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Development of fabric smoothness tester[a]

M S Parmar[b], Nidhi Sisodia & Maheshwar Singh

Northern India Textile Research Association, Sector 23, Rajnagar, Ghaziabad 201 002, India

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An instrument has been designed and developed to measure the smoothness behavior of finished cotton fabrics. The instrument is based on pendulum principle. The weight (hang on string) comprises a frictionless wheel movable along arc shaped platform. The platform acts as a sample holder. When the weight is subjected to push, it swings back and forth in the platform. The amplitude of the swing reduces due to friction of the fabric. The amplitude is inversely proportional to the friction or roughness of the fabric. Various types of finished cotton fabrics are tested on the developed instrument. The results are compared with Kawabata system to verify the working of instrument. These results are also compared with the bending length and crease recovery behavior of the particular fabric sample. It is found that the lesser the bending length the more will be the smoothness. If the crease recovery angle is high, the fabric will be smoother. One way analysis of variance has been applied to find out effect of different processes on fabric surface smoothness property.

Keywords: Bending length, Cotton, Crease recovery behaviour, Kawabata system, Smoothness behaviour

1 Introduction

Fabric smoothness-roughness has been considered as one of the most important factors of clothing comfort. It is also a significant factor in today's consumer buying decision. Fabric smoothness behaviour is influenced by many factors like weave particular, yarn characteristics, finishing treatments, etc. All these factors may increase or decrease the fabric surface friction behavior, which ultimately influence fabric surface smoothness property. It was found that the friction resistance of the fabric knitted with carded yarns was higher than that of fabric knitted with combed yarn[1]. One of the studies[2] indicated that increasing fabric cover factor considerable reduces the frictional properties of the fabric, as the surface of fabric becomes more uniform. It was also observed that the fibers content also influences frictional characteristics of fabric. The fabric structure with high amount of float has higher amount of frictional coefficient than the fabric with lower thread flat. The plain fabric has lower friction than twill fabric. Fabric friction, which is defined as the resistance to motion, can be detected when a fabric is rubbed mechanically against itself or tactually between the finger and thumb. Friction is considered to be the unique property of cloth which has considerable importance in the fields of both technological and subjective assessment. Subjective assessment[3-5] which specifies the fabric handle is undoubtedly influenced by the static and dynamic friction between the cloth surface and the thumb or finger, although other properties are also involved in the assessment. The human finger is a sensitive instrument capable of detecting small differences in the frictional behavior of fabrics. The results of hand tests are expressed in subjective terms, such as ‘clingy’, ‘greasy’, ‘mushy’, ‘oily’, ‘rough’, ‘scratchy’, ‘sheer’, ‘sticky’, ‘waxy’, etc., depending upon the sense of touch. So, it is important to assess the fabric friction quantitatively as well as the factors that may affect it. Objective measurement[6-9] of the frictional properties of fabrics helps in clear communication and the optimization of a particular process. It is well known that there are always disputes between buyer and manufacturer regarding feel of fabric, as there is no quantitative method available which can spell out the feel of the particular fabric.

Though fabric friction has gained much significance, there is no suitable instrument in the textile industry to measure fabric friction. Kawabata developed[10] the KES-FB4 for the measurement of surface friction and the surface roughness of the fabrics. This instrument is, however, not available to all due to its very high cost. Most researchers have used the Instron tensile tester with some attachments

[a]The novel tester has been patented (Application No. 2053/DEL/2015 dated 07.07.2015)

[b]Corresponding author
E-mail: msprmr@yahoo.com, drmsparmar@nitratextile.org

to measure the inter-fabric or fabric-to-metal friction[11], which again become costlier and complicated. Due to this, it is not being used in the industry. Hence, an indigenous cost effective instrument is required to be developed to address the above problems, i.e. to determine the smoothness characteristics of fabric and can give indication on change in surface characteristics after the various pre-treatment and finishing processes. The data generated by this instrument shall help the finishers to take appropriate decision to alter the recipe or process to meet the required smoothness characteristics of the fabric.

2 Materials and Methods

The study was carried out in two parts. In the first part, the instrument was developed and in the second part its performance was evaluated by analyzing different types of fabric samples for their smoothness behavior.

2.1 Development of Instrument

The instrument is based on pendulum principle. The weight (hang on string) comprised to a frictionless wheel movable along arc shaped platform. This acts as a sample holder. When the weight is subjected to push, it swings back and forth in the platform. The amplitude of the swing reduces due to the friction of the fabric. The amplitude is inversely proportional to the friction of the fabric. The schematic diagram of working principal is shown in Fig. 1. Line diagram and picture of instrument is shown in Fig. 2. Whole assembly is kept in a chamber, in which air flow is constant.

The apparatus includes three chambers, namely top, middle and bottom. The top chamber (**T**) accommodates display unit (**1**), on/off switch (**2**), geared motor with electromagnetic clutch, press button to actuate pendulum, rotor encoder in order to measure angle/amplitude and programmable logic controller (PLC) to control various parameters, such as humidity and temperature. The display unit reflects information pertaining to humidity, amplitude, time of completion of cycle, air velocity, etc. The on/off switch is provided to switch on or off said apparatus. The geared motor with electromagnetic clutch controls oscillation of the roller hanging from the roof of the middle chamber with a rod. The roller hanging from the roof by means of rod causes whole assembly to oscillate about the equilibrium position by swinging back and forth. This oscillation takes place

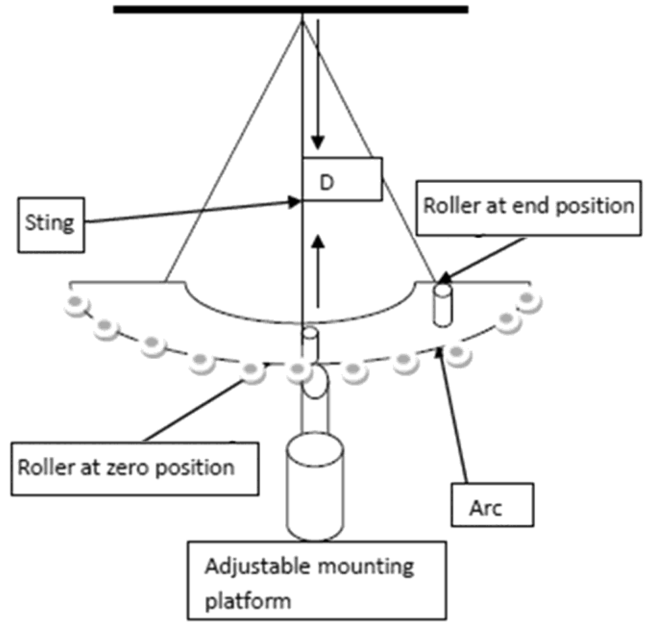

Fig. 1 — Schematic diagram of working principal

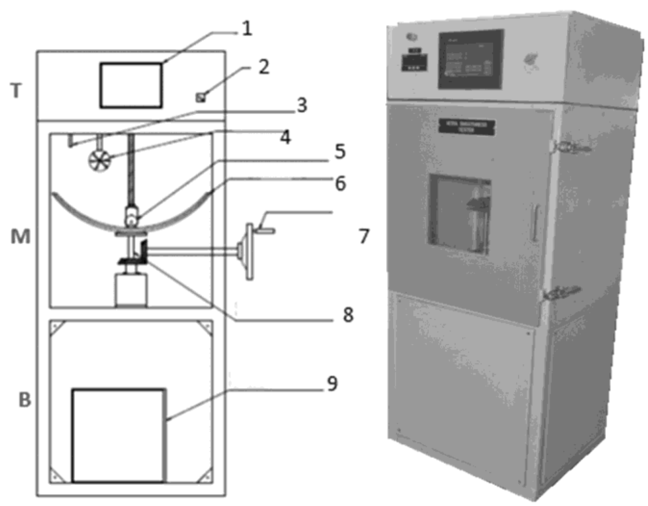

Fig. 2 — Line diagram and picture of smoothness tester (Patent application no. 2053/DEL/2015 dated 7.07.2015). [1 - display unit, 2 - on/off switch, 3 - temperature and humidity sensor, 4 - anemometer, 5 - revolving roller assembly, 6 - sample holder, 7 & 8 - screw arrangement and height adjustment, and 9 - steam generator]

with the help of geared motor. The electromagnetic clutch plays role to shift the roller assembly at the maximum angle on one side. When this roller assembly attains the maximum angle, it is released by means of a release button. Upon release of the assembly, it starts oscillating about the equilibrium position swinging back and forth. Said rotary encoder is provided to measure angle/amplitude of the roller assembly. The middle chamber (**M**) embodies temperature and humidity sensor (**3**), anemometer (**4**), revolving roller assembly (**5**), arc type sample holder (**6**) and screw arrangement and height adjustment (**7** & **8**). The bottom chamber (**B**) houses steam generator (**9**) to generate steam for changing humidity. Beside the above three chambers, an air conditioning unit is also employed with the apparatus to maintain required temperature in the course of the testing.

2.2 Preparation of Fabric

For this study, 100% cotton fabric was sourced from M/s Surya Processors Pvt Ltd, Ghaziabad. It was given pretreatments (desizing, singeing, scouring, bleaching and mercerizing) in the mill itself using standard recipe. The mercerized fabric sample was given various finishing treatment in the NITRA pilot plant, so the effect of these finishing treatments can be assessed using the proposed NITRA - fabric smoothness tester. Following five types of finishing chemicals at different concentrations were used to finish mercerized fabric sample using standard recipe recommended by the supplier following pad-dry-cure method:

(i) Product-6000 – Hydrophilic nano silicone softener (40, 50 and 60 g/L)

(ii) Jinguard Eco PCD (Water repellent finish) – Fluoro-alkyl based emulsion (5, 25 and 45 g/L)

(iii) DPT095- Resil – Modified polysiloxane micro emulsion (20, 60 and 100 g/L)

(iv) Ultra 196- Resil – Organo modified polysiloxane, micro emulsion (30, 50 and 70 g/L)

(v) Jinsof Eco MAS Conc– Concentrated silicone macro emulsion (40 and 60 g/L)

Total 20 samples are prepared as given in the Table 1 with code numbers. These fabric samples were analyzed for mass, thread density (EPI × PPI), tear and tensile strength, crease recovery angle, bending length and thickness as per IS 1964, IS 1963, ISO 13937-1, ISO 13934-1, IS 4681, IS 6490 and IS 7702 test methods respectively.

2.3 Evaluation of Smoothness Behavior of Samples

For analysis of smoothness property, 20 specimens (15cm × 15cm each) per sample (10 specimens warp-wise and 10 specimens' weft- wise) were cut and well ironed to remove wrinkles. The study was carried out on the side of fabric which is going to touch the skin. These specimens were conditioned for 2h in 65±3% RH at 27±2°C. After conditioning, these were mounted one by one on the sample holder fitted on the instrument. A constant load of 0.4 kg was applied on the specimen with the help of load cell. After adjusting load, test was started by pushing start button. This initiated the movement of pendulum arrangement. The test was considered completed once the pendulum movement was stopped completely. The instrument was provided with programmable logic controller (PLC). Once the pendulum stops, time taken to stop the pendulum in millisecond was displayed on the screen of the instrument. Finally, grading of specimen was also displayed in 1-5 Grades. Grade-1 means sample has very rough surface and Grade-5 means sample is very smooth surface. Grading system used is given below:

Table 1 — Fabric samples with code number

Sample	Code
Grey	G1
Singed	S1
Desized	D1
Scoured	SC1
Bleaching	B1
Mercerized	M1
Product 6000	
40g/L	T1
50g/L	T2
60g/L	T3
Jinguard Eco PCD	
5g/L	T4
25g/L	T5
45g/L	T6
DPT	
20 g/L	T7
60 g/L	T8
100 g/L	T9
ULTRA	
30g/L	T10
50g/L	T11
70g/L	T12
Jinsof Eco MAS Conc	
40g/L	T13
60g/L	T14

Time (ms) to stop pendulum	Smoothness grade
Up to 400	Grade 1 (very poor)
401 - 500	Grade 2 (poor)
501 - 600	Grade 3 (good)
601 - 700	Grade 4 (very good)
> 701	Grade 5 (excellent)

2.4 Statistical Analysis

Experimental data were analysed using SPSS (version 20). One-way ANOVA was used to compare means. The null hypothesis (H_o) means there is no relationship between type of processing treatment given on the fabric and fabric surface smoothness property. In the alternative hypothesis, there is a relationship between types of processing treatment and surface smoothness property. The H_o will be rejected when the p-value turns out to be less than a pre-determined significance level (0.05).

3 Results and Discussion

3.1 Effect of Finishing Treatment on Bending and Crease Recovery

The bending length is very important factor which determines the flexibility of the fabric. The bending length in both warp and weft direction of the fabric is important in determining the flexibility of the fabric. The values of the bending length of untreated and treated cotton fabrics are given in Table 2. Untreated fabric (grey) shows the maximum bending length (warp wise 2.45 cm and weft wise 1.75 cm) and finished samples after treatment with softeners (T1- T3 and T7 - T14) show lower bending length than other samples. Samples T4, T5 and T6 are finished with water repellent finish with different concentrations. These samples are found to be stiffer than the sample finished with various softeners. The variation of bending length in both directions of singed (S1), desized (D1), scoured (SC1) and bleached (B1) samples is very less, as shown in Table 2. The mercerized fabric sample (M1) is having lower bending length in both the directions than S1, D1, SC1 and B1 samples. From the study, it is clear that the grey cotton fabric is stiffer than other samples in both warp and weft directions. This is due to the presence of sizing chemicals as well as natural impurities in grey cotton fabric. The greater bending length along the warp direction of the all samples (Table 2) reveals that the fabric is stiffer in the warp direction than in the weft direction. This can be due to higher density of fabric in warp direction (ends/inch) than in weft direction (picks/inch). Greater stiffness of the fabric along the warp direction reveals that the fabric has less bending elasticity along warp direction than along the weft direction.

The values of crease recovery angle of untreated and treated cotton fabrics are also given in Table 2. It is evident that the crease recovery angle is increasing from grey to finished sample. Untreated fabric shows minimum crease recovery angle which is periodically increased after the treatments, such as desizing, scouring, bleaching, mercerization and finishing with softener. It is clear from Table 2 that the crease recovery (dry state) of different treated samples is higher than untreated or grey fabric sample. This may be due to swelling of the fibre in the fabric. It appears that the treatment has developed the ability of the

Table 2 — Fabric samples properties

Sample code	Mass g/m^2	Ends/inch	Picks /inch	Tensile strength, N		Tear strength, g		Crease recovery angle	Bending length, cm		Thickness mm
				Wp	Wt	Wp	Wt	(Wp+Wt), deg	Wp	Wt	
G1	128	120	72	576	259	1138	569	106	2.45	1.75	0.280
S1	124	122	72	560	270	1112	536	110	2.40	2.80	0.274
D1	118	126	78	520	230	1150	720	140	1.58	1.46	0.270
SC1	124	128	80	580	240	1064	676	144	1.55	1.42	0.272
B1	126	134	82	600	248	897	640	146	1.56	1.40	0.269
M1	127	136	80	681	258	977	670	156	1.40	1.38	0.264
T1	122	135	70	396	111	1342	823	173	1.26	1.16	0.260
T2	124	136	72	363	148	1380	790	178	1.22	1.12	0.269
T3	123	135	72	371	133	1340	773	180	1.18	1.10	0.270
T4	129	136	71	457	216	918	615	160	1.48	1.36	0.274
T5	121	136	72	452	185	919	652	162	1.44	1.30	0.264
T6	122	135	72	482	195	1001	685	164	1.40	1.28	0.270
T7	123	132	70	431	197	1380	892	180	1.30	1.24	0.254
T8	123	132	72	449	164	1496	940	182	1.22	1.20	0.250
T9	125	132	72	456	156	1516	947	186	1.18	1.16	0.268
T10	123	136	71	412	176	1338	913	188	1.18	1.14	0.261
T11	125	135	72	384	160	1340	849	182	1.16	1.12	0.261
T12	126	136	72	428	167	1404	821	184	1.12	1.10	0.279
T13	126	136	72	433	176	1428	959	186	1.20	1.16	0.260
T14	127	135	72	425	186	1426	949	190	1.14	1.12	0.260

Wp - warp direction, and Wt - weft direction.

fabrics to recover from deformation. The materials, which have good crease recovery properties, exhibit excellent soft handle, draping and appearance as well as a lack of flabbiness as washing proceeds. The grey fabric materials have less crease recovery angle, leading to more limp and flabby on washing.

Both of these studies show that the application of softener reduces the bending length and improves the crease recovery angle of the samples. Silicone emulsion acts as a lubricating agent between the fibres in the yarns and between the yarns of the fabric, imparting softness to the material. This softness causes a reduction in bending length of fabric. The bending length and rigidity of the textile material are directly related to each other. The drop in bending length is thus indicative of reduced rigidity or improved softness of the fabric samples. Silicon softening capability comes from siloxane backbone's flexibility and its freedom of rotation along the Si-O bond. This freedom of rotation leads to unique flexibility of siloxane molecules[12]. The improvement in softness due to silicone softener application is also reflected by enhancement of crease recovery angles.

Thickness values of all the samples are analyzed at 2 kPa pressure. Results are shown in Table 2. It is clear from the table that there is no significant change in thickness (ranging from 0.25 mm to 0.28mm) of the samples after various treatments.

3.2 Effect of Finishing Treatment on Smoothness Property

All the 20 samples were analyzed for smoothness behavior using newly developed smoothness tester. As fabric samples are very thin (Table 2), there will be negligible effect of compressibility on smoothness behavior of fabric when tested with newly developed smoothness tester.

This study also revealed the changes occurred on the surface characteristics of the fabric after various processing treatment. Results of these samples are given in Table 3. A comparison between smoothness grading and coefficient of friction (COF) obtained using Kawabata system is shown in Fig. 3.

From Table 3, it is revealed that there is no significant change in smoothness behaviour of grey

Table 3 — Testing smoothness behavior of cotton fabric at various stages of wet processing

Sample code	Average time required to stop pendulum, ms		COF[a]	
	Wp	Wt	Wp	Wt
G1	458(2)	434(2)	1.5	1.52
S1	419(2)	421(2)	1.51	1.50
D1	522(3)	460(2)	1.37	1.48
SC1	439(2)	444(2)	1.53	1.57
B1	430(2)	434(2)	1.53	1.52
M1	550(3)	554(3)	1.29	1.26
T1	515(3)	512(3)	1.32	1.34
T2	602(4)	574(3)	1.17	1.20
T3	618(4)	604(4)	1.12	1.14
T4	513(3)	530(3)	1.34	1.28
T5	570(3)	584(3)	1.20	1.18
T6	585(3)	530(3)	1.24	1.26
T7	505(3)	502(3)	1.35	1.35
T8	522(3)	501(3)	1.34	1.38
T9	589(3)	567(3)	1.16	1.22
T10	695(4)	693(4)	1.04	1.04
T11	615(4)	612(4)	1.12	1.14
T12	647(4)	638(4)	1.08	1.10
T13	713(5)	697(4)	1.02	1.04
T14	727(5)	685(4)	1.01	1.06

Figures in brackets are grading.
[a]COF - Coefficient of friction by Kawabata analysis. Wp - warp direction, Wt - weft direction.

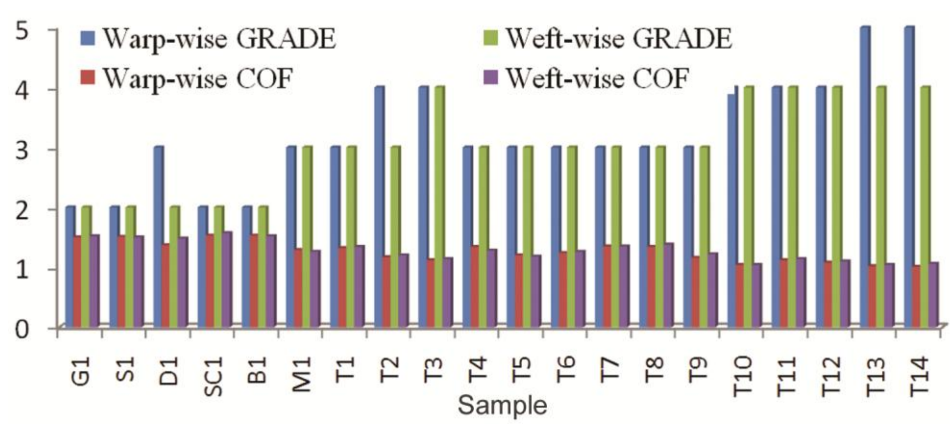

Fig. 3 — Smoothness grade *vs.* COF of warp - wise and weft - wise fabric samples

(G1) and singed (S1) samples in both warp and weft directions. There is little improvement after desizing (D1). This may be due to shrinkage in the fabric because of wet treatment. This shrinkage increases fabric density (ends/inch and picks/inch) as shown in Table 1. Increase in fabric density increases the fabric balance and fabric cover, but decreases the surface roughness[13] and thus fabric surface becomes smooth. After scouring (SC1) and bleaching (B1), sample becomes harsher than desized sample (D1), as also shown in Table 3. After mercerization (M1), time required to stop pendulum increases (warp-wise 550 ms and weft-wise 554 ms). It indicates that after mercerization, sample becomes smoother. It is well-known fact that mercerizing process improves surface smoothness of cotton fabric[14]. The results obtained from NITRA smoothness tester is also compared with the results of coefficient of friction (COF) obtained using Kawabata system. It is found that there is similar trend of surface smoothness results from both the instruments. It is also clear that COF of mercerized fabric (M1) is lower than other fabric samples. It indicates that mercerized fabric is smoother than others. Mercerized fabric sample (M1) is having grade 3 in both the directions. However, all the other samples are graded as 2, except warp direction of desized sample (D1), its grading is 3.

Samples coded as T1, T2 and T3 are treated with hydrophilic nano silicone softener at different concentrations, such as 40, 50 and 60 g/L respectively. After treatment with this softener, smoothness property of fabric is improved further in both warp - wise and weft - wise directions. It is also revealed from Table 3 that with the increase of softener concentration from 40 g/L to 60 g/L, fabric smoothness also increases. Similarly, other samples (T7 - T14) also treated with different softeners show higher smoothness. It is well-known fact that softener treatments improve fabric surface smoothness[15]. Samples coded as T4, T5 and T6 are obtained after treatment with water- repellent finishing agent. A water-repellent fabric is one in which the fibres are usually coated with a "hydrophobic" type of compound, and the pores are not filled in the course of the treatment. The latter types of fabrics are quite permeable to air and water vapor[16,17]. Due to this reason, there is no improvement in smoothness properties of these samples from the mercerized fabric sample (M1).

One-way ANOVA is used to compare relationship between fabric types (various processing treatments) and smoothness properties. The results are given in Table 4. It is clear that the p value is <0.05 for both warp and weft directions of smoothness properties (time required to stop pendulum in milliseconds) with fabric type (fabric after various treatments), and therefore null hypothesis is rejected. It indicates that various treatments have direct influence on fabric surface smoothness.

Table 4 — ANOVA analysis between type of fabric and smoothness [time required to stop pendulum in milliseconds]

Source	Dependent variable	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	Smoothness warp-wise	329939.143[a]	6	54989.857	54989.857	0.0
	Smoothness weft- wise	266436.000[b]	6	44406.000	44406.000	0.0
Intercept	Smoothness warp -wise	13492851.857	1	13492851.857	13492851.857	0.0
	Smoothness weft- wise	13812141.000	1	13812141.000	13812141.00	0.0
Type of fabric	Smoothness warp -wise	329939.143	6	54989.857	54989.857	0.0
	Smoothness weft -wise	266436.000	6	44406.000	44406.000	0.0
Error	Smoothness warp -wise	14.000	14	1.000		
	Smoothness weft -wise	14.000	14	1.000		
Total	Smoothness warp -wise	13822805.000	21			
	Smoothness weft -wise	14078591.000	21			
Corrected total	Smoothness warp -wise	329953.143	20			
	Smoothness weft -wise	266450.000	20			

[a] R Squared = 1.000 (Adjusted R Squared = 1.000).
[b] R Squared = 1.000 (Adjusted R Squared = 1.000).

4 Conclusion

An indigenous cost effective instrument is developed to determine smoothness behaviour of fabric. The instrument is capable to give indication on change in surface characteristics after the various pre-treatment and finishing processes. By this instrument, finisher can change finishing recipe or process to meet the required smoothness characteristics of the fabric.

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