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Fabric hand characteristics by nozzle extraction technique

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In this study, nozzle extraction principle has been used for measuring the fabric feel objectively. Fabric feel is one aspect for handle of fabric, related to its mechanical properties. The nozzle extraction instrument (fabric feel tester) measures radial force as well as extraction force during the pulling of fabric specimen through a circular nozzle. The radial and extraction forces are functions of many physical and mechanical characteristics of fabric, e.g. bending, shear, friction, compression, extensibility, etc. which influence fabric feel sensation. A unique parameter (fabric feel factor) has been derived and calculated by using different important parameters related to extraction behavior of fabrics. It gives a single value for fabric feel. Experiments have been conducted on denim fabrics. The effects of functional softener (silicon) concentration and different denim washing treatments on fabric softness are evaluated subjectively as well as objectively. Very good correlation is observed between subjective and objective measurements.

Keywords: Cotton, Denim, Extraction force, Fabric feel factor, Nozzle extraction, Radial force

1 Introduction

The touch and feel sensation of a fabric has multi-dimensional attributes and is impossible to quantify through a single physical property. Therefore, to find a method for the tactile comfort evaluation of textiles, the concept of 'fabric hand' is commonly used. Pan[1] reported that fabric hand, or handle is defined as the human tactile sensory response towards fabric, which involves not only physical but also physiological, perceptional and social factors; this fact complicates the process of fabric hand evaluation tremendously. Fabric hand refers to the total sensations experienced when a fabric is touched or manipulated by the fingers. Fabric hand or feel is often the fundamental aspect that determines the success or failure of a textile product.

Fabric softness is one important aspect of the handle feeling of the fabric related to its various properties. Fabric softness is one of the common expressions for the description of fabric handle subjectively. Soft/harsh or soft/hard is a bipolar pair of sensory attribute used in comparison technique in fabric quality. Chan *et al*[2]. defined softness as a feeling of springy with a smooth hand. Kawabata[3] defined fullness and softness as a result of bulky, rich and well-formed feeling. Valatkiene and Strazdiene[4] defined softness as resistance/non-resistance to compression or bending. Many finishing processes have been provided to strengthen the softness of fabric for improving the comfort of the garment according to Yuzheng *et al*[5].

Since the subjective methods are easily influenced by the personnel's perception, the objective method is preferred. Most of the objective methods are focused on the hand feeling of fabric. However, softness of the fabric is not discussed. So a new approach for objective evaluation of the fabric softness is provided. In nozzle extraction technique, the force generated while withdrawing a fabric specimen through a nozzle is measured. The extraction force is generated because of the deformation of the fabric due to the combined effect of bending, shear, buckling, compression, tensile and weight of fabric. Multiple regression analysis is used to develop a suitable equation, which could best predict fabric softness and give a single value to quantify, for example 'fabric feel factor'. The tactile, or haptic information is subject to Newton's "law of action and reaction" in the real world. From this perspective, real-world haptics is the key technology for future haptic communication engineering, as stated by Kouheirie and Ohishi[6]. Thus, research related to the extraction and reproduction of haptic information in the real world has been undertaken, but there have been few developments in research on the visual presentation of

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acquired haptic information. Nozzle extraction, which was first proposed by Alley[7], is not a new idea at all. Another study on nozzle extraction technique was reported by Ishtiaque *et al.*[8] But, literatures on correlation between the objective fabric extraction parameters and subjective assessment of fabric feel characteristics are not available.

This study proposes a method for haptic information called "extraction graph" as shown in Fig. 1. The extraction graph simulates the real hand feeling of fabric softness information. The schematic diagram of the experimental set up[9] shows that the radial and axial force sensors are used to measure the extraction and radial forces. By the method proposed in this study, it has now become possible to lane the intuitive and quantitative evaluation of haptic information, which in the past was presented only in qualitative form, such as 'soft' or 'hard'. The analog output of the sensor is converted via algorithms that represent mechanoreceptors magnitude of stimulus indentation and velocity of stimulus movement.

The main objective of the paper is to develop a unique and unit-less parameter, i.e. 'fabric feel factor', which represents the overall fabric handle and feel characteristics of different finish applied on denim fabrics. The other objective is to correlate the fabric feel factor with the subjective feel rating of wide range of assessors.

2 Materials and Methods

2.1 Materials

Woven twill 100% cotton denim fabric (340 g/m^2) was used in the present study. The fabric was given two different types of treatments, i.e. functional softener treatment using different concentrations and different denim washing treatments. The fabric was then treated with functional silicon softener (Microgenix SW 375) of different concentrations (20, 40, 60 g/L) for 20 min at room temperature, and 5-6 *p*H. To study the effect of different denim washing treatments on the fabric softness, the same fabric was subjected to different washing treatments as given in Table 1.

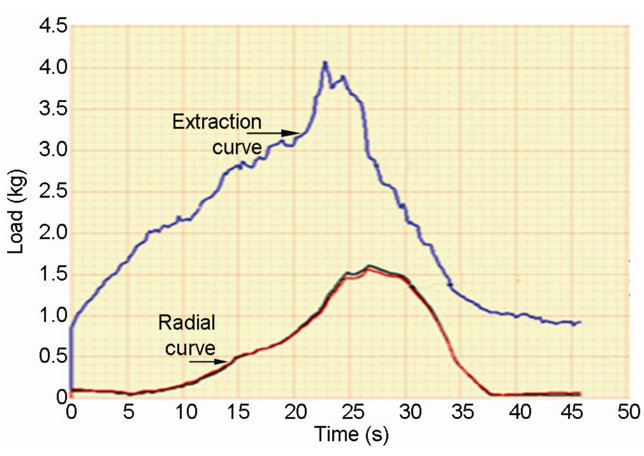

Fig. 1—Force displacement curve (crosshead speed – 200 mm/min)

2.2 Testing Procedure

2.2.1 Subjective Assessment

In order to evaluate the subjective fabric feel characteristics, the fabrics were cut into dimensions of 24 cm diameter circle. Two surveys were conducted for the subjective evaluation of softness. The first survey was for the functional softener treated samples and the second one for the denim washed samples. In the first survey, each assessor was asked to rank the softness of the fabric samples based on a five-point scale (1-very soft, 2-better soft, 3-modrate soft, 4-just soft, 5-least soft). In the second survey, each assessor was asked to rank the softness of the fabric samples based on a ten point scale [Softest: 1-high, 2-modrater, 3-low; Softer: 4-high, 5-modtare, 6-low; Soft: 7-high, 8-modrate, 9-low; Hard: 10]. In the first survey ten trained assessors (Group 1) and eleven non-trained assessors (Group 2) were asked to rank the softness of the fabrics. At the end, the ranks were summed and the smaller rank is related to the better softness. In the second survey, total 123 assessors were taken including both genders and they were divided into 8 groups according to their age, gender and textile knowledge (Table 2). In both the survey, assessors were reminded to ignore the effect of color and pattern while ranking the fabrics. At the end, the ranks were averaged and the smaller rank was taken related to the better softness.

Table 1—Different commercial finishing treatments

Sample code	Finish	Fabric mass, g/m^2
FB1	Raw wash – desize only	258.3
FB2	Enzyme wash for 60 min	257.4
FB3	Enzyme +heavy bleach wash	253.4
FB4	Enzyme + bleach +tint wash	260.9
FB5	Enzyme + tint wash	267.6
FB6	Enzyme + ice wash	258.3
FB7	Enzyme + ball wash	262.4
FB8	Stone wash for 75 min	269.8
FB9	Enzyme + slight bleach wash	256.7
FB10	Raw fabric	274.7

Table 2—Groups for subjective assessment of fabrics (2nd survey)

Group 1	Male untrained (15-30)	14 Assessors
Group 2	Male untrained (31-60)	15 Assessors
Group 3	Male trained (15-30)	45 Assessors
Group 4	Male trained (31-60)	10 Assessors
Group 5	Female untrained (15-30)	10 Assessors
Group 6	Female untrained (31-60)	10 Assessors
Group 7	Female trained (15-30)	10 Assessors
Group 8	Female trained (31-60)	9 Assessors

The definition and criteria of the softness rating were explained to the assessors, who were asked to reflect their perceptions towards softness. The fabric samples were presented to individual assessors for hand feeling and also these were rubbed, bent and squeezed by their hands for about 1-2 min, so as to rate the samples for softness.

In order to determine the consistency in subjective assessment by the assessors, Kendall coefficient (W) was calculated. It shows the level of agreement among experts, as reported by Gonca *et al*[10]. in following relationship:

$$W = \frac{12\sum_{j=1}^{n}\left(Rj - \overline{R}\right)^2}{r^2\left(n-1\right)\left(n+1\right)n} \quad \ldots (1)$$

where R_j is the sum of ranks given to each fabric sample; $\overline{R}$, the mean value of rank sums; r, the number of experts; and n, the number of samples.

In order to observe the rating tendency in each group of samples, the average values of each fabric attribute are used to analyze the accuracy in subjective hand evaluation, and Kendall's coefficient of concordance is computed.

2.2.2 Objective Measurement

The nozzle extraction instrument[9]was used to measure fabric handle characteristics objectively. In this method, the force generated while pulling or extracting a fabric specimen through a nozzle was measured. The fabric samples were cut into circular shape (diam. 240 mm) and attached to sample holder in the instrument. Then the samples were drawn through a conical shaped nozzle made up of steel (52mm height × 60mm length × 60mm width). The fabric sample should be free from wrinkles and crease. As the clamp with which the connecting pin is attached moves upward, it extracts the fabric specimens through the nozzle. The force required for extracting the fabric specimens through the nozzle changes as increasing portion of the fabric is introduced in the nozzle. The fabric specimen gets folded, sheared, rubbed, compressed and bent (multiple directions) during extraction. The instrument records the force. A typical force displacement curve is shown in Fig. 1.

3 Results and Discussion

The extraction force that has been obtained in the present system is a combination of fabric resistance to bending, compression, shear, extension and sliding. The forces involved in the initial deformations are related to the bending and the shear stiffness of the fabric. As the test progresses, forces due to compression play a larger role as the fabric specimen is squeezed to the dimension of the ring. Fabric friction with the inner surface of the nozzle and the extensibility of the fabric also affect the withdrawal force. The slope in Fig. 1 represents the rate of increase in extraction force. The slope depends on the level of difficulty of the compound deformation that is taking place. The greater the fabric resistance to bending, shear, compression and sliding, the higher will be the final extraction force and vice versa. The forces generated would depend not only on fabric properties but also on nozzle size and sample size. Some extraction curve parameters, which have been identified as a measure of fabric softness, are graphically shown in Fig. 2. These parameters are the area under the extraction curve (W_E) in kg.mm; unloaded fabric across orifice for extraction curve(a) in mm; peak distance for extraction curve (D_E) in mm; peak height for extraction curve (P_E) in kg; area under the curve for radial curve (W_R) in kg.mm; area under the curve for radial curve (W_R) in kg.mm; peak distance for radial curve (D_R) in mm; and peak height for radial curve (P_R) in kg.

3.1 Effect of Functional Softener

The individual value, sum and standard deviation of the subjective rating for fabrics treated with functional softener are given in Table 3. It is evident that the sum total for 80 gpL concentration is lower than that for 20 gpL or raw fabric. Table 4 shows the results of extraction force and radial force obtained from nozzle extraction instrument. The results show that as the concentration of softener is increased, the force reduces consistently (Fig. 3).

3.2 Effect of Denim Washing

The mean of each group, overall mean and overall standard deviation of the subjective softness ratings of

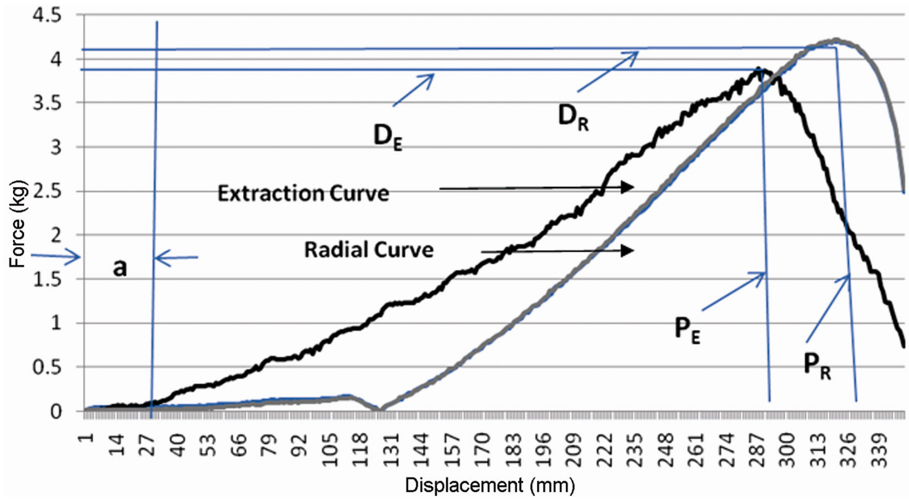

Fig. 2—A typical extraction curve showing asymmetry and definition of the parameters

Table 3—Subjective assessment rating value for functional softener treatment

Sl No.	Group 1					Group 2				
	Raw	20gpL	40gpL	60gpL	80gpL	Raw	20gpL	40gpL	60gpL	80gpL
1	4	5	3	2	1	4	5	2	1	3
2	5	4	2	3	1	5	4	1	3	2
3	5	3	4	2	1	5	4	2	3	1
4	5	3	2	4	1	5	4	1	3	2
5	5	2	4	1	3	5	4	3	1	2
6	5	4	3	2	1	5	4	3	1	2
7	5	4	1	3	2	5	4	2	1	3
8	5	4	3	2	1	5	4	2	1	3
9	5	1	4	3	2	3	5	4	2	1
10	5	4	3	2	1	3	4	5	2	1
11	-	-	-	-	-	4	5	2	3	1
Sum	49	34	29	24	14	49	47	27	21	21
SD	0.31	1.174	0.994	0.843	0.699	0.82	0.467	1.214	0.944	0.831

Table 4—Extraction and radial force value of different levels of silicon softener finished samples

Fabric softer level gpL	Peak radial force, kgf	Average radial force, kgf	Peak extraction force, kgf	Average extraction force kgf
Nil (raw)	4.936	2.108	4.674	2.29
20	4.671	2.022	4.402	2.16
40	4.859	1.954	4.564	2.16
60	4.747	1.846	4.166	1.95
80	4.845	1.670	4.378	1.70

fabrics are listed in Table 5. It is observed that considering the softness, the fabrics can be ranked as (softest) FB8>FB2> FB 6> FB4> FB5> FB3> FB7> FB1> FB9> FB10 (hardest).

The correlation among different groups of assessors is given in Table 6, which is prominently indicating the degree of relationship among ratings given by the assessors. It is clear that there is high correlation among different groups of assessors, except female trained assessors.

The coefficient of concordance (*W*) was calculated using the formula given in Eq.(1), based on all 123 assessors and is found to be 0.62. These higher and statistically significant *W* values indicate good agreement among the assessors, which is not by mere coincidence. Although, *W* is not so high but it shows significance in results. This shows that how much subjective assessment differs from person to person. In the present work, in order to determine the fabric feel by means of the mechanical and structural properties of the fabrics, different characteristics of the denim washed fabrics are determined with 25 mm diameter nozzle. (Table 7).

The correlation coefficients (R) among nozzle parameters are given in Table 8. The correlation between subjective assessment values and seven

Table 5—Average rank values for all subjective assessors groups

Group	FB 1	FB2	FB3	FB4	FB5	FB6	FB7	FB8	FB9	FB10
Male untrained (15-30)	7.79	3.00	5.71	4.36	4.79	3.36	6.43	2.21	7.50	10
Male untrained (31-60)	7.33	3.33	5.33	5.13	4.73	3.67	5.60	2.73	7.07	10
Male trained (15-30)	7.16	2.84	5.53	4.02	5.09	3.29	6.73	1.93	8.22	10
Male trained (31-60)	8.10	3.10	5.50	4.00	5.60	2.60	7.10	2.20	6.90	10
Female untrained (15-30)	8.30	3.20	6.30	4.80	4.30	3.90	5.10	2.60	6.20	10
Female untrained (31-60)	6.80	2.80	7.20	4.60	5.80	3.00	6.10	2.20	6.50	10
Female trained (15-30)	7.70	2.10	4.70	4.70	5.90	3.40	6.60	1.90	7.80	10
Female trained (31-60)	4.78	4.00	7.56	4.56	5.89	3.56	6.44	2.11	5.89	10
Overall ranking	7.26	3.00	5.81	4.40	5.17	3.34	6.37	2.17	7.38	10
Overall SD	1.82	1.90	2.06	1.70	1.86	2.06	1.96	1.53	1.96	0.00

Table 6—Correlation coefficients among different groups of assessors

Assessors	Male untr. (15-30)	Male untr. (31-60)	Male trained (15-30)	Male trained (31-60)	Female untr. (15-30)	Female untr. (31-60)	Female trained (15-30)	Female trained (31-60)	Overall ranking
Male untrained (15-30)	1	0.98	0.99	0.98	0.95	0.95	0.97	0.83	0.99
Male untrained (31-60)		1	0.96	0.95	0.96	0.93	0.96	0.81	0.98
Male trained (15-30)			1	0.97	0.90	0.94	0.97	0.84	0.99
Male trained (31-60)				1	0.92	0.94	0.96	0.82	0.98
Female untrained (15-30)					1	0.92	0.89	0.79	0.94
Female untrained (31-60)						1	0.92	0.93	0.96
Female trained (15-30)							1	0.78	0.97
Female trained (31-60)								1	0.86
Overall ranking									1

extraction parameters for 25mm nozzle size are 0.85(P_E), 0.54(D_E), 0.78(W_E), -0.86(a), 0.80(P_R), -0.16(D_P), and 0.75(W_R). Fabric feel factor is calculated by using the seven parameters, obtained from the radial and extraction curve. It is evident that out of the seven parameters, five parameters are found to be more significant, such as unloaded fabric width across orifice for extraction curve (a), area under the curve for extraction curve (W_E), peak distance for radial curve (D_R), and peak height for extraction (P_E) & radial (P_R) curves.

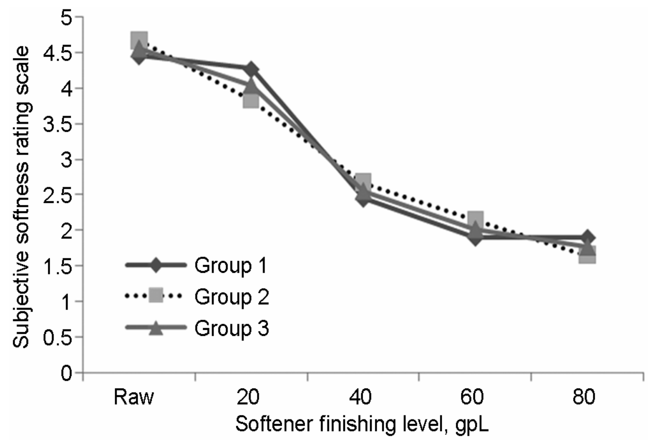

Fig. 3—Subjective assessments rating among groups

Multiple linear regression analysis was applied in order to relate the parameters of nozzle extraction with the subjective softness rating. In this analysis, the subjective softness value is taken as dependent variable and parameters of nozzle extraction are taken as independent variables. The contributions of some independent variables may not be statistically significant. Therefore, stepwise backward regression method has been adopted in this research. The initial regression equation has been developed using all the seven nozzle extraction parameters as inputs. Then the level of significance (p) of each of the parameters is checked and one of them having the maximum p-value is removed from the equation. This iterative procedure is followed until all the remaining parameters become statistically significant. The final regression equation is given below (R^2=0.9775):

$$\text{Fabric feel factor } (f) = 26.58 + 20.65\times P_E - 0.436 \times W_E - 0.131 \times a + 5.064 \times P_R - 0.361 \times D_R$$

This shows a high degree of correlation ($R^2 = 0.977$) between the fabric feel factor and the subjective

Table 7—Values of different nozzle parameters for 25 mm nozzle diameter

Fabrics	P_E	D_E	W_E	A	P_R	D_P	W_R
FB1	1.37	86.67	35.87	15.00	0.821	95.33	14.54
FB2	1.21	85.33	32.05	25.00	0.671	94.33	11.74
FB3	1.32	88.33	35.30	20.67	0.800	96.00	13.29
FB4	1.34	91.67	35.32	23.00	0.829	98.33	14.13
FB5	1.32	90.67	36.42	19.00	0.868	96.33	14.38
FB6	1.23	89.67	32.02	20.67	0.702	98.67	11.60
FB7	1.36	90.67	35.73	9.33	0.904	99.00	14.47
FB8	1.13	91.67	30.01	19.33	0.557	97.33	9.275
FB9	1.55	87.67	43.43	10.00	0.822	97.00	15.31
FB10	2.33	106.3	91.30	2.00	1.982	96.00	53.90

Table 8—Correlation coefficient among nozzle parameters for 25mm nozzle diameter

	P_E	D_E	W_E	a	P_R	D_P	W_R
P_E	1	0.856	0.989	-0.825	0.976	-0.198	0.976
D_E		1	0.899	-0.671	0.904	0.0666	0.914
W_E			1	-0.782	0.981	-0.228	0.994
a				1	-0.775	-0.05	-0.752
P_R					1	-0.177	0.99
D_P						1	-0.226
W_R							1

assessment value. This high correlation indicates that this instrument feels the softness of fabric like a human being. The measured peak extraction force is plotted against the subjectively assessed softness value of each fabric. A reasonable correlation (R^2= 0.7205) is observed. For other parameters the correlation coefficient values are already given.

4 Conclusion

The effects of functional softener concentration and different denim washing treatments on fabric softness have been evaluated subjectively. Good correlation is observed between subjective and nozzle extraction (objective) measurement. The fabric feel tester measures the radial force as well as the extraction force exerted during the pulling of fabric through a nozzle, which measures certain physical and mechanical characteristics of fabric that determines fabric feel.

In general, manufacturers and customers can get the softest and least soft fabrics, but the most important task remaining is to predict grading of softness between these limits, which can be quickly done by this instrument. Fabric feel tester is able to identify changes in fabric feel. This method would be useful in comparing a new fabric product with the old one. The fabric feel factor is calculated by using the seven parameters obtained from the radial and extraction curves.

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