

Development and characterization of socks with improved anti-odour, thermo-regulating and handle properties

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ABSTRACT – REZUMAT

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Due to awareness of the potential threats of spreading diseases, the demand for antimicrobial fabrics in the world market has grown significantly and, is, expected to increase the share of medical textiles in the future world market. The purpose of this study is to develop antibacterial socks with the application of silver particles and to study thermo-physiological properties as well as the evaluation of tactile sensory perceptions of treated socks against untreated socks. Socks, which are a necessary item of clothing, need to be comfortable and affordable. The materials used for this study are cotton and polyester fibre with three different cross-sectional shapes i.e., common Polyester (round shape), Coolmax (Channeled polyester) and Thermolite (Hollow polyester). Blend ratios with percentages of 80/20 Cotton/Polyester, 80/20 Cotton/Coolmax and 80/20 Cotton/Thermolite were used as main yarns in plain crew socks while elastane yarn is used in the same percentage in all developed socks. A comparison between the samples treated with silver particles and the corresponding control samples concerning the selected properties was done. The presence of particles on the treated fibre was confirmed through an SEM study. Testing of untreated and treated fabrics for antibacterial study and odour test was carried out and found significant. The thermo-physiological properties such as air permeability, relative water vapour permeability % and thermal resistance were also studied and found better results as compared to untreated samples. Later tactile sensorial comfort i.e., fabric hand value was compared which is improved for treated samples which makes the wearer comfortable hand feeling. These data present a great interest to socks manufacturers who can make better choices to manufacture, cost-effective anti-odour socks.

Keywords: socks, antibacterial, cotton, thermo-physiological comfort, polyester (PET)

Dezvoltarea și caracterizarea șosetelor cu proprietăți îmbunătățite anti-miros, termoreglare și tușeu

Datorită conștientizării potențialelor amenințări ale răspândirii bolilor, cererea de materiale textile antimicrobiene pe piața mondială a crescut semnificativ și, se așteaptă să crească ponderea textilelor medicale pe viitoarea piață mondială. Scopul acestui studiu este de a dezvolta șosete antibacteriene cu aplicarea de particule de argint și de a studia proprietățile termofiziologice, precum și evaluarea percepțiilor senzoriale tactile ale șosetelor tratate față de șosete netratate. Șosetele, care sunt un articol de îmbrăcăminte necesar, trebuie să fie confortabile și accesibile. Materialele utilizate pentru acest studiu sunt bumbacul și poliesterul cu trei forme diferite de secțiune transversală, adică poliester comun (formă rotundă), Coolmax (poliester cu canale) și Thermolite (poliester cu lumen). Rapoartele de amestec cu procente de 80/20 Bumbac/Poliester, 80/20 Bumbac/Coolmax și 80/20 Bumbac/Thermolite au fost utilizate ca fire principale în șosetele simple, în timp ce firele de elastan sunt utilizate în același procent în toate șosetele dezvoltate. S-a făcut o comparație între probele tratate cu particule de argint și probele de control corespunzătoare cu referire la proprietățile selectate. Prezența particulelor pe fibra tratată a fost confirmată prin studiul SEM. Testarea materialelor textile netratate și tratate pentru studiul antibacterian și testul de miros a fost efectuată și s-a constatat că este semnificativă. Proprietățile termofiziologice, cum ar fi permeabilitatea la aer, permeabilitatea relativă la vapori de apă și rezistența termică au fost, de asemenea, studiate și s-au înregistrat rezultate superioare în comparație cu probele netratate. Ulterior, a fost comparat confortul senzorial tactil, adică valoarea tușeului materialului, care este îmbunătățită pentru mostrele tratate care oferă senzația de tușeu moale pentru utilizator. Aceste date prezintă un mare interes pentru producătorii de șosete, care pot face alegeri mai bune pentru fabricarea șosetelor anti-miros rentabile.

Cuvinte-cheie: șosete, antibacterian, bumbac, confort termofiziologic, poliester (PET)

INTRODUCTION

Human Beings always want to find ways for achieving comfort, as it is their basic requirement. Comfort can be classified into three types which are sensorial/tactile comfort, physiological comfort and thermo-psychological comfort. Fabric hand is described as

“the tactile sensations or impressions which arise when fabrics are touched, squeezed, rubbed, or otherwise handled” [1, 2]. Thermo-physiological comfort defines the heat and moisture interaction between the human body and the clothing. Socks are designed for various purposes like protecting feet,

fashion etc. In either case, as socks are in direct contact with the human body, they need to possess comfort properties. The effects of fibre properties and fabric construction on comfort properties are studied by various researchers. Cimilli et al. investigated the comfort properties of socks produced with viscose, cotton, bamboo, modal, micro-modal, soybean and chitosan and concluded that chiton and soybean have high thermal resistance values as compared to others while cotton has the highest wicking properties [3]. Similarly, other researchers studied the effect of different materials on the comfort properties of socks [4–7]. M. Morris et al. also studied the relationship between fibre materials and fabric properties on the comfort of socks. Sock softness and dryness are such factors that are parallel with the concept of comfort [8]. Clothing can be contaminated with microorganisms due to warm temperatures and humid conditions. This type of environment is best suited for the growth of bacteria which can lead to unpleasant odours. Studies on the nature of body odour began in the 1960s with the discovery that axillary odour could be produced by the interaction of odourless apocrine secretions with inoculation by gram-positive bacteria found on human skin surface [9].

During physical activity, the textile fabrics affect sweating and odour formation. Poor material selection according to the requirements is one of the reasons for odour formation. Sweat secretion, the bacteria population and a moist environment are the three major components contributing to odour production by the skin [10]. As textile materials are organic materials and they are favourable substrates for microbial growth thus sweat produced by human skin, feeds the bacteria. In extreme conditions, microorganisms can cause serious problems like fabric rotting, unpleasant odours and health concerns like infections and diseases. Socks are pieces of clothing for enclosing the foot and are worn inside the shoes. The foot is among the heaviest producers of sweat in the body, which can produce over a pint of perspiration per day [11]. As 99% of the sweat is water and it forms a perfect medium for bacterial growth, which causes foot odour [12]. Researchers' interest has been increasing day by day in the development of textile fabric having antibacterial elements. Different types of substances like oxidizing agents, coagulants, and metallic or quaternary ammonium compounds are used for antibacterial properties but many of them are considered harmful and toxic [13, 14]. It is considered that silver has a wide range of activity for viruses, fungi and bacteria. In the literature, it was reported that it has good antibacterial properties against various types of bacterial strains [15–18]. Silver has been used as an antimicrobial agent since ancient times. For newborn babies' eyes to prevent blindness, Crede in 1881 used a dilute solution of AgNO_3 [19]. Its application has been exploited in wound dressings, creams, surgical prostheses, dental implants and coating on medical

devices [20]. Researchers focused to achieve antibacterial properties by using different concentrations of silver solution and application of the solutions on fabric surfaces. The use of silver for coating by electroless plating was done on nylon fibre but the coating has the disadvantage that the silver may be removed from the material by washing and the antimicrobial efficiency of the product will be decreased/finished [21]. In another invention, powdered metal alloy as an antimicrobial agent was used in an extruded polymer fibre [22]. Silver nanoparticles and colloidal silver have been used to impart antimicrobial properties in polymer fibres but they may migrate into the subject or can leach out [23–25]. In another invention, silver was used as a precursor of polymer for fibre formation, but this had the limitation of high cost and different cross-sections of fibre cannot be used [26]. It is required that antimicrobial effect can be attained by a minimum amount within the textile as a whole to produce cost-effective textiles. In the present study, this problem is considered. Such different studies of using silver were found in the literature but no studies found its application by the novel idea of deposition of silver particles on fibre in one step reaction procedure and without the involvement of any toxic chemicals. Additionally, it was also investigated, in the present work, its effect on thermo-physiological, fabric hand and hygiene/antibacterial properties against gram-positive (*Staphylococcus aureus*) bacteria.

MATERIALS AND METHODS

Cotton fibre which is cellulose fibre and the most widely used natural fibre was purchased from the local market. Common polyester fibre (PET) of the circular profile is a synthetic fibre that is widely used in clothing. Coolmax has 20% more surface area and is a modified polyester fibre with a multi-channel cross-section Thermolite is also modified polyester and it is a hollow polyester fibre and has coral gaps in the structure. Cross-sectional images of different PET fibres are shown in figure 1.

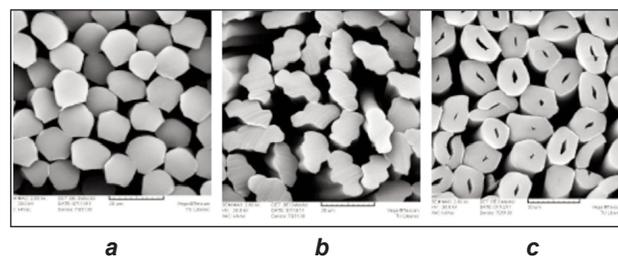


Fig. 1. Cross-sectional images of PET fibre: a – PET circular; b – Coolmax; c – Thermolite

Mechanism of deposition of silver particles in the fibre

Inorganic antimicrobial agents, particularly silver is considered very effective. Silver nitrate AgNO_3 offers several merits and is the least expensive salt of silver. It is relatively stable to light. It also dissolves in

numerous solvents, including water and its melting point is 209.7°C [21]. Silver nitrate (AgNO₃) solution of 600 ppm is prepared in distilled water with the quantity of 0.003552 mg/l and was used to treat the fabric with liquor ratio 1:10. When polyester fibre is heated at higher or above glass transition (T_g) temperature, so polymer chains become mobile or vibrate, increasing spaces and free volume. This creates an opportunity for the silver particles to penetrate the fibre-free volume which is trapped inside. When the temperature cools down, the fibre comes back to its original position and silver particles penetrate the fibre. So, all different shapes of polyester are treated at 130°C in the TUSJII Dyeing machine (high-pressure dyeing machine) for 20 min.

Characterization of silver particles

The morphology of silver particles deposited on the PET fibre surface was investigated by scanning under an electron microscope of Nova Nano SEM. The microstructure of blended silver-coated PET fabrics was observed on a scanning electron microscope at an accelerated voltage of 5 kV.

Preparation of socks

As different types of yarns are used for socks, the most important of them are main yarn and plaiting yarn. The yarn used on the face side of the fabric is called main yarn and the yarn used on the back side is called plaiting yarn. Due to the common availability and cost-effectiveness of cotton blended with different cross-sectional shapes polyester was selected as the main yarn. Through conducting pretests, a minimum of 20% polyester content was found to be suitable for bacterial efficiency.

In this study crew socks were produced from 20/1 Ne (29.5 tex) by blending 80:20 cotton fibre and treated polyester (PET), Coolmax (CM) and Thermolite (TL) fibres in the same machine settings in LONATI GL 544 (12 E, 144 needles and 4" diameter), labelled as S4, S5 and S6 respectively. Besides treated samples, cotton with untreated polyester, Coolmax and Thermolite fibre with the same above blend ratio was also produced to compare the properties having the same yarn count and on the same machine parameters. These samples are labelled as S1, S2 and S3 respectively.

All these yarns are used as the main yarn in socks. Main yarns are produced on a sample spinning machine LAYCOCK TEXTILE ENGLAND. This is miniature textile machinery which provides a quick approach for the evaluation of fibres and their blends. Yarns developed from all fibres had nominally the same structure, yarn count, and torsion value. Nylon-covered elastane was used in socks, in this study, as a plaiting yarn. 20 Elastane/Creora 70/24/1 i.e. 20D elastane as a core yarn, 70 Denier nylon as a covering yarn, and (24 is the number of filaments of nylon) is used as plaiting yarn. 11% of elastane in plaiting is constant in all samples. All the samples were produced by maintaining a constant stitch length of

0.57±0.01cm. Knitted socks were put under some basic finishing treatments, and appropriate scouring and bleaching processes were applied to cotton/PET, cotton/CM, and Cotton/TL samples. Scour and bleach process is performed by using 2% sodium bicarbonate and 2% hydrogen peroxide by keeping the liquor ratio 1:20 on the weight of socks at 90 centigrade temperature for 45 minutes.

Characterization

Mechanical testing of yarn

Uster Tensorapid tester was used to test all the treated and untreated yarns as per standard ASTM D 2256. An average of 10 samples were taken.

Thermo-physiological comfort properties testing

Air permeability is defined as the rate of air flow passing perpendicularly through a known area. All the samples were tested on SDL-ATLAS, M021 A, air Permeability tester as per standard ISO-9237. The air pressure differential between the two surfaces of materials was maintained at 100 Pa. The mean and SD of 10 repeats were calculated for each sock's samples.

The thermal resistance of all samples was tested by sweating-guarded hot plate SDL-ATLAS, M-2598 by the test method ISO 11092. The mean and standard deviation was calculated for 3 readings of each sample.

All the samples were tested for water vapour permeability on the PERMETEST instrument as per standard EN ISO 11092. The mean and Standard deviation of up to five measurements was noted. All the testing was done at standard conditions i.e. 21°C temperature and 65% R.H.

The PhabrOmeter system (Nu Cybertek) was used to quantify human tactile sensory perception.

PhabrOmeter determines the instrumental relative hand by standard AATCC, Test Method 202-2014, Relative Hand Value of Textiles, using the mechanical properties measured on a selected reference fabric and a comparable candidate fabric. The instrument finds relative hand value (RHV) by considering stiffness, smoothness, softness, drape and wrinkle recovery rate. It is a fabric sensory quality evaluation system that comes with intelligent software that analyses the complex, fabric force-displacement curve directly via pattern recognition theory and multivariate data analysis. The attributes tested for the present work were resilience/stiffness, softness, smoothness, and Relative hand value (RHV). The evaluation for before and after treatment of samples was done based on testing [27].

Antimicrobial properties testing/microbial inhibition

Antimicrobial properties were measured according to test method AATCC 147-1998. The bacterial strains of Gram-positive, *Staphylococcus aureus*, (ATCC 29213 strain) which had been incubated overnight, were spread on a sterile agar plate. Test specimens of each of the samples were placed onto inoculated agar plates at 37°C for 24 h. For comparison, the untreated samples were also tested for reference.

The agar plates were examined for inhibition of microbial growth underneath the samples and inhibition zone along the edges of the specimen.

Odour test

The odour test is conducted concerning SNV 19651 [28]. Before doing the test the 6 male participants were requested to wear the socks for normal working hours (8 hours) in the same working place and requested not to use any cosmetics or any other antibacterial product [29]. After the wearing trail time, the samples were separated and put into airtight bags. These samples were used for the analysis of the odour test. The control and treated samples were placed on top of 300 ml sodium carbonate solution and kept in a closed container for 15 hours. After this 6 people were requested to judge the odour intensity and rate it accordingly to the intensity scale (Grade 1: odourless, Grade 2: weak odour, Grade 3: tolerable odour, Grade 4: annoying odour and Grade 5: intolerable odour).

Statistical analysis

The mean of subjective analysis of odour intensity was calculated and ANOVA was carried out to analyse the effect of fabric structure on odour intensity. The analysis of variance was performed to study the effect of bacterial counts on the structure and participants. The correlation analysis was performed to analyse the interdependence between the factors. Both analyses were performed by using the data analysis feature in Microsoft Excel software.

RESULTS & DISCUSSION

SEM microstructure

The SEM was employed to observe the deposition of silver particles into the fibre. The SEM images shown in figure 2 depict the silver particles on the fibre, which is an indication of the efficacy of the deposition

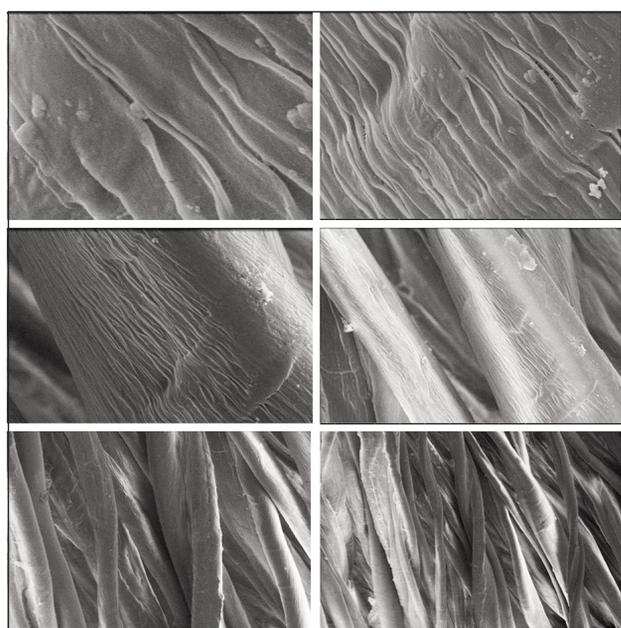


Fig. 2. SEM images of silver particle-treated antimicrobial fabric

technique. As % the age of silver particles used is very less, it has deposited in some places.

Mechanical properties of yarn

Yarn is the basic requirement for knitting and the strength of the yarn is the basic criterion for setting knitting tension. The knitting process is highly dependent on the mechanical properties of the yarn. A summary of the properties of treated and untreated yarns used in this study is given in table 1. Samples are labelled as S1-S3 for untreated and S4-S6 for treated.

Table 1

SUMMARY OF PROPERTIES OF YARN			
Sample #	Blend ratio	Breaking strength (cN/tex)	Elongation (%)
S1	C/PET	15.68	5.07
S2	C/CM	13.47	5.95
S3	C/TL	13.27	6.11
S4	C/PET	14.15	4.9
S5	C/CM	12.0	5.03
S6	C/TL	11.85	5.15

It is observed that mechanical properties are adversely affected after treatment i.e., breaking strength and elongation % of treated yarns, got decreased as shown in table 1. The results show that the deposition of silver particles affects the mechanical performance of the fibre. Ultimately, the reduction of breaking strength of treated yarn was in the range of 10 % in comparison with untreated yarn. It may be due to the heating of fibre at a high temperature and may lead to a reduction of the degree of orientation in the crystalline region of fibre during the deposition of silver particles which affects its load-bearing capacity [30, 31].

Further, it can be seen that yarn having solid circular cross-sectional fibres, has better breaking strength than channel and hollow core. Yarn made from circular cross-section fibre encourages better packing with adjacent fibres and hence leads to better inter-fibre cohesion and higher rigidness of fibres leads to the lowest elongation % [32]. The elongation % age of yarn made from circular cross-section has the lowest value due to better packing. While in hollow cross section due to higher crimp has the highest elongation %.

Thermo-physiological testing

Air permeability

The sweat could be discharged by diffusion, desorption, absorption, condensation, and air exchange rate /air passage through the fabric. The air permeability phenomenon affects sweat evaporation. It can be seen in figure 3 that treated samples have higher air permeability than the untreated ones. Air permeability of treated samples S4, S5 and S6 were found 149 mm/sec, 180 mm/sec, and 190 mm/sec respectively, while the air permeability for untreated samples S1,

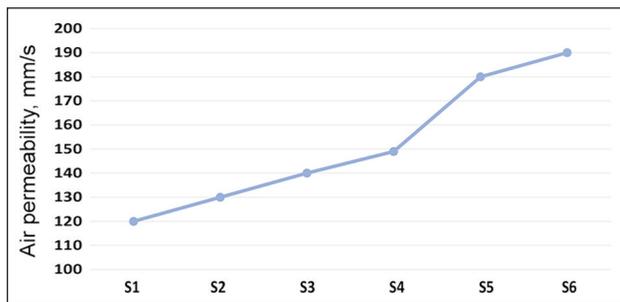


Fig. 3. Air permeability of untreated and treated socks

S2, and S3 was 120 mm/sec, 130 mm/sec and 140 mm/sec respectively. This indicates that the heating process during deposition statistically affects air permeability. Due to chain movement, the size of pores increases, and air permeability also increases [33]. It seems possible that the porosity of fabric increases. It was observed that there is not much significant difference between the air permeability values of socks knitted by different cross-sectional fibres which pointed out that the structure of fibre didn't affect much air permeability, rather fabric parameters are a more decisive parameter. Yarn made from circular cross-section fibre has the highest air permeability. Fabric knitted with circular cross-sectional fibre was observed to be more permeable to air due to the large size of their inter yarn pores [34]. The reason for this result may be because of the effect of surface area in the fabric. From the previous studies, it is also evident that the higher specific surface area of the modified cross-sectional shape offered more drag to airflow across the fabric [35].

Thermal resistance

The thermal properties of fabric determine thermal comfort sensation by measuring the heat flow through the fabric. The heat transfer from the human to the surroundings decreases as the thermal resistance of the fabric increases which increases the temperature in the microclimate. From figure 4 it can be seen that the thermal resistance of treated samples was slightly increased due to an increase in total pore volume which leads to an increase in air pockets. Air has lower thermal conductivity i.e. $0.025 \text{ Wm}^{-1}\text{K}^{-1}$ as compared to any textile fibre. The number of dead air pockets influences the overall thermal resistance of fabrics.

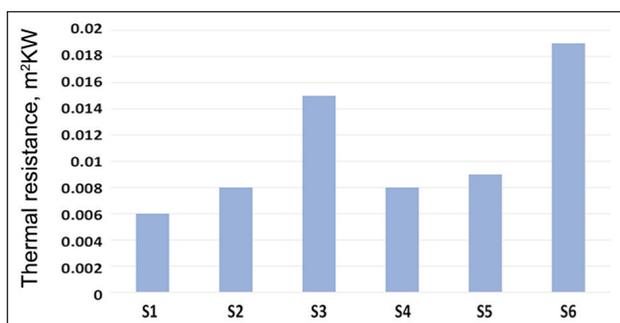


Fig. 4. Thermal resistance of untreated and treated socks

From figure 4, the results indicate that the yarns made from a blend of cotton and normal PET, Channeled PET and hollow PET provide higher thermal resistance properties that are similar to each other. It was expected that the hollow PET blended yarns would provide higher thermal resistance due to entrapped air within the fibre structure.

Relative water vapour permeability %

RWVP % defines the transfer of sweat from the body to the environment through the fabric. Fabric relative water vapour permeability % property is the replacement of fabric-air interface with fabric-water interface. A more porous structure means more resistance to water permeability. From figure 5, it can be seen that socks samples having silver deposition has a lower value than untreated which shows that during deposition, the molecular chain of different polyester fibres aligned in a new direction. The water vapour resistance showed only a minor difference, indicating that the comfort properties were conserved.

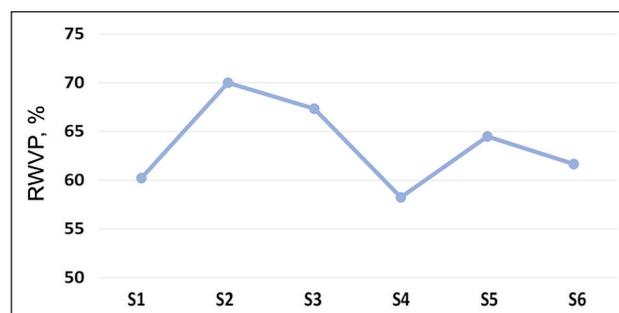


Fig. 5. Relative water vapour permeability % of untreated and treated socks

Natural fibres such as cotton don't have good moisture management properties due to their natural curly fibre structure. Changing the fibre shapes, which affect its surface area, is a reasonable way to improve the capillary force of hydrophobic PET fibre and to improve its wicking ability. As socks made of C/CM have the highest water vapour permeability % value due to channelled PET fibre which improves as reported in the literature that fabrics made of non-circular fibre exhibit higher mass flow rate than that of circular fibre. This situation can be explained by the principle of applied water vapour permeability test which is matched with the convection mass transfer law. In convection mass flow, the mass flow rate is directly proportional to the surface area along the direction of the flow. Thus, a higher (20%) fibre surface area of channelled structure leads to higher water vapour permeability characteristics as compared to conventional round polyester fibres [36]. The presence of channels on the fibre surface offers a less tortuous path for the liquid to travel. Hollow fibre can provide greater bulk and provide improved heat and moisture management properties as compared to normal polyester fibre. Due to higher surface area, samples made from these fibres have good RWVP % properties as compared to those made from conventional polyester fibres of round cross-sections.

QUANTIFIED DATA OF FABRIC HAND VALUE OBTAINED FROM PHABROMETER				
Sample #	Resilience/Stiffness	Softness	Smoothness	RHV
S1	37.43	80.8	65.15	0
S2	36.64	81.58	65.21	0
S3	32.63	81.93	64.65	0
S4	38	83.93	64.8	5.3
S5	38.5	80.5	64.96	1.32
S6	38.5	80.5	64.96	2.62

Sensorial comfort properties testing

A fabric handle is getting increasing attention in the textile and clothing industry. Sensory tactile perception without objective evaluation is very difficult to quantify and interpret hand attributes such as stiffness, softness, and smoothness. Stiffness indicates the bending of fabric which gives an objective evaluation of whether the fabric is flexible or rigid. Softness indicates the compressibility of fabric and smoothness indicates how fabric behaves when sliding a fingertip across a fabric surface i.e., resistance faced. From table 2, it is quite clear that there is not much difference between untreated and treated samples for different attributes. All the samples were as mentioned in table 2 compared for RHV, which is improved for treated samples which makes the wearer comfortable hand feeling.

Antimicrobial properties

The antimicrobial activity of treated and untreated samples was tested against *S. Aura* in figure 6, *b* shows the zone of inhibition around the sample swatch. The micrographs of the zone of inhibition indicate that all treated samples have a clear zone

and are quite effective against *S. Aura*. Whereas the untreated fabric figure 6, *a* showed no antimicrobial activity, bacterial growth can be seen in the plate containing the untreated samples (under the test specimen). The results indicate that the treated fabric reduces the bacterial population next to the skin fabric which in turn reduces the odour formation.

Effect of antimicrobial treatment on odour intensity

The subjective study was performed for control and treated samples as explained in the experimental part. The evaluation is done, specifying that almost the same trend appeared for all treated blended PET fabric. There is a significant reduction observed in all blended PET treated fabrics ($p < 0.05$). For treated fabric odour intensity is in the range of grades 1 and 2 while for untreated it is in the range of grades 4 and 5.

CONCLUSIONS

In the present work blend of cotton with different cross-sectional shapes of polyester before and after silver deposition was studied. The yarn strength, thermo-physiological comfort properties, sensorial comfort properties, antibacterial properties and odour

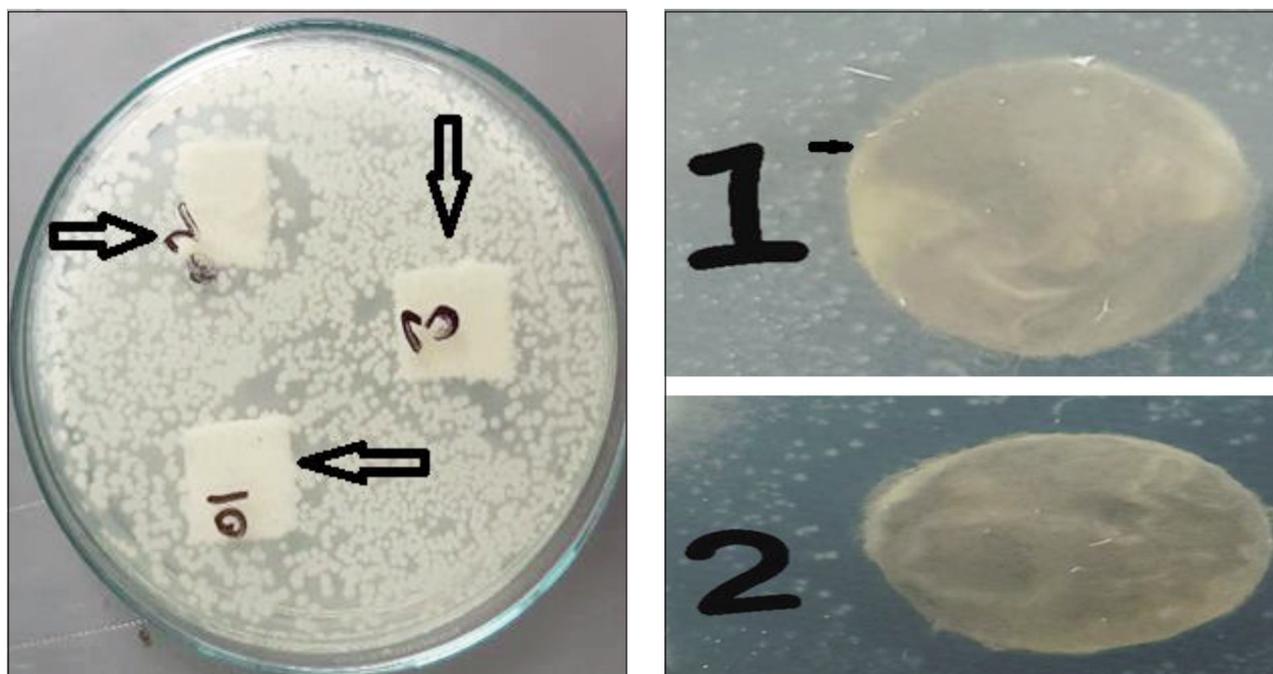


Fig. 6. Zone of inhibition against the odour-forming bacterial strain: *a* – untreated samples; *b* – treated samples

properties of developed socks were investigated. The advantage of the process that is described in this paper is a simple, efficient and one-step process. The SEM images show the deposition of silver particles without any significant damage to the structure of the fibre. Thermo physiological properties were discussed. Overall, all properties are conserved in treated samples. The performance of treated socks was investigated and the excellent killing effect of bacteria was demonstrated. A subjective assessment of

odour was also performed, and good grading is assessed. The deposition mechanism can be used for other applications of apparel products at low cost and commonly available material.

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