Interaction of a non-aqueous solvent system on bamboo, cotton, polyester and their blends: the effect on abrasive wear resistance

M. Uzun[1,2], K. Kanchi Govarthanam[1,3], S. Rajendran[1], E. Sancak[2]
[1] Institute for Material Research and Innovation, The University of Bolton, Bolton, BL3 5AB, UK
[2] Department of Textile Education, Marmara University, 34722, Goztepe, Istanbul, Turkey
[3] Fothergill Engineered Fabrics, Littleborough, OL15 0LR, UK
Corresponding to: S. Rajendran (E-mail sr2@bolton.ac.uk)

ABSTRACT

This paper investigates the use of Trichloroacetic acid-Methylene chloride (TCAMC) solvent system with a view to study the abrasive wear resistance of bamboo, cotton, organic cotton, polyester (PES), cotton/bamboo and polyester/cotton blended woven fabrics. The fabrics were treated with different concentrations of 1%, 5% and 10% of TCAMC for 5, 30, 60 mins at room temperature. Martindale Abrasion Tester was employed to test the abrasive wear resistance of fabrics. The weight loss of fabrics was checked after every 1000 abrasive cycles. The results indicate that the bamboo fabric, without TCAMC treatment, possesses an abrasive wear resistance that is comparable to that of organic cotton fabric. However, cotton/bamboo blend fabric was found to have enhanced abrasion wear resistance than that of 100% bamboo fabric. The results also indicate that the TCAMC treatment enhanced the abrasion wear resistance of 100% bamboo and 100% organic cotton fabrics. The treatment does not influence the wear resistance of 100% cotton and its blends. The abrasive wear resistance of untreated polyester (PES) fabric was tested and compared with cellulosics and it was found that PES possessed higher abrasive wear resistance. However, the abrasive wear resistance of TCAMC treated PES decreased considerably.

Keywords: Trichloroacetic acid-Methylene chloride modification, polymer modification, bamboo, organic cotton, polyester, abrasive wear resistance.

1. Introduction

The interest in sustainable and organic natural fibres has increased significantly in the recent years due to the increasing environmental issues with synthetic fibres. Among natural fibres, bamboo fibre is considered as more environment friendly because of its quick degradability. Bamboo fibres are lignocellulosic and they are very soft, have higher dye take-up, antimicrobial, require no pesticide during planting and are classed as organic. Bamboo fibres are used in various applications such as textile garments, textile reinforced composites [1-4].They can be blended with a range of synthetic fibres such as polypropylene, polyamide, polyester and polyolefin. Blended yarns and reinforced composites containing bamboo fibres possess enhanced thermo mechanical characteristics, impact resistance, flexural modulus, oxygen permeation, chemical and moisture properties [5]. Although bamboo is a emerging natural fibre, cotton is still dominated for a variety of applications. However, cotton is not considered to be fully environment friendly fibre as it is highly susceptible to infestation. It is reported [6-8] that more than 10% of pesticides (including herbicides, insecticides and defoliants) are used on cotton crops. Organic cotton is fully environmental friendly because it does not involve genetic modification of the seeds or pesticides and chemical fertilisers. Production of organic cotton has superior advantages for the environment but is more expensive than normal cotton due to the increase in production cost and lower efficiency. Due to the economic and efficiency reasons, organic cotton production currently is around 1% of all the normal cotton crops in the world [9-10].

The abrasion and tensile strength of textile fibres depend mainly on molecular structure (crystalline and amorphous regions) and arrangement of molecular chains in fibres. The properties of fibres can be improved either by changing their genetic character or by suitable chemical modification to reorganise fibre structure. Since changing the fibre genetic is a time consuming long-term process, the surface modification by using suitable chemicals is mostly preferred [11]. In addition, the mechanical properties of cotton can also be affected by convolutions, spiral angles, structural reversals, strength of inter-fibrillar bonds and inherent strains. The presence of weak links in cotton fibre, which depends on the growth of cotton, also affects the tensile properties.. It is known that increase in moisture content of cellulosic fibres increases the tensile strength and elongation. Moisture allows the residual stresses present in cotton to relax and hence the increase in tensile property [12]. Among various properties, abrasive wear resistance is considered to be crucial during weaving and for determining the durability of fabrics, apparels and garments. It should be mentioned that cellulose and cellulosic blends influence the abrasive wear resistance. For instance, the abrasive wear resistance of bamboo fibres and their blends with cotton are inferior to that of viscose and their blends with cotton although these fibres are cellulosics [13-16].

It is known that the functional properties of wearable textiles depend on fibre types, polymer molecular structure and fabric structures. It is possible to alter the properties of polymeric materials by solvent-polymer- modification process. One approach that has been explored to a considerable extent is the structural modification of regular polymeric fibres making use of highly interacting solvents. It has been demonstrated that the interacting power of Trichloroacetic acid-methylene chloride (TCAMC) solvent system with Polyethylene terephthalate (PET) is very high and the regent attacks the polymer matrix, disintegrates and finally dissolves out the PET at about 25% (w/v) concentration in 5 minutes at room temperature condition [17-21]. It is expected that at certain lower concentration of TCAMC treatment, the compact structure of PET opens up and as a result, molecular rearrangements may take place. Due to this polymeric change, several physico-chemical properties of the yarn could be modified. Accordingly it can be explained that the solubility parameter of TCAMC reagent is very close to the solubility parameter of PET. It was hypothesized that at certain lower concentrations of TCAMC treatment the compact structure of polyester opens up [17-21]. The effect of TCAMC on cellulosics such as cotton yarns were published elsewhere [11]. It is concluded that the TCAMC reagent modifies the internal structure of the cellulose and consequently this alters the mechanical and physical properties of the fibres. In this paper, the influence of TCAMC reagent on fabrics made from bamboo, normal cotton, organic cotton and their blends with polyester are discussed. It is expected that the action of the TCAMC reagent on bamboo and cotton would not be the same because the bamboo, being a bast fibre, contains not only pure cellulose but also significant amount of non-cellulosic constituents that include lignin. This significantly affects the abrasive wear resistance of materials.

2. Experimental

2.1. Materials

Plain woven fabrics that possess the following dimensional properties (Table 1) were procured in the UK.

Table 1 Fabric properties

Fabrics	100% Bamboo	100% Cotton	100%Organic Cotton	100% Polyester	70% Bamboo 30% Cotton	65%Polyester 35%Cotton
Weight (g/m^2)	177.56	160.94	157.72	213.92	199.23	200.15
Height (mm)	0.20	0.45	0.35	0.45	0.25	0.15
Bulk density (g/m^3)	0.888	0.358	0.451	0.856	0.443	1.334

2.2. TCAMC treatment

The laboratory grade Trichloroacetic acid ($CCl_3.COOH$), Methylene chloride ($CH_2.Cl_2$), and Acetone ($CH_3.CO.CH_3$) were used for treating the fabrics. To prepare the reagent, desired amounts of trichloroacetic acid is weighed and added into 100 ml of methylene chloride. For example, 1% concentration is prepared by mixing 1g of trichloroacetic acid with 100 ml of methylene chloride. The fabric specimens of 100mm×100mm were prepared and weighed. Pre-treatment of these fabrics with reagent was carried out in a specially made closed trough at room temperature (20^oC). The fabric specimens were immersed in the reagent of desired concentrations of 1%, 5% and 10% (w/v) for 5, 30, and 60 min durations. The fabrics to solvent ratio were maintained at 1:100 and the contents were shaken manually at regular intervals to ensure uniform treatment. After the treatment, the specimens were rinsed with pure methylene chloride followed by acetone to remove any adhering reagent on the fabrics. The treated fabrics were squeezed and air dried at atmospheric condition, taking advantage of the quick evaporation of acetone at room temperature [22].

2.3. Abrasive test specimen preparation and testing

The test was performed using Martindale Abrasion Tester (James Heal Abrasive Cloth SM25) (Fig. 1) in accordance with EN ISO 12947-2:198. Standard wool abradant fabrics were used which is plain weave with warp 17 yarns/cm and weft 13 yarns/cm. The abradant was kept same for each sample. Before testing, the fabrics were conditioned for 24 hours at atmospheric conditions of 20^{o}C and 65% RH. The test was stopped end of the day and restarted following day. The abrasive wear test determines the resistance to abrasion of textile fabrics. The measurement of the resistance to abrasion of textile fabrics relies on several parameters such as the mechanical properties of the fibres, the dimensions of the fibres, the structure of the yarns, the construction of the fabrics, the type and kind of finishing [22-23].

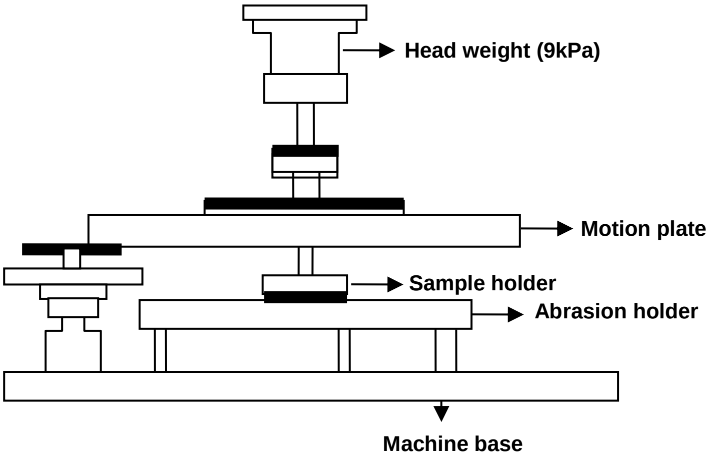


Fig. 1. Martindale abrasion tester

Firstly the treated and untreated fabrics specimens were cut into circular specimens of 38mm diameter using a press cutter and placed on the specimen holder. The test was performed at a pressure of 9kPa and during that time the machine speed was maintained at 50 rubs per minute. After every 1000 rubs, samples were reweighted to determine the weight loss due to abrasion. The endpoint was determined by a specified number of cycles or the formation of a hole in the specimen's test area, whichever comes first.

3. Results and discussion

3.1. Effect of TCAMC treatment on fabric structure

The changes in the number of ends and picks of normal cotton, organic cotton, bamboo, PES and blends after TCAMC treatment are depicted in Table 2 and Table 3 respectively. It can be observed that there are no noticeable changes in the ends and picks of cellulosic fabrics after the TCAMC treatment, irrespective of concentration and time. However, the ends and picks of synthetic fabric (100% PES) increase with increase in concentration and time. A maximum of 11% increase in ends and 15% in picks are observed in the case of 10% at 60mins. A similar increasing trend is also seen in the case of treated PES/cotton blended fabrics but the extent of increase is decreased when compared to plain 100%PES treated fabric. This could be explained by the fact that the interaction of TCAMC with the PET polymer is higher than that of cellulosic fibre. The high interaction of PET polymer and solvent system may be linked with their solubility parameter values. It is published elsewhere [13] that the interaction of the solvent and the polymer is high when the solubility parameter value of the solvent is close to the solubility parameter value of the polymer. The changes in ends and picks of TCAMC treated PES fabrics are mainly due to the changes in the morphology of fibres and fine structure of fibres. The morphological structure of cellulosics and polyester is described in detail elsewhere [24]. increase in ends and picks in a specific area of fabric after the treatment is explained by the fact that the diameter of yarn is influenced by the treatment and consequently the fibres swell, followed by shrinks, and ultimately the fabric structure tightens which resulted in high number of ends and picks.

Table 2 Number of ends per centimetre in treated and untreated fabrics

	Untreated	5 Minute Treatment			30 Minute Treatment			60 Minute Treatment		
	Fabrics	1%	5%	10%	1%	5%	10%	1%	5%	10%
100% Cotton	30	28	30	30	30	30	31	30	30	30
100% Organic Cotton	36	36	36	36	38	36	36	36	38	38

100% Bamboo	60	60	60	62	58	60	58	60	60	58
70/30% Bamboo/Cotton	70	70	73	72	72	70	72	72	70	70
100% Polyester	27	28	28	27	31	29	28	30	30	30
65/35% Cotton/Polyester	41	40	40	40	40	42	42	42	40	44

Table 3 Number of picks per centimetre in treated and untreated fabrics

	Untreated	5 Minute Treatment			30 Minute Treatment			60 Minute Treatment		
	Fabrics	1%	5%	10%	1%	5%	10%	1%	5%	10%
100% Cotton	26	25	25	25	25	25	25	25	26	26
100% Organic Cotton	13	12	12	12	12	12	12	13	12	12
100% Bamboo	44	44	46	44	46	44	46	46	42	46
70/30% Bamboo/Cotton	44	45	46	44	46	45	46	46	44	46
100% Polyester	27	26	28	25	30	29	26	30	30	31
65/35% Cotton/Polyester	24	24	26	24	24	26	26	24	25	26

3.2. Effect on abrasive wear resistance

The abrasive wear resistance of normal cotton, organic cotton, bamboo, polyester and blends are depicted in Table 4. It should be mentioned that the extent of damage due to abrasion was inspected and specimens were weighted at the end of 1000 rubs interval, and found that there is no noticeable abrasive wear in all the fabrics up to 10000 rubs. However, it is observed that the treated organic cotton shows the appreciable sign of degradation after 10000 rubs irrespective of treatment concentration and time (Fig. 3c). After 25000 rubs, the untreated organic cotton fabric started deteriorating whereas untreated normal cotton, bamboo, polyester and blends fabrics withstand the resistance against abrasion (Fig. 3 a-f). It is obvious from Table 4 that after 32000 rubs, unlike normal cotton, bamboo, PES and blends, the organic cotton did not resist the abrasive force, perhaps due to less number of picks in a specific area (Table 3) and consequently the fabric structure is severely deteriorated.
After 34000 rubs the 100% bamboo fabric was damaged, (Fig. 2a). At 70000 rubs cotton, cotton/bamboo and polyester/cotton blended fabric showed a few weak points but after 90000 rubs they are severely deteriorated (Fig. 2b, h, i) and thus ceasing its resistance to abrasion.

The TCAMC treatment helps to enhance the abrasion properties of organic cotton, the probable reasons are discussed in following sections.

After 100.000 rubs 100% Polyester still has not abraded. 100% PES based fabrics were subjected to 250.000 rubs to find the effect of TCAMC treatment on the fabrics. It can be observed from Table 4 that the abrasive wear resistance of polyester decreased as the treatment time and the concentration increased. It has been shown in previous study that, at extreme treatment condition (5% TCAMC), the abrasive wear resistance of flat polyester yarn increased 4 times than that of the control [24]. It is well known that PET fibres are partially crystalline in nature and are comprised of repeated ethylene segment units as well as aromatic rings, which influence the intrinsic stiffness of the chain [25]. The current study was conducted on 100% Polyester fabric. It is likely that the action of solvent on fabric would be different from that of flat polyester yarn published earlier [24].

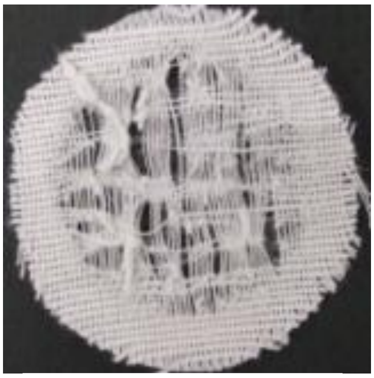
There has been no noteworthy difference between control and TCAMC treated cotton, cotton/bamboo, cotton/polyester and polyester fabrics in terms of abrasion. But, 100% bamboo fabric's abrasive wear resistance increased by 25% and organic cotton fabric's abrasive wear resistance also increased by 35% with 5% TCAMC treatment for 5 minutes. It is found, in previous studies, that the cotton yarns treated with TCAMC possesses higher work of rupture than the untreated control ones. There is a significant increase in fibre cohesion of treated sample over the control. The increase of abrasion properties of fabrics can also be explained owing to the higher elongation and increase in work of rupture of TCAMC treated yarns [12].

Table 4 Effect of abrasive wear resistance on cellulosics and polyester

	Untreated Fabric	5 Minute Treatment			30 Minute Treatment			60 Minute Treatment		
		1%	5%	10%	1%	5%	10%	1%	5%	10%
100% Cotton	90000	90000	90000	90000	90000	90000	84000	90000	90000	90000
100% Organic Cotton	32000	44000	54000	52000	44000	52000	34000	46000	54000	52000
100% Bamboo	34000	30000	44000	36000	48000	40000	28000	40000	42000	40000
70/30 Bamboo/Cotton	90000	90000	90000	90000	90000	90000	70000	84000	90000	90000
100% Polyester	250000	235000	175000	140000	210000	160000	140000	210000	160000	100000
65/35 Cotton/ Polyester	100000	100000	100000	100000	100000	100000	100000	100000	100000	100000

A. 100% Bamboo after 34,000 rubs (untreated)

B. 100% Cotton after 90,000 rubs (untreated)

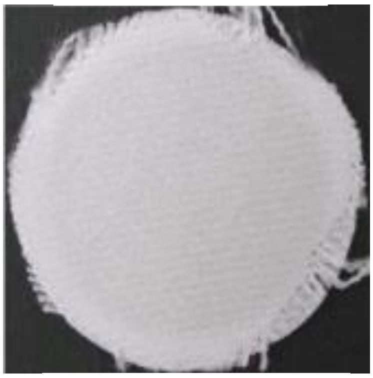


C. 100% Organic Cotton after 32,000 rubs (untreated)

D. 100% Bamboo after 40,000 rubs (treated)

E. 100% Cotton after 90,000 rubs (treated)

F. 100% Organic Cotton after 52,000 rubs (treated)



G. 100% Polyester after 250,000 rubs (untreated)

H. 70% Bamboo / 30% Cotton after 90,000 rubs (untreated)

I. 65% Cotton / 35% Polyester after 100,000 rubs (untreated)

J. 100% Polyester after 100,000 rubs (treated)

K. 70% Bamboo / 30% Cotton after 90,000 rubs (treated)

L. 65% Cotton / 35% Polyester after 100,000 rubs (treated)

treatment due to their cellulosic nature. It can be explained that cellulosic fibres, after treatment with TCAMC solvent system, increases the cohesion between fibres and ultimately the friction increases which contributes to the increase in abrasive wear resistance and strength. This is further supported by the surface modification of fibres observed on SEM (Fig 4). Previous research has also shown that such treatments increase the cohesion between fibres [17,18].

3.3. The weight loss of fabrics

The percent weight loss and cumulative losses after abrasive wear resistance are shown in Table 5 and Figure 3 (A-F) respectively. It is observed that the weight loss of 100% bamboo fabric increased substantially after TCAMC treatment. Similarly the increase in weight loss is also observed in normal cotton irrespective of treatment time and concentration except 10% treatment for 60 minutes. Besides, it is also observed there are considerable differences noticed between treatments of normal cotton (Fig 3(A)). It can also be seen that the rate of weight loss is comparable between organic cotton and bamboo. Similar observation is also observed in normal cotton and its blends.

It can be observed that the weight loss of 70/30 bamboo/cotton is (Fig 3(D)) is similar for up to 40,000 rubs and the difference becomes noticeable after 40,000 rubs. Whereas, the weight loss was similar for up to 60000 rubs for 100% cotton (Fig 3(A)). Similarly, 100% bamboo (Fig 3(B)) and 100% organic cotton (Fig 3(C)) lost their weight at a similar rate for up to 15% and 20% respectively. The weight loss between samples is at acceptable levels. In the case of polyester, both control and treated, the fabrics withstand the abrasive forces up to 50,000 rubs without noticeable changes in loss b/w samples and beyond that the change in weight loss is not noticeable.

Table 5 Weight loss percentage of TCAMC treated samples

	Untreated Fabric	5 Minute Treatment			30 Minute Treatment			60 Minute Treatment		
		1%	5%	10%	1%	5%	10%	1%	5%	10%
100% Cotton	10.6%	20.1%	12.3%	12.0%	20.9%	13.9%	19.9%	12.0%	10.1%	8.0%
100% Organic Cotton	24.0%	20.4%	27.6%	22.6%	28.0%	27.6%	29.7%	20.7%	19.5%	16.8%
100% Bamboo	28.7%	31.3%	32.1%	33.8%	33.1%	30.2%	35.5%	30.1%	31.1%	26.3%
70/30 Bamboo/Cotton	19.4%	37.3%	24.1%	16.5%	24.8%	32.8%	36.0%	32.3%	23.9%	17.0%
100% Polyester	5.2%	5.5%	4.4%	6.2%	5.5%	8.0%	5.5%	5.9%	12.0%	9.1%
65/35 Polyester/Cotton	10.6%	12.4%	10.8%	9.7%	14.8%	10.8%	15.2%	12.8%	10.2%	8.2%

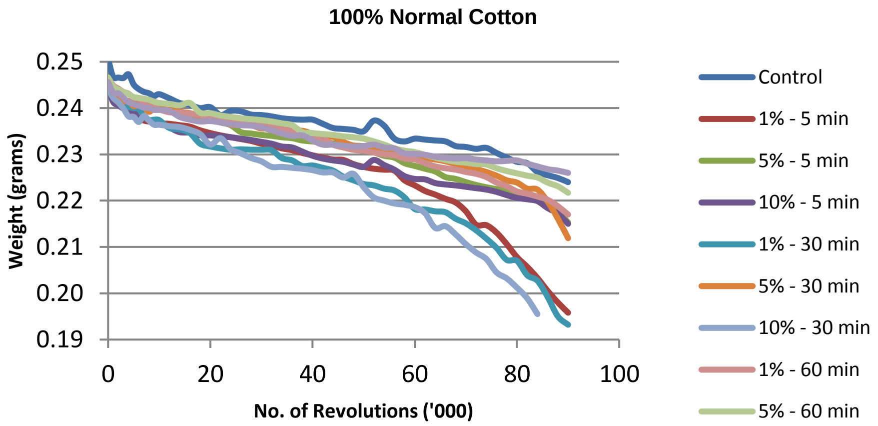


Fig. 3(A). Cumulative weight loss of 100% cotton fabric treated with TCAMC

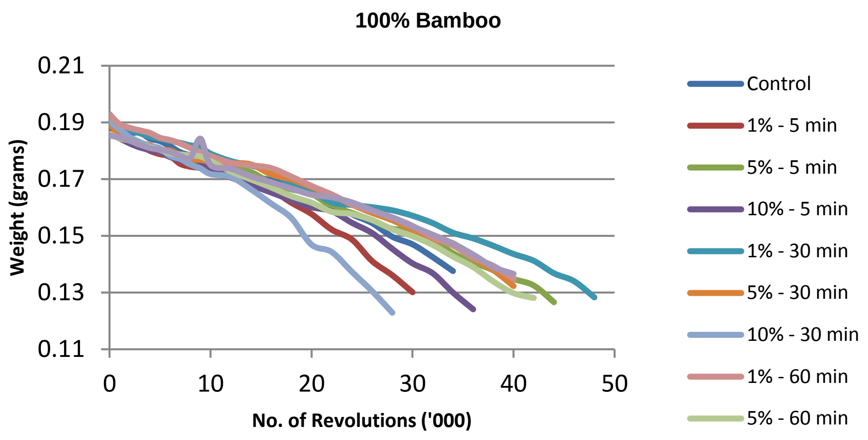


Fig. 3(B). Cumulative weight loss of 100% bamboo fabric treated TCAMC

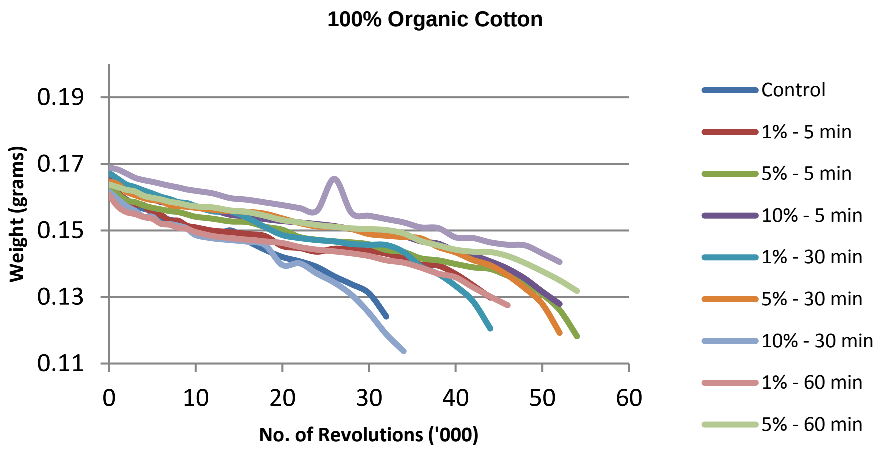


Fig. 3(C). Cumulative weight loss of 100% organic cotton fabric treated with TCAMC

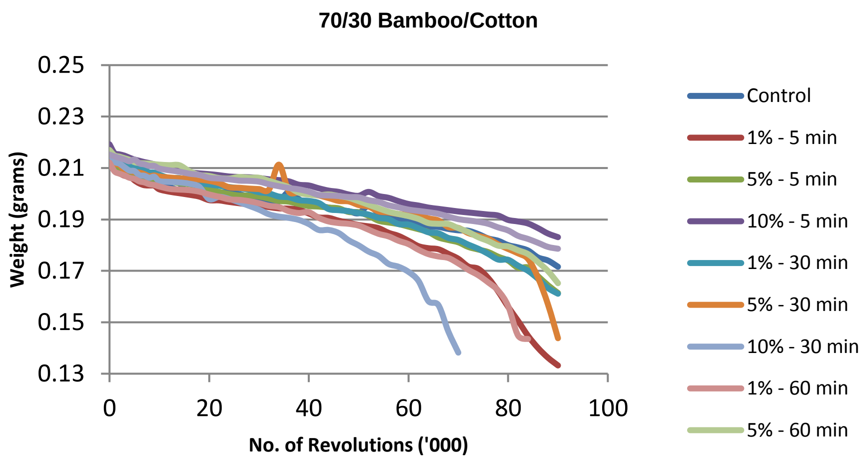


Fig. 3(D). Cumulative weight loss of 70/30 bamboo/cotton fabric treated with TCAMC

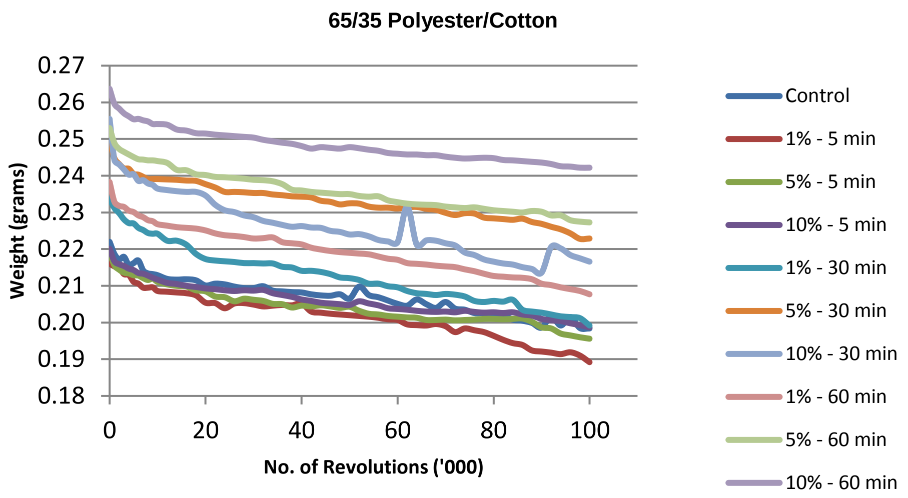


Fig. 3(E). Cumulative weight loss of 70/30 polyester/cotton fabric treated with TCAMC

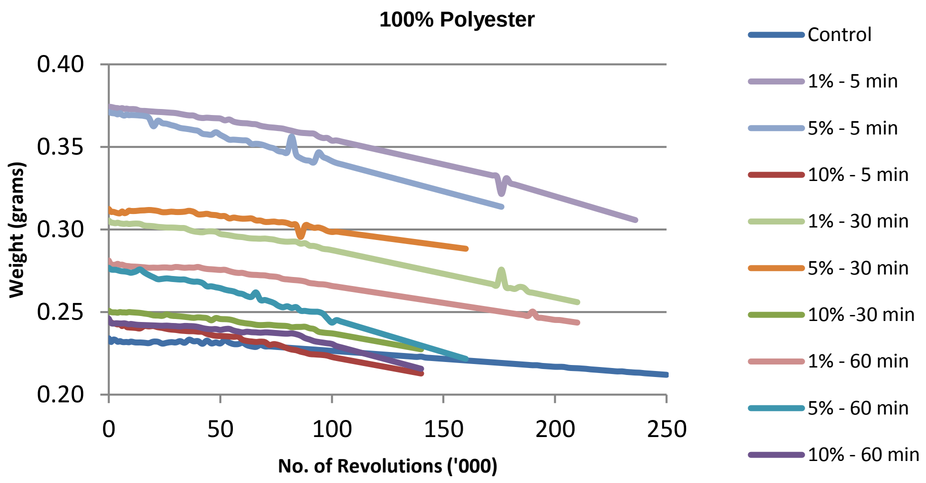
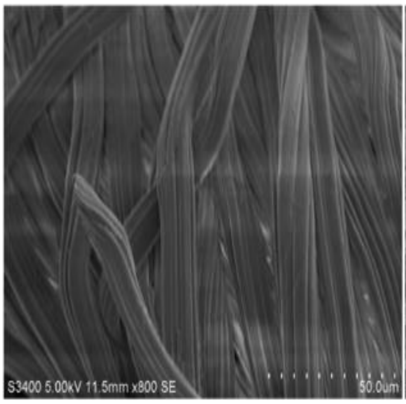


Fig. 3(F). Cumulative weight loss of 100% polyester fabric treated with TCAMC

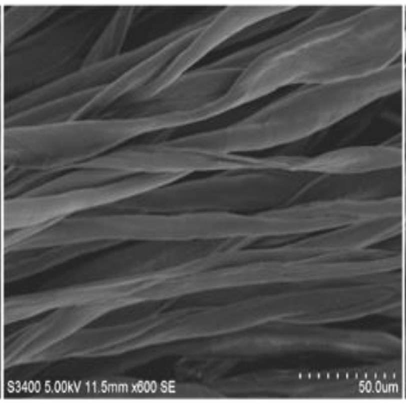
3.4. Scanning Electron Microscopy Studies

The surface characteristics of the fabrics were investigated before after treating the fabrics, with different concentrations of the solvent system over different time periods, by SEM (HITACHI S-3400) in the normal mode. All the fabric specimen were fixed by adhesive tape onto the sample holder and were coated with gold by using Sputter Coater (SC 7620). Fig. 4 represents the SEM images of fabrics treated at 10% for 60min.

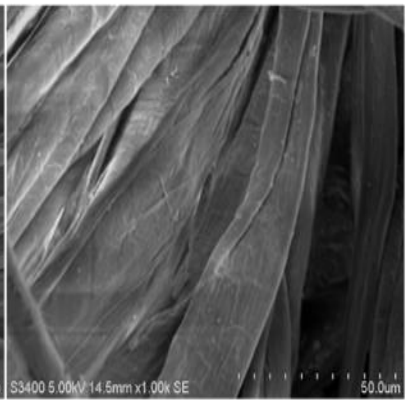
SEM examination of 100% bamboo fabrics (Fig. 4) reveals that there is no swelling but there are changes in the fibre structure and this makes the fibre surface smoother, perhaps the treatment removes the non cellulosic constituents from bamboo. [10] This is substantiated by the increase in the number of revolutions during abrasion from 34000 to 40000. It can also be observed that the convolutions on the surface of the 100% organic cotton treated with the reagent (Fig 4) are increased noticeably when compared with untreated ones. It is likely that this contributes to the increase in the abrasive wear resistance of 100% organic cotton from 32000 revolutions to 52000 revolutions. Similar trend is also observed on treated 100% normal cotton. However, the degree of increase in convolutions in the treated normal cotton is less and therefore the abrasive wear resistance is unaffected.



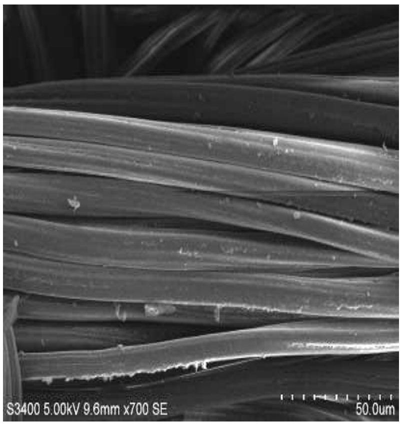
A. 100% Bamboo before



B. 100% Cotton before treatment

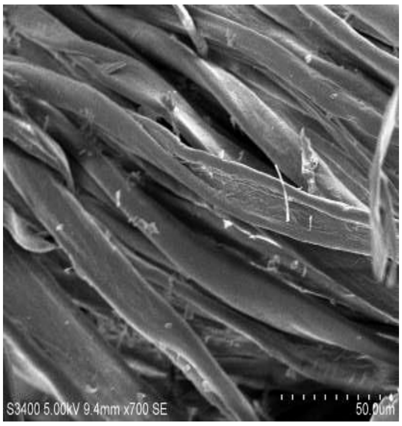


C.100% Org. Cotton before treatment

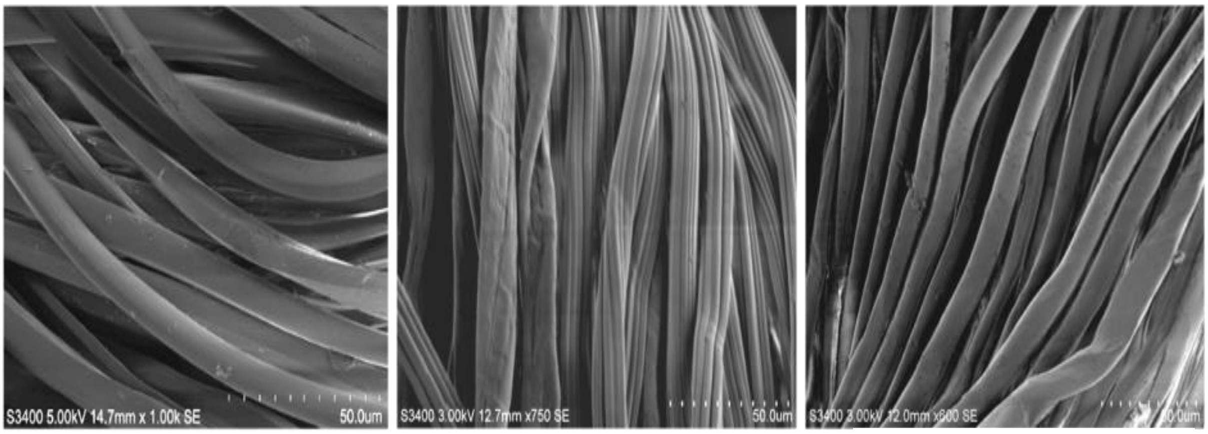


D. 100% Bamboo after treatment

E. 100% Cotton after treatment



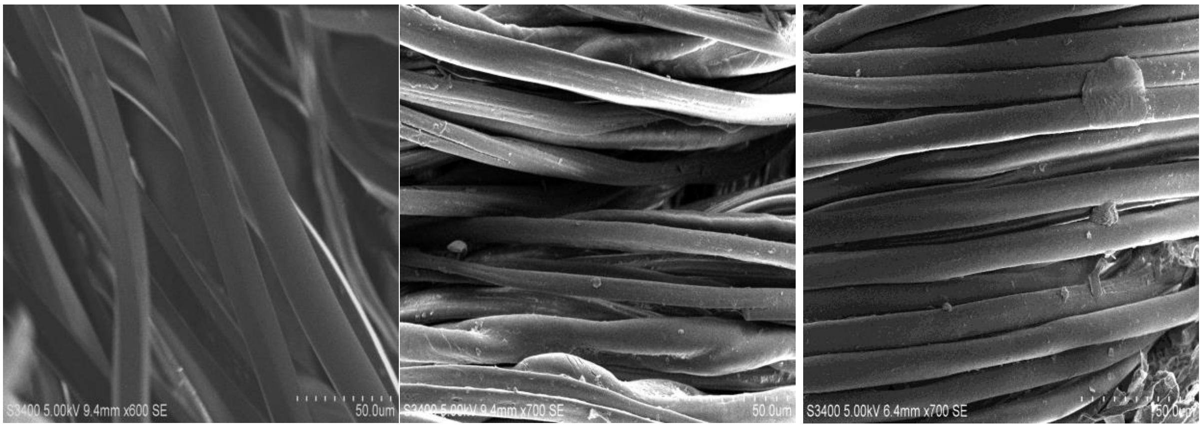
F. 100% Org. Cotton after treatment



G. 100% Polyester before treatment

H. 70/30% Bamboo/Cotton before treatment

I. 65/35% Polyester/Cotton before treatment



J. 100% Polyester after treatment

K. 70/30% Bamboo/Cotton after treatment

L. 65/35% Polyester/Cotton after treatment

Fig. 4. Comparison of SEM morphologies of fabrics before treatment and after treatment with 10% TCAMC solvent system for 60 minutes.

4. Conclusions

The influence of TCAMC reagent on abrasive wear resistance of fabrics made from normal cotton, organic cotton, bamboo, polyester and its blends has been investigated. Different concentrations of TCAMC reagent are used at varying times to study the effect of structural changes and its influences on abrasive wear resistance. TCAMC reagent interacts with the fibres by opening the fibrillar interstices and entering the interlinking regions between crystallites and changes their surface characteristics. It can be observed that the abrasive wear resistance of 100% bamboo fabric increased by 25% when treated with 5% TCAMC for 5 minutes or 1% TCAMC treatment for 30 minutes. The abrasive wear resistance of treated organic cotton fabric increased irrespective of concentration of reagent and time. It is also observed that the change in abrasive wear resistance between organic and normal cotton is mainly due to the difference in number of ends and picks in a specific surface area. It is established that the TCAMC reagent increases the abrasive wear resistance of both bamboo and organic cotton fabrics. However, the degree of interaction between the reagent and the normal cotton is less and consequently the abrasion is unaffected. In the case of blends, the noticeable increase in abrasive wear resistance is observed in 70/30 bamboo/cotton fabric than that of 100% bamboo fabric. The abrasive wear resistance of 100% polyester fabrics is considerably decreased due to the TCAMC treatment, but, 65/35cotton/polyester blended fabric is unaffected by the TCAMC treatment.

The effect of TCAMC on the weight loss is negligible in most of the fabrics which were analysed in this study. The highest weight loss changes have been observed in normal cotton fabric that is around 10%. The above conclusions were further confirmed by comparing the SEM images of the fibres, before and after treatment.

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