colani airbrush with pre-optimised parameters, i.e. a nozzle setting of 0.4 mm, a working pressure of 1 bar and a distance between the sample and airbrush of 15 cm. The coated sample was dried at room temperature for 24 hours, and then cured at 100 °C for 5 minutes to form a cross-linked network. The schematic of the proposed processes is presented in Figure 1.

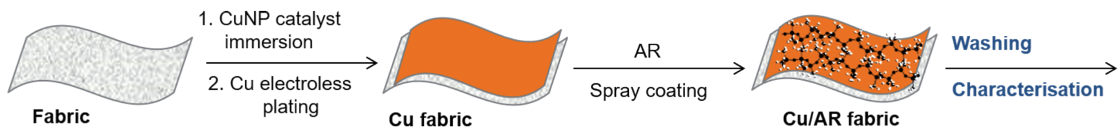


Figure 1: Schematic presentation of samples preparation

Both samples, Cu-metallised (Cu) and Cu-metallised/AR-protected (Cu/AR), were washed for up to 30 cycles in a Labomat (Werner Mathis AG, Switzerland) at 40 °C for 30 minutes, using 1 g/L of standard detergent and a liquor-to-fabric weight ratio of 50:1. After each washing cycle, the samples were rinsed three times under tap water for 1 minute and dried at room temperature.

2.2 Characterisation of conductive textiles

Electrical resistivity, reflectance and the colour of samples were determined before and after a selected set of washing cycles; electrical resistivity after 5, 10, 20 and 30, and colour after 5, 15 and 30 washings. Also, the changes in surface morphologies of samples after the washing tests were inspected using Optical Microscopy (OM) and Scanning Electron Microscopy (SEM).

The electrical resistivity of samples was measured and the average value was calculated using a set of standardised measuring electrodes between two measuring points (2, 3 and 4 cm) at three positions on each test sample, using a 34410A 6½ digital multimeter (Agilent Technologies, USA). Reflectance measurements of samples were carried out within a spectral range of 400-700 nm wavelengths by a two-ray spectrophotometer Spectraflash SF 600 PLUS (Datacolor, USA) equipped using an Ulbricht sphere and measuring geometry of d/8° under a standard illuminant D65 (LAV/Spec. Incl.), from which CIE L*a*b* colour values were calculated using Datacolor QC 600, V3.3 software. In addition, the CIE colour differences (da*, db*, dL* and dE*) were calculated from the coordinate differences in all three directions of the colour space, i.e. brightness L*, red/green axis a* and yellow/blue axis b*, as stated in [11]. The surface appearance of samples after 30 washing cycles was observed using an Axiotech 25 HD (+pol) Zeiss optical microscope (Carl Zeiss NTS GmbH, Germany) equipped with an Axiocam MRc (D) high-resolution camera. All measurements were performed in light transmission mode, with a halogen light as the light source using 10x magnification. In addition, the surface morphologies of the Cu and Cu/AR fabrics after 30 washing cycles were inspected by attaching a fabric sample measuring approximately 0.5 cm^2 to an adhesive carbon band fixed to a brass holder, and observed using a Zeiss Gemini Supra 35 VP Scanning Electron Microscope (Carl Zeiss NTS GmbH, Germany). The hydrophilic/ hydrophobic features of the washed samples were determined by Water Contact Angle (WCA) measurement using the sessile drop technique on a Goniometer (DataphysicApparatus). A detailed description of the method is provided in [12].

2.3 Designing of clothing concept using a co-creation approach

Two co-design workshops with an average length of four hours were organised in two countries (Slovenia and France), with a focus on the design of smart clothing [13]. Seventeen older adults (65+) took part in co-creation activities, working together with fashion designers, clothing manufacturers, psychologists and material experts. First, the participants were asked to highlight possible health-related concerns or problems, generating ideas or solutions in response. There were also active discussions about the acceptability of the existing AT, with the aim of discerning the participants' views and concerns, and challenges associated with their independent living. The participants were then given 11 factors affecting independence, and were asked to agree on their top four. After that, participants were asked to sift through a collection of product images (provided by designers for these workshops) and indicate which they would purchase and wear for which activities, and the features they liked/did not like and why. Finally, the participants (teamed with an engineer, human factor specialist, designer and/or manufacturer) proposed several design ideas, embedding smart textiles and providing assistive functionality that would address the key independence needs while considering their style preferences. The design brief was translated by the designer into two clothing concepts, a dress and a coat, that predicted the inclusion of copper metallised textile and different ATs.

3 Results and discussion

3.1 Characterisation of conductive textile

Cu and Cu/AR samples were washed for up to 30 cycles and analysed: i) determination of electrical resistivity before and after 5, 10, 20, and 30 washing cycles (Figure 2); ii) study of optical properties by measuring the fabrics' reflectance before and after 5, 15, and 30 washing cycles, followed by the calculation of CIE total colour differences (Table 1); and iii) evaluation of surface morphologies by means of OM and SEM (Figure 3), and the evaluation of the hydrophilic/hydrophobic features of samples (Table 2).

It is evident from Figure 2 that the electrical resistance of the Cu sample was 0.11 ± 0.06 Ω, while Cu/PDMS was a bit higher at 0.42 ± 0.09 Ω, revealing the good conductivity of both samples, irrespective of the upper silicone protective coating. Compared to other engineering materials, textiles are not homogeneous and anisotropic products. Thus, electrical resistivity (and consequently, conductivity) varied within the same sample, as also reported in [10]. Also, electrical resistance is associated with the uniformity and thickness of electroless Cu deposition across the entire fabric surface, which depends on the specific surface and physical-mechanical properties of the textile material. Washing increased samples´ electrical resistivity, depending on the number of cycles and presence of AR as a protective coating. The Cu sample without AR became non-conductive after 20 washing cycles compared with Cu/AR, which remained conductive after 30 washing cycles (5.23 ± 0.52 Ω), providing successful protection of Cu-metallised surfaces against water, detergent and mechanical forces during washings, meaning it could be employed for the fabrication of AT clothing prototypes.

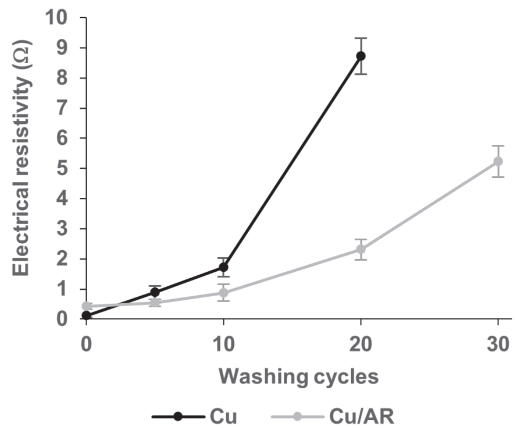


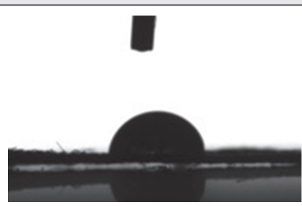
Figure 2: Electrical resistivity before and after washing of Cu and Cu/AR samples

It is evident from Table 1 that lightness decreased drastically after the application of AR protective coatings, resulting a darker hue. Moreover, the sample became less red and less yellow (greener and bluer) than the Cu sample. The metallised sample had enormous dE* after 30 washing cycles compared to the Cu/AR

*Table 1: CIE L*a*b* colour values and colour differences (dL*, da*, db* and dE*) of two samples, Cu and Cu/AR, non-washed and washed samples (up to 30 cycles)*

Sample	CIE values			CIE colour differences / Washing cycles											
				5				15				30			
	L*	a*	b*	dL*	da*	db*	dE*	dL*	da*	db*	dE*	dL*	da*	db*	dE*
Cu	46.32	17.05	19.01	−3.34	−3.49	−5.94	7.65	−3.24	−6.13	−7.78	10.42	−10.8	−9.4	−11.8	18.5
Cu/AR	37.34	13.14	18.77	−0.38	-1.13	−0.84	1.46	−1.73	−2.36	−1.76	3.41	−1.57	−3.09	−2.18	4.10

Table 2: WCA of samples after 30 washings

Sample	Reference	Cu	Cu/AR
Drop images			
WCA [°]	47 ± 2.8	115 ± 5.5	133 ± 3.4

sample, revealing the corrosion process on the surface of the fabric, as could also be perceived from the electrical resistivity measurement. These changes are not linear, and are dependent on the uniformity of Cu deposition and polymer coatings, as well as the location of the measuring area on an individual sample.
Figure 3 displays, in the upper row, a uniform coating of dense Cu particles on the surface of the fabric obtained though electroless plating, wrapping the entire surface of an individual fibre. The AR changed the surface in that it became smoother, although the Cu particles are still visible because of the transparency of the AR. It is also evident from the SEM images that AR filled the pores between fibres, forming a thick film on the surface. In addition, AR remained on the surface after 30 washing cycles, although some deterioration/cracking of the polymer film can be observed.
It is evident from Table 2 that the reference sample was hydrophilic in character (47 ± 2), and became hydrophobic after electroless Cu deposition, with a WCA of 115 ± 5.5°. The application of the AR protective polymer increased the fabric's hydrophobicity, although it was washed 30 times. This result implies the good protection of AR against the corrosion of Cu in washing conditions, providing sound confirmation of the aforementioned results.

3.2 Clothing concept with AT inclusion

The study sought to prioritise the daily and future needs of older adults in the context of their daily activities. Based on the results of the co-creation workshops, the "top 4" priorities were identified, taking into account a specific country. Slovenia: i) alert others when I need help; ii) provide information regarding my vital signs; iii) the ability to control body temperature; and iv) remind and/or help me to keep moving. France: i) remind and/or help me to keep moving; ii) the ability to control body temperature; iii) help check hydration levels and remind to eat; and iv) help manage medications.
The older adult participants participated actively and debated the use of smart technology and how it could be adapted to make it functional, discreet and unobtrusive. The majority of participants prioritised comfort over high fashion, but they still wanted to be elegant and not old-fashioned. The most important characteristics were comfort, functionality, easy maintenance and a little or no ironing. Moreover, many elderly people have problems with maintaining constant body temperature; it changes and causes an unpleasant cold-warm feeling. AT products should be mindful of their personalities, and encourage social interaction and physical activity. Some comments are presented below:
″I like dresses, but they need to be functional! I do not like feeling restricted″.
″The textile should consider changes in the body, particularly for women, especially the elderly″.
″I like young fashion, not things for old people″.
″Clothes for strong people tend to be, excuse the expression, granny, old-fashioned and for all″.
″I like to be warmed when I am cold, but I also like to be cooled when I am hot″.
″The fabrics for the elderly should keep the body warm and maintain a constant temperature″.
Based on the priorities, suggestions and comments, two clothing concepts were designed, which predicted the inclusion of Cu metallised textile and ATs: Concept

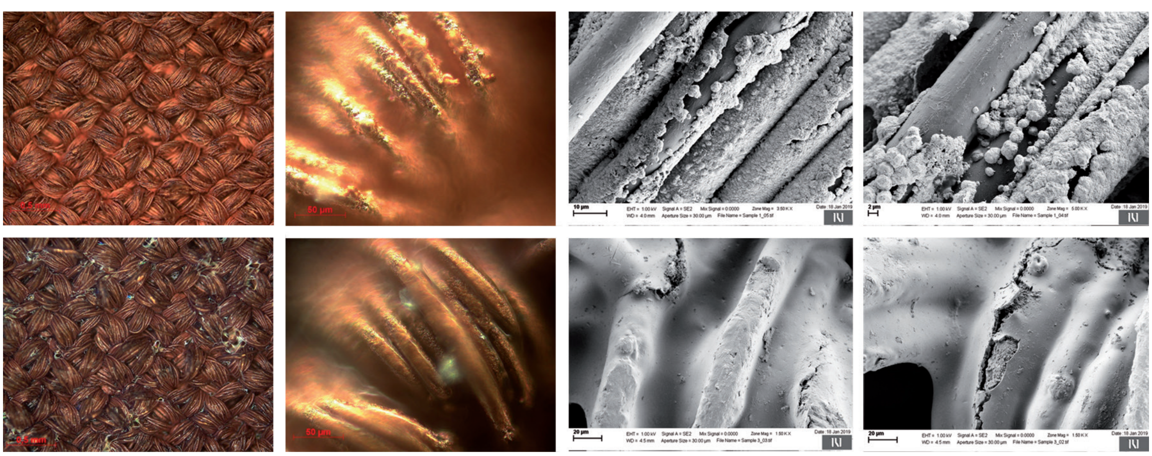


Figure 3: OM (1st and 2nd column) and SEM (3rd and 4th column) micrographs of Cu (1st row) and Cu/AR samples (2nd row) after 30 washings, at different magnifications

1 – a dress included a sensor for monitoring the blood sugar and a help button (Figure 4); and Concept 2 – a coat included a sensor for body temperature control with a heating element (Figure 5). The aim was to address the needs of elderly end-users.

Figure 4 presents the smart clothing concept of a comfortable and soft woman's outfit, with a model that hides unwanted body changes, which, in most cases, cannot be avoided over time. The sensor button for monitoring blood sugar level is located on the sleeve for easier accessibility when self-control is needed/desired. Depending on the length of the sleeve, the button can be positioned differently. The idea of button operation is as follows: when the user simply wants to check their sugar level, they press the button and an audible function provides information about the sugar level. If the user does not want or forgets to self-check, they will be warned promptly by an audio signal to take action.

On the other hand, the help button with a built-in loudspeaker and a call sensor on the collar area should be near the mouth due to the need for communication. The concept of the help button function is as follows: by pressing the help button, a signal is sent to a dispatch centre, which simultaneously receives all the basic information about the caller: diseases, psychological problems, etc. There are two options available for providing help: i) communication with the caller, if possible; and ii) if there is no response, the help desk will immediately dispatch someone to the address of the caller.

Figure 5 shows a woman's double-layered coat for different seasons. The presented coat is basically composed of two outer and inner layers and hidden "pockets" in the shoulder area, where heating elements can be inserted additionally. The coat has a sensor in the button that automatically detects rises and falls in body temperature, sending a message to heating elements that activate the cooling or heating of the body. The shape of the coat allows for the choice of different clothing too be worn under it. During a warm period, it is possible to have only a suit, a shirt or a blouse under the coat, while in a cold period, a warm inner layer can be added. It fastens with buttons, from which only the first (elegant) button with a sensor is visible, while the others are hidden. Instead of a fixed collar, a scarf is added, which can be worn or removed according to individual needs.

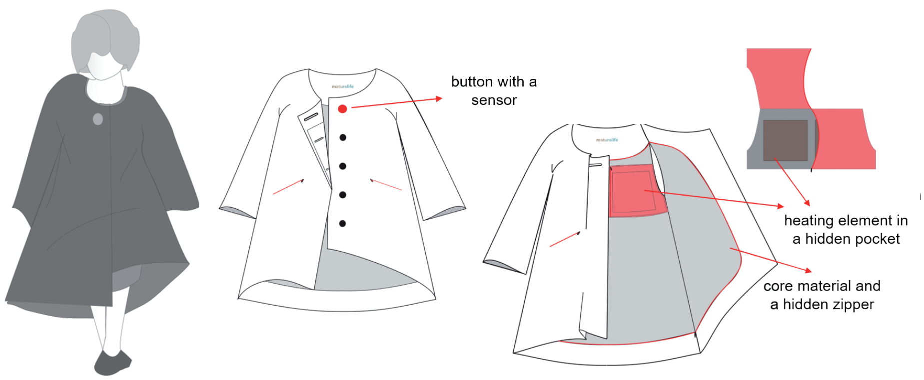


Figure 5: Clothing concept with a sensor for controlling body temperature (collar area) with heating element (shoulder area)

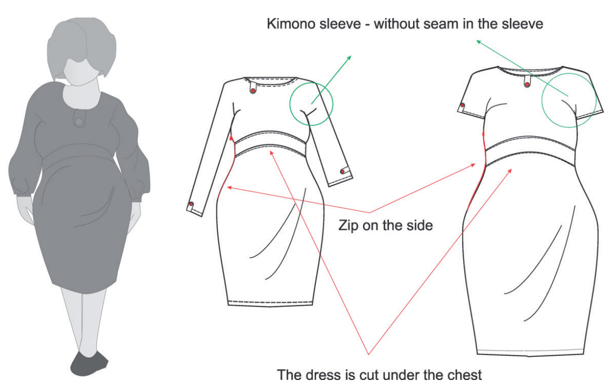


Figure 4: Clothing concept with a sensor for monitoring blood sugar (sleeve area) and a help button (collar area)

4 Conclusion

In the first part of this study, dyed/finished blue woven fabric was coated successfully using the Cu electroless plating process to obtain a highly conductive material (electronic connectivity), as confirmed by SEM images and electrical resistivity measurement. The electroless Cu deposit was then protected for durability using an AR polymer (through a spray-drying procedure), which was confirmed by the determination of electrical resistivity, colour differences, SEM and WCA after 30 washing cycles. The developed Cu conductive textile enables the embedding of AT without a significant increase in weight, and will be employed in the development of 'smart' clothing prototypes (an ongoing project). The second part of the study resulted in the designing of two smart clothing concepts with the inclusion of ATs: Concept 1 – a dress included a sensor for monitoring the blood sugar and a help button; and Concept 2 a coat included a sensor for body temperature control with a heating element. The aim was to address the needs of older adults. To that end, a co-creation approach was used, where seventeen older adults (65+), together with a design team and material specialists, participated in two workshops in Slovenia and France.

Ongoing activities focus on the inclusion of a combination of integrated electronic AT items on conductive textiles, taking into account the co-created smart clothing concept for older people outlined here. The process of development is iterative, with the aim of involving older adults in continued development. In the latter stage of the project, the resulting prototypes will be tested with end-users.

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