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A Study on Silk and Its Mixed Fabric for Functional Properties

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Abstract

Silk is a valuable protein fiber in the textile industry. It is used for delicate applications in many areas, such as in sarees, suitings, curtains, and luxurious interiors. Lyocell textiles are categorized as cellulose polymeric products of natural fibers. They have their individual uses in the textile, apparel, and garment fields. Polyester (PET) is a synthetic textile with very good resistance towards chemical and microbial attacks. To diversify its properties and usages, silk is mixed with polyester and lyocell. The fabrics are dyed with both natural dyes (kum kum, indigo, bar berry) and synthetic dyes (reactive dye (H), reactive dye (M), and sulfur dye). This mixed fabric is compared with 100 % silk for some of the basic properties, like k/s value, fastness property, antimicrobial property, air permeability, UV-protection behavior, and SEM analysis. The silk mixed fabric gives appreciable results compared with the 100 % silk fabric.

Keywords: Silk, lyocell, antimicrobial activity, UV-protection behavior, SEM

Introduction

The demand of blended silk fabric is increasing day by day, due to the constantly increasing price of silk fabric. Hence, novel specific technologies are needed to create textile materials with new advanced functionalities and environmental responsiveness [1]. This would make the conjugation of silk and synthetic fabrics more popular in the market [2]. Silk proteins are natural polymers, and are biodegradable with reactive functional groups, allowing the possibility of them to be cross-linked with other polymers to be used in controlled delivery [3]. The polymer chains of silk fibroin form β-sheet structures. Silk fiber is highly crystalline in nature [4]. The mechanical strength of silk fiber is in the range of 1.9 - 5.2 g/den. Silk fiber is thin, long, light, and soft. It is well known for its water absorbency, dyeing affinity, thermo tolerances, insulation properties, and luster [5]. Silk contains many advantageous properties of the luxurious, having dyes in beautiful and rich colors, and being absorbent, strong, moderately wrinkle resistant, mildew and moth resistant, and not melting [6]. However, silk has the following limitations: being weakened by sunlight, perspiration, and chlorine bleach, absorbing body oils and grease stains, being affected by water spots, yellowing and fading with age, being subject to attack by carpet beetles unless treated, being affected by high temperatures, losing strength when wet, needing to be pressed with a press cloth, being color damaged by hair spray, and being damaged by perfumes [7].

Lyocell fibers may be defined as cellulosic fibers that are produced by regenerating cellulose into fiber form out of a solution in N-methylmorpholine-N-oxide (NMMO) [8]. Solvent spun lyocell fibers consist of crystalline cellulose-II and amorphous cellulose, and have a higher degree of crystallinity (80 %) in comparison with other regenerated cellulosic fibers, such as modal (49 %) and viscose (41 %) [9]. The characteristic properties of lyocell are softness when handled, luster, and moisture absorbency, which makes it suitable for a blend or a union fabric [10]. It is 100 % natural in origin, as it is made from wood pulp, and is fully biodegradable. Lyocell has similar appearance, moisture content, strength, and luster to that of silk. Lyocell has a functional group (–OH) similar to that of cotton, whereas silk contains different functional groups, such as –OH, $–SO_3H$, –COOH, $–C_6H_5OH$, $–NH_2$, that are highly useful when they are involved in chemical processing and subsequent end use products [11]. The cost of lyocell is less than $1/3^{rd}$ of silk. It has a dry strength higher than other cellulosics, approaching that of polyester. It also retains 85 % of its strength when wet. Under certain conditions, lyocell fibers fibrillate, which enables fabrics to be developed with interesting aesthetics. Non-fibrillating versions are also available. Lyocell fibers are mostly used for apparel fabrics, especially outerwear, but it has been shown that, due to the fibrillating property, some very interesting nonwoven fabrics can be made as well [12].

Poly(ethylene terephthalate) fiber is widely used in the production of garments because of its low production cost and good fiber properties, such as mechanical strength, high stability against heat and chemicals, wrinkle resistance, retention of heat-set pleats and creases, resistance to damage from abrasion, strong sunlight, weather conditions, moths, mildew and most strong chemicals, and its wash and wear properties [13-15]. Polyester materials have some limitations, such as accumulation of static electricity, absorption of body oils, tendency to pill and attraction of lint, absorption of perspiration odor, and melting if too hot [16,17]. The present study focused on the development of silk mixed fabric; silk (warp), and lyocell & polyester (weft). The fabrics were dyed using both natural dyes (indigo, kum kum, & bar berry) and synthetic dyes (reactive (M), reactive (H) & sulfur), and the dyed fabrics were subjected to different tests, such as k/s value, fastness property, anti-microbial activity, air permeability, and UV-protection behaviors. The results obtained are in an appreciable manner compared with 100 % silk.

Materials and methods

Materials

The 2 types of fabrics (1. 100 % silk (both warp & weft), and 2. Silk (warp 100 %) and 50 % lyocell and 50 % polyester (weft) mixed fabrics) used were as mentioned in the following **Table 1**.

Table 1 Fabric details.

S. No.	Parameters	100 % Silk	50 % Silk + 50 % polyester & lyocell
1	Warp Count	$2/80^s$	Silk : $2/80^s$
2	Weft Count	$2/80^s$	Polyester and Lyocell (50 : 50) : $2/80^s$
3	Ends / Inch	100	100
4	Picks / Inch	60	68
5	GSM	95	101
6	Cloth Width (Inch)	44	44

Natural dyes (kum kum, indigo, bar berry) and synthetic dyes (reactive dye (M), reactive dye (H) and sulfur dye) used were of commercial grade. The chemicals and auxiliaries mentioned elsewhere for this study were of AR grade.

Methods

Pretreatment of silk and mixed fabric

The above mentioned materials were treated with 10 gpl hydrochloric acid for 60 min in suitable separate baths, with a material to liquor ratio of 1:30 at 30 °C to get rid of the substrates added during weaving.

Dyeing of silk and its mixed fabric

The silk and its mixed fabric were dyed with natural (indigo, kum kum, & bar berry) and synthetic (reactive dye (M), reactive dye (H) and sulfur dye) dyes. Dyeing was carried out at boiling temperature for 2 h with a material to liquor ratio of 1:20, as per the established technique of dyeing for natural and synthetic dyes. The dyed samples were washed, soaped, and dried [18,19].

Measurement of K/S value on dyed silk and its mixed fabric:

Color intensities of the dyed silk and its mixed fabrics were measured using a spectrophotometer (model: Premier Colorscan SS 5000 A) within the range of 400 - 700 nm. Reflectance values were measured and the relative color strength (K/S) was calculated using the Kubelka Munk equation [20]. (K/S) defines the relationship between the spectral reflectance (R) of a sample and its absorption (K) and scattering (S) characteristics. $K/S = \{(1-R)^2/2R\}$.

Color Fastness Test on dyed silk and its mixed fabric

Color fastness of the dyed silk and its mixed fabric to washing, light, and rubbing was determined by standard test methods. The results were assessed in ratings from grade 1 (very poor) to grade 5 (excellent). The color change was assessed according to grey scale from grade 1 (much altered) to grade 5 (unaltered).

Wash fastness of dyed silk and its mixed fabric

The wash fastness of the dyed silk and its mixed fabric was determined by the IS 764-test 3 method [21]. The fabrics (10×4 cm) were sewn along all 4 edges with same size of multi-fiber fabric. The composite specimen was washed at 60 °C for 30 min using detergent solution 5 g/l, maintaining a fabric to liquor ratio of 1: 50. The change in color of the specimen and the staining of the adjacent fabric were assessed by grey scale.

Light fastness of dyed silk and its mixed fabric

The light fastness of the dyed silk and its mixed fabric was determined by the AATCC test method 16E-2004 [22]. These dyed fabrics were exposed separately for 10 h under an artificial light source- a xenon arc lamp. The color change of the exposed portion was compared with the masked portion of the test specimen.

Fastness to rubbing on dyed silk and its mixed fabric

Color fastness to crocking was determined by the AATCC test method 8-2007 [23]. An AATCC standardized crockmeter was used to determine the rubbing fastness of the dyed fabrics under wet and dry conditions.

Extraction process of aloe vera

The matured leaves of aloe vera were identified, collected, and washed with lukewarm water. The aloe vera gel was collected from the leaves, stored in a clean glass vessel, and dried in an oven at 75 °C for about 2 days and then powdered [24]. The powder was then subjected to soxhlet extraction [25] using methanol for 12 h. This extract was used as an antibacterial finishing agent.

Direct application of aloe vera extract on silk and its mixed fabric

The silk and its mixed fabrics were treated with aloe vera extract, using citric acid (8 %) as a cross-linking agent by the pad-dry-cure method, with a material-to-liquor ratio of 1:10 at 50 °C. After padding for 30 min, the samples were removed and dried at 110 °C for 5 min and cured at 180°C for 3 min [26,27].

Antibacterial activity assessment of aloe vera treated silk and its mixed fabric

To analyze the antimicrobial activity, the aloe vera treated silk and its mixed fabric samples were subjected to the agar diffusion test (SN 195920) and the modified Hohenstein test (JIS L 1902). The organisms used in both the tests were *Staphylococcus aureus* (AATCC 6538) and *Escherichia coli* (AATCC 11230). The former is used as a representative gram positive organism, and the latter is used as a representative gram negative organism. The evaluation of the agar diffusion test was made on the basis of the zone of inhibition of bacteria around the test sample, and the evaluation of the modified Hohenstein test was made on the basis of the percentage reduction of bacteria in the sample. Percentage reduction was calculated using the formula;

$$R = (B-A) / B$$

where **R** is the percentage reduction, **A** is the number of bacteria recovered from the inoculated treated test sample swatches in the jar incubated over the desired contact period (18 h), and **B** is the number of bacteria recovered from the inoculated treated test sample swatches in the jar immediately after inoculation, i.e., at zero contact time [28,29].

Air Permeability of silk and its mixed fabric

The ASTM - D737 method was used for measuring the air permeability of silk and its mixed fabric. This test gave the rate of airflow through a material under a differential pressure between the 2 faces of a fabric [30].

UV protection finishing silk and its mixed fabric

UV protection finishing (Super FX Anti UV) was given to the dyed silk and its mixed fabric. The finished fabrics were then tested according to the standard method [31,32].

SEM analysis of silk and its mixed fabric

The surface morphology of silk and its mixed fabric was observed using an SEM (JOEL JSM-6360 model microscope, Japan) [33].

Results and discussion

K/S values of dyed silk and its mixed fabric

The colorimetric data of indigo, kum kum, bar berry, reactive dye (M), reactive dye (H), and sulfur dyes applied on silk and its mixed fabric are given in **Table 2**. It is seen from **Table 2** that the silk and its mixed fabric, dyed with indigo, kum kum, bar berry, reactive dye (M), reactive dye (H), and sulfur dye show good colorimetric data. The K/S values are obtained based on the color coordinates, such as L*, a*, b*, C, and h°, where L* refers to lightness-darkness values from 100 to 0 representing white to black, a* values run from negative (green) to positive (red), b* values run from negative (blue) to positive (yellow), C values refer to the chroma or color brilliance, and h° indicates the color hue. The average K/S value for the silk mixed fabric dyed with indigo, kum kum, bar berry, reactive dye (M), reactive dye (H), and sulfur dye is around 14.7, whereas this value is less for 100 % silk fabric (around 14.1). The K/S value in silk mixed fabrics for reactive dyes (M & H) is around 14.85, followed by 14.65 (sulfur dye), 14.60 (indigo), 14.54 (bar berry), and 14.50 (kum kum), respectively. The 100 % silk fabric also follows the same trend of colorimetric data, such as for reactive dyes (M & H), around 14.36, followed by 14.21 (sulfur dye), 14.01 (indigo), 13.95 (bar berry), and 13.70 (kum kum), respectively. From this table, it is seen that both types of fabrics show good values, indicating good dyeing. The difference in the K/S values between the 2 types of fabrics is only marginal. The reason for good dyeing and K/S values is the reaction between the reactive dye and the reactive site of the polymers in the fabric materials. The silk polymer contains multiple functional groups, like –OH, $-SO_3H$, –COOH, $-C_6H_5OH$, $-NH_2$. Likewise, in lyocell, the reactive group –OH is present throughout the polymeric chain. These functional groups are responsible for the good dyeing and K/S values in silk and silk mixed fabrics. A K/S value of around 12, or more than 12, is considered to be good a color strength. Hence, the colorimetric data on 100 % silk and its mixed fabrics dyed using indigo, kum kum, bar berry, reactive dye (M), reactive dye (H), and sulfur dye are in the accepted value.

Table 2 K/S values of dyed silk and its mixed fabric.

S. No.	Dyes	Colorimetric data of silk and its mixed fabric											
		100 % Silk						Silk (warp) Polyester & Lyocell (Weft – 50: 50)					
		L*	a*	b*	C	h°	K/S	L*	a*	b*	C	h°	K/S
1	Indigo	26.2	-6.06	-14.41	23.1	262	14.0	37.9	-6.15	-15.30	21.6	251	14.6
2	Kum kum	27.7	-5.84	-15.95	23.5	251	13.7	31.0	-5.98	-15.52	22.0	255	14.5
3	Bar berry	29.5	-5.96	-14.24	22.9	262	13.9	32.0	-5.30	-15.08	21.6	251	14.5
4	Reactive Dye (M)	36.8	-4.65	-16.84	23.0	256	14.3	27.4	-5.30	-14.87	22.1	265	14.8
5	Reactive Dye (H)	36.5	-6.95	-16.62	22.8	253	14.4	35.3	-4.32	-15.15	23.5	241	14.9
6	Sulfur Dye	28.7	-4.75	-16.16	23.5	246	14.2	33.3	-4.62	-15.18	24.0	268	14.7
Mean							14.1	Mean					14.7
Standard Deviation							0.27	Standard Deviation					0.16
Variance							0.07	Variance					0.02

Fastness properties of dyed silk and its mixed fabric

The fastness properties (wash, light, and rubbing) of natural and synthetic dyes (indigo, kum kum, bar berry, reactive dye (M), reactive dye (H), and sulfur) applied on silk and its mixed fabric are given in **Table 3**. The wash fastness of the dyed silk materials is good as compared with other fastnesses, like light and rubbing fastness properties. The good wash fastness property is due to the strong reaction between the functional groups of the polymer in the fabric materials, and also of the dye. It is obvious that the light fastness and rubbing fastness properties are moderate to poor only due to their behavior towards these applications.

Table 3 Fastness properties of dyed silk and its mixed fabric.

S. No.	Dyes	Fastness properties of reactive dyed silk and its mixed fabric							
		100 % Silk				Silk (warp) Polyester & Lyocell (Weft - 50 : 50)			
		Wash	Light	Rubbing		Wash	Light	Rubbing	
				Dry	Wet			Dry	Wet
1	Indigo	4	4	2	1-2	4	4	2	1-2
2	Kum kum	3	3	3	1-2	3-4	2-3	2-3	1
3	Bar berry	3	3	2-3	1-2	3	3	2-3	1-2
4	Reactive Dye (M)	3-4	3-4	3	2	3	3-4	2-3	1-2
5	Reactive Dye (H)	3-4	3-4	3	1-2	3-4	3-4	2-3	1-2
6	Sulfur Dye	4	4	2	1-2	4	4	2	1-2
Mean		3-4	3-4	2-3	1-2	3-4	3.0	2.0	1.0
Standard Deviation		0.447	0.447	0.492	0.204	0.447	0.585	0.258	0.204
Variance		0.2	0.2	0.242	0.042	0.2	0.342	0.067	0.042

Antimicrobial property of dyed silk and its mixed fabric

The data of antibacterial property of silk and its mixed fabrics dyed with indigo, kum kum, bar berry, reactive dye (M), reactive dye (H), and sulfur dye for Staphylococcus aureus and Escherichia coli are given in **Table 4**. The antimicrobial activity of the silk and its mixed fabric dyed with indigo, kum kum, bar berry, reactive dye (M), reactive dye (H), and sulfur dye was assessed by the qualitative test method. All these dyed samples showed a higher zone of inhibition against Staphylococcus aureus when compared to Escherichia coli. In general, the silk mixed fabric that contained hydrophobic polyester showed a higher zone of inhibition (for both Staphylococcus aureus and Escherichia coli) over 100 % silk fabric. The reactive (H) dye showed maximum inhibition, followed by reactive (M) dye and sulfur dye, in the synthetic dye category, whereas indigo gave maximum inhibition, followed by kum kum and bar berry, in the natural dye category, in fabrics exposed to staphylococcus aureus and escherichia coli.

Table 4 Antimicrobial property of dyed silk and its mixed fabric.

S. No.	Dyes	Antibacterial activity (Zone of Bacteriostasis - mm)			
		Staphylococcus aureus		Escherichia coli	
		100 % Silk	Silk (warp) Polyester & Lyocell (Weft - 50 : 50)	100 % Silk	Silk (warp) Polyester & Lyocell (Weft - 50 : 50)
1	Indigo	39	42	36	38
2	Kum kum	36	40	33	36
3	Barberry	36	39	33	35
4	Reactive dye (M)	37	42	34	37
5	Reactive dye (H)	38	42	35	38
6	Sulfur dye	39	43	36	39
Mean		37.5	41.33	34.5	37.17
Standard deviation		1.38	1.51	1.38	1.47
Variance		1.9	2.27	1.9	2.17

Air Permeability of silk and its mixed fabric

The values of air permeability of silk and its mixed fabric dyed with indigo, kum kum, bar berry, reactive dye (M), reactive dye (H), and sulfur dye are given in **Table 5**. Air permeability is the rate of air flow passing perpendicularly through a known area under a prescribed air pressure differential between the 2 surfaces of a material. Air permeability is an important factor in the performance of textile materials such as gas filters, fabrics for air bags, clothing, mosquito netting, parachutes, sails, tentage, and vacuum cleaners. Air permeability can also be used to provide an indication of the breathability of weather resistant and rain proof fabrics, or of coated fabrics in general, and to detect changes during the manufacturing process. The air permeability test gives the rate of airflow through a material under a differential pressure between the 2 faces of a fabric. It is expressed as the quantity of air in cubic centimeters passing per second through a square centimeter of the fabric.

It is seen from **Table 5** that the silk mixed fabric dyed with indigo, kum kum, bar berry, reactive dye (M), reactive dye (H), and sulfur dye gives excellent air permeability behavior compared with the corresponding 100 % silk fabric. The average air permeability value of silk mixed fabric is 109.3, while that for silk fabric is 55.0 only. There is a nearly one fold increase in the air permeability value of silk mixed fabric compared with that of 100 % silk fabric, due to the presence of the multiple functional groups (–OH, $-NH_2$, –COOH, $-CONH_2$, etc.) present in the lyocell and silk polymers of silk mixed fabric. The silk mixed fabric contains the presence of lyocell, which comprises full of –OH functional group in the polymer with more amorphous character, and accessible for the attraction leads for higher air permeability.

Table 5 Air permeability of silk and its mixed fabric.

S. No.	Dyes	Air Permeability l/min	
		100 % Silk	**Silk (warp) Polyester & Lyocell (Weft – 50: 50)**
1	Indigo	55.8	110.2
2	Kum kum	54.1	109.8
3	Bar berry	55.8	108.8
4	Reactive dye (M)	55.1	108.3
5	Reactive dye (H)	54.2	109.5
6	Sulfur dye	55.0	109.3
Mean		55.0	109.32
Standard deviation		0.7403	0.6853
Variance		0.548	0.4697

UV Protection factor for dyed and UV protection finished silk and its mixed fabric

The UV transmittance of the dyed and finished fabrics (100 % silk and silk mixed fabrics) was determined using a UV visible spectrophotometer. The standard chart for determining the UV protection factor is presented in **Table 6**, and data of the UV protection factor for these fabrics are given in **Table 6(a)**. The UV protection factor for the silk and silk mixed fabrics is given in **Table 7**. The UV protection factor (UPF) values of all the dyed and finished fabrics were between 35 and 39, respectively. The maximum UPF value (39) was given by the silk mixed fabrics dyed with indigo (natural dye) and reactive dye and sulfur dye (synthetic dyes), whereas the minimum UPF value (36.5) was seen in 100 % silk fabrics dyed by kum kum and barberry (natural dyes) and reactive dye (synthetic dye). From these data (**Tables 6** and **7**) it is clear that there is a very good UV protection category, as revealed by the UPF rating (35 - 39) for the dyed and finished silk and silk mixed fabrics. Therefore, based on this, as indicated in **Table 7**, the percentage UV radiation blockage by these fabrics (dyed and finished silk and silk mixed fabrics) would be between 96 and 97.4 %. However, the presence of lyocell in the silk mixed fabric increases the hydrophilic character, which attracts more finishing agents onto the fabric, thereby leading to an improved UPF rating (> 5 %) compared with that of the 100 % silk fabric.

Table 6 Standard chart for UPF rating for the fabric.

UPF rating	Protection category	% UV radiation blocked
15 to 24	Good	93.3 - 95.9
25 to 39	Very Good	96 - 97.4
40 to 50	Excellent	97.5 or more

Table 7 UV Protection factor for the dyed and UV protection finished silk and its mixed fabric.

S. No.	Dyes	UPF rating of the dyed and finished fabrics	
		100 % Silk	**Silk (warp) Polyester & Lyocell (Weft – 50: 50)**
1	Indigo	37	39
2	Kum kum	36	38
3	Bar berry	36	38
4	Reactive dye (M)	37	38
5	Reactive dye (H)	36	39
6	Sulfur dye	37	39
Mean		36.5	38.5
Standard deviation		0.55	0.55
Variance		0.3	0.3

SEM Analysis of Silk and Its Mixed Fabric

The analysis of SEM images of dyed and finished silk and its mixed fabrics are given in the representative **Figures 1** and **2**. **Figure 1** shows the antimicrobial treated & UV protection finished dyed silk fabric. **Figure 2** shows the antimicrobial treated and UV protection finished dyed silk mixed fabric. These figures clearly show that the presence of the corresponding ingredients (antimicrobial and UV protection agents) in the respective fabrics that contain the functional groups (–OH, –SO3H, –COOH, –C_6H_5OH, –NH_2) are responsible for the impartation of the effect on the fabrics concerned.

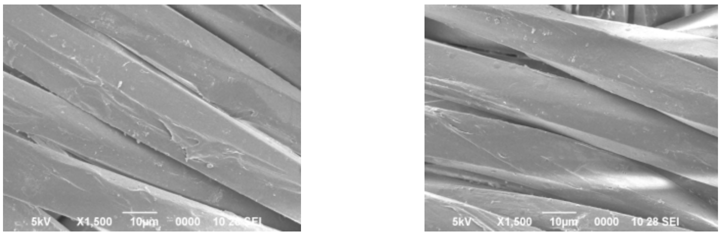

Figure 1 Antimicrobial treated & UV protection finished dyed silk fabric.

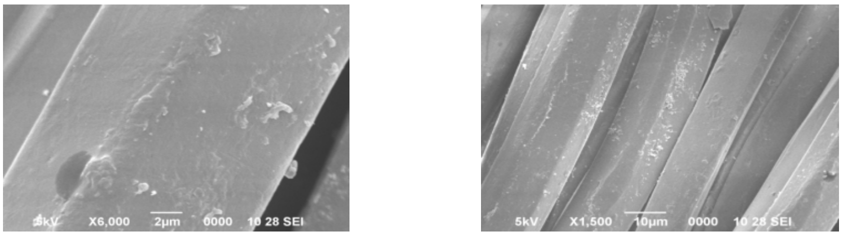

Figure 2 Antimicrobial treated & UV protection finished dyed silk mixed fabric.

Conclusions

From this research work on 100 % silk and silk mixed fabric dyed with natural dyes (indigo, kum kum, & bar berry) and synthetic dyes (reactive (M), reactive (H), & sulfur), the following conclusions are arrived at;

The K/S values are mostly similar in both the 100 % silk fabric and silk mixed fabric, but the fastness properties (wash, light and rubbing) are quite less in the silk mixed fabrics, due to the presence of polyester material. In the overall fastness properties, washing fastness is more compared with the corresponding light and rubbing fastnesses. The antimicrobial character of silk mixed fabric dyed with both natural dye (indigo, kum kum, & bar berry) and synthetic dye (reactive dye (M & H) and sulfur) is good when compared with the corresponding 100 % silk fabric.

The silk and its mixed fabric give good values of air permeability, due to the presence of lyocell in the mixed fabric, which facilitates the increase of air permeability values. There is a very good UV protection category for the dyed and finished silk and silk mixed fabrics. SEM analysis confirms the presence of the ingredients responsible for antimicrobial and UV protection effect on the silk and silk mixed fabrics.

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