

Developing faded denim using surface-modified disperse dye dyeable cotton yarn

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In this study, faded denim fabrics have been developed using an unconventional route. The surface of cotton yarn is modified using an unsaturated polyester-based resin, thus making this yarn disperse dye dyeable. FTIR spectroscopy has been used to confirm the presence of resin on the surface of the yarn. A twill (3 up 1 down) weave fabric is produced using a combination of surface-modified and gray cotton yarns. After curing at 180°C, the fabric has been dyed in CDR using low-energy disperse dyes in the presence of vanillin as a carrier. Statistical analysis (ANOVA) has been carried out to establish a relationship between the concentration of vanillin and the colour strength. The surface-modified disperse dyed yarn in the fabric is found to have a ring dyeing effect, as only the surface of the yarn is dyed. The developed fabric is washed using two different methods (mild and harsh) to get different fading effects. The unwashed and washed samples are analyzed for tensile strength, tear strength and bending length properties. The tensile strength of unwashed samples is found to be between 585 - 648 N and 516 - 588 N for warp-wise and weft-wise directions respectively and after various washing conditions, it decreases to 395 - 594 N and 395 - 550 N for warp-wise and weft-wise directions respectively. In the case of tear strength, the warp-wise and weft-wise values of unwashed samples lie at 33.5 - 38 N and 30 - 33 respectively and after various washing conditions, these values are 19.5 - 22 and 17.5 - 21 N respectively. The bending length of the unwashed fabric samples are 1.9 - 3.0 mm and 1.8 - 2.9 mm for warp-wise and weft-wise respectively and after washing, the bending length decreases to 1.5 - 2.7 and 1.3 - 2.5 mm for warp-wise and weft-wise respectively.

Keywords: Cotton denim, Disperse dye, Sizing, Unsaturated polyester resin, Twill weave fabric, Vanillin

1 Introduction

Denim fading is one of the most widely used effects to create an attractive look in garments made out of denim. Mostly warp face 3/1 twill weave is used to manufacture denim fabric. In such denim fabric, the warp is indigo dyed and the weft remains undyed or white. Although Indigo is a vat class of dye, it has a low affinity with cotton and remains only on the surface of cotton yarn, thus producing a ring dyeing effect. As the dye remains on the surface of the yarn, it comes out during the finishing process by rubbing action of stones or interaction with cellulase enzymes. Many techniques are used to create a fading effect on denim, some of them are a stone wash, mill wash, moon wash, bleach, distressed look, whisker effect, 3D effect, PP spray, sandblast, etc. It has been observed^{1,2} that there is a huge quantity of water (8000 - 15000 L) used to convert about 600 g of cotton into one pair of jeans made out of denim fabric. In 2018, worldwide more than 4.5 billion pairs of jeans were reportedly produced³. This shows the popularity of jeans as well as concern regarding the

huge quantity of water used. This is posing a serious problem with drinking water supplies. In the study carried out by Levi Strauss & Co., the average pair of jeans uses 42 L of water in the finishing process⁴.

To reduce the consumption of water during the denim fading process, the CO₂ laser technique has been used. It was found that with the increase of laser power, colour fading effect was also increased⁵. In one of the studies⁶, denim made out of open-end yarn and ring-spun yarn are compared for water consumption to achieve a similar fading effect. Studies showed that the penetration of indigo dye is less in ring-spun yarn as compared to that in open-end yarn. Due to this, in the washing process, the surface colour of ring-spun yarn showed fast colour bleeding. Hence, less water is required to get a similar fading effect in ring denim. In another study⁷, to conserve water, DREF technology was used to develop denim fabric. Instead of dyed indigo warp yarn, a Dref yarn was developed, in which the core was undyed or white yarn and the sheath was made out of dyed cotton fibre. During the stone or enzyme washing process, some of the dyed fibres from the sheath are abraded or removed, thus exposing undyed or white yarn of the core. It gave a fading type effect on the

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overall garment. A lot of studies have been carried out to reduce the consumption of water in wet processing through various new approaches and automation in technology⁸. Surface modification of cotton fabric to enhance dye uptake and water conservation using various techniques, like plasma treatment, laser treatment, deposition of a nanocellulose hydrogel loaded with a mixture of fine natural indigo particles & chitosan and nanocellulose hydrogel loaded with a mixture of fine natural indigo particles & chitosan and cationization, has been used by various researchers⁹⁻¹³.

Unsaturated polyester resin is having varying applications, depending upon its type. One of the common uses is thermoset resins. It has good resistance to high and low temperatures. Besides this, it has good mechanical properties, low weight, and corrosion resistance properties. It is used as a polymer matrix in composites, such as polymer concrete, fibre-reinforced plastic, and glass fibre-reinforced polyester composites¹⁴. The water-soluble unsaturated polyester resin is also found to be used in the sizing process of polyester filament yarn¹⁵. The water-soluble polyester resin was developed by chemical recycling of waste poly (ethylene terephthalate) fabrics and was used in the sizing of polyester filament yarn¹⁶. Besides this, unsaturated polyester resins are also available in a solution of unsaturated oligomers in monomers (like styrene), which are able to copolymerize in the presence of an initiator. The resultant polymer has many applications¹⁷.

Polyester is dyed with disperse class of dyes. This dye is having very low water solubility. For the sake of efficient diffusion into textiles, the particles of disperse class of dye should be as fine as possible. As water is the medium to dye any textile fibre, it is required to make the dispersion of this with the help of a surface-active agent, which is called a dispersing agent. The dyeing of polyester can be carried out using high-temperature high pressure (HTHP), pad thermosol dyeing, and carrier dyeing methods. In

HTPH and thermosole methods, dyeing is carried out at a very high temperature. On the other hand, in the carrier dyeing, dyeing is carried out at around 90 - 100°C in the presence of the carrier. During the dyeing process, polyester absorbs the carrier and swells, thus creating free volume due to the movement of the polymer chain. This accelerates the distribution of the dye into the fabrics¹⁸. Most of the carriers used in this dyeing process are toxic in nature. For making low-temperature and environment-friendly dyeing of polyester, vanillin is used as a potential carrier in place of toxic carriers¹⁹. Various studies^{20, 21} have shown that vanillin is non-toxic.

This study deals with the development of a new method to manufacture faded denim fabric by modifying the surface of cotton yarn used in the fabric with unsaturated polyester resin followed by dyeing with disperse class of dye. Due to the over exploitation of ground water for use of various purposes, the level of water is decreasing and this resulted in the scarcity of water. The Textile industry is one of the most water-consuming industries. Therefore, the aim of this study is also to reduce the consumption of water during denim manufacturing without using a costlier yarn sheet and rope dyeing machine.

2 Materials and Methods

A low molecular weight unsaturated polyester resin [Fig. 1(a)] having a good affinity with disperse class of dye was procured from the local market. The whitish-yellow powder of unsaturated polyester resin is having 98±2% solid content with anionic in nature. Two low-energy disperse dyes (Foron Dark Blue SE-RD and Foron Rubine SE RdgFLI 200) were procured from Archroma India Pvt Ltd. Other ingredients used in the study were acetic acid and vanillin (dyeing carrier). Vanillin is a white powder, its molecular weight is 150 and the melting point is around 178°C. The chemical structure is shown in Fig. 1 (b). These were procured commercially. Grey cotton single yarn of 9s count (Open End) was procured from the local industry.

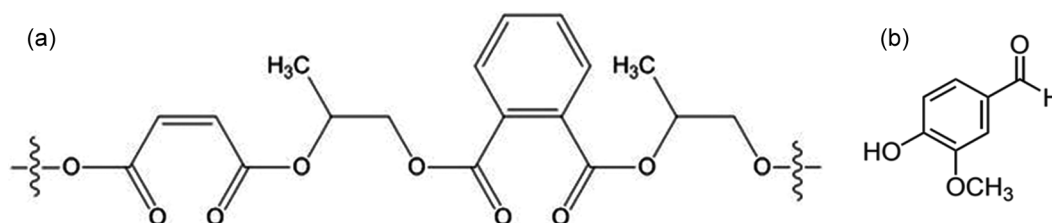


Fig. 1 — Chemical structure of (a) unsaturated polyester resin and (b) vanillin

2.1 Optimization of Resin Concentration for Sizing

To optimize unsaturated polyester resin (UPR) concentration for sizing purposes, 10, 30, 50, 70, 90, and 120g/L solutions were made. Cotton yarn (9^s count) was sized with each solution using CCI sample sizing machine (model no SS 565). The sized yarn samples were analyzed for size add-on%, tensile strength, and elongation (ASTM D 2256), and hairiness (ASTM D 5647) properties.

2.2 FTIR Analysis

Fourier-transform infrared (FTIR) spectra of polyester resin, gray cotton yarn (control sample), and sized (polyester resin-treated) cotton yarns were recorded on Perkin Elmer UATR TWO instruments using ATR method to identify the presence of resin on the sized yarn.

2.3 Optimisation of Vanillin Carrier Concentration in Dyeing

The sized cotton yarn was first cured at 180±3°C for one minute and then dyed using a 5% shade of Foron Rubine SE RdgFLI 200 disperse dye at 85°C, maintaining pH at around 5 with acetic acid in the presence of vanillin carrier in lab model IR dyeing machine. The dyeing study was carried out using 4, 8, 12, 14, 16 and 20 g/L of vanillin carrier. The K/S value of each dyed yarn was determined with Macbeth Color Eye 3100 under the illuminant D65 using 10° standard observers.

The effect of varying concentrations of vanillin on colour strength was also analyzed using SPSS (version 20). The null hypothesis (H_0) states that there is no relationship between the concentration of vanillin used as a carrier in the dyeing and the colour strength of the dyed yarns. An alternative hypothesis states the possibility of a relationship between the concentration of vanillin (g/L) and the colour strength of dyed yarns. H_0 is rejected if the p-value is less than the predetermined significance level, which is ideally 0.05.

2.4 Surface Roughness Index

The digital image processing (DIP) method^{22,23} was used to analyze the surface of sized fabric coded as WpS/WtU and desized fabric of the same. The yarn samples were scanned at 600 dpi and simulation graphs for roughness on the surface were plotted using Matlab software. The images obtained were first inverted so that the lighter areas represented the densely populated part of the fabric and the dark parts – the thinly populated region. The images were transformed to grayscale and then loaded into Matlab. To remove noise, Gaussian filters were applied. The

degree of smoothening of the surface of the yarn was determined by the standard deviation of the Gaussian, which is generally taken as 5. The colour of individual pixels was plotted as the height in the graph. As there is a difference between the colour of different regions of the yarn, this causes a variation in the height of the plot. This difference is used to determine the surface roughness. In this study WpS/WtU (warp sized and weft unsized) and desized fabric sample of the same code were taken. The roughness index is determined using the following equation²³:

Decrease in roughness index (%) =

$$\frac{\text{Peak height of WpS/WtU fabric} - \text{Peak height of desized fabric}}{\text{Peak height of WpS/WtU fabric}} \times 100 \quad \dots (1)$$

2.5 Fabric Manufacturing

The optimized concentration of UPR was used as a sizing agent. It was dissolved into warm water by stirring. The solution was then applied to cotton yarn using a CCI sample sizing machine. The sized yarn was dried at 100±5°C and then wound on a cone. The warping of sized yarn is carried out on the CCI sample warping machine (model no SUU 550) for making the warping beam. This warping beam was placed on the CCI sample rapier loom (model no SL 8900 EG) for making fabric samples of 3/1 twill weave structure with 48 ends/inch and 42 pick per inch. Three different types of fabric samples were developed with the combination of sized and unsized yarns. The coding of these samples is given in Table 1.

2.6 Dyeing of Fabric

The dyeing was carried out on a Continuous Dyeing Range (CDR) machine. The woven fabric was first cured in the lab stenter for one minute at 180±3°C and then dyed using 5 g/L dye with 14 g/L of vanillin as a carrier. The dyeing temperature was maintained at 85°C with 1.0 m/min of dyeing machine speed. The padding was done using 2 dips and 2 nips process and the padding pressure was kept at as 1 Bar as dyed material was washed and then dried on CDR at 120°C at 0.5 m/min speed. The coding of dyed samples is given in Table 1.

2.7 Fading Effect

To get fading effect, samples were washed in a launderometer as per ISO 105 C10 with two washing conditions C(3) and D(4). In condition C(3), fabric

Table 1 — Sample code

Sample particular	Code of woven fabric without dyeing	Code of dyed fabric	
		Dyed with Foron Dark Blue SE-RD	Dyed with Foron Rubine SE RdgFLI 200
Warp and weft both sized	WpS/WtS	WpS/WtS -Blue	WpS/WtS- Rubine
Warp sized with resin and weft having 20 sized and 20 unsized yarns	WpS/Wt (S+U)	WpS/Wt (S+U)-Blue	WpS/Wt (S+U)-Rubine
Warp sized and weft unsized	WpS/WtU	WpS/WtU-Blue	WpS/WtU-Rubine

was washed at 60 °C for 30 min and with condition D(4), fabric was washed at 95°C for 30 min with 10 numbers of steel balls. In both the washing conditions, 5g of soap, and 2g of sodium carbonate in one litre of water were used. The material-to-liquor ratio (MLR) was maintained at 1:50. The condition C(3) is mild as compared to condition D(4). Condition C(3) was applied only on two samples coded as WpS/WtS-Blue and WpS/WtS-Rubine and condition D(4) was applied to all the samples. To study the colour retention property, WpS/WtS-Rubine sample was given 10 cycles of washing treatment as per condition C(3). After each wash, *K/S* value of the washed sample was measured.

2.8 Fabric Mechanical Property

The tensile and tear strength along with the coefficient of variation percentage (CV%) of all the unwashed and washed samples were measured as per the ASTM D 5035 and ASTM D 1424 test methods respectively. The areal density in g/m² was measured as per ASTM D 3776. The stiffness of the fabric was measured as per ASTM D 1388 by evaluating bending length. In all the cases, 10 specimens of the individual sample were tested.

3 Results and Discussion

3.1 Sizing of Cotton Yarn

The UPR concentration for sizing purposes was optimized by determining yarn strength, elongation, and hairiness. For this purpose, 10, 30, 50, 70, 90, and 120 g/L solutions of UPR were used as sizing agents. The add-on % of each solution of the sizing agent was determined. It is observed that the add-on% of 10, 30, 50, 70, 90, and 120 g/L solutions of sizing agents is 3.4, 5.5, 6.8, 7.2, 7.4 and 7.4 respectively. With the increase of concentration of resin, the size add-on % on yarn also increases. However, this increase in size add-on % is found to be not much after 50 g/L of UPR concentration. The properties of yarn before and after sizing with different add-on % of UPR are given in Table 2. It is evident that with the increase of resin

Table 2 — Effect of add-on% on yarn properties

Add-on %	Breaking force, N	Elongation, %	Tenacity, RKM	Hairiness
0	6.47	6.66	8.94	6.80
3.4	6.74	6.08	9.32	6.62
5.5	7.22	5.83	9.97	3.73
6.8	7.54	5.48	10.42	3.31
7.2	7.54	5.34	9.88	3.47
7.4	7.45	5.15	10.29	3.42
7.4	7.51	4.91	10.39	3.33

concentration, the breaking force of the sized yarn increases up to 50 g/L concentration of resin (6.8% add-on). After that, there is no significant improvement in breaking force observed. The results of tenacity also show similar trends. The yarn sized with 50 g/L or more concentration of resin, shows lower hairiness as compared to the yarn sized with 10 g/L (3.4 % add-on) and 30 g/L (5.5 % Add-on) concentration of UPR. So, 50 g/L concentration of UPR is selected for sizing yarn for weaving purposes.

3.2 FTIR analysis

The FTIR spectra of unsized cotton yarn (control), 50 g/L UPR-treated (sized) cotton yarn, and UPR (used for sizing purposes) are shown in Fig. 2. It can be observed that sized cotton yarn with 50 g/L UPR consists of all the peaks of unsized cotton yarn (control sample).

The broad peak centered at around 3323.9 cm⁻¹ in unsized cotton yarn and at 3333.6 cm⁻¹ in sized yarn represent characteristics of the -OH functional group present in cotton in the form of cellulose. A broad peak is also observed in the 2917 cm⁻¹ region in unsized yarn and 2920 cm⁻¹ region in sized yarn, indicating C– H stretching. A strong absorption band with a maximum at 1029 cm⁻¹ (unsized yarn) and 1036 cm⁻¹ (sized yarn) is a result of the overlapping bands, attributed to functional groups of cellulose, namely the C–C, C–O, and C– O–C stretching vibrations²⁴.

The peak in yarn sized with UPR and only UPR samples found at around 1720 cm⁻¹ is attributed to

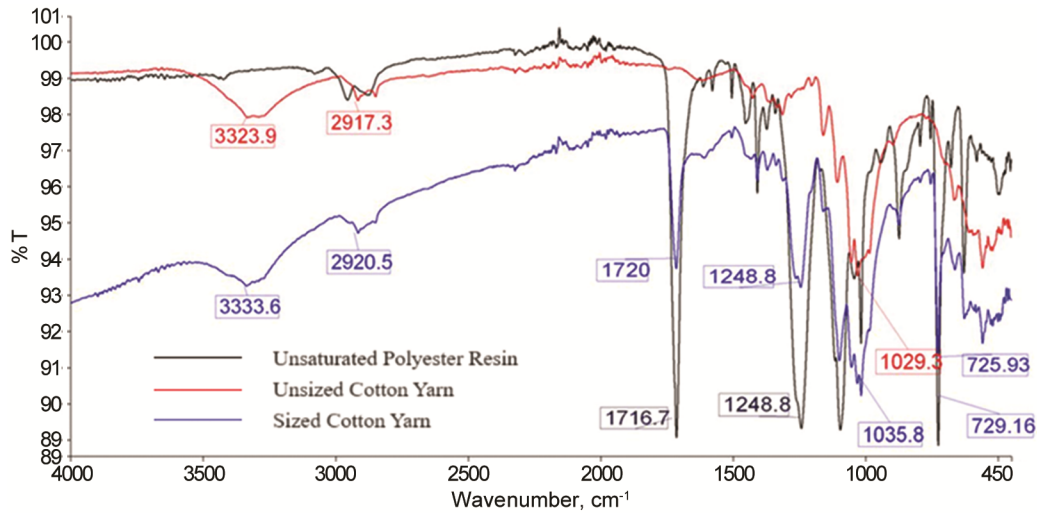


Fig. 2 — FTIR spectra of unsized cotton yarn, sized cotton yarn with UPR and UPR

ester C=O stretch. A strong peak is found in both sized yarn and polyester resin at around 1246 cm^{-1} , indicating -C-O-C- ester group of the polyester. The peak at around 725 cm^{-1} in both sized yarn and UPR is due to the aromatic bond C-H. This confirms the presence of polyester resin on the sized cotton yarn²⁵.

3.3 Optimisation of Concentration of Vanillin as a Carrier

The optimization of vanillin concentration required for dyeing is carried out by measuring the K/S value of dyed yarn. The results are shown in Fig. 3. It is clear that at 14 g/L of vanillin carrier, dyed yarn (Foron Rubine SE RdgFLI 200) gives a maximum K/S value. After 14 g/L of vanillin, no significant improvement in K/S value is obtained. Therefore, for further study, a 14 g/L concentration of vanillin is selected.

The ANOVA results for studying the relationship between vanillin concentration and colour strength (K/S) of dyed samples are shown in Table 3. The null hypothesis (H_0) was rejected p-value was less than a pre-determined significance level (0.05). The regression coefficient (R^2) value of dyed yarn was found to be 0.990, which indicated a very strong relationship between the vanillin concentration and colour strength.

3.4 Manufacturing of Fabric and Dyeing

Following three combinations of fabrics have been manufactured on a rapier sample loom:

- (i) Both warp and weft are sized with 50 g/L UPR (solid denim effect) coded as WpS/WtS
- (ii) Warp sized with 50 g/L UPR and weft remains unsized (light shade denim effect) coded as WpS/WtU

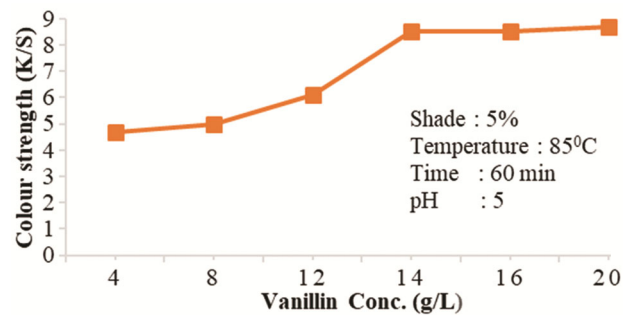


Fig. 3 — Effect of vanillin on colour strength

- (iii) Warp sized with 50 g/L UPR and weft having mixed sized and unsized yarns (striped design denim effect) coded as WpS/Wt(S+U)

These fabric samples are cured for one minute at $180\pm 3^\circ\text{C}$ using stenter and then dyed in two colours using CDR. The mechanism of the effect of vanillin as a carrier on the UPR treated cotton yarn followed by dyeing with disperse dye is shown in Fig. 4. It is observed that with the treatment with vanillin at 85°C , the swelling in unsaturated polyester resin on the surface of cotton yarn takes place, which facilitates diffusion of disperse dye into the amorphous regions of UPR film during dyeing. After washing, the unsaturated polyester resin regains its original form and thus traps the disperse dyes.

It is a well-known²⁶ fact that the carrier improves adsorption and acceleration of the diffusion of the disperse dye into the pet fibres during dyeing at low temperature and pressure conditions. As the carrier molecules are smaller in size than the dye molecules, they diffuse more rapidly into the amorphous regions of fibre after their adsorption onto PET fibre. There is

Table 3 — Univariate ANOVA between vanillin concentration and *K/S* value

Source	[Dependent variable: Colour strength]				
	Type III Sum of squares	df	Mean square	F	Significance
Corrected model	181.043 ^a	5	36.209	1144.594	<.001
Intercept	2852.462	1	2852.462	90169.483	<.001
Vaniline conc	181.043	5	36.209	1144.594	<.001
Error	1.708	54	0.032		
Total	3035.213	60			
Corrected total	182.751	59			

^aR squared = 0.991 (Adjusted R squared =0.990).

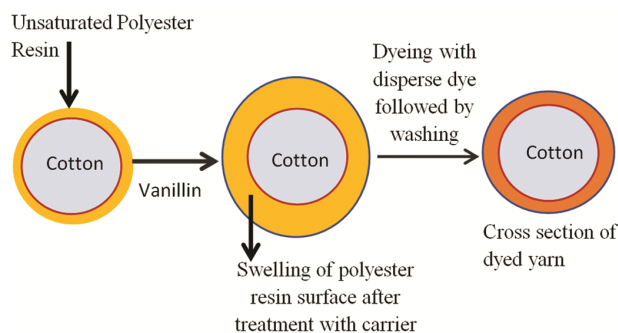


Fig. 4 — Mechanism of dyeing UPR-treated cotton yarn in presence of vanillin carrier

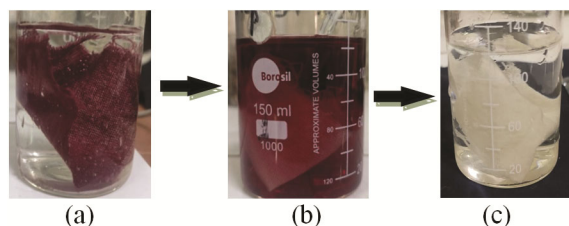


Fig. 5 — Reaction of alkaline methanol with disperse dyed cotton fabric [(a) dyed cotton with alkaline methanol, (b) intermediate reaction with dyed fabric and alkaline methanol, and (c) removal of UPR and colour from surface]

then swelling of PET fibre and the creation of spaces between PET macromolecular chains. Amorphous regions then become more easily accessible to the dye molecules. The molecular structure of vanillin is similar to that of traditional carriers, which confers to all of them a solubility parameter close to that of PET. A similar role is expected during the use of vanillin as a carrier for dyeing unsaturated polyester resin-treated cotton yarn.

3.5 Ring Dyeing Effect

In the indigo-dyed denim fabric, the fading effect is obtained by abrading the surface of the dyed yarn using stones or enzymes during the garment-washing process. This fading effect occurs, as in the indigo-

dyed denim fabric, only the surface of the yarn is dyed and the inner or core portion remains undyed. This type of dyeing is also called ring dyeing. So, when this denim garment is washed using stone or enzyme in the drum washing machine, the dye attached to the surface of the yarn comes out and exposes the white core portion, which is seen as a fading effect. In this study similar ring dyeing effect is created by dyeing surface-modified cotton with disperse class of dye. To establish this fact, this study has been carried out. The dyed sample is treated with alkaline methanol, which has the property to dissolve polyester as per AATCC TM 20A: 2020. As the surface of cotton is modified using UPR, which is dyed with disperse dye, during the treatment with alkaline methanol, UPR present on the surface of yarn is dissolved, thus making the fabric white. The complete process is shown in Fig. 5.

3.6 Digital Image Processing Method

This method is used to obtain surface plots for desized fabric (obtained after removal of sizing i.e UPR from the fabric coded as WpS/WtU using Alkaline methanol) and WpS/WtU fabric (warp is sized with UPR and weft unsized). These plots are shown in Fig. 6. The surface of the WpS/WtU fabric is rougher than that of the desized fabric sample. It has been observed that the WpS/WtU fabric sample has the largest number of local maxima [Fig. 6 (a)], indicating the roughest surface, which decreases with the removal of the sizing chemical, i.e. polyester resin as shown in Fig. 6 (b).

The decrease in the surface roughness or increase in smoothness of the desized fabrics is found to be 58.8% more than that of the WpS/WtU fabric, in which warp yarn is sized and weft remains gray. The main reason for the roughness of WpS/WtU fabric is the variation in the thickness of warp and weft yarns used in the construction of the fabric. As a warp yarn

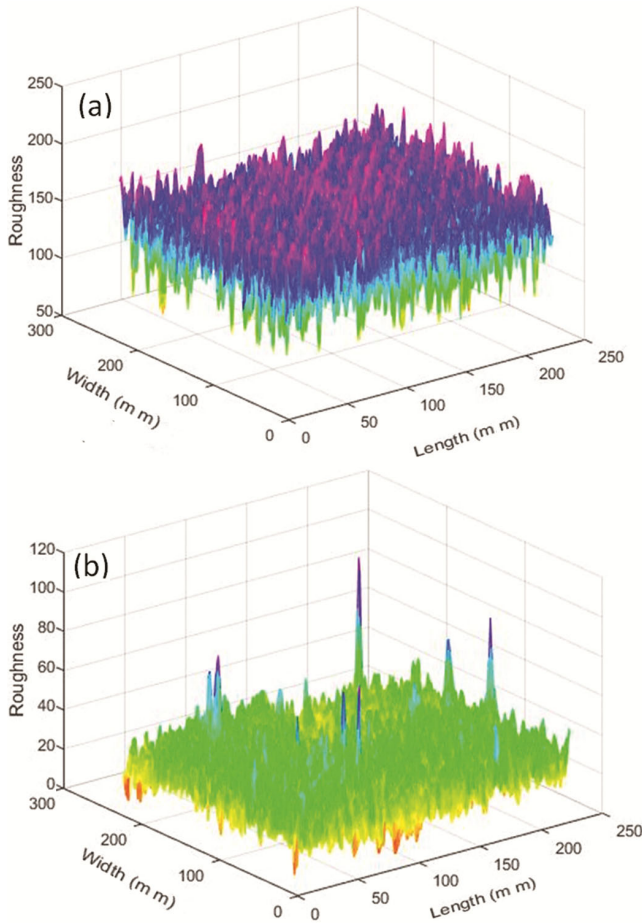


Fig. 6 — Digital Images of (a) WpS/WtU and (b) desized fabrics is sized with UPR, its thickness is greater than that of unsized or gray weft yarn. After desizing, both warp and weft yarns diameter become almost the same as both have the same count and hence the fabric surface smoothness increases.

3.7 Fading Effect

The fading effects obtained on fabrics after washing are shown in Fig. 7. It is clear that the samples washed using condition C(3) give a low fading effect as compared to the samples washed using condition D(4). In this study, only one cycle of washing is done on fabric to get the fading effect. Total water consumption for 1 kg of denim fabric is 50 litres only. However, in conventional cotton denim washing using stone and enzyme combination, the first step is to remove sizing to prepare it for the enzymatic stone washing process. This process requires an additional quantity of water. During the enzymatic stone washing, several cycles of washing are carried out to remove the dust of the stone from

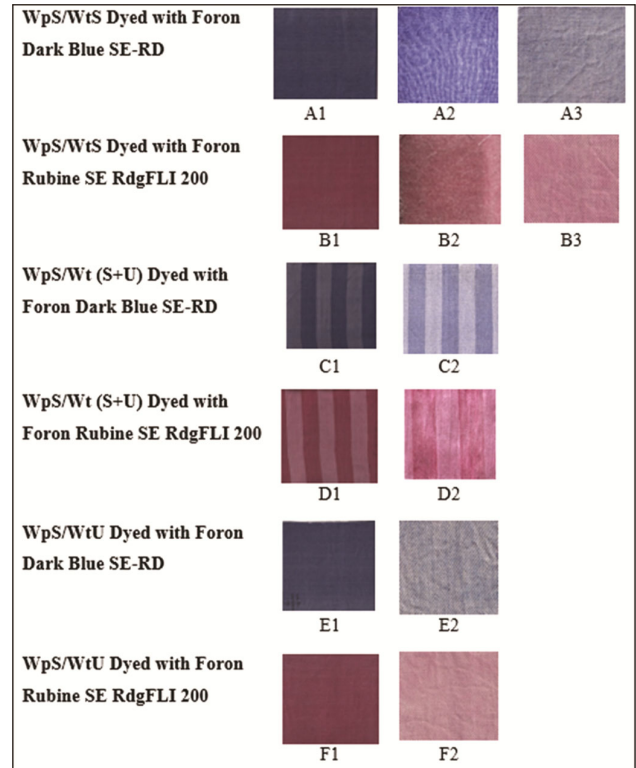


Fig. 7 — Dyed and washed samples [A1, B1, C1, D1, E1, and F1 - unwashed samples; A2, and B2- samples washed with conditions C(3); and A3, B3, C2, D2, E2, and F2 - washed samples with condition D(4)

the denim. The stone used during the washing process creates an environmental problem due to the production of grit. The study reveals that for getting a fading look in denim, more than 70 litres of water is consumed²⁷. It does not include water used in the desizing process. The change in *K/S* values of WpS/WtS Blue and WpS/WtS Rubine samples after the wash is also shown in Fig. 8(a). From the figure, the *K/S* values of unwashed samples coded as WpS/WtS Blue and WpS/WtS Rubine are 7.84 and 7.04 respectively. After washing using condition C(3), the *K/S* values of samples coded as WpS/WtS Blue and WpS/WtS Rubine decrease to 4.85 and 3.74 respectively. When these samples are washed at 95°C using washing conditions D(4), the *K/S* value is found to be 1.31 and 1.18 respectively. The results of *K/S* values, reflectance value, CIEL*a*b* values, DE, DL, DA, and DB values of unwashed and washed samples are shown in Table 4. It is revealed that the colour difference (DE) between unwashed WpS/WtS dyed with Foron Dark Blue SE-RD sample and sample washed using condition C(3) is 0.928 and colour difference (DE) between unwashed dyed fabric

and sample washed as per condition D(4), is 5.461. In the case of WpS/WtS dyed with Foron Rubine SE-Rdg FLI 200 sample after washing conditions C(3) and D(4), the DE values are found to be 7.683 and 3.355 respectively. From Table 4, it is clear that after washing with conditions C(3) and D(4), the sample becomes darker and lighter respectively than an unwashed sample of WpS/WtS dyed with Foron Dark Blue SE-RD as shown by DL values. In the case of WpS/WtS dyed with Foron Rubine SE-Rdg FLI 200, after washing in both conditions, samples are lighter than an unwashed sample. WpS/WtS dyed with Foron Dark Blue SE-RD is redder after washing with condition C(3) as compared to the unwashed sample and after washing with condition D(4), it becomes less red, as indicated by its DA values. A similar trend is seen in the case of WpS/WtS dyed with Foron Rubine SE-Rdg FLI

200. The DB values of the washed and unwashed samples of WpS/WtS dyed with Foron Dark Blue SE-RD show that after washing with condition C(3), the sample is bluer than the unwashed sample, while after washing with condition D(4), sample is less blue. Similar trends are seen in WpS/WtS dyed with Foron Rubine SE-Rdg FLI 200 sample after washing.

It is seen that after the wash, most of the superficial dye comes out from the fabric. This is the reason, the decrease in *K/S* value is on the higher side.

To see the effect of repeated washing, a sample coded as WpS/WtS Rubine is washed 10 times and its colour strength in terms of *K/S* value is measured. The results of the *K/S* value after each washing cycle are shown in Fig. 8(b). It is also clear from the figure that after 5 washes the bleeding of the colour is almost stopped as there is no significant change in *K/S* value found.

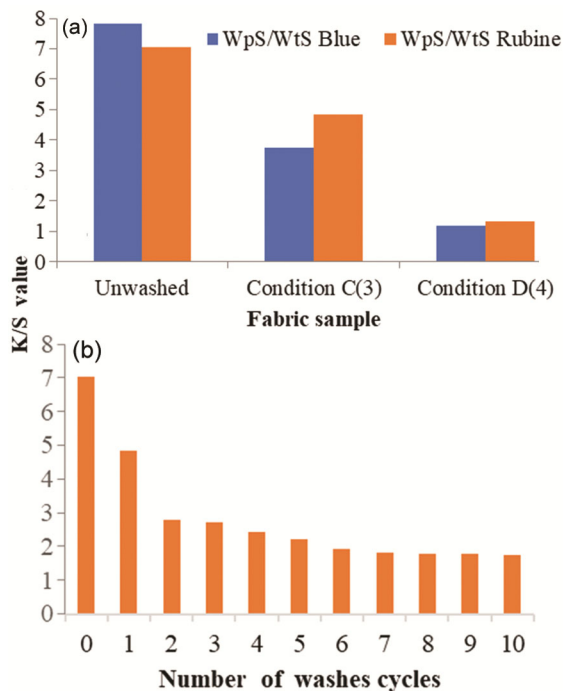


Fig. 8 — *K/S* values of (a) washed samples with different conditions and (b) WpS/WtS-Rubine sample after repeated washing

3.8 Mechanical Properties

The tensile and tear strengths of unwashed and washed samples are given in Table 5. The CV% of these properties are also given in Table 5. It is found that unwashed dyed samples (dyed in Foron Dark Blue SE-RD and Foron Rubine SE RdgFLI 200) coded as WpS/WtS, WpS/Wt (S+U), and WpS/WtU are having higher tensile (warp-wise: 585 - 650N, weft-wise: 516 - 588N) and tear strength (warp-wise: 33.5 - 38N, weft-wise: 31.5 - 33N) as compared to the washed samples in tensile strength (warp-wise: 468 - 594N, weft-wise: 395 - 550N) and tear strength (warp-wise: 19.5 - 22N, weft-wise: 17.5 - 21N). The result shows that the washing process reduces the tensile and tear strength significantly in the warp and weft directions than unwashed fabric. As washing condition C(3) is milder than the condition D(4), the loss in tensile and tear strength is also lower in the samples washed with condition C(3), as shown in Table 5. It is assumed that during washing due to rubbing action surface colour is removed along with resin and fibre²⁸, thereby reducing tensile and tear strength after washing.

Table 4 — Colour strength, reflectance and CIE values of unwashed and washed dyed fabric samples

Sample	Treatment	<i>K/S</i> at 520 nm	Reflectance at 520 nm, %	CIE values			DE	DL	DA	DB
				L	a	b				
WpS/WtS dyed with Foron Dark Blue SE-RD	Unwashed	7.04	6.25	33.299	0.025	-12.788	-	-	-	-
	Wash C(3)	4.85	8.60	33.234	0.418	-13.626	0.928	-0.065	0.393	0.838
	Wash D(4)	1.31	22.77	33.584	-2.962	-8.225	5.461	0.285	-2987	4.563
WpS/WtS dyed with Foron Rubine SE-Rdg FLI 200	Unwashed	7.84	5.67	34.205	22.349	2.149	-	-	-	-
	Wash C(3)	3.74	10.68	36.898	29.542	1.945	7.683	2.693	7.193	0.204
	Wash D(4)	1.18	24.30	35.125	21.353	5.218	3.355	0920	-0.996	3.069

Table 5 — Mechanical properties of fabric samples

Fabric code	Dyed with Foron Dark Blue SE-RD					Dyed with Foron Rubine SE RdgFLI 200						
	Areal density, g/m ²	Tensile strength, N		Tear strength, N		Areal density, g/m ²	Tensile strength, N		Tear strength, N		Bending length, mm	
		Warp	Weft	Warp	Weft		Warp	Weft	Warp	Weft	Warp	Weft
WpS/WtS	315	648 (8.5%)	580 (8.2%)	38 (7.2%)	32 (7.4%)	320	650 (9.2%)	588 (9.8%)	37 (6.9%)	33 (6.9%)	3.0	2.9
WpS/WtS -after washing as per condition-C(3)	290	580 (9.2%)	550 (9.4%)	22 (8.3%)	21 (8.5%)	295	594 (9.6%)	545 (9.9%)	21.8 (7.5%)	19.4 (7.8%)	2.7	2.5
WpS/WtS -after washing as per condition-D(4)	270	536 (9.4%)	520 (8.9%)	21.5 (8.1%)	19.5 (8.4%)	275	524 (9.2%)	500 (9.3%)	20.7 (7.2%)	19.2 (7.4%)	2.0	1.8
WpS/Wt (S+U)	304	610 (8.8%)	550 (9.1%)	34 (7.8%)	31 (8.2%)	310	620 (9.4%)	538 (10.1%)	35 (7.2%)	30 (6.9%)	2.7	2.5
WpS/Wt (S+U) after washing as per condition-D(4)	268	490 (9.9%)	440 (9.8%)	20.5 (8.6%)	20.0 (8.8%)	273	505 (9.5%)	460 (9.3%)	21.0 (8.5%)	19.5 (9.1%)	2.1	1.9
WpS/WtU	306	590 (8.2%)	520 (8.3%)	33.5 (8.0%)	32.0 (8.4%)	313	585 (8.7%)	516 (9.1%)	34.5 (8.9%)	31.5 (9.8%)	1.9	1.8
WpS/WtU after washing as per condition-D(4)	270	468 (9.2%)	400 (9.8%)	19.5 (8.2%)	18.5 (8.5%)	280	475 (8.4%)	395 (8.9%)	20.2 (8.2%)	17.5 (8.4%)	1.5	1.3

Values in parentheses represent CV%.

The areal density of the unwashed and washed samples is also determined and reported in Table 5. The areal density of unwashed samples varies between 304 g/m² and 320 g/m² and washed samples from 268 g/m² to 280 g/m².

The bending length of the fabric sample dyed with Foron Rubine SE RdgFLI 200 in different conditions has also been determined (Table 5). It is clear that after washing, fabric samples become flexible as compared to the unwashed samples, as their bending length is decreased. The reason for improving flexibility is due to the removal of some unfixed polyester resin material from the surface of the yarn.

4 Conclusion

In this study, the surface of cotton yarn has been modified using disperse dye dyeable polyester resin. This surface-modified yarn, along with gray yarn is used to manufacture denim fabric. The FTIR study has been conducted to confirm the presence of polyester resin on the yarn. The concentration of unsaturated polyester resin and vanillin carrier used in disperse dyeing has been optimized. The optimized concentration of polyester resin is found 50 g/L and the optimized concentration of vanillin carrier is

14 g/L. After curing, fabric samples are dyed in CDR using disperse dye with a vanillin carrier. These dyed samples are then washed with two types of washing conditions. One is milder and the other is harsher to get different fading effects. These washed samples along with unwashed samples are analyzed for colour strength, areal density, tensile strength and tear strength, etc properties. Results show that colour strength, areal density, tensile, and tear strength properties decrease after washing. The flexibility of the fabric sample improves after washing. The following are the advantages of this newer route of denim manufacturing over conventional denim manufacturing:

- (i) There will be a reduction in air pollution as sodium hydrogen sulfite is not being used in the newer system.
- (ii) No costlier yarn dyeing machines, like sheet form or rope form dyeing machines, are required in this newer system of denim manufacturing. Conventional dyeing techniques can be used to dye fabric.
- (iii) Reduction in consumption of water is envisaged as no scouring of cotton yarn and desizing is required.

- (iv) The time duration is reduced to get denim fabric as compared to a conventional process where sheet form or rope form dyeing system is used.

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