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The Effects of Quat-Silane Antimicrobials on the Physical and Mechanical Properties of Cotton and Cotton/Elastane Fabrics Used for Clothing

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Abstract Samples were treated with quat-silane to achieve antimicrobial property for further designs to help bacteria resistant during use. In this study, the physical and mechanical properties of quat-silane treated cotton and cotton/elastane fabrics in comparison with untreated control samples were investigated. Results showed that a small significant decrease was observed for tensile strength (strip and grab methods), tear strength and seam strength. A small significant decrease was observed with the increase in quat-silane concentration for all samples. Panama weaves showed the lowest tensile strength and the highest tear strength and a small significant decrease was observed for all treated samples. Antimicrobial tests showed that all treated samples have a very good antimicrobial activity.

***Keywords*— Quat-silane, tensile strength, tear strength, seam strength, cotton, elastane.**

I. INTRODUCTION

Antimicrobial textiles are classified as those textile and fibrous materials subjected to various finishing techniques to afford protection for both the user of textile materials (against bacteria, yeast, dermatophytic fungi and other related microorganisms for aesthetic, hygienic or medical purposes) [1]. The textile itself (biodeterioration caused by mould, mildew and rot producing fungi) without negatively affecting the other important characteristics of the textiles [2-5].

With a view to develop antimicrobial textile materials, considerable research has been carried out by making use of organic and inorganic compounds, antibiotics, heterocyclics, quaternary ammonium compounds [6]. Several studies have been carried out ranging from fundamental aspects to development of antimicrobial fabrics. Antibacterial polyester fabrics have been developed by imbuing antibacterial agents into the structure of fibers rather than depositing on their surface for longer durability and effect. It is stated that the efficacy of the finished fabric to arrest the growth of Staphylococcus aureus and Escherichia coli is about 5 times higher than the conventional materials. A synergistic system of formulation comprising of inorganic chemicals involving a metal salt of a monocarboxylic acid, a carbonic acid derivative, a chelating agent, a boron compound, a dimethylene siloxane derivative and an alkane polymer has been proved to serve as an effective antimicrobial agent in arresting the growth of several bacteria, fungi and mildew. Hospital trials showed a dramatic decrease in bacteria, fungi and mildew growth in treated fabrics. The treatment also prevents the deterioration of fabrics by microorganisms [7]. Chitosan treatment on cotton renders antimicrobial activity. Chitosan treated cotton fabric showed a high reduction rate in the number of colonies [8]. Fabrics made from viscose fibers containing polysilicic acid (Visil) and aluminum silicate (Visil AP) have been given urea peroxide treatment to make them antibacterial as well as deodorizing. Instead of treating the surface of the fabrics with polymer coating, antibacterial additives have been imbedded into the fabric's polymer fibers for the production of antibacterial gowns [9].

The ideal biocidal textile materials for medical use should possess rapid inactivation of a broad spectrum of microorganisms [10,11], non-selective and non-immutable to pathogens, non-toxic and environmentally friendly, durable to repeated washes and easy to recharge in laundering or disinfection processes [12]. In addition, the recharging agents should be non-toxic, available at home, and compatible with our laundering chemicals such as detergents or bleaching agents [13]. The number of healthcare equipment manufacturers incorporating antimicrobial properties in their products has increased dramatically in recent years. Various types of antimicrobial chemical agents are used to impart antimicrobial properties to textiles. They have different properties and mechanisms [14,15]. Quaternary ammonium cations, also known as quats, are positively charged polyatomic ions of the structure NR4+, R being an alkyl group or an aryl group (Figure 2.6) [16,17]. Quats have antimicrobial effect against; Vegetative bacteria, yeast, molds, algae, viruses [18-22]. The chemical structure is presented in Figure 1.

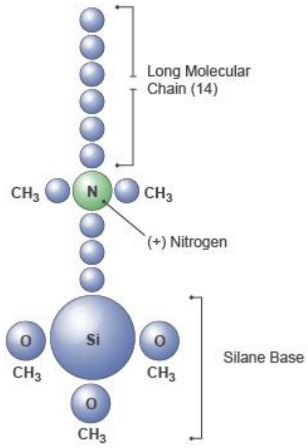

Fig.1. Chemical Structure of QAC [23].

QAC ANTIMICROBIAL MECHANISM

QACs have antimicrobial effect against a broad range of microorganisms including vegetative bacteria, yeast, molds, algae, and viruses [24-26]. The growth inhibitory activity of QACs is higher for gram-positive bacteria and algae compared with gram-negative bacteria and molds. Quats are positively charged polyatomic ions of the structure. It disrupts the virus, bacteria etc, by use of chemicals [27-29]. Silanes are extremely efficient bonding agents that can be coupled to other molecules and then used to permanently bond those molecules to a target surface [30-33].

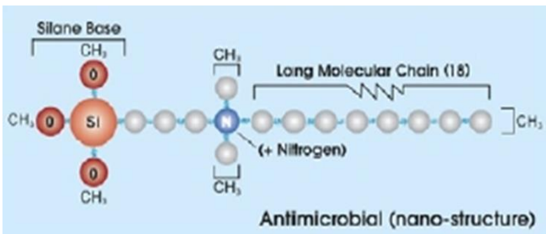

Fig. 2. Quat-silane working mechanism [33].

In this study, the physical, and mechanical properties of quat-silane treated samples in comparison with untreated control samples was investigated in order to point out the change in performances of cotton and cotton elastic fabrics that will be used for clothing for further designs.

II. EXPERIMENTAL PART

A. Materials

Quat-silane was obtained from Aegis Microbeshield. Fabrics were obtained from Wallmart. They are desized, scoured and bleached 100% cotton (Co) and 97% Co / 3% cotton/elastane fabrics. Initial properties of the fabrics are presented in Table 1.

TABLE 1.
INITIAL PROPERTIES OF FABRICS

Fabric Code	Fabric Structure	Fiber Content	Weight (g/m^2)
A	1/1 plain	97% Co / 3% elastane	132.5
B	1/1 plain	100% Co	112.8
C	2/2 panama	100% Co	120.3
D	2/1 twill	100% Co	262.1

B. Treatment of fabric samples with quat-silane

First quat-silane hydrolyzed to 2% active quat-silane for 24h at room temperature and stirred continuously for 10 min at magnetic mixer. Pad-dry-cure method was used to apply quat-silane antimicrobial using a laboratory type padding machine. The fabrics were squeezed to a wet pickup of %85. The samples were treated with 2,0 wt. %, 2,5 wt.%, 3,0 wt. % quat-silane antimicrobial agents for 30min. for 1h, dried at 85oC for 5 min and cured at 160oC for 3 min.

In the referencing system for fabric samples, the cotton/elastane plain wovens were prefixed with a ‘A’, ‘B’ for the cotton plain wovens, ‘C’ for the cotton 2/2 panama wovens, ‘D’ for the cotton 2/1 twill wovens, for fabric samples treated with different concentrations, the samples treated with 2,0 wt. % quat-silanes were prefixed with a ‘X’, ‘Y’ for the fabric samples treated with 2,5 wt.% quat-silanes, ‘Z’ for the fabric samples treated with 3,0 wt. % quat-silanes and ‘U’ for the untreated samples.

C. Methods

Antimicrobial Activity

The experimental method used to determine the antimicrobial effects was AATCC Test Method 100: 2004 “Assessment of Antibacterial Finishes on Textiles” Standards, using Staphylococcus Aureus ATCC 6538 (2.00 x 105 CFU/ml) test inoculum. The variables were calculated from Equation (1) respectively.

$$R = (100\,(C-A))/C \qquad (1)$$

R is the percentage reduction of bacteria,
A is the number of bacteria recovered from the inoculated treated sample,
C is the number of bacteria recovered from the inoculated untreated control sample.

Physical and Mechanical Properties

Physical and mechanical properties were tested in order to evaluate the fabric properties in terms of tensile strength (strip and grab method), stitch strength and tear strength before and after antimicrobial treatments. The samples were conditioned for 24 hours at 20ºC, 65% relative humidity in the physical testing lab before testing. Tensile strength (strip method), tensile strength (grab mehod), tear strength, and seam strength were measured according to relevant standards (ISO 13934-1, 2013; ISO 13934-2, 2014; ISO 13937-1, 2000; ISO 13936-1, 2004).

Statistical Analysis

The statistical analysis of the experimental data was performed using JMP version 8.0.2 software package (SAS Institute, Inc., Cary, NC). The statistical analysis includes the analysis of variance (ANOVA). For the one-way ANOVA, p-values less than 0.05 were considered statistically significant.

III. RESULTS AND DISCUSSION

A. Antimicrobial activity

The antimicrobial properties of the control and quat-silane samples bound with cotton and cotton/elastane samples are presented in Table 2. The total population of Staphylococcus aureus (S. aureus) ATCC 6538 on each sample was determined. After the antimicrobial tests were performed, the live vibrio concentration of the standard blank sample at zero contact time, as well as that of a standard blank sample oscillated for 24h and that of the antimicrobial fabric sample oscillated for 24h, were compared. It has found that quat-silanes were strongly fastened to cotton and cotton/elastane fabrics and the modified fabrics have a very good antimicrobial activity. No significant change was observed with the increase in quat-silane concentration from X to Y and when the quat-silane concentration increased from Y to Z, the percentage of bacteria showed a small significant decrease.

TABLE 2.
ANTIMICROBIAL TEST RESULTS OF THE CONTROL AND QUAT-SILANE BOUND WITH COTTON AND COTTON/ELASTANE SAMPLES.

Samples	Test Organism: ATCC 6538 Staphylococcus Aureus (CFU/sample)		Percentage Reduction of Bacteria (R)
	Inoculated Sample at 0 contact time (cfu/mL)	Inoculated Sample at 24 hours oscillation (cfu/mL)	
U	0	0	0
X	$1.94x10^5$	$1.40x10^3$	99
Y	$1.94x10^5$	$1.40x10^3$	99
Z	$1.93x10^5$	$1.03x10^4$	95

B. Tensile strength (strip method)

Results are presented in Figure (3-4). A small significant decrease in tensile strength was observed after quat-silane treatments and a small significant decrease was observed with the increase in quat-silane concentration. It was observed the quat-silane treatment caused a restriction in the movement of yarns in the structure resulting a significant decrease in the elasticity. Cotton plain fabrics showed the highest tensile strength in warp direction. Panama fabrics showed the lowest tensile strength in warp direction while they showed the highest tensile strength in weft direction.

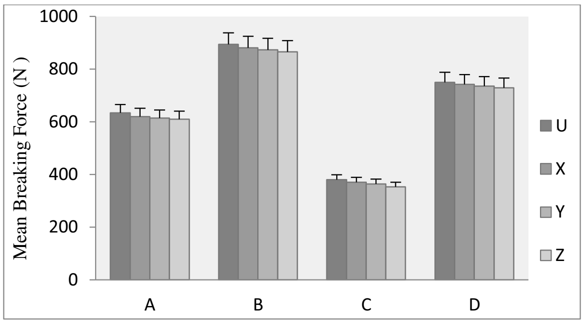

Fig. 3. Tensile strength (strip method) in warp direction for untreated and treated fabric samples

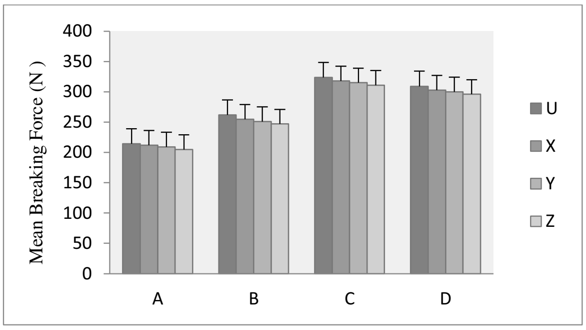

Fig.4. Tensile strength (strip method) in weft direction for untreated and treated fabric samples.

C. Tensile strength (grab method)

Results are presented in Figure (5-6). A small significant decrease in tensile strength was observed after quat-silane treatments and a small significant decrease was observed with the increase in quat-silane concentration. This is attributed to quat-silane treatment caused a swelling of fibers in the fabric structure which decreased the number of yarns per area resulting a restriction in the movement of the yarns. Cotton plain fabrics showed the highest tensile strength and panama fabrics showed the lowest tensile strength in warp direction. Twill fabrics showed the highest tensile strength and cotton/elastane fabrics showed the lowest tensile strength in weft direction.

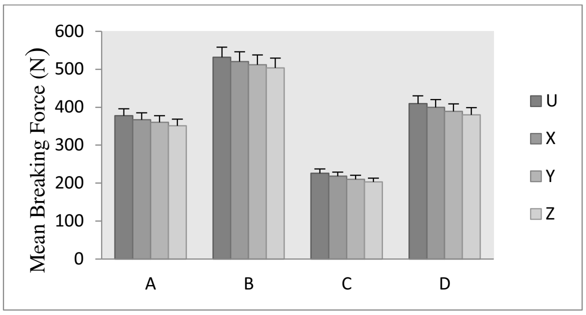

Fig.5. Tensile strength (grab method) in warp direction for untreated and treated fabric samples.

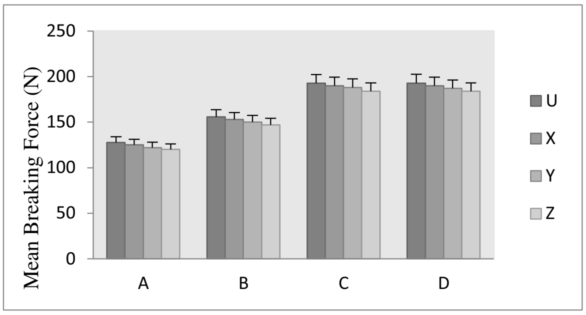

Fig.6. Tensile strength (grab method) in weft direction for untreated and treated fabric samples

D. *Effect of quat-silane treatment on tensile strength*

ANOVA one-way was used to analyze the effect of quat-silane treatment on tensile strength. Using one way analysis of variance, p-value was found as 0.01. The result of the analysis is shown in Table 3. As p-value is smaller than 0.05, it can be estimated that quat-silane treatment has a significant effect on tensile strength.

TABLE 3.
ANOVA AND ESTIMATION OF PARAMETERS FROM TENSILE STRENGTH.

ANOVA one way

Source of Variance	SS	df	MS	F	P-value	F crit
Between Groups	80.0833	1	80.0833	8.1028	0.0173	4.9646
Within Groups	98.8333	10	9.8833			
Total	178.9166	11				

E. *Tear strength*

Results are presented in Figure (7-8). A small significant decrease in tear strength was observed after quat-silane treatments and a small significant decrease was observed with the increase in quat-silane concentration. It was observed the quat-silane treatment caused a significant decrease in the number of yarns in the del shape in the region of tear. Panama fabrics showed the highest tear strength and cotton/elastane plain fabrics showed the lowest tear strength in warp direction and panama fabrics showed the highest tear strength and cotton plain fabrics showed the lowest tear strength in weft direction.

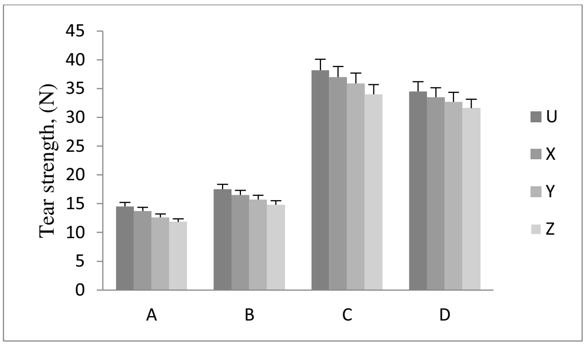

Fig.7. Tear strength in warp direction for untreated and treated fabric samples

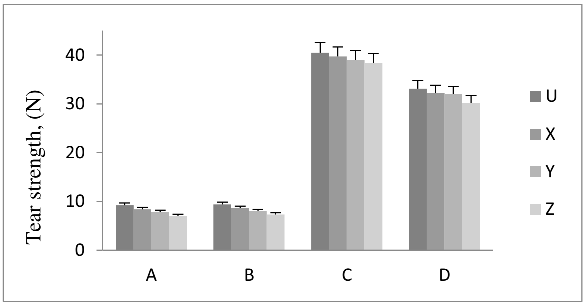

Fig.8. Tear strength in weft direction for untreated and treated fabric samples

F. Effect of quat-silane treatment on tear strength

ANOVA one-way was used to analyze the effect of quat-silane treatment on tear strength. Using one way analysis of variance, p-value was found as 0.008. The result of the analysis is shown in Table 4. As p-value is smaller than 0.05, it can be estimated that quat-silane treatment has a significant effect on tear strength.

TABLE 4.
ANOVA AND ESTIMATION OF PARAMETERS FROM TEAR STRENGTH

ANOVA one way

Source of Variance	SS	df	MS	F	P-value	F crit
Between Groups	560.3333	1	560.3333	21.8595	0.0008	4.9646
Within Groups	256.3333	10	25.63333			
Total	816.6666	11				

G. Seam strength

Results are presented in Figure (9-10). A small significant decrease in seam strength was observed after quat-silane treatments and a small significant decrease was observed with the increase in quat-silane concentration. This is attributed to quat-silane treatment caused a restriction in the movement of yarns in the fabric structure resulting a significant decrease in the elasticity. Cotton/elastane plain fabrics showed the highest seam strength and panama fabrics showed the lowest seam strength in warp direction. Twill fabrics showed the highest seam strength and panama fabrics showed the lowest seam strength in weft direction.

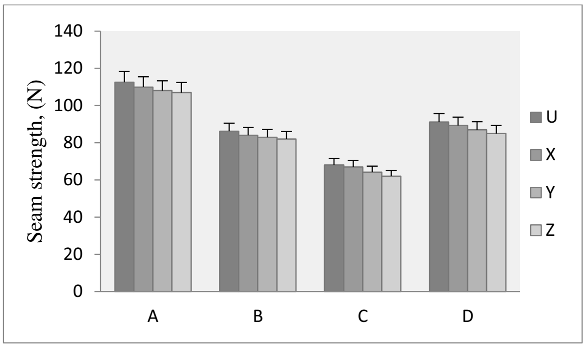

Fig. 9. Seam strength in warp direction for untreated and treated fabric samples

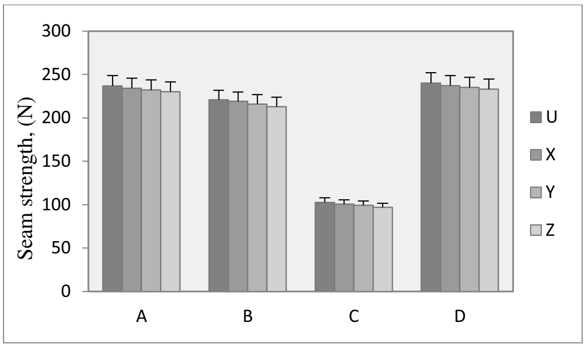

Fig.10. Seam strength in weft direction for untreated and treated fabric samples

H. *Effect of quat-silane treatment on seam strength*

ANOVA one-way was used to analyze the effect of quat-silane treatment on seam strength. Using one way analysis of variance, p-value was found as 0.0005. The result of the analysis is shown in Table 5. As p-value is smaller than 0.05, it can be estimated that quat-silane treatment has a significant effect on seam strength.

TABLE 5.
ANOVA AND ESTIMATION OF PARAMETERS FROM SEAM STRENGTH.

ANOVA one way

Source of Variance	SS	df	MS	F	P-value	F crit
Between Groups	425.0417	1	425.0417	16.4363	0.0005	4.3009
Within Groups	568.9167	22	25.85985			
Total	993.9583	23				

IV. CONCLUSION

Physical and mechanical properties of cotton and cotton/elastane fabrics used for clothing in further designs and treated with quat-silane agent procedure, were tested in terms of tensile strength (strip method), tensile strength (grab method), tear strength and seam strength. The tensile strength (strip and grab method), tear strength and seam strength showed a small significant decrease after quat-silane treatments. This is attributed to a small significant decrease in elasticity after processes which are related with the restriction of the slippage of yarns in the fabric structure which decreased the elasticity of the fabric samples resulting a limitation in the movement of yarns. Cotton plain fabrics showed the highest tensile strength (strip and grab methods) in warp direction before and after quat-silane treatments. This is attributed to higher fabric density caused a less fabric shrinkage after quat-silane treatments thus a higher breaking load per yarn. Panama fabrics showed the highest tear strength both in warp and weft directions before and after treatments which is attributed to higher number of yarns in the del shape in the region of tear. Twill fabrics showed the highest tensile strength (grab method) and seam strength in weft direction before and after treatments which is attributed to higher elasticity of the fabric structure in weft direction. Cotton/elastane plain fabrics showed the highest seam strength in warp direction before and after treatments which is attributed to elastane in the fabric structure provided more elasticity resulting a significant increase in seam strength. A small significant decrease was observed with the increase in quat-silane concentration. The results showed that all samples showed a very good antimicrobial activity since quaternary ammonium compounds are very durable due to covalent bonding with textiles. Finally, it's found that the quat-silane treatments altered the mechanical and physical properties of cotton and cotton/elastane fabrics but the treated samples still protected their physical and mechanical properties which will still provide comfort during use as clothings in further designs.

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