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Low-stress mechanical properties of sericin-coated polyester fabric for sportswear application

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Polyester fabric has been treated with sericin using different methods to improve the comfort of sportswear. Five different coating methods have been investigated, namely polyester fabric treated with alkali, alkali and sericin, sericin with DMDHEU and glutaraldehyde mixture, plasma followed by sericin and glutaraldehyde, and plasma followed by sericin and DMDHEU. The low-stress mechanical properties of the samples have been investigated. Sericin-treated fabric samples show higher tensile resilience, shear rigidity, shear hysteresis, bending and bending hysteresis, compressional energy and compressional resilience and lower extensibility, surface friction and surface roughness. The hand values of all the samples have improved, and the raw fabric treated with plasma, sericin, and DMDHEU has produced the highest overall hand value of the samples.

Keywords: Fabrichand value, Glutaraldehyde, Low-stress mechanical property, Polyester, Sericin, Sportswear, Surface treatment

1 Introduction

Invariably, polyester is an essential fibre for sportswear applications due to its durability, strength, low density, abrasion resistance, and so on[1]. According to Xu*et al.*[2], the textile industry frequently uses poly(ethylene terephthalate, or PET), which has outstanding qualities like high tensile strength and good dimensional stability. But, it lacks in several ways due to its hydrophobic nature. Pure polyester textiles have incredibly poor hydrophilicity, due to which they possess poor moisture vapour transporting property and hence, the wearer feels uncomfortable[3]. PET fibre further suffers from the formation of static charges due to rubbing, which can further limit the usage of PET fibre in sportswear and other industrial applications[2]. A lot of research work is going around the world to utilize PET fibres for sportswear applications by blending them with hydrophilic fibres and coating them with hydrophilic substances. Natural biopolymers, such as sericin and chitosan, have the potential to become major resources in creating sustainable technical textiles in light of these ecological and environmental issues[4]. Silk sericin is a biopolymer with a unique structure that provides superior performance. It comes from the silkworm *Bombyxmori* and is a water-soluble globular protein[5].Sericin contains 18 amino acids, most of which have strong polar side chains, such as hydroxyl, carboxyl, and amino groups, and accounts for 20–30 per cent of the total cocoon weight[6,7]. Gupta *et al.*[8] treated the PET fabric with sodium hydroxide and glutaraldehyde as pretreatment for sericin coating. After sericin coating, they found an improvement in bending length, tensile strength, friction, surface roughness, moisture regain,wicking property, antistatic property, and antimicrobial and antioxidant properties of the PET fabric. Doakhan*et al.*[9] have coated the sericin and TiO_2 nanoparticles on cotton fabric for high-performance application and found that the breaking strength of the cotton fabric was improved multi-folded along with the improvement in antimicrobial activity. Sericin treatment over the surface of cotton and polyester fabrics got improvement in its wrinkle recovery, moisture absorption and wicking properties[10,11]. Sericin, a by-product of silk, finds a lot of applications, such as antimicrobial agent, antioxidant and ultraviolet protection, due to its number of amino acids[1,12]. Rajendran*et al.*[7] have adequately demonstrated the antimicrobial effect of sericin applied on fabrics of polyester fabrics. Gulranjani *et al.*[10] have studied

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the application of sericin on polyester fabric and its effect on absorption and dyeability, ultraviolet protection, and crease recovery. Deepti[13] found that sericin-treated polyester fabric has higher air permeability than the control fabric.Although a great deal of work has been done on the application of sericin on textile clothing,it is hard to find work related to the low-stress mechanical properties of sericin-treated textiles. In this research work, sericin is coated over the woven polyester fabric through different methods.The treated samples are studied for their low-stress mechanical properties through the Kawabata tester.

2 Materials and Methods

2.1 Materials

A 100% polyester spun yarn with 40s Ne (14.76 tex) was used in the warp and weft directions of the plain woven fabric. Analytical grade chemicals were procured, such as sodium hydroxide, glutaraldehyde, DMDHEU (dimethyloldihydroxy ethylene urea), magnesium chloride and acetic acid. The sericin was obtained from the Central Silk Technological Research Institute, Bangalore. The fabrics of the specifications: ends/cm 55, pick/cm 33, GSM 133, thickness 0.32 mm, tenacity 21.90 cN/tex and elongation 11.80%, were used.

2.2 Methods

Five alternative techniques were used to treat sericin on polyester fabric (Table 1).

2.3 Sericin Treatment Method

2.3.1 Alkaline Treatment (Sample A)

All the polyester fabric samples were pre-treated with 15% NaOH(owf) at 80°C for 45 min with a 1:40 material-to-liquor ratio to create functional groups on their surface[10].

Table 1 — Sericin treatment sampling procedure

Sample code	Treatment types
A	Polyester fabric treated with alkali(PA)
B	Alkali-treated polyester coated with sericin using glutaraldehyde
C	Alkali-treated polyester treated with Sericin,DMDHEU and glutaraldehyde
D	Alkali-treated polyester fabric treated with plasma followed by sericin and glutaraldehyde(PSG).
E	Alkali-treated polyester fabric treated with plasma followed by sericinand DMDHEU

2.3.2 Application of Sericin over Alkali Pre-treated Sample (Sample B)

On modified polyester fabric, sericin was added using a cross-linking agent. As a cross-linking agent, glutaraldehyde was employed to bind sericin to alkali-modified polyester[8].In this process, the polyester fabric was treated with 20 gpLglutaraldehyde with the material-to-liquor ratio of 1:9[10] in the 2dip/2nip method of padding[14]. Alkali pre-treated and cross-linking agent-coated PET fabric was padded with 20gplsericin solution in a laboratory padding mangle. The padded fabric was dried at 80°C for 3 min and cured at 130°C for 2 min. Cured samples were then washed and dried.

2.3.3 Treatment with DMDHEU and Glutaraldehyde (Sample C)

The same untreated polyester fabric was treated with 15% NaOH(owf) with the material-to-liquor ratio kept at 1:40 at 60°C for 30 min. This alkaline-treated polyester fabric was then treated with a mixture of 20 gpLsericin, glutaraldehyde(20gpL), magnesium chloride(10gpL) and acetic acid(1mL/L). Subsequently, the treated fabric was padded with DMDHEU(50% owf), polyethylene emulsion (2gpL) in combination with 2nip/2dip procedure[15].

2.3.4 Treatment with Plasma and Glutaraldehyde (Sample D)

The alkaline-treated polyester fabric was prepared in the required dimension of 50cm × 50cm and weighed. This fabric was clamped to the frame and inserted in the plasma chamber between the two plates and pressure in the chamber was brought to 0 bar. Then the oxygen gas was passed to the chamber with aflow rate of 2 bar pressure. Initially, the top side of the fabric was exposed to the plasma current of 1.06amp, voltage 350 volt at a temperature of 290°C, andthis was continued for 5min. After that, for 5 min, the bottom side of the fabric was subjected to a plasma with a current of 1.53 amps, a voltage of 300 volt, and a temperature of 290°C. After the process, the fabric was weighed again to determine the weight loss percentage. The required dimension of the alkali and the plasma-treated fabric was weighed. The fabric was wetted in water along with a wetting agent (TRO) and then treated with the solution of sericin(20gpL), glutaraldehyde(20g/L), magnesium chloride (10g/L) and acetic acid (1ml/L) using a material-to-liquor ratio of 1:9 with 2dip/2nip procedure.The above procedure was followed for both padding and curing[16].

2.3.5 Treatment with Plasma and DMDHEU (Sample E)

The alkaline and plasma-treated fabric was then wetted in water along with Turkey Red Oil (TRO)

(2g/L) and immersed in the prepared solution containing sericin(20gpL), dimethyloldihydroxy ethylene urea (150%,owf), polyethylene emulsion (2g/L) for dipping process using a material-to-liquor ratio of 1:9. This fabric was padded in the 2dip-2nip padding mangles, and then the curing process was carried out at 130°C for 2min[17].

2.4 Characterization

Kawabata evaluation system(KES-FB) was usedtomeasure the low-stress mechanical properties of the sericin-treated fabric samples, such as tensile properties (tensile linearity, tensile energy, tensile resilience and EMT) of the fabric.In the case of the shear study, shear stiffness(G), shear stress at 0.5º (2HG), and shear stress at 5º(2HG5) shear angles were measured. Bending rigidity (B) and bending moment (2HB) were measured under the bending property. Compressional linearity, compressional energy and compressional resilience parameters were measured under the compression property. Fabric thickness has been measured at two different pressure, such as 0.5gf/cm^2 and 50gf/cm^2. Further, surface properties, such as coefficient of friction(MIU), mean deviation of friction(MMD), surface roughness (SMD) and total hand value, have also been analyzed.

3Results and Discussion

3.1 Tensile Properties

The tensile behaviour is closely related to the inter-fibre friction, the ease of crimp removal and the load extension properties of yarns. Through the KES apparatus, the tensile properties of treated fabric were tested, and its results are shown in Table2.

The larger the EMT, the more extensible the fabric. A proper amount of extensibility is desirable, while both excessive and insufficient extensibility will cause problems for clothing production. Almost all the test samples yield sufficient EMT value. Tensile linearity (LT) is the linearity of the load extension curve, and lower LT means the specimen is more extensible. Fabric Samples A, C and D, show lower LT values. WT and EMT are interrelated. Fabric Sample A (treated only with alkali) and Sample E (treated with plasma followed by sericinand DMDHEU)show a higher tensile resilience value. An interesting observation is that tensile resilience is

Table 2 — Low-stress mechanical properties of sericin-treated polyester fabric

Parameters	Sample A	Sample B	Sample C	Sample D	Sample E
Tensile properties					
Tensile (EMT), %	2.16	3.79	2.6	2.83	3.18
Tensile (LT)	0.837	0.88	0.808	0.779	0.818
Tensile (WT), g.cm/cm^2	2.32	3.82	2.79	2.77	3.35
Tensile (RT),%	50.32	63.22	65.01	62.81	68.63
Shear properties					
Shear (G), g/cm.deg	1.29	1.43	2.16	4.17	2.35
Shear (2HG), g/cm	1.13	3.95	2.63	5.91	3.23
Shear (2HG5),g/cm	4.57	6.47	8.51	12.94	10.46
Bending properties					
Bending (B), g.cm^2/cm	0.1414	0.1915	0.2161	0.2912	0.3364
Bending (2HB), g/cm/cm	0.0708	0.1984	0.1428	0.1504	0.2293
Compressional properties					
Compression (LC)	0.406 (±0.234)	0.382 (±0.102)	0.356 (±0.28)	0.5 (±0.123)	0.382 (±0.059)
Compression (WC), g.cm/cm^2	0.041 (±0.003)	0.032 (±0.023)	0.143 (±0.102)	0.163 (±0.006)	0.116 (±0.041)
Compression (RC), %	43.58 (±4.133)	43.33 (±5.312)	44.27 (±6.133)	51.38 (±2.754)	50.25 (±1.846)
Fabric thickness					
Fabric thickness at 0.5gf/cm^2(T_o)	0.373(±0.017)	0.426(±0.030)	0.691(±0.263)	0.424(±0.017)	0.553(±0.059)
Fabric thickness at 50gf/cm^2 (T_M)	0.319(±0.036)	0.354(±0.021)	0.363(±0.023)	0.379(±0.018)	0.432(±0.026)
Surface properties					
Surface MIU	0.270	0.195	0.192	0.177	0.195
Surface MMD	0.0834	0.0674	0.0614	0.0617	0.0728
Surface SMD	9.826	10.31	12.082	8.746	8.826

higher in all sericin-treated samples than in alkali-treated samples.

3.2 Shear Properties

Whenever bending occurs in more than one direction, the fabric is subject to double curvature,which is referred to as shear deformations. Shear property in conjunction with bending property, is thus a good indication of the ability of fabric to drape. Shear rigidity (G) provides a measure of the rotational movement of the warp and weft threads within a fabric when subjected to a low level of shear deformation. The lower the value of G, the more readily the fabric will conform to three-dimensional curvatures. Fabric shear properties are probably the most complex characteristics, including tensile bending, friction, and compression at cross-over points between fibres and yarns in a given fabric structure. In the shear study, shear stiffness(G), shear stress at 0.5º (2HG), and shear stress at 5º(2HG5) shear angles of the treated samples have been evaluated. The overall shear properties of sericin-treated fabrics are given in Table 2.

Warp way G values are greater than those of the weft way. 2HG and 2HG5 values follow the same trend in many cases. Overall, shear rigidity shows the highest value for samplespretreated with alkali(E) followed by plasma treatment(D). The alkaline-treated sample exhibits the lowest value. An increase in shear hysteresis shows the influence of inter-fibre friction. Sample A, which is only treated with alkali, shows the lowest value.

3.3 Bending Properties

The bending property of a fabric is a function of the bending property of its constituent yarns. Bending rigidity (B) is a measure of the ability of the fabric to resist bending deformation. In other words, it reflects the difficulty with which a fabric can be deformed by bending. This is, particularly, critical in the tailoring of lightweight fabrics. The higher the bending rigidity, the higher a fabric's ability to resist when bent by an external force.The samples are bent between the curvature -2.5cm and + 2.5cm with a constant rate of curvature change. The bending properties are in the forms of bending rigidity (B) and bending moment (2HB). Smaller values of B and 2HB mean that the fabric has betterbending recovery ability and is more flexible. The overall properties of the five samples are shown in Table 2.

Treated fabrics possess greater bending rigidity. The highest value of B is exhibited by Sample E, which has been treated with plasma followed by sericinand DMDHEU. Sample C, which is sericin coated with DMDHEU and glutaraldehyde, shows lower values of B and 2HB. The bending properties of a fabric depend on the bending resistance properties of fibres and yarns as well as the fabric structure. The friction between fibre and yarns also affects the bending rigidity. The lowest values of B and 2HB are also noticed in sample A which is only treated with alkali.

3.4 Compression Property

Fabric compression is one of the most critical factors when assessing fabric's mechanical properties. It is highly related to fabric handle, i.e. fabric softness and fullness and fabric surface smoothness. Compressional property can be influenced in many ways.This property can reflect the integrated effect of fabric structure like yarn crimp level and thickness, and the constituent fibre. The three important indicesare compressional linearity, compressional energy, and compressional resilience parameters (Table 2).

The decrease in LC indicates that the fabric can be easily compressed. Samples B, C, and E exhibit lower LC values.Compression energy is the measure of the energy required to compress the fabric. The fabric SamplesD and E have shown higher compression energy.The thickness may be correlated with the amount of weight loss due to alkali treatment and the percentage of add-on on the fibres/yarn.Compression resilience is the ratio between the recovery to compression energy, and it is expressed as a percentage.Fabric Samples D and E have shown higher compression resilience %. Samples A, B, and C show lower values of RC, implying that the fabrics have become softer due to the treatment and their retention ability has enhanced.

3.5 Fabric Thickness Properties

Fabric thickness parameters have also been measured through the KES system by applying 0.5gf/cm^2 and 50gf/cm^2 pressures on the fabrics. Their thickness is expressed by T_0 and T_m, respectively (Table 2).The fabric thickness values To is high for Sample C, and T_m is high for Sample E. It refersthat the fabric Sample C is fluffier and has a soft feel as compared to other treated samples.

3.6 Surface Properties

Surface properties comprise coefficient of friction(MIU), mean deviation of friction(MMD), and surface roughness (SMD). The findings for all the samples are tabulated in Table2.It is found that the

MIU is lower for all the sericin-treated samples than that of the control sample. SMDis lower for fabric samples D and E. Highest value of SMD is obtained for fabric Sample C due to alkali and DMDHEU surface coating, which would cause this increment in surface roughness.

3.7 Total Hand Value

The total hand value(THV) of all the test samples has been calculated. The THV values for samples A,B,C,D and E are 2.4,3.68,5.56,3.46 and 4.59 respectively. It is found that thefabric Sample C shows the highest THV and Sample A shows the lowest value. It is further interpreted that all the treated samples show an improvement in handle as compared to Sample A.

3.8 Statistical Analysis

Thestatistical significance of all the low-stress mechanical properties has been analysed, and depicted in Table 3.

Table 3 shows the T-value, degree of freedom, significance value, mean difference, and confidence interval. All the tested low-stress mechanical properties have a significant difference between the samples due to their different treatment methods since their p-value is <0.05. So, it is further concluded that the coating method has significance on the low-stress mechanical properties of the fabric samples.

3.9 SEM Analysis

The scanning electron microscopic study of all the test samples isshown in Fig. 1. Samples B,C,D and E have shown smoothsericin coating throughout the

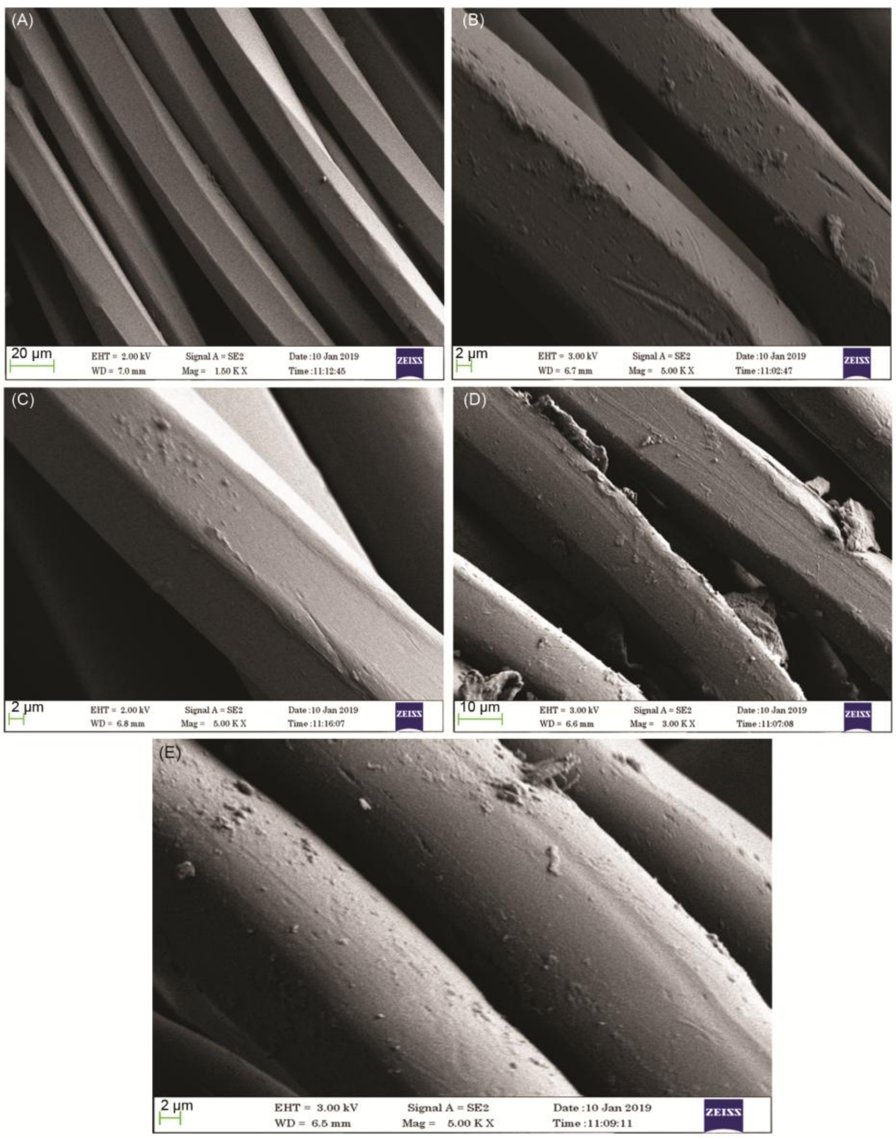

Fig. 1 — SEM images of sericin-treated samples

Table 3 — T-test statistic of low-stress mechanical properties between samples

Properties	t	df	P- value Sig. (2-tailed)	Mean difference	95% Confidence interval of the difference	
					Lower	Upper
Tensile (EM), %	10.590	4	0.000	2.91200	2.1485	3.6755
Tensile (LT)	49.174	4	0.000	0.82440	0.7779	0.8709
Tensile (WT), g.cm/cm^2	11.569	4	0.000	3.01000	2.2876	3.7324
Tensile (RT),%	20.031	4	0.000	61.99800	53.4048	70.5912
Shear (G), g/cm.deg	4.432	4	0.011	2.28000	0.8515	3.7085
Shear (2HG), g/cm	4.285	4	0.013	3.37000	1.1862	5.5538
Shear (2HG5), g/cm	5.853	4	0.004	8.59000	4.5151	12.6649
Bending (B), g.cm^2/cm	6.730	4	0.003	0.23532	0.1382	0.3324
Bending (2HB), g/cm/cm	6.126	4	0.004	0.16434	0.0899	0.2388
Compression (LC)	16.218	4	0.000	0.40520	0.3358	0.4746
Compression (WC), g.cm/cm^2	3.649	4	0.022	0.07900	0.0189	0.1391
Compression (RC), %	26.573	4	0.000	46.56200	41.6970	51.4270
Fabric thickness at 0.5 gf/cm^2 (T_o)	8.560	4	0.001	0.49340	0.3334	0.6534
Fabric thickness at 50 gf/cm^2 (T_M)	19.991	4	0.000	0.36940	0.3181	0.4207
Surface MIU	12.554	4	0.000	0.20580	0.1603	0.2513
Surface MMD	16.947	4	0.000	0.06934	0.0580	0.0807
Surface SMD	16.367	4	0.000	9.95800	8.2688	11.6472

fabric surfaces. Due to the plasma treatment, Samples Dand E show some surface cracks. Sample A is treated with alkali and it shows a smooth surface. Sample C has shown smooth evenly distributed sericincoating.

4Conclusion

The coating over the polyester woven fabric has been done successfully.Five different treatment methods have been employed for coating. Low-stress mechanical properties are investigated to analyze the influence of the sericintreatment method. This study shows that sericin-treated fabrics are characterized by lower extensibility, higher tensile resilience, higher shear rigidity&shear hysteresis, higher bending & bending hysteresis, higher compressional energy &compressional resilience, lower surface friction and lower surface roughness. Handle shows an improvement in all the treated samples. Among the samples,plasma-treated PET fabric followed by sericinand DMDHEUtreatment has yielded the highest total hand value than other samples. Finally, through SEM analysis, the sericin coating effectiveness of all test samples isstudied.

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