

Effect of different mercerization techniques on tactile comfort of cotton fabric

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The effect of different mercerization techniques on tactile comfort properties of woven cotton fabric has been studied. Desized, scoured and bleached cotton fabrics are subjected to four different mercerization treatments at two levels of temperature (20°C and 65°C) under two different conditions (tension and slack). Non-mercerized fabric is served as control. Results show that mercerization treatments improve the tensile strength of cotton fabrics owing to reduced fibre crystallinity after mercerization. Highest increase in tensile strength is observed in case of hot mercerization in slack condition. Increase in low-stress mechanical properties, such as tensile energy, bending rigidity and shear rigidity values, indicates higher stiffness/toughness of mercerized fabrics. This is further reflected in their high Koshi (stiffness/firmness), low Sofutosa (softness) and medium Fukurami (fullness) values. However, mercerization causes significant decrease in frictional coefficient and surface roughness, and results in improved total hand value (THV). Total hand values range from 3 to 3.61; with highest being presented by fabric mercerized under hot and slack conditions. High hand value indicates fair suitability of this fabric in wear comfort.

Keywords: Cotton fabric, Mercerization, Tactile comfort, Tensile strength, Total hand value

1 Introduction

Clothing comfort, a pleasant state arising out of physiological, psychological and physical harmony between a human being and environment, is a fundamental and universal need of consumers, although it is a complex concept¹. It is generally classified into three broad categories, viz (i) psychological/aesthetic comfort, (ii) thermo-physiological comfort, and (iii) tactile comfort. Psychological comfort is mainly related to the aesthetic appeal, which includes size, fit, colour, luster, style, etc. Aesthetic appeal is based on subjective feelings and fashion trends that influence customer preferences. Thermo-physiological comfort relates to the ability of the fabric to maintain thermal equilibrium between a human body and environment. Thermal, moisture and air resistance properties of the clothing material collectively contribute to the state of thermo-physiological comfort of the wearer². The tactile comfort is related to mechanical interaction between the clothing material and the human body. It is an intrinsic and essential performance requirement in clothing¹. Fabric tactile

properties are generally evaluated by a subjective method called as fabric hand value or fabric handle. Hand value together with the measured transport properties determines the true quality of apparel fabrics.

The final comfort level of the fabric is influenced by many factors, such as the type and structure of fibre, yarn and fabric properties, finishing chemical applied and the way it has been processed. The most effective parameter that determines the comfort of the end product is fabric material, i.e. fibre type³. Among all the natural and synthetic fibres, cotton is the most comfortable fibre, characterized by smooth hand feel, high moisture absorbency, reasonable strength, ability to adapt the shape and good thermal capacity⁴. As an individual fibre, cotton has certain luster, but as soon as it is spun into yarn, its luster decreases considerably on account of the very uneven surface of the yarn produced by the combination of individual fibres⁵. In addition, cotton suffers from some limitations such as poor dye-absorbency, low tensile strength, no dimensional stability and high wrinkling ability. In this regard, cotton fabric is failed to satisfy the requirements of consumers who prefer for the appearance of the fabric. Therefore, fabric manufactures try to improve

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these shortcomings by application of different finishing treatments to cotton, making it more ideal for consumers. By using various finishing treatments, different kinds of end products can be produced from the same unfinished woven or knitted fabric⁶. One of the finishing treatments applied to cotton fibres/fabrics is mercerization.

Mercerization is one of the most common finishing processes. It involves treatment of cotton with strong caustic alkaline in order to enhance its tensile strength, dyeing behaviour and luster⁷. The treatment is generally applied either to yarn or fabric itself, and either in the slack or tension state⁸. Mercerization is known to strengthen the weak links in the fibres. It improves crystalline orientation by changing the crystal structure from cellulose I to II and conformation of the cellulose chains. The advantages of mercerization mainly depend on the process conditions like concentration of caustic, time of impregnation, fabric tension and caustic temperature⁹. These alterations increase sorption, tensile strength and luster of fibres. Mercerized fabrics however suffer from certain demerits like stiffening of fibres which results in high bending rigidity¹⁰. In other words, mercerization improves some properties of cotton fabrics and weakens some other, which may lower the fabric handle.

Plethora of research has been published on clothing comfort. However, the volume of literature available on influence of mercerization on tactile comfort of cotton fabrics is grossly inadequate. Against this background, the present study was proposed to evaluate the effect of different mercerization techniques on tactile comfort and handle behaviour of woven cotton fabric.

2 Materials and Methods

2.1 Materials

The plain woven 100% cotton fabric (GSM 123.92, thickness 0.38 mm, warp count 32.34 Ne, weft count 34.37 Ne, ends per inch 79 and picks per inch 74) was procured from Quality Evaluation and Improvement Division of ICAR-CIRCOT. The fabric was then desized, scoured and bleached before subjecting to mercerization treatments.

2.2 Mercerization Treatments

Desized, scoured and bleached cotton fabric was cut into 30 × 30 cm specimen size, weighed and subjected to different mercerization treatments as described in Table 1. The process include exposing

the samples to 23% w/w (298.7 g/L) NaOH solution with liquor ratio of 1:50 at two levels of temperature (20°C and 60°C) for 90 s under two conditions (slack and tension) separately. For slack mercerization, fabrics were immersed in mercerizing bath without any stretching or tension. However, in case of tension mercerization, fabrics were stretched to 2% of their original length using square shaped frame with pins on its perimeter, before immersion in the mercerizing bath. The treated fabric samples were coded as HT (hot mercerization in tension condition), HS (hot mercerization in slack condition), CT (cold mercerization in tension condition) and CS (cold mercerization in slack condition). Untreated (unmercerized) fabric was served as control and compared with all mercerized fabrics for degree of mercerization, tensile strength, crystallinity and low-stress mechanical properties.

2.3 Testing and Analysis

The barium activity number was determined according to AATCC 89-1998 test method to express the degree of mercerization of the mercerized cotton fabric. Tensile strength (kg) of cotton fabrics was assessed by ASTM D5035-06 method using Instron tensile testing machine (5566 model, England), equipped with 2 kN load cell. X-ray diffraction analysis using X-ray diffractometer (PANalytical X'Pert PRO, Netherlands) was conducted to determine the crystallinity of fabrics. In order to evaluate the tactile comfort of unmercerized and mercerized fabrics, low-stress mechanical properties, such as tensile, bending, shear, compression and surface properties, were assessed using the entire set of Kawabata evaluation system for fabrics (KESF) (KATO TECH Co. Ltd., Japan). Based on 16 low-stress mechanical properties, the primary hand value (PHV) of mercerized and unmercerized cotton fabrics in terms of Koshi, Numeri, Fukurami and Sofutosa and total hand value (THV) were estimated using the Kawabata system of regression equations.

Table 1 — Details of different mercerization treatments

Treatment	Recipe		
	NaOH conc. % w/w	Temp. °C	Time s
Hot mercerization- tension, (HT)	23	65	90
Hot mercerization- slack, (HS)	23	65	90
Cold mercerization-tension, (CT)	23	20	90
Cold mercerization-slack, (CS)	23	20	90

3 Results and Discussion

3.1 Tensile Strength

The effect of mercerization on tensile strength (TS) of unmercerized/control and mercerized cotton fabric samples are presented in Table 2. TS of control sample is found to be 22.5 kg.f and 20.1 kg.f in warp and weft directions respectively. Mercerization causes significant ($p < 0.05$) increase in TS of cotton fabrics under all treatment conditions. The major reason for the increased TS may be an alleviation of internal stresses and removal of convolutions and false twists of the fibres in the fabric during swelling process¹¹. The presence of many convolutions and false twists in the fibres causes weak spots to be present. With removal of weak spots, the fibres exhibit enhanced TS as compared to unmercerized fabric.

For hot mercerization, fabrics in slack condition (HS) cause higher TS increase (41.33 %) than those under tension condition (HT) (12.89 %) over control fabric. Similar increase is observed in case of cold mercerization. This may be related to the easier penetration of caustic solution into fibre structure in slack mercerized samples and thus increase in swelling of fibres. On account of longitudinal shrinkage and lateral swelling, fibres appear close to each other with an increased thickness, which results in high tensile strength¹².

Increase in mercerization temperature from 20°C to 65°C under slack and tension conditions results in marked increase of TS values. This is mainly attributed to total penetration of caustic solution into the fibre structure at an elevated temperature. A far greater proportion of the cellulose is modified and fabric becomes highly plastic and less elastic; therefore it is capable of being readily stretched, leading to improvement in the properties of the fabric^{13, 14}.

3.2 Crystallinity

The XRD results show significant changes in the crystalline structure and crystallinity of cotton fibres

after mercerization treatments. The X-ray diffraction pattern of unmercerized cotton fabric has three characteristic peaks of cellulose I crystal structure at $2\theta = 14.62^\circ$ (110), 16.29° (110), and 22.48° (002) (graph not shown). The crystallinity index (CI), before and after mercerization is listed in Table 2. The CI values for control, hot mercerized under tension (HT), hot mercerized under slack (HS), cold mercerized under tension (CT) and cold mercerized under slack (CS) fabrics were 0.86, 0.73, 0.68, 0.73 and 0.71 respectively. There is a significant ($p < 0.05$) decrease in crystallinity of mercerized samples; with highest decrease (0.68) being manifested by fabrics mercerized in hot and slack condition. This is mainly because of the changes occurred during mercerization such as, microfibril swelling, crystalline area disruption and new crystalline lattice formation. Conversion from cellulose I to cellulose II takes place in the amorphous regions and gradually converts crystals of increasingly larger dimensions. Thus, mercerization yields more amorphous microstructure, resulting in reduced crystallinity. Similar decrease in crystallinity for reconstituted cellulose II have been previously reported^{15, 16}.

3.3 Effect of Mercerization on Low-stress Mechanical Properties of Cotton Fabrics

3.3.1 Tensile Properties

The low-stress tensile properties of fabrics such as linearity of load extension curve (LT), tensile energy (WT), tensile resilience (RT) and tensile strain or extensibility (EMT) are given in Table 3.

- **Linearity**

All mercerized fabrics represent significant increase in linearity (LT) value as compared to control fabric. LT values of mercerized samples range from 0.761 to 0.818, indicating non-significant difference among different treatments. Increase in LT is mainly due to swelling effect of mercerization. Penetration of caustic solution into the fibre structure causes modification in cellulose structure; the fabric becomes highly plastic and less elastic and therefore it is capable of being readily stretched¹³.

- **Tensile Strain/Extensibility**

Control sample has Extensibility (EMT) value of 10.98 %. Slack mercerization shows increase in EMT values of fabric. Reverse is the trend for tension mercerization, demonstrating slight decrease in EMT. Fabric extensibility generally increases with the

Table 2 — Effect of mercerization on tensile strength and crystallinity of fabric samples

Fabric	Tensile strength, kg.f		Crystallinity index
	Warp	Weft	
Control	22.5	20.1	0.86
HT	27.4	23.6	0.73
HS	31.8	30.2	0.68
CT	25.4	22.5	0.73
CS	30.5	28.7	0.71
P value ^a	7.988E-14	3.87E-12	0.00048

^aP value at 5% level of significance.

Table 3 — Effect of mercerization on low-stress mechanical properties of cotton fabrics

Property	Fabric					P value ^a
	Control	HT	HS	CT	CS	
Tensile						
LT (Linearity)	0.635	0.778	0.778	0.761	0.818	0.000159
EMT (Tensile strain), %	10.98	9.91	14.70	9.97	15.93	3.279E-08
WT (Tensile energy), gf.cm/cm ²	17.4	19.27	28.23	18.82	32.33	1.556E-08
RT (Tensile resilience), %	33.25	38.42	35.02	43.08	33.94	1.242E-15
Shear						
G (Shear rigidity), gf/cm.deg	0.91	1.47	2.47	0.91	2.39	0.019296
2HG (Hysteresis of shear force at 0.5 deg), gf/cm	2.23	2.2	3.84	0.88	2.74	0.317499
2HG5 (Hysteresis of shear force at 5 deg), gf/cm	3.93	5.46	6.00	3.52	5.50	0.003928
Bending						
B (Bending rigidity), f.cm ² /cm	0.033	0.1028	0.1035	0.1369	0.1348	8.445E-06
2HB (Hysteresis of bending movement), gf.cm/cm	0.0402	0.0725	0.0873	0.0802	0.0954	7.467E-06
Compression						
LC (Linearity of compression)	0.283	0.296	0.327	0.279	0.314	1.963E-05
WC (Compression energy), g.cm/cm ²	0.253	0.299	0.266	0.224	0.252	0.0516
RC (Compression resilience), %	36.17	36.86	40.02	42.11	42.79	3.162E-18
Surface						
MIU (Coefficient of friction)	0.181	0.165	0.165	0.158	0.165	0.0606
MMD (Mean deviation of MIU)	0.0175	0.0193	0.0181	0.0187	0.0199	0.0584
SMD (Geometrical roughness), µm	6.453	6.462	5.404	6.673	5.541	7.881E-06

^aP value at 5% level of significance.

increase in areal density. It implies that the slack mercerized fabrics are heavy fabrics with high density due to shrinkage; thus has better handle property due to their high extensibility at low-stress deformation¹⁷. Furthermore, application of tension in warp and weft directions during mercerization results in high alignment of crystalline region in the axis direction, leading to decreased extensibility of fabrics².

• *Tensile Energy*

It is observed that mercerization of cotton fabric results in increased tensile energy (WT), elucidating higher toughness of mercerized fabrics. The main reason for increase in WT after mercerization is transformation of cellulose I to cellulose II. Fibres become more amorphous and less crystalline, enhancing the tensile strength of fabric¹¹. The slack mercerized fabrics are tougher than tension mercerized fabrics due to high mercerization effect in slack condition. Highest increase in WT is manifested by HS fabric. The findings are in line with the results of tensile strength test.

• *Tensile Resilience*

It is interesting to note that although mercerized fabrics are tougher with a high degree of crystallinity

of cellulose molecules, they exhibit high resiliency than unmercerized cotton fabric. Improvement in tensile resilience (RT) is found more pronounced in case of tension mercerization; depicting higher degree of molecular relaxation.

3.3.2 *Bending Properties*

Table 3 shows bending properties of mercerized and unmercerized cotton fabrics. The results indicate that the values of bending rigidity (B) and hysteresis of bending movement (2HB) for mercerized fabrics is greater as compared to control fabric. Mercerization facilitates the swelling and straightening of cotton fibres, thus causing increment in fibre radius. As a result, stiffness and thus bending rigidity of fabric increase. Increase in bending properties can further be explained by the fact that bending properties are influenced greatly by the crystallinity of cellulose and cross-sectional shape of the fibre¹⁷.

3.3.3 *Shear Properties*

Shear rigidity (G), hysteresis of shear force at 0.5 degree (2HG) and 5 degrees (2HG5) for various fabrics are shown in Table 3. Control cotton fabric has lower value of G (0.91 gf/cm.deg). Irrespective of treatment conditions, mercerization is found to

increase G value of fabrics. The swelling accompanied by shrinkage of mercerized fibres tends to decrease the rotational movement tendency of warp and weft threads within fabric when subjected to low levels of shear deformation. This decrease with an increase in bending rigidity (B) results in increased B values of fabrics². Higher values of G in case of slack mercerized fabrics (i.e. HS and CS) may be traced back to their high shrinkage values; as contact between threads greatly affects the G value.

It is also observed that hysteresis of shear increases after mercerization. Unexpectedly, 2HG and 2HG5 values of CT fabric (cold mercerized in tension condition) are found to be lower than that of control fabric.

3.3.4 Compression Properties

The low-stress compression properties of fabric such as linearity of compression curve (LC), compression energy (WC) and compression resilience (RC) are presented in Table 3.

- **Linearity of Compression Curve**

Linearity of compression (LC) of fabric mainly depends on fabric thickness and compression characteristics of yarn. Mercerization causes significant ($p < 0.05$) changes in LC values of cotton fabrics. As expected, LC values follow exactly similar trend to that of thickness values of fabrics. Increased LC in slack mercerization and decreased LC in tension mercerization are due to thickness of corresponding samples.

- **Compression Energy**

Compression energy (WC) implies the fluffy feeling of the fabric. With increasing WC value, the fabric will appear fluffier. WC mainly depends on linearity and amount of compression¹⁸. It is interesting to note that no significant ($P > 0.05$) change in WC values is obtained among mercerized and unmercerized fabrics. Low WC values of cotton fabrics demonstrate their low fluffiness.

- **Compression Resilience**

The results indicate that the mercerized fabrics with high RC values recover better than the control fabric. Cold mercerization results in marked increase in RC value over hot mercerization. This may be attributed to high fabric cover, leading to compact structure and higher surface area which results in better interlocking of the structure and lower compressibility. Generally, RC has a direct bearing on the fabric areal density.

3.3.5 Surface Properties

Mercerized fabrics display lower coefficient of friction (MIU) and geometrical roughness (SMD) values as compared to control fabric (Table 3). However, the variation in values is non-significant ($P > 0.05$). Mean deviation of MIU (MMD) value is observed to have no perceptible change after mercerization. It means that the fabric becomes smoother and is felt cooler after mercerization process. It is expected that the increase in crystallinity of cotton fibres after mercerization may increase its surface friction and roughness. Non-significant ($p > 0.05$) change in surface properties is due to the dominance of fibre smoothening effect over crystallinity effect.

3.4 Effect of Mercerization on Hand Value of Cotton Fabrics

The primary hand value (PHV) of mercerized and unmercerized cotton fabrics in terms of Koshi, Numeri, Fukurami and Sofutosa are depicted in Table 4.

In a fabric, Koshi (stiffness/firmness) depends on its bending properties. Medium Koshi values of fabrics (3.34-6.1) reveal their low to medium stiffness. An increase in Koshi values of mercerized fabrics is due to the combined effect of high bending rigidity, high shear rigidity and high tensile resilience. Koshi value of CT fabric is found to be the highest amongst all fabrics.

Numeri (smoothness) value of fabric is a function of surface characteristics of fibres and yarns used for fabric manufacturing. Control sample has Numeri value of 5.45, whereas values of mercerized samples range from 4.51 to 4.93; depicting slight decrease in Numeri after mercerization. All low-stress mechanical properties are responsible for Numeri, but major role is played by compression energy. Negligible change in Numeri values among mercerized fabrics is attributed mainly to the non-significant differences in their compression energy.

Table 4 — Effect of mercerization on primary hand value (PHV) and total hand value (THV) of cotton fabrics

Sample	PHV				THV
	Koshi	Numeri	Fukurami	Sofutosa	
Control	3.34	5.45	5.48	4.29	3.10
HT	5.43	4.51	4.92	2.52	3.07
HS	5.74	4.93	5.47	2.65	3.61
CT	5.52	4.69	5.03	2.96	3.20
CS	6.10	4.68	5.32	2.40	3.33
P value ^a	0.00096	0.00129	0.09701	0.00018	0.04148

^aP value at 5% level of significance.

Fukurami is bulky, rich and well-formed feeling. It is an indicator of fullness and softness of fabric, depends mainly on fabric bulk and compressional properties. For all fabrics, Fukurami values are found to be between 5 and 6; demonstrating their medium fullness and softness.

As far as Sofutosa is concerned, it reflects the soft feeling of fabric. Mercerization causes significant ($p < 0.05$) decrease in Sofutosa values of fabrics, indicating reduction in softness after mercerization treatments. Increased toughness or tensile strength of mercerized fabrics has direct impact on their low softness.

It is interesting to observe that mercerization of cotton fabrics improves the THV, and thus wearing comfort of cotton fabric. THV values range from 3 to 3.51, presenting medium suitability of fabrics in wearing comfort. Highest increase in THV is observed in case of hot mercerization in slack condition.

4 Conclusion

In this study, the effect of mercerization on comfort properties of woven cotton fabric is investigated. Mercerization causes significant changes in tensile strength and crystallinity of cotton fabrics, facilitating changes in their tactile comfort properties. After mercerization fibres become less crystalline and thus contribute in improved tensile strength. Improvement in low-stress mechanical properties such as, tensile energy, bending rigidity and shear rigidity indicate toughening of mercerized fabrics. The findings are further corroborated by high Koshi (stiffness/firmness), low Sofutosa (softness) and medium Fukurami (fullness) values of mercerized fabrics. Although improvement in some mechanical properties of mercerized fabrics is noticed, it seems that the clothing tactile comfort is slightly improved on account of high extensibility and resiliency over unmercerized fabrics. Furthermore, low frictional coefficient, low surface roughness, high tensile

linearity and high compressional resilience imparted better handling property to the mercerized fabrics. THV values range from 3 to 3.61; with highest being presented by fabric mercerized under hot and slack conditions. High hand value indicates fair suitability of this fabric in wear comfort. Overall, it can be concluded that while imparting tensile strength to cotton fabric, mercerization also maintains optimum fabric comfort.

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