Objective Evaluation of the Sharpness and Stability of Deliberate Crease Lines and Pleats in Apparel Products

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Abstract: This paper describes the behaviour of deliberate creasing or pleating of apparel fabrics formed, for example, in skirts and trousers. In this study, woven fabric samples of two fibre groups were prepared. One is pure wool and woolblend-based group, and the other is vegetable and protein fibre-based fabric group (cotton, ramie etc.). The beauty or quality as measured in terms of the sharpness of creases of different fabric groups was evaluated.

Keywords: quality of creases and pleats, mechanical properties, sensory test, wool

1. INTRODUCTION

From ancient times people put on good appearance garments that have pleats or creases. The beautiful form of crease lines and pleats has been regarded as an essential appearance feature of trousers and pleated skirts. It is important for designers, textile manufactures and consumers to know the quality of creases and pleats, i.e. how sharp and stable the pleats or crease lines are going to be. In general the neat front and back crease lines of a pair of trousers and folding lines along the pleated skirts add elegance to people who like to dress well. Nowadays people have many kinds of clothing made from a range of fabric constructions and fibre types. Various aspects of creases and pleats have been studied for a long time; for example, crease recovery , crease sharpness with crease height and angle and washing stability.

The purpose of this study is to evaluate crease sharpness and beauty based on crease shape for a range of woven fabrics in different fibre types such as pure wool, wool blend, cotton, ramie, silk, polyester and nylon. A sensory test was carried out for the subjective evaluation of crease quality of these fabrics. Their low-stress mechanical properties such as bending and compression characteristics were measured on the KES-F system. Besides a cross-section of their crease shape and recovery was observed by a light microscope and then angles and curvatures measured at the apex point of the creases.

2. EXPERIMENTAL

2.1 Subjective Crease Evaluation

Three samples of size 3 cm long (warpways) x 6 cm wide (weftways) were cut from each fabric. The weftways length contained 1 cm margin for a seam at each end (Figure 1). These samples were cut weftways to the margins into three test samples 1cm wide warpways. The weftways edges were joined together and sewn. At this stage, each sample of dimensions 1 cm warpways x 2 cm weftways was folded.

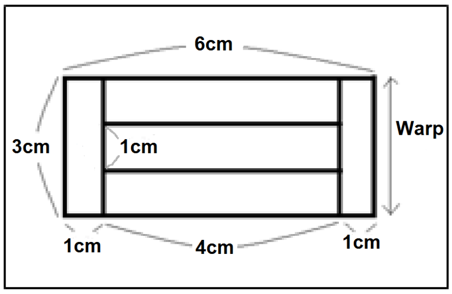


Fig 1: Sample size

These test samples were folded and pressed on a domestic steam iron for experiment A and also on a Hoffman steam press for experiment B. A domestic steam iron used was Sunbeam Model SR5400 type424 (1650-1800W, 230-240V, ~50Hz). Pressing temperature was about 200 degree and each sample was pressed for 20 sec. On Hoffman steam press, the test samples were pressed under steam pressure of 80 lb/in^2 for 10 sec which was followed by vacuuming for 10 sec. For observing crease stability, these samples were also open-steamed for 10 sec. After pressing and steaming, these samples were cut through the margins lines. Each of these pressed samples, with its crease-line placed on a thin stainless steel wire (diameter 0.45 mm), was let to recover for 5min under the standard conditions of 20-22 ^oC and 60-64% RH.

To take a photo of the cross section of samples, samples were suspended about their crease-lines on the wire for 5 min before taking their photographs. The camera used was Nikon D100 with Nikon Macro Speed Light SB-21. The sample used for this purpose was the middle of the three folded samples, 1 cm warpways x 2 cm weftways. Photographs of outlines of cross-sections of folded samples were then digitised using an image analysis method based on Coral Paint Shop Pro Photo (graphics software of Coral Corporation) and Open Source Computer Vision Library developed by Intel/Willow Garage. The outline is converted into numerals as (x,y) data by Graph Click (a digitizer shareware of Arizona Corporation).

To estimate the curvature of a crease cross-section outline, a quadratic equation was fitted to the line using the least square method. The curvature at the top of the crease, K, represents the curvature of the crease line.

2.2 Sensory Test

For subjective evaluation of various aspects of fabric crease, human *Kansei*, two human sensory tests were carried out. For Test A, five undyed, white fabric samples were used. These were fabrics of different fibre types such as wool, cotton, silk, ramie and polyester. For Test B, six samples were used, which were wool and wool/polyester types. Each sample was 10 cm x 10 cm.

Fig 2: Sensory test A chart

To make a crease or folded line along the middle line of the sample, each sample was pressed by the domestic iron at 200 °C for 20 sec.

The evaluation method only allows assessors to observe, not allowed to touch the fabric samples. Eleven assessors or judges were used to grade the various fabrics for their different crease aspects in a standard conditioned laboratory (20-22 °C and 60-64% RH). Judges were not allowed to handle the fabrics. Evaluation charts used are shown in Figures 2 and 3. Figure 2 is a chart for Test A and Figure 3 is a chart for Test B.

Fig 3: Sensory test B chart

This is evaluated on a scale of 1 to 5. Grade 5 means that the sample has excellent sharp/ natural/ fresh/ fine/ beautiful/ formal look crease and is the most favourite. On the contrary, Grade 1 means that the sample has very poor crease, namely having not sharp/not natural/aged/roundish/ugly/casual look/dislike crease. Judges graded each fabric sample on these charts. Samples were presented in a tubular form, with its top edge in line with the eyes. After pressing, the top edge of each sample, with its crease-line running in the vertical direction, was wrapped and mounted on the top surface of a cylinder, leaving the bottom 80% of its length under zero or low tension.

2.3 Mechanical Properties

The low-stress mechanical properties were measured on the Kawabata Evaluation system for Fabrics, KES-FB. Samples were 20 cm x 20 cm size and conditioned under standard conditions, 20 ± 2 °C and 65% RH. Each sample was measured three times and the mean values of their mechanical parameters were calculated. The mechanical and physical properties considered in this study are summarized in Table 1.

Table 1. KES mechanical properties of fabric

Property	Parameter	Parameter	Unit
Bending	B2	Bending rigidity (weftways)	gf·cm^2/cm
	2HB2	Bending hysteresis (weftways)	gf·cm/cm
Compression	LC	Compressional linearity	-
	WC	Compressional energy	gf·cm/cm^2
	RC	Compressional resilience	%
	To	Thickness under 0.5 gf/cm^2	mm
	Tm	Thickness under 50 gf/cm^2	mm
Weight	W	Weight per unit area	mg/cm^2

2.4 Fabric Samples

Constructional details of experimental fabric samples are provided in Table 2.

Table 2. Fabric constructional details

Fabric	Fibre	Weave	Thickness (mm)	Fabric	Fibre	Weave	*Thickness (mm)
R1	100% ramie	Plain	0.575	W1	100% wool	Plain	0.370
R2	100% ramie	Plain	0.462	W2	100% wool	Plain	0.462
Rc	Ramie/cotton (weft: 100% ramie)	Plain	0.505	W3	100% wool	Plain	0.398
Rs	Ramie/silk (weft: 100% ramie)	Plain	0.447	W4	100% wool	2/1Twill	0.556
C1	100% cotton	Plain	0.422	W5	100% wool	Plain	0.496
C2	100% cotton	Plain	0.672	W6	100% wool	Plain	0.499
C3	100% cotton	Plain	0.540	W7	100% wool	2/1 Twill	0.490
S1	100% silk	Plain	0.319	W8	100% wool	2/1 Twill	0.457
S2	100% silk	Plain	0.378	W9	100% wool	2/1 Twill	0.536
S3	100% silk	Plain	0.325	W10	100% wool	2/1 Twill	0.505
P1	100% polyester	Plain	0.354	W0	100% wool	Plain	0.397
P2	100% polyester	Plain	0.206	N1	100% nylon	Plain	0.164
BW1	Wool/bamboo (weft: W 54, B 46%)	3/1 Twill	0.599	BW2	Wool/bamboo (weft:W54,B46%)	3/1 Twill	0.552
SW1	Wool/silk (weft:W83.3,S16.7%)	Satin	0.533	SW2	Wool/silk (weft: W 100%)	Satin	0.552
WN1	Wool/nylon (weft: W90, N 10%)	Plain	0.858	WN2	Wool/nylon (weft:W80,N20%)	2/1 Twill	0.680
WP1	(weft: W 80, P20%)	Plain	0.446	WP2	Wool (weft:W 80,P20%)	2/1 Twill	0.549

3. EVALUATION OF FABRIC AREA

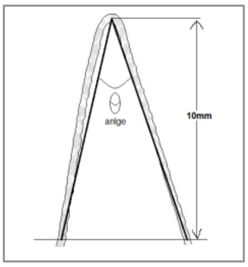


Fig 4: Angle θ

In this study of fabric crease evaluation, we focused not only on the crease angle θ (Figure 4) but also on the shape of the crease at and around the crease-line. From the observation of crease sharpness and crease recovery of various fabrics, we found that even though some fabrics had similar crease angle (~±2°), they did not have same shape at and around the top of their crease. Crease angles of some samples recovered by steam did not sharp line to more roundish. Consequently only the crease angle change after steaming but their crease shapes at and around the top of the crease had significantly changed, for example from measurement is not sufficient to characterise the different crease shapes before and after crease relaxation or recovery. In order to express the shape of the top of the crease (cross-section of the crease-line), we measure the curvature at the top point of the crease and this value is denoted as *K-out*. The method for estimating *K-out* is mentioned above in section (2.1).

Figure 5 shows that there are a number of fabric samples which have similar crease angles but significantly different curvatures, for example, fabrics P1 and P2 as shown in Figure 6. Therefore, both the parameters, crease angle and crease curvature are required to describe the crease shape adequately.

Figure 7 shows the graph between the values of crease angle *θ* and *K-out* of pressed creases of various fabric samples before and after open steam relaxation. An inspection of this graph reveals three different types of crease recoveries based on fabric construction and properties. The first type results in change in crease angle only. The second type results in change in both crease angle and crease curvature, and the third type involves change in crease curvature only.

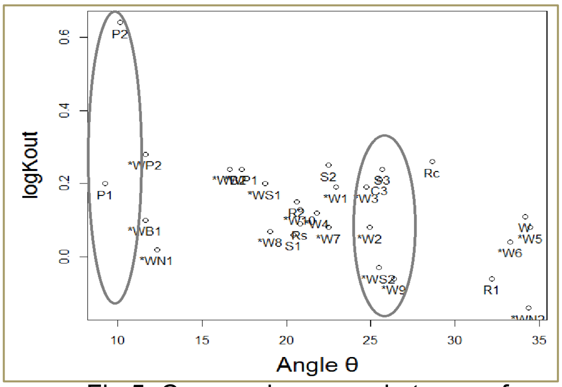


Fig 5: Crease sharpness in terms of crease angle *θ* and curvature *K-out*

Figure 8 shows photographs of the crease shape of the fabric after pressing (top) and after pressing and open steaming (bottom). It can be seen that the steam relaxation did not cause much change in the crease angle but caused a large change in the curvature at the top of the crease. It is evident that only the crease angle parameter is not enough to measure the crease stability or changes in the crease shape due to relaxation, for example by open steaming. The curvature at the top of the crease, *K-out*, can describe the shape of the top point or surface before and after relaxation.

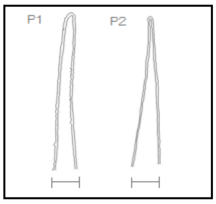
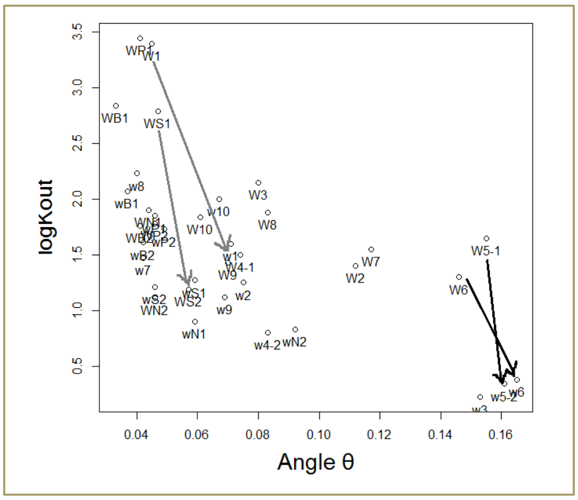
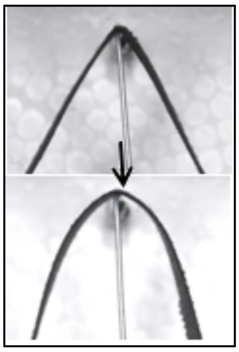


Fig 6: Fabrics P1 and P2 showing similar angles but significantly different curvatures

Crease angle *θ* is already defined in Figure 4 above. Curvature *K*-out defines the curve shape just at the top point of the crease. In addition to these crease parameters, the crease linearity, *CL*, is also important to describe the crease shape. The crease linearity means how straight or curved the outline of the crease is. This value is based on the area under the crease at 5 mm height from the top of the crease, and integrated between both sides of the crease outline as shown in Figure 9.



Let A_s be the area under the straight crease outline (averaged for left and right hand sides), A_c be the area between the curved and straight outlines (averaged for left and right hand sides)



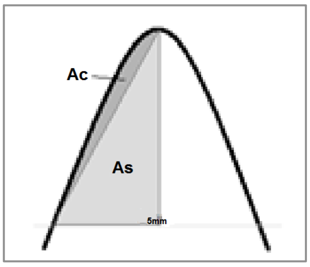


Fig 7: Crease recovery due to open steaming

Fig 8: Photographs showing change in crease curvature

Fig 9: Crease linearity due to open steaming

and A_t be the total area under the crease curve
where

$$A_t = A_s + A_c. \quad (1)$$

Then crease linearity

$$CL = A_t / A_s$$
$$= (A_s + A_c) / A_s \quad (2)$$

For a completely straight line crease outline, A_c = 0, and, therefore, *CL* = 1. For a concaved outline, *CL* > 1. As *CL* increases, the crease shape becomes more roundish and curved outside.

Correlation coefficients among these values are as follows; between Angle θ and *K-out*: -0.446, between *K-out* and *CL*: -0.029, and between Angle θ and *CL*: -0.540 (significance level is 0.01). These are not strong correlations. Therefore, these crease parameters differ from one another and are independent.

4. RESULTS AND DISCUSSION

4.1 Comparison between sensory and objective evaluations

An objective of the sensory test A is to subjectively grade a range of fabrics, produced from different fibre types, for the various characteristics of the crease as mentioned in section 2.2. The results of sensory test A are given in Table 3 and are graphically presented in Figure 10 .

Values of Spearman's correlation coefficient (ρ) were calculated to determine the level of agreement in the rankings between two different crease characteristics such as sharpness and beautiful (Table 3).

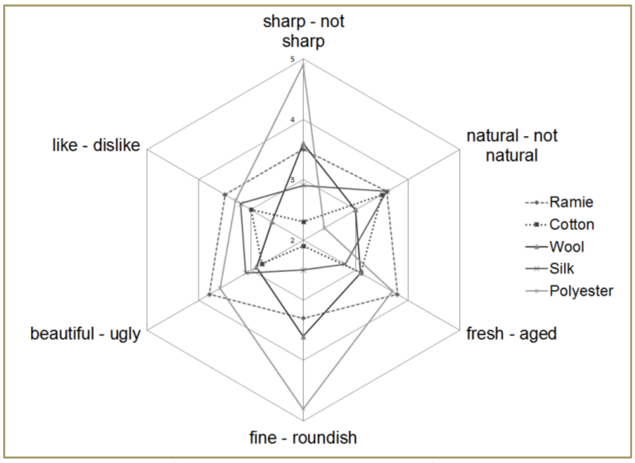


Fig 10: Subjective evaluation for fabrics of different fibre types

Results showed that fabrics having excellent sharp crease also have excellent fine crease (ρ=0.99) but these tend to look unnatural (ρ =-0.67). "Beautiful", "like" and "fresh" characteristics of the crease show high correlation between one another, as expected. Polyester, ramie and wool fabrics have very sharp creases but ramie fabric's crease gave the judges an impression of a natural looking crease. Creases of ramie, cotton and silk fabrics look more natural by comparison with those of wool and PET fabrics.

The results of sensory test B conducted on wool and wool/polyester fabrics are shown in Table 4. An objective of this sensory test B is to identify the human feeling differences between various crease characteristics of 100% wool and wool/polyester blended fabrics which contain 20% polyester in weft yearn.

Table 3. Spearman's correlation coefficients for sensory tests A and B

	Test A						Test B					
	(a)	(b)	(c)	(d)	(f)	(g)	(a)	(c)	(d)	(e)	(f)	(g)
(a)Sharp-not sharp	1.00	-0.67	0.46	0.99	0.50	0.20	1.00	0.16	0.99	0.90	-0.26	-0.23
(b)Natural-not natural	-	1.00	-0.16	-0.67	0.21	0.31	-	-	-	-	-	-
(c)Fresh-aged	-	-	1.00	0.46	0.67	0.67	-	1.00	0.26	0.17	0.66	0.40
(d)Fine-roundish	-	-	-	1.00	0.50	0.20	-	-	1.00	0.94	-0.12	-0.09
(e)Formal-casual look	-	-	-	-	-	-	-	-	-	1.00	-0.06	0.03
(f)Beautiful-ugly	-	-	-	-	1.00	0.90	-	-	-	-	1.00	0.93
(g)Like-dislike	-	-	-	-	-	1.00	-	-	-	-	-	1.00

Values of Spearman's correlation coefficient show that the fabrics that are adjudged to have an excellent sharp crease also have a crease that is fine (ρ=0.99) and has formal look (ρ=0.90). "Fresh" and "beautiful" characteristics of the crease are also positively correlated (ρ=0.66), but there is no tendency that "sharp" crease is also "beautiful". From their principal component analysis, this sensory evaluation data resulted in two crease types. One relates to crease sharpness and the other relates to crease beauty. Crease sharpness components are "sharp – not sharp", "fine - roundish" and "formal – casual look". Beauty components are "fresh - aged", "beautiful - ugly" and "like - dislike".

Table 4. Mean grades for various crease characteristics for sensory tests A and B

Crease characteristic (Grade 5 to 1)	Test A					Test B					
	Ramie	Cotton	Wool	Silk	PET	W1	W2	W3	W4	W/P1	W/P2
Sharp-not sharp	3.5	2.3	3.6	2.9	4.9	3.36	4.55	2.36	3.09	4.55	4.27
Natural-not natural	3.6	3.5	3.0	3.6	2.4	-	-	-	-	-	-
Fresh-aged	3.8	3.1	3.1	2.8	3.7	3.64	3.73	3.18	3.45	3.18	3.00
Fine-roundish	3.3	2.1	3.6	2.5	4.8	3.27	4.09	2.73	2.91	3.45	3.91
Formal-casual look	-	-	-	-	-	3.09	4.27	2.27	2.73	3.82	3.73
Beautiful-ugly	3.8	2.8	2.9	3.1	3.6	3.27	3.73	3.45	3.45	2.91	3.09
Like-dislike	3.5	3.0	2.6	3.2	3.3	3.18	3.82	3.45	3.36	2.82	3.27
Total grade points	21.5	16.8	18.8	18.1	22.7	19.8	24.2	17.4	19.0	20.7	21.3

Table 5 shows correlations between the results of sensory and objective tests. It can be seen that crease sharpness correlates better with curvature *K-out* than crease angle. This means crease sharpness discriminated by human sense relates to the top point of the crease which can be represented by curvature *K-out*. Also crease sharpness correlates well with thickness T_0 which is measured at pressure 0.5 gf/cm^2 and T_m which is measured at pressure 50 gf/cm^2. In particular, wool and wool/polyester fabrics have very high correlation coefficient between crease sharpness and T_m. When crease freshness is related with crease linearity, *CL*, we find that fabrics of different fibre types in Test A having high freshness value tend to have high *CL*, but for Test B wool and woolblend fabrics, fresh creases tend to be negatively correlated with *CL*. Also positively/negatively of correlation between angle θ and *K-out* are showed opposite one. It means among various fibre-based fabrics, evaluation of "fresh" is focused at fabric stiffness and crease sharpness. On the other hand, among wool and wool-blended fabrics, no matter whether the crease is sharp or not, high linearity, which means straight line crease, makes an impression of a "Fresh" crease. In addition, "Beautiful" and "Sharp" characteristics do not correlate well with each other. It means it is not always the sharp crease that is beautiful crease for human sense.

Table 5: Correlation coefficients between subjective and objective evaluations of crease

Crease characteristic	Test	Angle θ	*K-out*	*CL*	T_o (mm)	T_m (mm)
Sharp - not sharp	A	-0.62	0.78	0.43	-0.80*	-0.69
	B	-0.48	0.70	0.38	-0.69	-0.90***
Fresh - aged	A	-0.68	0.45	0.91*	0.73	0.65
	B	0.77	-0.52	-0.86*	-0.61	-0.14
Beautiful - ugly	A	-0.72	0.43	0.94*	-0.38	-0.19
	B	0.42	-0.47	-0.58	-0.29	0.20

(Significance level: *: $p<0.05$, **: $p<0.02$, ***: $p<0.01$)

4.2 Crease Stability

Crease stability means stability of crease under effects of conditions such as: elapsed (recovery) time, open steaming, washing etc. Three crease shape parameters, namely, Angle θ, *K-out* and *CL*, which are independent in nature, have been defined to express the crease shape. Changes in their values affect the change in the area under the inside of the top of the crease. In this study, crease stability is determined by considering changes in the area due to steam relaxation. This area is the area inside the outline of the crease between the top and the height 3 mm as shown in Figure 11.

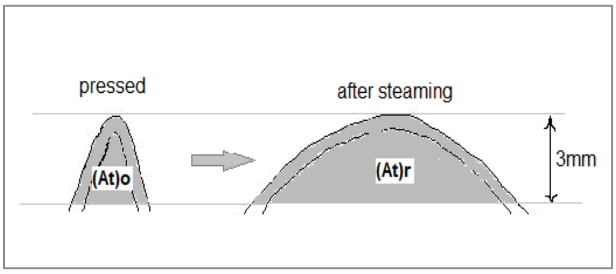


Fig 11: The crease stability

For this study, experiment B was carried out, which has been described in section 2.1 above.

Let total area before steam relaxation = $(A_t)_o$
and, total area after steam relaxation = $(A_t)_r$

Then,

$$\text{crease stability (\%)} = 100 \times [\, 1- \{(A_t)_r - (A_t)_o\} / (A_t)_r \,] \qquad (3)$$

This crease stability based on the area can be represented by a multiple regression function in terms of Angle θ, *K-out* and *CL* as follows. This function is derived by using a multiple regression analysis.

$A_t = f\,(\theta, K\text{-}out, CL)$

$$= a_0 + a_1 \ \text{Angle} (\theta/180) + a_2 \ \log(K\text{-}out) + a_3 \ CL \qquad (4)$$

where

$a_0 = 17.6599$, $a_1 = -2.3786$, $a_2 = 12.7740$, and $a_3 = -9.5141$.

Regression equation (4) gives a good fit as indicated by R^2 value of 0.833 (R^2 (adjusted) 0.826 and p-value is infinitesimally small).

The results of crease stability as calculated by using Equation (3) are shown in Figure 12. When there is no change in the crease shape due to steam relaxation, the crease stability is equal to 100%. Lower the % crease stability, poorer the crease stability or larger the loss in the crease characteristics such as sharpness. Crease stability of over 100% means the crease has become sharper and of higher curvature, and therefore, of smaller A_t due to steaming. This peculiar behaviour is exhibited by fabric samples W7 and W8 probably due to their high density, W/T, (Figure 13) and high drapability, which on steam relaxation makes them droop downwards.

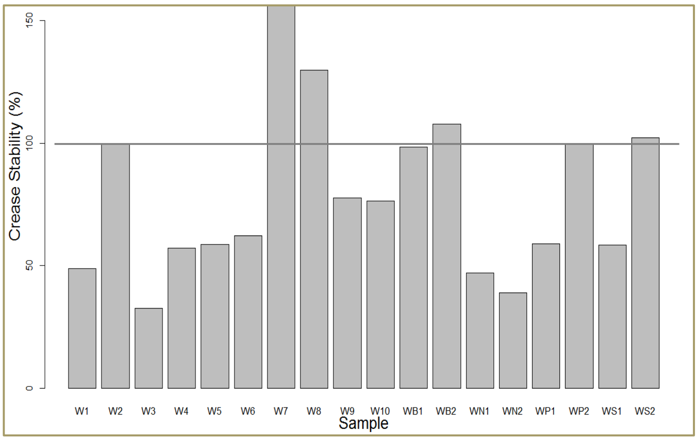


Fig 12: Crease stability for various wool and wool/polyester fabrics

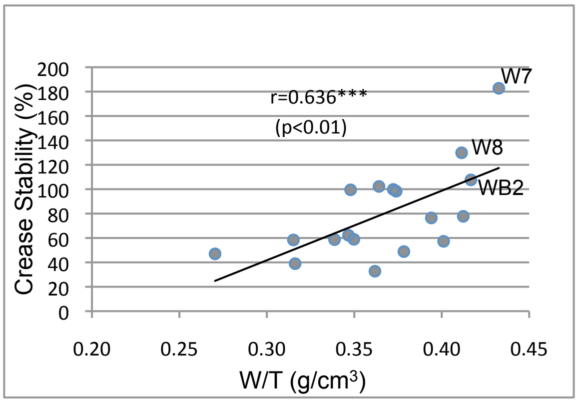


Fig 13: Relationship between crease stability and fabric density

5. SUMMARY

When a fabric is creased or pleated, the crease takes one of the various shapes depending on fabric construction and finish, pressing and steam setting conditions. To express the crease shape, only the crease angle is not enough; the characteristics crease curvature and linearity are also needed. In human sensory evaluation, the results for crease sharpness correlate better with the curvature than the angle. For both fabric groups, i.e. the fabric group based on different fibre types, and the other based on wool and woolblend fabrics, the evaluation of “Fresh” crease characteristic is found to be dependent on different objective values, namely θ, *K-out*, and *CL*. In addition, “Beautiful” and “Sharpness” crease characteristics do not always correlate with each other. Crease stability based on the area under the crease expresses the stability of the crease very well. We can explain variations in the stability of the crease shape in terms of changes in angle θ, curvature *K-out* and linearity *CL*.

This study used a limited range of fabrics in terms of thickness, considering mainly thin fabrics. In order to generalize our research findings, we will now extend the research further to fabrics of other yarn types and of a wide range of thickness. However, the present study provided a good insight into the fabric crease behavior, crease shape characteristics and crease relaxation.

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BIOGRAPHY

Rino Ouchi is a Master course student of Hokkaido University of Education. She studies about clothing materials and apparel sciences. Bachelor's degree thesis was *Control of Wool Fabric's Kansei by Various Finishing Methods*.

Dr. Takako Fujimoto belonged to 1)Niigata University (1977-1981), and then has belonged to 2) Hokkaido University of Education (1992- at present) and has been professor since 1992. She has been i) Head, Japan Section of The Textile Institute of UK (2005-), ii) a member of council of TI, iii) a council member of Japan Research Association for Textile End-uses, iv) a visiting professor, University of University of New South Wales, Australia (1996.9-1997.3). Her major research areas in scientific achievement are a) theory of heat transfer of fibrous materials, b) mechanical properties and handle estimation of clothing fabrics, c) objective evaluation of clothing materials, d) durability of clothing materials. The number of her published original books is 5, of her published original papers and articles is around 130. She received three prizes and awards related to the above scientific achievements.

Dr. Surinder Tandon

AgResearch Ltd, Textile Science & Technology, Lincoln, Christchurch, NEW ZEALAND
Dr Surinder Tandon is Senior Scientist at AgResearch Ltd where he has been working for 25 years. He specialises in textile technology, structural mechanics, objective measurement technology, technology transfer and commercialization. His current interests are in development of new fit-for-purpose woven and knitted apparel wool products including active sportswear and next-to-skin apparel, and functional interior textiles; development of sustainable wool textile processes and products.

Surinder has B.Text (Hons) from TIT Bhiwani, M.Tech from IIT Delhi and PhD from Leeds University. He is Fellow of the Textile Institute and recipient of 2011 Institute Medal of the Textile Institute. He has 70 publications.

Machiko Murakami graduated the master course of Nara Women's University in 1978 and belonged 1) Kobe Gakuin Women's College (1978-1979), 2) Mimasaka Women's University (1978-1983) and has belonged 3) Gifu City Women's College (1988-at present) and has been professor since 2007. Her major research areas in scientific achievement are 1) mechanical properties and handle estimation of clothing fabrics, 2) objective evaluation of clothing materials and 3) mechanical properties of bi-fabrics related to clothing silhouette.

Dr. Masukuni Mori

1. Born in 1929
2. Retired from a dyeing and finishing company in 1996 after 45 year's service
3. Established Mori Consultant Engineering Office just after retired
4. Got a Doctor Degree from Shizuoka University in 2006, Title of doctor thesis: Shrink-proofing of wool by low temperature plasma treatment
5. Now consultation service in and outside Japan