*ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 19, No. 3. 2013*

# Interaction of Alginate/Copper System on Cotton and Bamboo Fabrics: The Effect on Antimicrobial Activity and Thermophysiological Comfort Properties

**Muhammet UZUN** *

*Institute for Materials Research and Innovation, The University of Bolton, Deane Road, Bolton, BL3 5AB, UK*

crossref http://dx.doi.org/10.5755/j01.ms.19.3.1217

*Received 15 February 2012; accepted 16 December 2012*

Antimicrobialagent treated materials have been widely used clinically as medical devices and articles, in which the active substances, such as antimicrobial molecules, are present on or in the matrix of the surface of the devices and articles.This study aims to treat a selection of fabrics with alginate/copper, and then determine the treated fabrics'antimicrobial activity against two common Gram-positive and Gram-negative bacteria. It is also aimed to analyse and evaluate the thermophysiological properties of the treated fabrics. Cotton, organic cotton and bamboo woven fabrics were employed. The fabrics were applied in 1 %, 3 % and 5 %w/v copper solutions andsubsequentlyspecimens were subjected to 10 min and 20 min ultrasonic energy treatment. The results clearly demonstrated that the cotton and organic cotton fabrics were successfully treatedwith the alginate/copper and the treated fabrics showed considerable zone of inhibitions. The bamboo fabric did not appear to bond effectively with the copper alginate, andas the result,the fabrics did not display any improved bacterial protection against the chosen bacteria. In fact the bamboo fabric lost its natural antimicrobialproperties after the alginate and copper treatment.The thermophysiological comfort properties of the treated cotton fabrics changed significantly; on the other hand, the treated bamboo fabrics were not affected by the copper treatment.

*Keywords*: copper treatment, ultrasonic energy, antimicrobial testing, bamboo, cotton, thermophysiological comfort.

## INTRODUCTION

A common threat with antibiotic resistant bacteria is that they are spread very easily through patient-staff and patient-patient contact. These prevalent bacteria are often found on general surfaces such as the floor, radiators, and beds and are also harboured on fabrics such as hospital gowns, gloves, bed linen and curtains [1–4]. Therefore it is important that bacterial contamination in the hospital environment is minimised as this can lead to the spread of hospital-acquired infections. To prevent reservoirs of bacteria from forming, surfaces such as bed rails, bedside tables and door handles, must be cleaned and disinfected properly. However, some bacteria now have the ability to survive even after thorough treatment with disinfectant [5]. Thus there is a greater need for biocidal surfaces to help reduce cross-contamination. This has led researchers to investigate antimicrobial agents such as copper to produce biocidal surfaces. Copper has been identified as being effective against a broad spectrum of microorganisms such as *Clostridium difficile* [6], *Escherichia coli O157:H7* [7], Influenza *A* (H1N1) [8], *Listeria monocytogenes* [9], and methicillin-resistant *Staphylococcus aureus* [10]. Its antimicrobial mechanism is still unknown however there are many mechanisms that have been hypothesized, come of which include:

- copper ions have the ability to accept or donate electrons which allows the ion to participate in chemical reactions that can cause oxidative damage to microorganism cells [11, 12];
- copper ions are also believed to cause cell membrane lesions, which can lead to intracellular component leakage and thus cell apoptosis [13–14]. The important components that are leaked through the outer membrane of the microorganisms are potassium and glutamate;
- the inhibition of components of the respiratory chain and/or the $H^+$ -ATP synthesis. Complete cessation of respiration of the bacteria strain *Pseudomonas syringae* was observed by Cabral when the cells were treated with (20–25) µM $Cu^{2+}$. Cabral also noted that cells that had completely blocked respiration had lost most of their intracellular unbound potassium ions. Respiration could be restored by preventing the release of potassium ions from copper-treated bacterial cells [15–18].

It is also important to acknowledge that the spread of bacteria can also be caused by fabrics used in hospitals such as bed linen, drapes, gowns, and aprons. As these fabrics become infected they then act as vectors for bacterial transmission, which can increase the risk of hospital-acquired infections [19–21]. Of the few studies that have been conducted it is has become apparent that Gram-positive bacteria such as *staphylococci* and *enterococci* have the ability to remain on fabrics commonly used in hospitals, such as cotton, polyester and cotton-synthetic blends, for extended periods of times ranging from hours to months [22–24].

Ultrasonic washing uses ultrasonic agitation to clean or homogenize materials and to accelerate both physical and chemical reactions. Ultrasonic agitation also reduces the amount of fibre migrations when compared against conventional washing methods. These sound waves radiate into a solution in the form of a vertical wave, which causes negative acoustic pressure that causes the solution to fracture and form millions of vapour bubbles or cavities with high frequencies. These cavities then collapse

*Corresponding author: Tel.: +44-1204-903157; fax: +44-1204-900600.
E-mail: *m.uzun@marmara.edu.tr* (M. Uzun)

violently during the positive acoustic pressure cycle causing the formation of fluid jets and shockwaves, which constantly strike at the target material surface, causing stresses that erode any impurities [25 – 29].

Sodium alginate is a linear polysaccharide and it is the major component of marine brown algae. Sodium alginate can form a hydrophilic gel when in the presence of divalent cations such as copper ($Cu^{2+}$) via a unique ion exchange mechanism whereby the sodium ions attached to the carboxyl groups on the uronic acid monomers are exchanged by the copper ions, which subsequently cross-links the alginate chains together, forming a crystalline structure [30]. In this study,a novel technique of incorporating copper into some commonly used hospital fabrics by making use of sodium alginate, copper sulphate and ultrasonic energy hasbeen effectively established for the cotton based fabrics.In order to investigate the antimicrobial activity of fabrics,three different specimens of alginate absorbed fabrics were prepared by immersing them into different concentration of copper sulphate solution for 10 and 20 minutes ultrasonic energy applications. The advantage of alginate'sunique ion exchange mechanism was takento form alginate/copper soaked cotton, bamboo and organic cotton fabrics.

## MATERIALS AND METHODS

### Materials

Cotton, bambooand organic cotton were purchased from different sources in the UK market. All the fabrics were used in the as-received conditions.The fabric dimensional properties are given in Table 1. Sodium alginate, MANUCOL ® DH, was obtained from Ashland Ltd. (formerly ISP) (SA, medium viscosity (40 – 90) mPa·s (1 %), M:G ratio 61/39). Copper (II) sulphate pentahydrate was obtained from Fisher Bioreagents Ltd.

**Table 1.** Dimensional properties of woven fabrics

| | Area density (g/m$^2$) | Thickness (mm) | Bulk density (g/m$^3$) | Warp no. (cm$^{-1}$) | Weft no. (cm$^{-1}$) |
|---|---|---|---|---|---|
| Cotton | 168 ±5 | 0.5 ±0.05 | 0.335 | 30 | 20 |
| Bamboo | 170 ±5 | 0.4 ±0.05 | 0.425 | 45 | 22 |
| O.cotton | 160 ±5 | 0.5 ±0.05 | 0.320 | 36 | 13 |

Fabric area density (g/m$^{-2}$), thickness (mm) and the number of weft and warp yarn per cm were determined in accordance with BS EN 12127:1998, ASTM D1777, and ISO 4602:2010 respectively. The density of three specimens of each fabric was measured individually and the mean mass per unit area of the specimens was calculated. The thicknesses of fabrics were determined using the Shirley thickness tester.

### Methods

The fabric specimen sizes were prepared 20 cm×20 cm. The fabric specimens were fully immersed into the sodium alginate solution (2.5 % w/v) for 24 hours and then they were rinsed thoroughly with distilled water. After the rinsing, the fabrics were then bathed in thecopper sulphate solutions of different concentrations, (1 %, 3 % and 5 % (w/v))for two hours. Ultrasonic energy was applied to the fabrics under a 25 ºC degree bathing temperature under two application times, 10 and 20 minutes. The ultrasonic bath Bamdelim Sonorex Digitalwas employed for the ultrasonic applications. Thetreated fabrics were rinsed three times in distilled water and finally, the fabrics were left to dry at room temperature for 24 hours.

Antimicrobial tests – agar diffusion method (AATCC 147). The antimicrobial activities of the fabrics were tested qualitatively using the zone of inhibition method. Standard strains of bacteria were used: Gram-positive, *Stapholycoccus epidermidis* and Gram-negative organisms *Escherichia coli*. Test specimens and the untreated fabric specimens (control) were cut into 2 cm×2 cm of square pieces. The agar plates were prepared using Oxoid nutrient agar (CM0003). Sterilized agar medium was dispensed by pouring 20 ml into each of standard flat-bottomed Petri dishes. The agar was allowed to solidify and was inoculated with 500 µl culture of the test organisms. The same amount was added to all plates prior to their lawning. After lawning, all the pre-cut specimens were placed on the middle of the plates and pressed down firmly to ensure even contact and then were placed in the incubator (Swallow incubator) held at 37 ºC for 24 hours.At the end of the incubation time, the test specimens were observed. The agar under the specimen was also evaluated specifically if no zone of inhibition was observed. This assessment was made by visual examination. The evaluation was made on the basis of absence or presence of bacterial effects in the contact zone under the specimen and the possible formation of a zone of inhibition around the test specimen. Zone of inhibition method is commonly employed for determining the antibacterial efficacy of treated textile structures. The zone of inhibition is used to determine the diffusion of antimicrobial agent from its carrier into the appropriate growth media. However, the rate of diffusion of antimicrobial agent is directly related to its chemical structure, composition and concentration. The area formed without microbial growth around the test specimen, is generated by the antimicrobial substance which is diffused from the specimen. This area represents the "zone of inhibition" wherein the effect of antimicrobial agent ceases the bacterial growth. Figure 1 illustrates the zone of inhibition. The antimicrobial activity images were taken by using Nikon COOLPIX L120 digital camera under 5× magnifications.

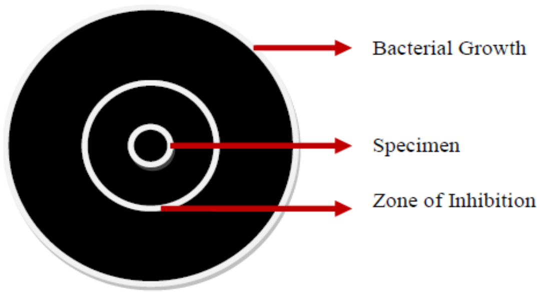


**Fig. 1.** Zone of inhibition

## Thermophysiological testing

The thermo physiological properties of the woven fabrics were determined by using an Alambeta instrument (Sensora Instruments, Czech Republic). The Alambeta instrument provides values for thermal conductivity, thermal resistance (insulation) and thermal absorbtivity (warmth-to-touch), fabric thickness and thermal diffusion. The test instrument was used to determine the transient and steady state thermo physical properties of the fabrics. The specimen's size of 20 cm×20 cm were prepared and placed in between two plates. With the two plates the heat flow through the fabric due to the different temperature of the bottom measuring plate (at ambient temperature) and the top measuring plate which is heated to 40 ºC. The thermal absorptivity of the textile structure is a measure of the amount of heat conducted away from structure surface per unit time [31 – 33]. The test was performed on dry specimens and on wet specimens, which were wetted with 0.2 mL of water on the centre of the fabrics and allowed 4 minutes to thermal recovery of the fabric. For each side (back and front side of fabric) of the untreated and treated fabrics 10 measurements were made, and the main values of the measured parameters were calculated.

Water vapour permeability and the resistance to evaporative heat loss of the fabrics were tested using the Permetest instrument (Sensora Instruments, Czech Republic). This instrument is based on a skin model, which simulates dry and wet human skin in terms of its thermal feeling [34]. The instrument uses the same principle as specified in ISO 11092 developed by Hohenstein Institute whereby a heated porous membrane is used to simulate sweating skin. The heat required for the water to evaporate from the membrane, with and without a fabric covering, is measured.

# RESULTS AND DISCUSSIONS

## Antimicrobial activity test results

Figure 2 represents the antimicrobial activity of the untreated specimens. From the images it is clear that the untreated cotton did not show any antimicrobial activity against both Gram-negative and Gram-positive bacteria as there is no apparent zone of inhibition. Whilst, for the bamboo fabric, a small zone of inhibition can be observed which is slightly larger for the Gram-positive bacteria than the Gram-negative bacteria. From previous research it has been established that the antimicrobial activity of bamboo fibre is allotted to its unique antimicrobial properties [35 – 37]. It can therefore be assumed that the untreated bamboo fabric has superior antimicrobial property as compared to the untreated cotton fabric. It can thus be suggested that to use bamboo fabric in hospital environment could be beneficial to prevent the bacterial activity.

From Figure 3, it can be observed that cotton has shown the biggest zone of inhibition as compared to bamboo and organic cotton in any stipulation i. e. for both Gram-negative and Gram-positive bacteria over the time span of 10 and 20 minutes. Also the size of the cotton and organic cotton zones of inhibition has increased with increased time of immersion in the copper sulphate solution. It is also apparent from this figure that cotton and organic cotton have shown less antimicrobial activity against the Gram-positive stains of bacterium when compared to the Gram-negative strain. This is logical as Gram-positive bacteria posses a much thicker, petidoglycan cell wall than Gram-negative bacteria and hence it is much harder to kill Gram-positive bacteria [38].

There was an unusually negligible zone of inhibition for the bamboo fabric this maybe due to some interaction between alginate/copper and the hereditary mechanism of bamboo fabrics, which might be responsible for the inactivity of bamboo fabric's natural antibacterial agent (Bamboo Kun) [39]. However, more research on this topic needs to be undertaken before association between chemical reactions of bamboo and copper is more clearly understood.

Figure 4 presents the images obtained from the preliminary visual assessment of 3 % copper treated fabrics. The experiments using a 3 % copper solution has revealed more or less similar results to 1 % copper. In this case cotton did also show the highest antimicrobial activity. Antimicrobial activity was increased with increased immersion time.

The treated bamboo fabrics did not show any sign of a zone of inhibition. For both cotton and organic cotton, their zones of inhibition were greater when compared to the 1 % solution for the same time periods. Noticeably, organic cotton fabrics did show a higher fold of increase in its antimicrobial activity compared to its activity with 1 % copper than to cotton fabrics.

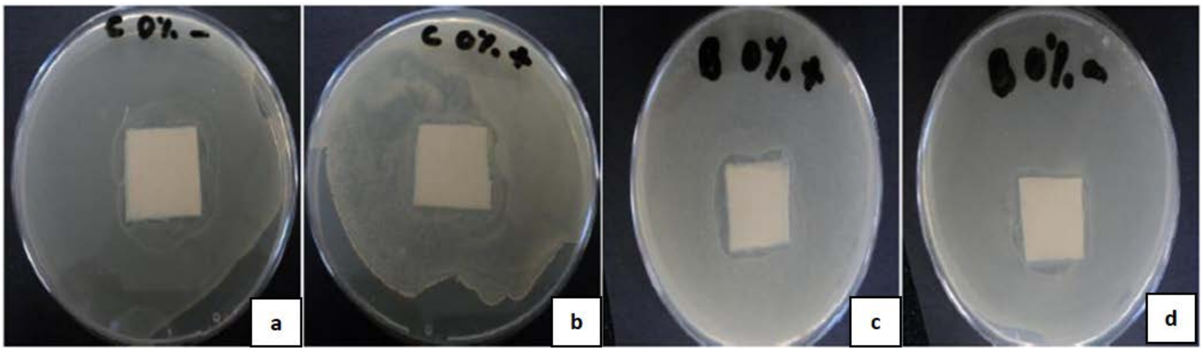


**Fig. 2.** Antimicrobial activity of untreated (a) cotton on Gram-negative bacteria (b), cotton on Gram-positive bacteria (c), bamboo on Gram–positive bacteria (d), bamboo on Gram-negative bacteria without any treatment (Blank) (AATCC147). Visual assessment

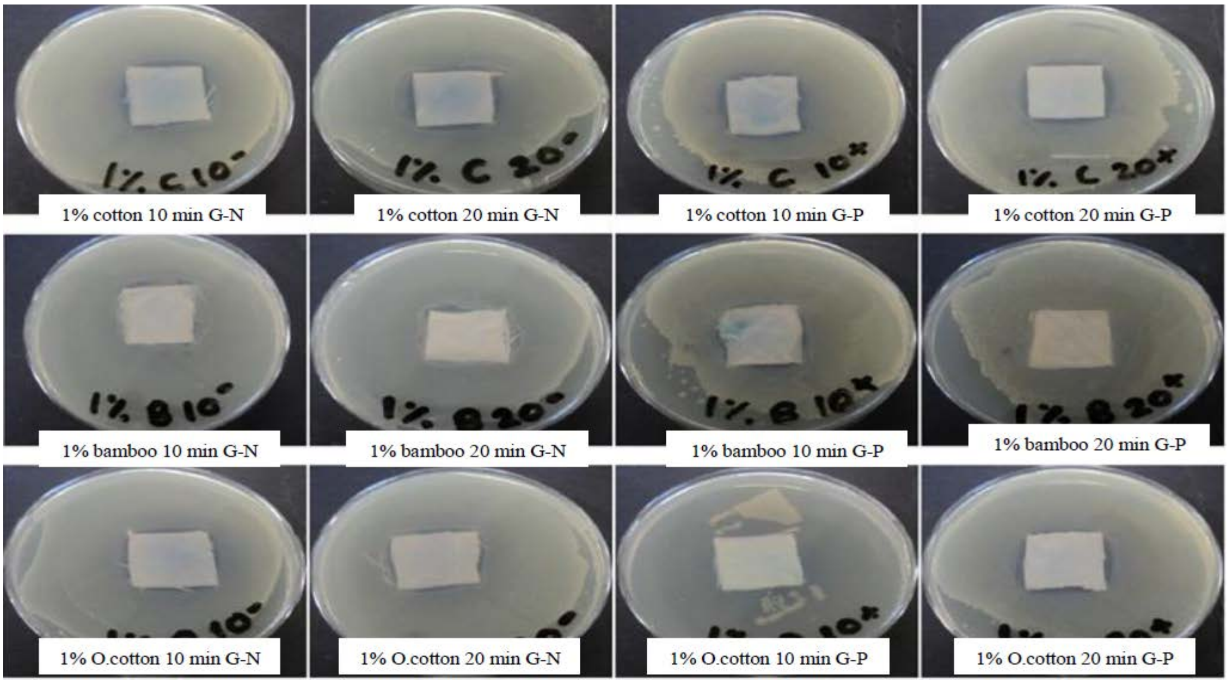


**Fig. 3.** Antimicrobial activity of cotton, bamboo and organic cotton fabrics on Gram-negative (G-N) and Gram-positive (G-P) bacteria after treatment with alginate and 1 % copper solution consecutively for time period of 10 and 20 minutes (AATCC 147). Visual assessment

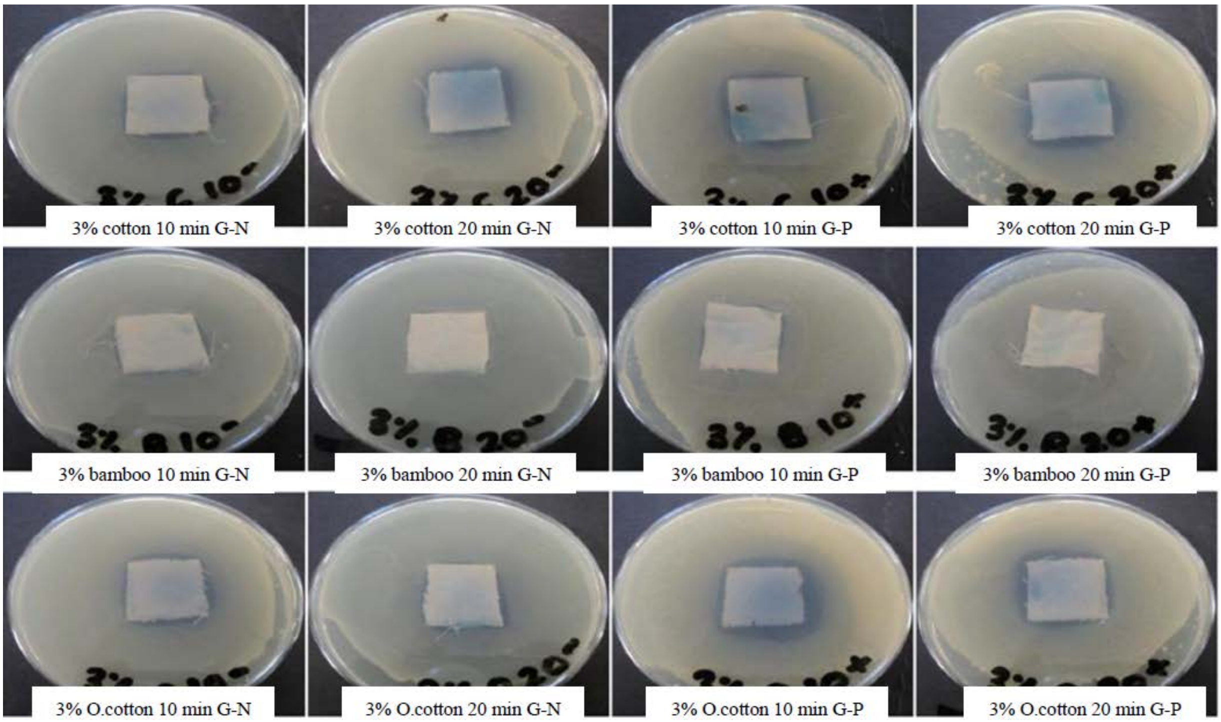


**Fig. 4.** Antimicrobial activity of cotton, bamboo and organic cotton fabrics on Gram-negative (G-N) and Gram-positive (G-P) bacteria after treatment with alginate and 3 % copper solution consecutively for time period of 10 and 20 minutes (AATCC 147). Visual assessment

Figure 5 provides the visual assessments of the 5 % treated fabrics. The results with 5 % copper solution have shown slightly decreased in antimicrobial activity with both cotton and organic cotton as compare to 3 % copper solution; however, in some cases, the differences were found to be insignificant. It is also interesting to note that even after 5 % copper treatment, the bamboo based fabrics did not show any sign of a zone of inhibition. The results of this study indicate that there is no obtained zone of inhibition against tested bacteria after the copper treatment for the bamboo fabrics. The results of this study also clearly showed a significant decrease for the treated bamboo fabrics in terms of antimicrobial property. Therefore it can be concluded that the presence of alginate/copper in the specimen may have interfered with the release of bamboo's active substance. There are several possible explanations for this result. A possible explanation for this might be that the reaction between

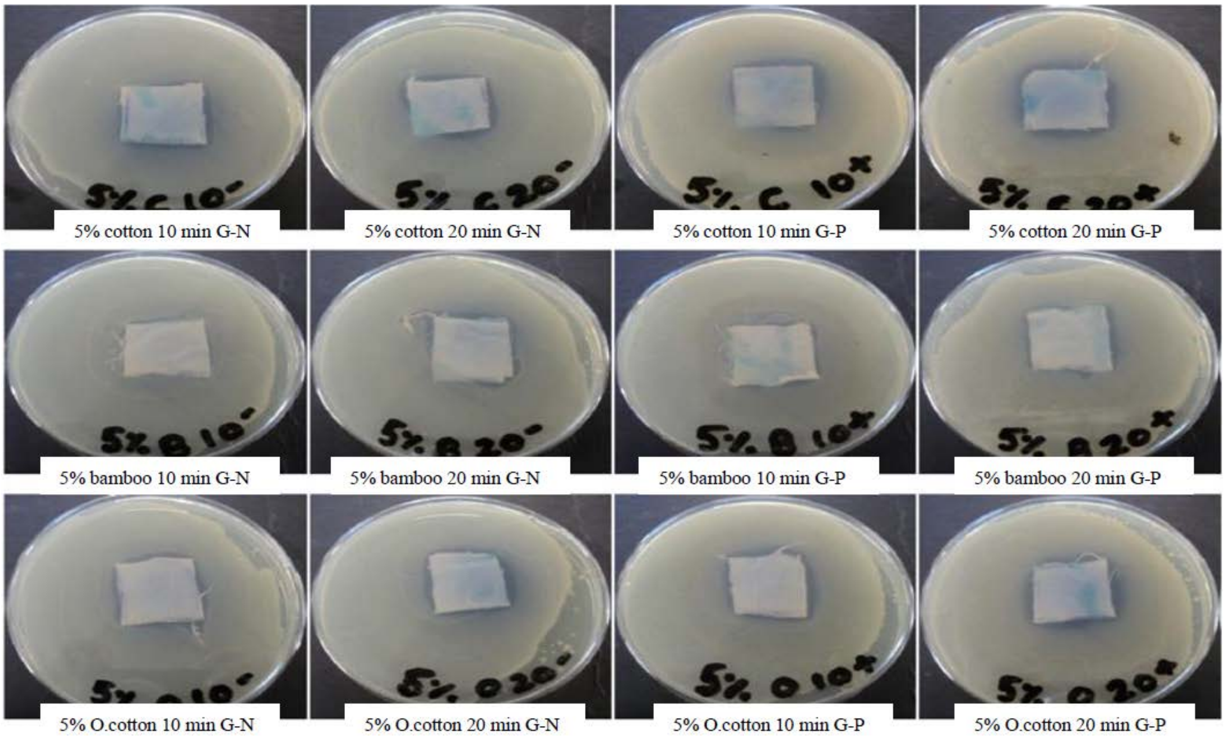


**Fig. 5.** Antimicrobial activity of cotton, bamboo and organic cotton fabrics on Gram-negative (G-N) and Gram-positive (G-P) bacteria after treatmentwith alginate and 5 % copper solution consecutively for time period of 10 and 20 minutes (AATCC 147)

bamboo fibre and copper treatment. Further research should be done to investigate the reaction, which is out of scope for this research paper. Another possible explanation for this is that the colour changes of the fabrics after the copper treatment. It was clearly observed that the cotton fabrics had colour change after the treatment due to the bright blue colour of the copper solution. It is somewhat surprising that no colour change for the bamboo fabrics were noted in this condition. It is one of the evident and explanation for the lack of antimicrobial property of the treated bamboo fabrics. In future investigations it might be possible to use a different bamboo fabric structure for a higher immersion of the copper solution and also it is possible to increase copper treatment percentage for the bamboo fabrics then it could be treated with this novel method.

## Thermal conductivity of woven fabrics in dry and wet state

There are three fundamental ways by which heat energy can be transferred through the porous materials such as woven fabrics conduction, convection, and radiation. Depending on the fibre's specific thermal conductivities, the size and configuration of the space between the fibres in the woven specimen, heat transfer mechanisms – conductive, radiative, and convective – will provide very different contributions to the overall heat transfer throughout the specimens. Very complex interactions and contributions of various heat transfer mechanisms in the overall thermal properties of woven fabrics makes the direct instrumental measurement of the thermal conductivity. The Alambeta basically gives the amount of heat, which passes from 1 $m^2$ area of tested structure through the distance 1 m within 1 s and create the temperature difference 1 K. The thermal conductivity can be calculated by using the following expression [40].

$$\lambda = (Q/F\tau)\times(\Delta T/\sigma), \text{ in } Wm^{-1}\,K^{-1}, \qquad (1)$$

where: $Q$ is the amount of conducted heat, $F$ is the area through which the heat is conducted, $\tau$ is the time of heat conducting; $\Delta T$ is the drop of temperature, $\sigma$ is the fabric thickness.

The thermal conductivity ranged from 30.1 W/mK×$10^{-3}$ to 36.6 W/mK×$10^{-3}$ in the dry state and 40.3 W/mK×$10^{-3}$ to 63.2 W/mK×$10^{-3}$ in the wet state (Table 2). The cotton fabrics obtained had the highest thermal conductivity values in their dry and wet states for all test combinations. It has been clearly seen that the presence of cotton fibres within the fabrics increases the thermal conductivity of the structures. Previous studies by the author have reported that the thermal conductivity of fabric is found to be dependent on the fibres into the structure and treatment. This thermal conductivity study produced results, which corroborate the findings of a great deal of the previous work in this field [41 – 42]. In the wet state of the fabrics, in order to allow for the thermal recovery of the fabrics, there was significant increase of the thermal conductivity of the fabrics associated with the water.

The copper treatment increases the thermal conductivity of the cotton fabrics and there is a regular increase in the cotton based fabrics. The changes are at significant level in the dry and wet states for the treated cotton fabrics. The cotton fabric, which was treated with 5 % copper solution, had the highest thermal conductivity as compared to the other combinations. This is perhaps due to the increase of copper particles on the fabric structures. The results, as shown in Table 2, indicate that the thermal conductivities of the treated bamboo fabrics were not changed in any cases. This finding supports the

**Table 2.** Thermal conductivity ($\lambda$) of woven fabrics in dry and wet states (W/mK×$10^{-3}$)

| | Untreated | | 1% | | 3% | | 5% | |
|---|---|---|---|---|---|---|---|---|
| | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet |
| Cotton | 30.1 | 52.2 | 33.1 | 58.3 | 35.7 | 60.9 | 36.6 | 62.7 |
| O. cotton | 31.2 | 60.1 | 33.9 | 61.2 | 34.5 | 63.2 | 34.9 | 63.0 |
| Bamboo | 32.9 | 40.5 | 31.8 | 40.3 | 32.2 | 41.2 | 32.0 | 42.1 |

antimicrobial and the colour observation into the treated bamboo fabrics, which they also did not show any sign of inhibition and colour change.

## Thermal resistance of woven fabrics in dry and wet state

A higher thermal resistance will cause the wearer to become uncomfortable and extremely warm. The thermal resistance property of the structures depends on the fabric thickness and thermal conductivity. The resistance is expressed by the following relationship:

$$R = h/\lambda, \text{ in } W^{-1}K\ m^2\times10^{-3}, \quad (2)$$

where: $h$ is the fabric thickness; $\lambda$ is the thermal conductivity.

The thermal resistance results are presented in Table 3. The thermal resistance of the untreated fabrics ranged from 53.2 to 69.1 $W^{-1}K\ m^2\times10^{-3}$ for the dry state and from 39.8 to 53.3 $W^{-1}K\ m^2\times10^{-3}$ for the wet state. In the dry and wet states, the untreated bamboo fabric had relatively higher thermal resistance value as compared to the other fabrics. It has been observed that when the fabrics were wetted, the thermal resistance of the fabrics decreased significantly. The copper treatment influences the resistance properties of the cotton fabrics significantly. The treated cotton fabrics had significantly higher thermal resistance than their untreated counterparts.

This study produced thermal resistance of the cotton fabric results which corroborate the findings of a great deal of the previous copper treated studies by the author. It is also interesting to note that in contrast to earlier findings on laundering and comfort relationships; however, it has been also found that the thermal resistance of treated fabrics increases, although the cotton fabrics were washed and rinsed before the retesting [42]. The most likely causes of this increase due to the deterioration of fibres' moisture regain because of the copper treatment. The moisture regain has a great influence on wear comfort of fabrics. Contrary to expectations, the copper treatment kept the resistance properties of bamboo fabrics similar to the untreated form, it was expected that the rinsing process after the treatment could reduce the resistance drastically. The thermal resistance properties of bamboo fabrics did not change significantly.

In general, there was a correlation between thermal resistance and copper concentrations for the treated cotton fabrics and the differences between varied ratios of the treatment are important and 5 % treated fabrics have higher thermal resistance as compared to 1 % and 3 % treated cotton fabrics. The results of this study indicate that the copper treatment influence the thermal resistance of the cotton fabrics, conversely. The untreated fabrics can give relatively drier and cooler feelings when in contact with the skin as compared to the treated fabrics.

## Thermal absorptivity of woven fabrics in dry and wet state

Lower thermal absorptivity causes a warm feeling and diametrically higher thermal absorptivity value tends to give a cooler feeling. The thermal absorptivity can be measured by an Alambeta instrument and the value and is calculated by the following equation [31]:

$$b = \sqrt{\lambda\times\rho\times c}, \text{ in } Ws^{1/2}\ m^{-2}\ K^{-1}, \quad (3)$$

where: $\lambda$ is the thermal conductivity; $\rho$ is the fabric density; $c$ is the specific heat of the fabric.

The thermal absorbtivity of the fabrics are given in Table 4. The untreated and treated bamboo fabricswere observed to have the lowest thermal absorbtivity. The cotton fabrics had superior thermal absorbtivity. The

**Table 3.** Thermal resistance ($R$) of woven fabrics in dry and wet states ($W^{-1}K\ m^2\times10^{-3}$)

| | Untreated | | 1 % | | 3 % | | 5 % | |
|---|---|---|---|---|---|---|---|---|
| | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet |
| Cotton | 53.2 | 39.8 | 73.5 | 50.9 | 81.8 | 55.6 | 88.1 | 65.2 |
| O. cotton | 63.6 | 41.1 | 70.5 | 48.2 | 90.5 | 59.9 | 101.5 | 68.9 |
| Bamboo | 69.1 | 53.3 | 73.3 | 55.0 | 72.5 | 55.2 | 75.0 | 55.5 |

**Table 4.** Thermal absorbtivity ($b$) of woven fabrics in dry and wet states (W $m^{-2}$ $s^{0.5}$ $K^{-1}$)

| | Untreated | | 1 % | | 3 % | | 5 % | |
|---|---|---|---|---|---|---|---|---|
| | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet |
| Cotton | 88 | 148 | 76 | 135 | 73 | 128 | 70 | 125 |
| O. cotton | 75 | 145 | 69 | 138 | 66 | 130 | 62 | 125 |
| Bamboo | 42 | 89 | 40 | 92 | 43 | 90 | 40 | 93 |

**Table 5.** Water vapour permeability (WVP) (%) and the resistance to evaporative heat loss (REHL) ($m^2$ Pa $W^{-1}$)

| | Untreated | | 1 % | | 3 % | | 5 % | |
|---|---|---|---|---|---|---|---|---|
| | WVP | REHL | WVP | REHL | WVP | REHL | WVP | REHL |
| Cotton | 66.9 | 2.8 | 65.0 | 3.0 | 64.0 | 3.3 | 63.1 | 3.4 |
| O. cotton | 65.1 | 2.9 | 64.8 | 3.1 | 63.5 | 3.3 | 62.0 | 3.5 |
| Bamboo | 58.5 | 3.6 | 58.3 | 3.6 | 58.5 | 3.8 | 58.1 | 3.9 |

thermal absorbtivity wet states of the fabrics were found to be significantly higher as compared to the dry state of the fabrics. The difference between 1 % and 5 % treated cotton fabrics are also found to be noteworthy. The 1 % treated cotton fabrics had higher thermal absorbtivity than the 5 % treated cotton fabrics. It is apparent from this table that the thermal absorbtivity of the treated cotton fabrics are significantly lower as compared to the untreated cotton fabrics. The absorbtivity of bamboo fabrics were not affected by the treatment due to the lack of interfering between copper and bamboo fabrics.

## Water vapour permeability and resistance to evaporative heat loss (Permetest)

The Water Vapour Permeability (WVP) depends on the water vapour resistance, which indicates the amount of resistance against the transport of water through the fabric structure. The amount of water present in a garment (which has a crucial importance in the level of comfort) must to be a minimum. The relative WVP is expressed using the following formula:

$$WVR = Q_s\,(Wm^{-2}) \,/\, Q_0\,(Wm^{-2}) \times 100, \text{ in } \%, \quad (4)$$

where: $Q_s$ is the the heat flow with the fabric specimen; $Q_0$ is the the heat flow without the fabric specimen

The WVP and resistance to evaporative heat loss (REHL) results are presented in Table 5. The study of WVP and REHL was performed by using Permetest instrument. The treated cotton fabrics had lower WVP as compared to their untreated counterparts. It is clear from Table 5 that the copper concentrations have a significant effect on the WVP properties of the tested cotton fabrics. This is perhaps due to the effect of treatment, which could make the fabric structures more close and tight, therefore the permeability of treated fabrics decrease drastically. Table 5 also shows that the REHL of the treated cotton fabrics were reported significantly higher than the untreated cotton fabrics. The bamboo containing fabrics had better REHL as compared to the cotton fabrics. The treated bamboo fabrics had the similar WVP and REHL values which their untreated forms had.

## CONCLUSIONS

In conclusion, it may be stated that application of alginate/cotton treatment imparts the antimicrobial properties in the cotton fabrics. The results clearly demonstrated that the cotton and organic cotton fabrics were successfully treated with the alginate/copper and the treated fabrics showed considerable zone of inhibitions. The treated bamboo fabrics did not display any improved bacterial protection against the chosen bacteria. In fact the bamboo fabric lost its natural antimicrobial properties after thecopper treatment. From the result of 3 % and 5 % copper solution it revealed that after reaching to certain level of copper concentration fabric became saturated and it did not show antimicrobial activity in linear relation with copper concentration. Also exposure time to ultrasonic application has shown linear relationship with the antimicrobial activity of the fabrics in cotton and organic cotton regardless of the concentration of copper solution. In all the cases higher antimicrobial activity was observed against the *Escherichia coli*.

The bamboo fabric's surface did not appear to bond effectively with the alginate/copper. There are three evidences found in this study that could prove the lack of effective chemical bonding between the copper treatment and bamboo fabric. a) There is no colour change after the treatment (in visual assessment); b) As shown in the results part of the study, there is no antimicrobial activity for bamboo fabrics after the treatment; and c) Both Alambeta and Permetest results clearly proven that the thermophysiological comfort properties of the treated bamboo fabrics did not have any significant changes in comparison with their untreated forms. By contrast, the copper treated cotton fabrics had significantly different test results than their untreated counterparts. One of the more significant findings to emerge from this study is that regenerated cellulose bamboo fibre based fabrics had a great different reaction with copper treatment as compared the cellulosic cotton fibre based fabrics.


## *Acknowledgments*

The author would like to thank Ms India Rose Sweeney and Mr Vijay Parikh for supports during the project and gratefully acknowledge the support of the Turkish Higher Education Foundation.


### REFERENCES


1. **Dancer, S. J.** The Role of Environmental Cleaning in the Control of Hospital-acquired Infection *The Journal of Hospital Infection* 73 (4) 2009: pp. 378 – 385.
2. **Ray, A. J., Hoyen, C. K., Das, S. M., et al.** Nosocomial Transmission of Vancomycin-resistant Enterococci from Surfaces *The Journal of the American Medical Association* 287 2002: pp. 1400 – 1401.
3. **Hochmuth, P., Magnuson, J., Owens, K.** Survival of Vancomycin-resistant Enterrococcus Faecium on Acrylic Nails, Bed Linen, and Plastic Keyboard Covers *American Journal of Infection Control* 33 (5) 2005: p. 32.
4. **Hillocks, L. A., Owens, K. L.** Cross-contamination of Clostridium Difficile Spores on Bed Linen during Laundering *American Journal of Infection Control* 36 (5) 2008: pp. 24 – 25. http://dx.doi.org/10.1016/j.ajic.2008.04.025
5. **Russell, A. D.** Bacterial Resistance to Disinfectants: Present Knowledge and Future Problems *Journal of Hospital Infection* 43 1999: pp. 57 – 68. http://dx.doi.org/10.1016/S0195-6701(99)90066-X

6. **Weaver, L., Michels, H. T., Keevil, C. V.** Survival of Clostridium Difficile on Copper and Steel: Futuristic Options for Hospital Hygiene *Journal of Hospital Infection* 68 2008: pp. 145 – 151. http://dx.doi.org/10.1016/j.jhin.2007.11.011
7. **Noyce, J. O., Michels, H., Keevil, C. W.** Potential Use of Copper Surfaces to Reduce Survival of Epidemic Methicillin-resistant Staphylococcus Aureus in the Healthcare Environment *Journal of Hospital Infection* 63 2006: pp. 289 – 297.
8. **Noyce, J. O., Michels, H. T., Keevil, C. W.** Inactivation of Influenza A Virus on Copper versus Stainless Steel Surfaces *Applied and Environmental Microbiology* 2007: pp. 2748 – 2750.
9. **Wilks, S. A., Michels, H. T., Keevil, C. V.** Survival of Listeria Monocytogenes Scott A on Metal Surfaces: Implications for Cross-contamination *International Journal of Food Microbiology* 111 (2) 2006: pp. 93 – 98. http://dx.doi.org/10.1016/j.ijfoodmicro.2006.04.037
10. **Noyce, J. O., Michels, H. T., Keevil, C. V.** Potential Use of Copper Surfaces to Reduce Survival of Epidemic Methicillin-resistant Staphylococcus Aureus in the Healthcare Environment *Journal of Hospital Infection* 62 2006: pp. 289 – 97.
11. **Kuwahara, J., Suzuki, T., Funakoshie, K., Sugiura, K. Y.** Photosensitive DNA Cleavage and Phage Inactivation by Copper (II)-camptothecin *Biochemistry* 25 (6) 1986: pp. 1216 – 21. http://dx.doi.org/10.1021/bi00354a004
12. **Rodriguez, M. L., Cruz-Rodriguez, L. D., et al.** Membrane-Associated Redox Cycling of Copper Mediates Hydroperoxide Toxicity in Escherichia Coli *Biochimica et Biophysica Acta* 1144 1993: pp.77 – 84.
13. **Borkow, G., Okon-Levy, N., Gabbay, J.** Copper Oxide Impregnated Wound Dressings: Biocidal and Safety Studies *Wounds* 22 (12) 2010: pp. 301 – 310.
14. **Cervantes, C., Gutierrez-Corana, F.** Copper Resistance Mechanisms in Bacteria and Fungi *FEMS Microbiological Reviews* 14 1994: pp. 121 – 137.
15. **Cabral, J. P. S.** The Antimicrobial Action of Cupric Ions in Pseudomonas Syringae *FEMS Microbiology Letters* 79 1991: pp. 303 – 308. http://dx.doi.org/10.1111/j.1574-6968.1991.tb04546.x
16. **Sani, R. K., Peyton, B. M., Brown, L. T.** Copper-Induced Inhibition of Growth of Desulfovibrio Desulfuricans G20: Assessment of Its Toxicity and Correlation with Those of Zinc and Lead *Applied and Environmental Microbiology* 67 (10) 2001: pp. 4765 – 4772.
17. **Nies, D. H.** Microbial Heavy-metal Resistance *Applied Microbiology and Biotechnology* 51 1999: pp. 730 – 750. http://dx.doi.org/10.1007/s002530051457
18. **Kuhn, P. J.** Doorknobs: A Source of Nosocomial Infection? *Diagnositic Medicine* Nov/Dec. 1983.
19. **Esel, D., Dogan, M., Bozdemir, N., et al.** Polymicrobial Ventriculitis and Evaluation of an Outbreak in a Surgical Intensive Care Unit due to Inadequate Sterilization *Journal of Hospital Infection* 50 2002: pp.170 – 174.
20. **Standaert, S. M., Hutcheson, R. H., Schaffner, F.** Nosocomial Transmission of Salmonella Gastroenteritis to Laundry Workers in a Nursing Home *Infection Control* and *Hospital Epidemiology* 15 1994: pp. 22 – 26. http://dx.doi.org/10.1086/646813
21. **Scott, E. Bloomfield, S. F.** The Survival and Transfer of Microbial Contamination via Cloths, Hands and Utensils *Journal* of *Applied Bacteriology* 68 1990: pp. 271 – 278. http://dx.doi.org/10.1111/j.1365-2672.1990.tb02574.x
22. **Beard-Pegler, M. A., Stubbs, E., Vicery, A. M.** Observations on the Resistance to Drying of Staphylococcal Strains The *Journal* of *Medical Microbiology* 26 1988: pp. 251 – 255.
23. **Neely, A. N., Maley, M. P.** Survival of Enterococci and Staphylocooci on Hospital Fabrics and Plastic *Journal of Clinical Microbiology* 38 (2) 2000: pp.724 – 726.
24. **Hurren, C., Cookson, P., Wang, X.** The Effects of Ultrasonic Agitation in Laundering on the Properties of Wool Fabrics *Ultrasonic Sonochemistry* 15 2008: pp.1069 – 1074. http://dx.doi.org/10.1016/j.ultsonch.2008.04.002
25. **Sun, D., Guo, Q., Liu, X.** Investigation into Dyeing Acceleration Efficiency of Ultrasound Energy *Ultrasonic* 50 2010: pp. 441 – 446.
26. **Juan, A. G. J.** High-power Ultrasonic Processing: Recent Developments and Prospective Advances *Physics Procedia* 3 2010: pp. 35 – 47.
27. **Akalin, M., Merdan, N., Kocak, D., Usta, I.** Effects of Ultrasonic Energy on the Wash Fastness of Reactive Dyes *Ultrasonic* 42 2004: pp. 161 – 164.
28. **Canoglu, S., Gultekin, B. C., Yukseloglu, S. M.** Effect of Ultrasonic Energy in Washing of Medical Surgery Gowns *Ultrasonic* 42 2004: pp. 113 – 119.
29. **Uzun, M. Patel, I.** Mechanical Properties of Ultrasonic Washed Organic and Traditional Cotton Yarns *Journal* of Achievements in *Materials and Manufacturing Engineering* 43 2010: pp. 608 – 612.
30. **Grant, G. T., Morris, E. R., Rees, D. A., et al.** Biological Interactions between Polysaccharides and Divalent Cations: The Egg-box Model *FEBS Letter* 32 1973: pp. 195 – 98. http://dx.doi.org/10.1016/0014-5793(73)80770-7
31. **Pereira, S., Anand, S. C., Rajendran, S. Wood, C.** A Study of the Structure and Properties of Novel Fabrics for Knee Braces *Journal of Industrial Textiles* 36 2007: pp. 279 – 300.
32. Alambeta Measuring Device: Users' Guide Version 2.3, Sensora Instrument Liberec, Company Brochure.
33. **Splendore, R., Dotti, F., Cravello, B., Ferri, A.** Thermo-physiological Comfort of a PES Fabric with Incorporated Activated Carbon-Part 1: Preliminary Physical Analysis *International Journal of Clothing Science and Technolog*y 22 (5) 2010: pp. 333 – 341.
34. **Hes, L.** Non-destruction Determination of Comfort Parameters during Marketing Functional Garment and Clothing *Indian Journal* of *Fibre* & *Textile Research* 33 2008: pp. 239 – 245.
35. **Devi, M. R., Poornima, N. Priyadarshini, S. G.** Bamboo-The Natural, Green and Eco-friendly New-type Textile Material of the 21st Century *Journal of Textile Association* Jan. – Feb. 2007
36. **Gericke, A., Van der Pol, A.** Comparative Study of Regenerated Bamboo, Cotton and Viscose Rayon Fabrics. Part 1: Selected Comfort Properties *Journal of Family Ecology and Consumer Sciences* 38 2010.
37. **Erdumlu, N. Ozipek, B.** Investigation of Regenerated Bamboo Fibre and Yarn Characteristics *Fibres & Textiles in Eastern Europe* 16 4 (69) 2008: pp. 43 – 47.
38. **Beveridge, T. J.** Structures of Gram-Negative Cell Walls and Their Derived Membrane Veiscles *Journal of Bacteriology* 181 (16) 1999: pp. 4725 – 4733.
39. http://www.swicofil.com/bamboo.pdf (Accessed on 20.07.2012)
40. **Frydrych, I., Dziworska, G., Bilska, J.** Comparative Analysis of the Thermal Insulation Properties of Fabrics Made of Natural and Man-made Cellulose Fibres *Fibres & Textiles in Eastern Europe* October/December, 2002: pp. 40 – 44.
41. **Uzun, M.** An Investigation of the Effects of Ultrasonic and Traditional Washing Methods on Thermal Comfort Properties of Woven Fabrics *The Journal of Textiles and Engineers* 86 19 2012.
42. **Uzun, M.** Ultrasonic Washing Effect on Thermophysiological Properties of Natural Fabrics *Journal of Engineered Fibres and Fabrics* 8 (1) 2013 (in press).