Part IV

Appendices

Appendix A

The Standardization and Analysis of Hand Evaluation* (second edition)

S KAWABATA, The Textile Machinery Society, Japan

A.1 History of the committee

A.1.1 Publication of the HESC Standard of Hand Evaluation

A confused situation of hand evaluation in Japan when the committee started

There is no doubt that the hand judgement of fabric is one of the important tests of fabric property and has been used widely by many people. We can classify these into two categories, experts in factories and general consumers. The experts in factories, especially in the fabric-finishing factories, have used hand judgement to control the property of their products on a daily basis. Furthermore, each consumer also examines the property of the fabric by his 'hand' to select a good clothing material according to his feeling and experience when he is going to purchase it.

In both cases, fabric hand is judged mainly by the sense of touch on the basis of individual standards of the hand feeling and then the hand feeling is expressed by many words such as 'stiff', 'soft', 'paper-like', etc.

The experts usually use some common terms for the hand expressions although these terms were not clearly defined. Koshi (stiffness), Numeri (smoothness) and Fukurami (fullness and softness) are examples of them. On the other hand, every consumer expresses his feeling of hand in his own language which is not classified. Moreover some consumers confuse hand feeling with colour sense and fashion sense. Such different conceptions on hand have confused every communication about the hand property so we were in a complicated situation.

Everybody says that hand is important and related closely to the quality

*In memory of Professor Sueo Kawabata (courtesy of the Hand Evaluation and Standardization Committee), The Textile Machinery Society, Japan.

of fabric but the simple question how the hand is defined cannot be answered.

Conversely, many kinds of hand expressions are often used by many people every day and everywhere for business and for reseach of textiles.

The conception of hand

In 1968, Kawabata proposed a conception of the hand by the two following main hypotheses:

(1) One mainly judges the hand by the feeling which comes from the mechanical property of fabric.
(2) Criteria for hand judgement are based on whether or not the fabric possesses suitable properties for its use as a clothing material.

These hypotheses were established after many discussions with many experts on hand judgement in factories in Japan.

For the second hypothesis, the problem is who can judge whether the fabric is suitable for its intended use. Kawabata's idea about this was as follows.

Consumer judgement is essentially important and the source of the criterion of hand judgement. But each consumer has not enough experience of wearing many kinds of fabric in general, but it is certainly true that each opinion has been noted over a long time. And the opinions of the consumers were fed back to the fabric producers, especially to the engineers of the finishing process, because they had to know whether or not their fabric products were of good quality. Thus, Kawabata considered that these experts in the finishing process must be the most appropriate people to judge the hand based on the hypotheses given above, and began to consult them in 1970, together with his coworker, Dr M. Niwa.

As mentioned before, the experts use some common expressions for hand evaluation. But it has been found that these expressions are not classified and not defined yet, and sometimes they have some different connotations for the feeling of each of these expressions.

The organizing of the committee

As a result of the situation outlined above, Kawabata organized the 'Hand Evaluation and Standardization Committee' as one of the research committees which belongs to the Textile Machinery Society of Japan.

The subjects of this committee's activity were as follows.

(1) Selection of the important hand expressions from a number of these expressions.

(2) Definition of the feeling with respect to each of these important expressions.
(3) Establishment of the standard samples which indicate the feeling with respect to each of the expressions and its intensity by numerical value.
(4) Analysis of experts' hand feeling and establishment of the translation formulae that can translate the mechanical properties of fabric into experts' hand.

For the subjects (1), (2) and (3) above, ten experts from the leading textile companies in Japan gathered together as committee members and continued discussions about the above items for three years.

The mechanical measurement of fabric properties

On the other hand, Kawabata continued his fundamental research on the mechanical properties of fabrics at that time with his coworker, Dr M. Niwa.

This work was very helpful for the research on subject (4), that is, for the scientific analysis of the hand evaluation.

Being based on the fundamental research, the author designed a system of instrumentation for measuring the fundamental mechanical properties of fabric and constructed the system which was named KES-F.

After that, 12 people who were engineers or scientists from companies and universities, joined with this committee to help the research on subject (4) mainly. A number of fabrics were measured by the measuring system KES-F and the data from it were analyzed using a computer by Kawabata and Dr M. Niwa.

The main purpose of the activity of this committee covered subjects (1), (2) and (3), that is, the establishment of the standard of hand evaluation.

Members of the committee who contributed to the establishment of the standard of hand evaluation

The following members of the committee contributed to the establishment of this standard for hand evaluation.

Chairman:

Dr Sueo Kawabata — Department of Polymer Chemistry, Kyoto University, Kyoto, 606

Secretary:

Dr Masako Niwa — Department of Clothing Science, Nara Women's University.

Committee members: (*: executive member)

Sub-committee-A (Hand Evaluation Group. All of them are experts in the factories).

T. Adachi*	Miyuki Woollen Textile Co., Ltd
K. Furuichi	Seiren Co., Ltd
H. Hatakama*	Daido Worsted Mills Ltd
M. Kondo*	Kanebo Co., Ltd. Ogaki Mill
S. Kurihara*	Mitsuboshi Sensei Co., Ltd
S. Miyamoto	Gisen Co., Ltd
Masao Mori*	Tokai Senko K.K. Those experts, T. Kato, H. Mugikawa, T. Murasawa and T. Ryochi who are engineers of the Tokai Senko K.K. assisted Mr Mori at the evaluation.
Masuichi Mori*	Tsuyakin Kogyo Co., Ltd
M. Morioka*	The Japan Wool Textile Co., Ltd
T. Nakai	Crown Finishing Co., Ltd
S. Nakano	Toa Wool Spinning and Weaving Co., Ltd Mr Matsuzaki, engineer of Toa Wool Spinning and Weaving Co., Ltd. assisted Mr Nakano at the evaluation.
M. Okada	Gisen Co., Ltd
K. Saito*	Kurabo Industries Ltd. Tsu Mill
K. Tamada*	Unitika Ltd T. Suzuki, engineer of Unitika Ltd. Miyagawa Mill, assisted Mr Tamada at the evaluation.
Y. Tamura*	Miyuki Woollen Textile Co., Ltd
E. Tanita*	Crown Finishing Co., Ltd
Y. Watanabe	Toyobo Co., Ltd Those experts, M. Takada and R. Toriyama who are engineers of the Toyobo Co., Ltd. assisted Mr Watanabe at the evaluation.

Sub-committee-C (contributed to the measurement of the mechanical properties of the fabrics and the arrangement of the data.)

T. Karakawa*	Kurabo Industries Ltd, Tsu Mill
Y. Kawai	Aichi Syukutoku Junior College
S. Kawase*	Kanebo Co., Ltd
M. Kiriyama	Chori Co., Ltd
K. Kita*	Toray Industries, Inc.
K. Kusunose*	Nara Women's University
H. Morooka	Osaka Seikei Women's Junior College
M. Sakamura	Kuraray Co., Ltd
T. Sato	Kao Soap Co., Ltd
Y. Shibata*	International Wool Secretariat, Japan Branch, Inchinomiya Technical Center
R. Sugishita	Nara Women's University

I. Tabayashi*	Toray Industries Inc.
S. Yamaguchi*	Kuraray Co., Ltd

The following people, who were students of Nara Women's University, assisted the activity of sub-committee-C:

A. Akamatsu, Y. Kikuchi, S. Murata and R. Nagasawa.

Contribution from the companies for the publication of The HESC standard of hand evaluation, first edition

The following companies offered samples for publishing the reproduced standard samples of the *HESC Standard of Hand Evaluation*.

Daido Worsted Mills Ltd
Daitobo Co., Ltd
Fukaki Woollen Textile Co., Ltd
Gisen Co., Ltd
International Wool Secretariat, Japan Branch
Kanebo Co., Ltd
Kurabo Industries Ltd
Kuraray Co., Ltd
Mitsuboshi Sensei Co., Ltd
Miyuki Woollen Textile Co., Ltd
Ootsuka K.K.
Seiren Co., Ltd
The Japan Wool Textile Co., Ltd
Toa Wool Spinning and Weaving Co., Ltd
Tokai Senko K.K.
Toray Industries, Inc.
Toyobo Co., Ltd
Tsuyakin Kogyo Co., Ltd
Unitika Ltd.

A.1.2 Publication of *The HESC Standard of Hand Evaluation* (second edition)

Since the first edition of the *HESC Standard of Hand Evaluation* was published, five years have passed, and there are almost no copies left. Under these circumstances, the publication of the second edition was planned in 1979.

In the same manner as the publication of the first edition, the publication committee was organized. The members of the committee consist of nine experts on hand evaluation, all of them are HESC committee members and six of them were the publication committee members of the first edition.

Careful work has been carried out by the publication committee in order to reproduce the copies of the standards.

A small change in the situation from the time of the first edition is that we have the formulae by which hand values can be estimated from the basic mechanical properties of fabric with considerably higher accuracy.

Firstly, the samples collected were measured, their basic mechanical properties and the hand values were estimated by calculation, then the experts decided the samples to be used for the reproduced standard by their hand judgement. This procedure has considerably reduced the labour of the experts.

The members of the editorial committee are as follows:

Editor:
Sueo Kawabata, Kyoto University
Secretary of the editorial committee:
Masako Niwa, Nara Women's University

Editorial committee members:

S. Kurihara,	Mitsuboshi Sensei Co., Ltd
M. Kondo,	Kanebo Co., Ltd
K. Saito,	Kurabo Co., Ltd
S. Sōma,	Unitika Ltd (present, Durban, Inc.)
E. Tanita,	Crown Finishing Co., Ltd
H. Fujiwara,	The Japan Wool Textile Co., Ltd
M. Mori,	Sumi Sōgōkenkyusho
M. Morioka,	

K. Nakajima (publication business officer), The Textile Machinery Society of Japan

Some of the samples used for the reproduced standards were contributed by the companies to which the committee members belonged.

The following members of the HESC and students assisted the editorial work.

K. Komatsu,	Nara Women's University, member HESC
Y. Okamoto,	Nara Saho Women's Junior College, member HESC
K. Izumi,	Sakai Women's Junior College, member HESC
Y. Hirata,	Nara Women's University, student
S. Maeda,	Nara Women's University, student

A.1.3 Publication of the standard of hand evaluation for women's thin-dress fabrics

Several years ago, the standard of hand evaluation for women's dress fabrics had been investigated by the HESC and in 1979, the editorial committee was first organized.

Editor:
Sueo Kawabata, Kyoto University
Secretary of the editorial committee:
Masako Niwa, Nara Women's University
Editorial committee:

H. Fujiwara	The Japan Wool Textile Co., Ltd
H. Maeda	Kanebo Synthetic Fibers, Ltd
T. Mizohata	Unitika Ltd
S. Yamaguchi	Kuraray Co., Ltd
O. Wada	Teijin Ltd

K. Nakajima (publication business officer), The Textile Machinery Society of Japan.

Some of the samples used for the reproduced standard were contributed by the companies to which the editorial memebers belonged.

The editorial committee members of the *HESC Standard of Hand Evaluation*, 2nd edition (standards 1–7), which was published at the same time have taken part in the hand evaluation of the samples and in discussions about the standardization.

The following HESC members and students have given great assistance in the editorial work.

K. Izumi	Sakai Women's Junior College, member HESC
Y. Okamoto	Nara Saho Women's Junior College, member HESC
N. Makado	Nara Women's University, student
K. Moro,	Nara Women's University, student
M. Uematsu,	Nara Women's University, student.

A.2 Selection of the standard samples for hand evaluation

A.2.1 Standard of the hand for men's suit fabrics

Selection of important hand expressions

From hypothesis (2) on page 390, the criterion of fabric hand is based on the end-use of the fabric. The committee consisting of the experts accepted that this hypothesis was true, and they limited the object of the discussion to the hand evaluation of the fabric for men's suits. After many discussions, four of the primary hand expressions were selected, and at same time, the proportion of the importance of these terms in the evaluation of quality of fabrics were estimated as shown in Table A.1.

Table A.1 Primary hand expressions and the degree of their importance for quality evaluation

Expressions	Importance in percent	
	Winter suit	Summer suit
Numeri (Smoothness)	30	0
Shari (Crispness)	0	35
Koshi (Stiffness)	25	30
Hari (Spread, anti-drape)*		
Fukurami (Fullness and softness)	20	10
(Appearance of surface)	15	20
(Others)	10	5
Total	100	100

*In the first edition of the HESC Standard, the expression 'Hari' was omitted, and recently, Koshi and Hari were separated.

The coordinated feeling of each of the expressions

All of the expressions shown in Table A.1 are closely related with the mechanical properties except 'appearance of surface'. Thus the committee selected Numeri, Koshi and Fukurami as three primary hand expressions for winter suits and Shari and Koshi as two for summer suits. And recently, the Fukurami and the Hari have been added as the primary hand expressions for summer-suit fabrics. The reason for this new addition is that these two expressions are necessary for quality judgement of summer-suit fabrics. Next, the answers to the following questions were discussed and the coordinated definitions were obtained for each of these expressions.

(a) What kind of feelings are related with its hand expressions?
(b) Which properties of fabric are related to the judgement?

The coordinated answers of the committee are as follows.

Numeri

Answer against questions (a) and (b) are:

(a) A mixed feeling come from smooth, limber and soft feeling. Its typical feeling is given by the fabric woven with cashmere fibre. Experts express this feeling by their professional words which means 'the softness comes from fine and high quality wool fibres'.
(b) Flexibility, smoothness, touch of smooth bending and springy property in bending.

Shari

(a) 'Shari-shari' feeling. This 'shari shari' is the crisp and sharp sound which is made by rubbing the surface of the fabric with itself when the surface is slightly rough and slightly hard just as dry sand. This 'shari' feeling brings us a cool feeling. And this feeling is brought by hard and strongly twisted yarn. For example, woolen plush fabric usually possesses this feeling strongly.
(b) Mainly surface touch. All kinds of hardness of fabric promote this feeling.

Koshi

(a) and (b) A stiff feeling from the bending property and springy property promotes its feeling. High density fabrics made with springy and elastic yarn usually possess this feeling strongly.

Hari

Anti-drape stiffness, no matter whether the fabic is springy or not. This word means 'spread'.

Fukurami

(a) Feeling come from a bulky, rich and well formed feeling.
(b) Springy property in compression and thickness accompanied with warm feeling.

The experts from different companies had not discussed with each other about these definitions before the organizing committee, but they had an almost common understanding about the hand, and there was not so much difference in their conception and understanding of these expressions. The primary hand expression and their definitions are shown in Table A.2.

Determination of the standard samples

In 1973, membership of the committee was increased and a sub-committee which consisted of 20 experts was organized in the committee. On the other hand, 500 samples for men's winter suits had been collected from many textile companies in Japan. All samples were collected randomly from the commercial products for use in men's suits. That is, some of the samples were knitted fabrics and some were polyester fabrics, but all of them are used for 'men's suit'.

After reconfirmation of the definition of each of the primary hands was

Table A.2 Primary hand expressions and their definitions

Men's winter suit fabric

Hand (Japanese)	(English)	Definition
1. Koshi	Stiffness	A feeling related with bending stiffness. Springy property promotes this feeling. The fabric having compact weaving density and woven by springy and elastic yarn makes this feeling strong.
2. Numeri	Smoothness	A mixed feeling come from smooth, limber and soft feeling. The fabric woven from cashmere fibre gives this feeling strongly.
3. Fukurami	Fullness and softness	A feeling come from bulky, rich and well formed feeling. Springy property in compression and thickness accompanied with warm feeling are closely related with this feeling. (Fukurami means 'swelling')
Men's summer suit fabric		
1. Koshi	Stiffness	Same as Koshi in Table A.1.
2. Shari	Crispness	A feeling come from crisp and rough surface of fabric. This feeling is brought by hard and strongly twisted yarn. This feeling brings us a cool feeling. (This word means a crisp, dry and sharp sound arisen by rubbing the fabric with itself)
3. Hari[a]	Anti-drape stiffness	Anti-drape stiffness, no matter whether the fabric is springy or not. (This word means 'spreading')
4. Fukurami*	Fullness and softness	Same as Fukurami in Table A.1.

[a]These are recently added to the primary hand group for the summer men's suit fabric.

made by the sub-committee, and a few differences among the understandings with respect to the hand expressions were coordinated, the experts of the sub-committee have judged many samples as follows to set up the standard.

(1) The first step. All samples were divided into three groups according to the intensity of the hand feeling for each of the hand expressions.
Group A: samples having strong feeling-intensity
Group B: samples having medium feeling-intensity
Group C: samples having weak feeling-intensity

(2) The second step. Same procedure as the first step was taken into each of the groups A, B and C, that is, each of these groups was again

divided into three sub-groups. As we have three sub-groups in each of the three main groups, we have nine groups in order of the intensity of the feeling.

(3) The third step. Samples possessing extremely strong feeling were separated from the highest group (A–A) and the samples possessing the extremely weak feeling were also separated from the lowest group (C–C) respectively. Also some adjustments were made between the adjacent two sub-groups each of which belongs to the different main groups (for example, A–C and B–A, and so on).

(4) The final step. Total number of the groups becomes finally 11 as shown in Table A.3. Each of the groups was labeled by a number from 0 to 10 according to the intensity of the feeling. The numbers were called *Hand value*, the largest number denoting the strongest feeling of hand.

Table A.3 Hand values. Samples are divided into three groups A, B and C following the intensity of the hand feeling and then the samples of each of those groups are again divided to three groups. The XH and XL are picked out from A–A and C–C groups respectively. Finally the 11 groups are obtained and labeled by numbers, 10, 9, 8, . . . , 0. This number is named Hand Value (HV) and the highest value corresponds to the strongest feeling of the hand

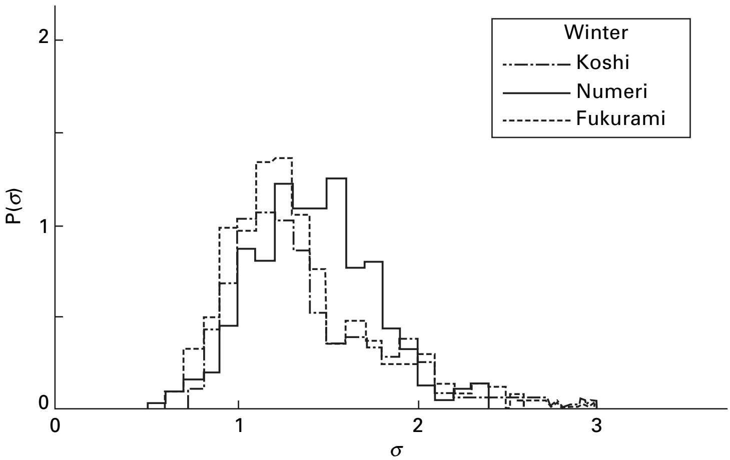
Group	XH	A (strong)			B (medium)			C (weak)			XL
		A–A	A–B	A–C	B–A	B–2	B–C	C–A	C–B	C–C	
HV	10	9	8	7	6	5	4	3	2	1	0

Each of the 20 experts had followed this procedure for all samples and for each of all the primary hand expressions.

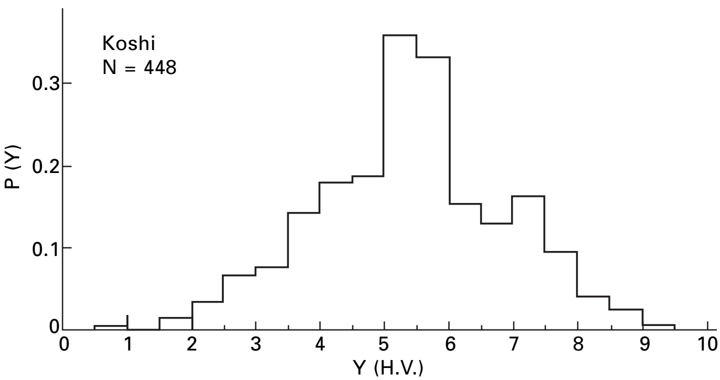
Thus, a sample has 20 hand values evaluated by the 20 experts for each of the primary hand expressions. The mean of these values was taken as the hand value of this sample. Of course, the fluctuation in the evaluated values by the 20 experts was observed for each of the samples so that the standard deviation was calculated as well as the mean value. Figure A.1 is an example of the histogram of the standard deviations observed from each of the 448 samples. The distribution of the standard deviation is narrow and this shows a good agreement among the hand values evaluated by each of the 20 experts.

On the other hand, the histograms of the mean values shown in Figs A.2–A.8 are useful to show the distribution of the hand values of commercially produced fabrics for men's suit in Japan. The mean and the standard deviation of each distribution of hand values is shown numerically in Table A.4.

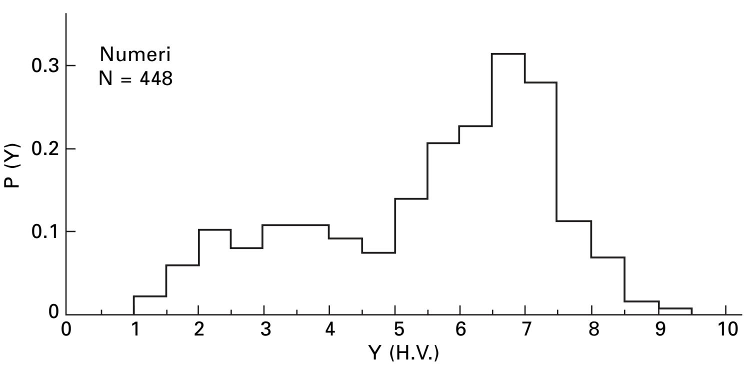
As mentioned before, the 448 samples used here consisted of many kinds of fabrics. But most samples are worsted fabrics, that is, 52% of the samples



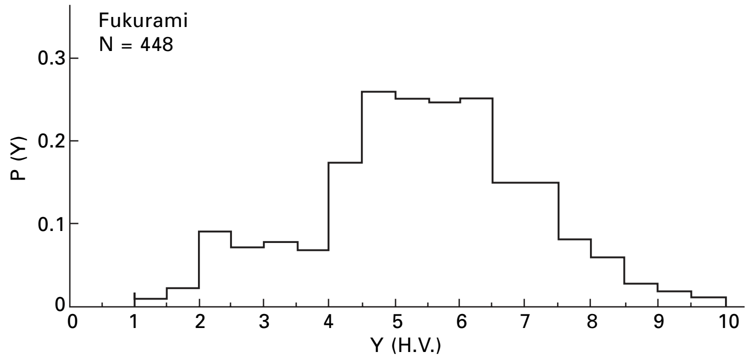
A.1 Distribution of standard deviation of the evaluation hand values by 20 experts.



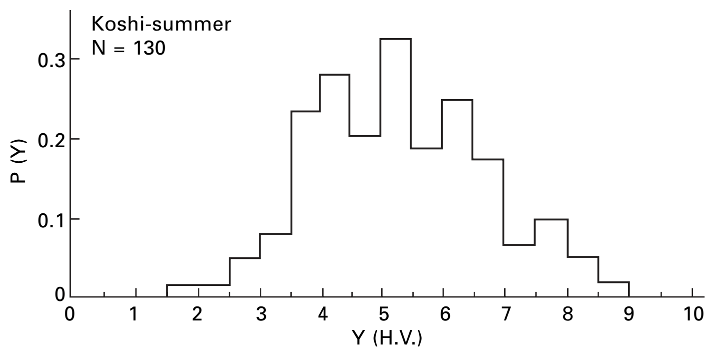
A.2 The distribution of hand values of the fabrics commercially produced in Japan shown by normalized histogram P(Y) – Koshi.



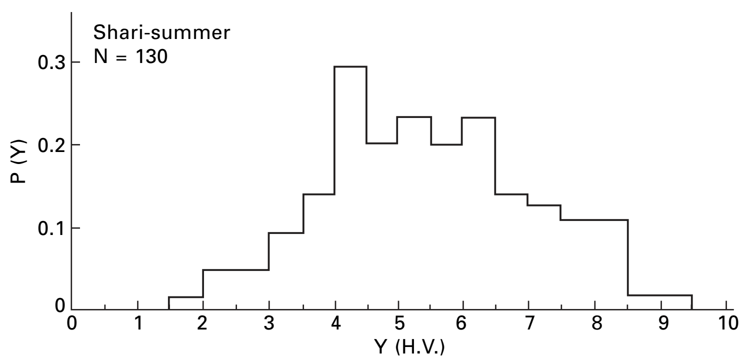
A.3 The distribution of hand values of the fabrics commercially produced in Japan shown by normalized histogram P(Y) – Numeri.



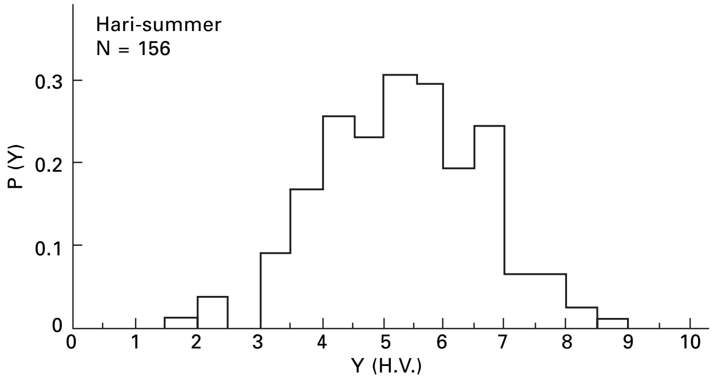
A.4 The distribution of hand values of the fabrics commercially produced in Japan shown by normalized histogram P(Y) – Fukurami.



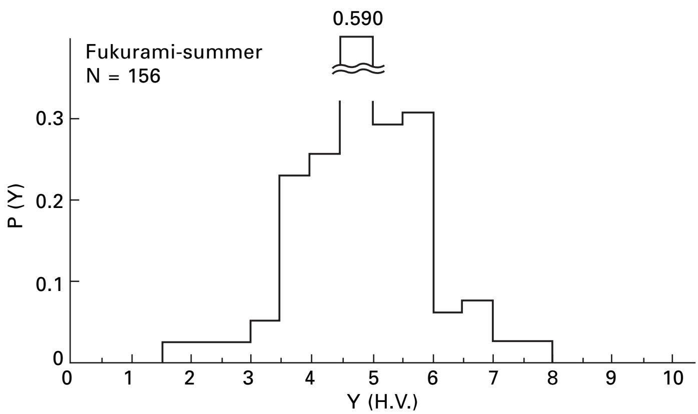
A.5 The distribution of hand values of the fabrics commercially produced in Japan shown by normalized histogram P(Y) – Koshi-summer.



A.6 The distribution of hand values of the fabrics commercially produced in Japan shown by normalized histogram P(Y) – Shari-summer.



A.7 The distribution of hand values of Hari-summer. These data were obtained from the fabrics which were collected for developing the basic mechanical properties–hand value translation formula. The histogram has little deviation from that of randomly collected samples; however, it is considered to be fairly similar to the histogram obtained from the randomly sampled fabrics.



A.8 The distribution of hand values of Fukurami-summer. These data were obtained from the fabrics which have been collected for developing basic mechanical properties–hand value translation formula. The histogram has little deviation from that of randomly collected samples; however, it is considered to be fairly similar to the histogram obtained from the random sampling case.

are worsted, 31% polyester-wool blended, 9% woolen and 6% textured yarn fabrics.

According to the preliminary work described above, all samples were evaluated for their hand and represented by the hand values as shown in Table A.5.

As shown later, this numerical expression of hand became a powerful tool

Table A.4 Mean and standard deviation of the hand values of the fabrics produced in Japan

Hand		Mean value	Standard deviation
Winter	Koshi	4.94	1.46
	Numeri	5.08	1.83
	Fukurami	4.96	1.68
Summer	Koshi	4.81	1.43
	Hari	5.39[a]	1.30[a]
	Shari	4.98	1.61
	Fukurami	4.92[a]	1.02[a]

[a]These data are taken from the samples collected for the development of basic mechanical properties HV translation formula. The values are similar to those of randomly sampled fabrics.

Table A.5 Expression of hand values

Sample no. (Winter)	Hand value		
	Numeri	Koshi	Fukurami
.	.	.	.
.	.	.	.
.	.	.	.
201	6.6	2.1	3.0
202	3.2	3.0	4.0
.	.	.	.
.	.	.	.
.	.	.	.

for the analysis of the relation between the experts' hand and the mechanical properties of fabrics.

Standard samples

All of the samples, each of which was labeled by the hand values, were examined by the committee for the purpose of picking up a set of standard samples for hand evaluation.

At the time of this selection, the following items were considered.

(1) Sample of which standard deviation of the hand values evaluated by the 20 experts is as small as possible.
(2) Sample of which hand value takes the value nearest a round number such as 1 or 2 or 3 and so on.

Table A.6 shows the hand values of the selected samples as the original set of the standard sample for men's suit fabrics.

Table A.6 Original standard

Winter	Hand value								
No. 1 Koshi									
worsted (twill)	1	2	3	4	5	6	7	8	
worsted (plain)		2	3		5	6	7	8	
wool and polyester blended			3	4	5	6	7		9
textured		2	3	4	5	6	7		
woolen	1	2	3	4		6	7		
No. 2 Numeri									
worsted	1.5	2	3.6	4	5	6	7	8	
woolen				4		6			
No. 3 Fukurami									
worsted	1	2	3	4	5	6	7	8	9
textured	1		3		5	6			
Summer									
No. 4 Koshi-summer		2		4	5	6	7	8	
No. 5 Shari-summer	1.6		3	4	5	6	7	8.3	8.6
No. 6 Fukurami-summer[a]		2		4	5	6		8	
No. 7 Hari-summer[a]	1		3		5		7		9

[a]These expressions were added in the 2nd edition of HESC Standard.

As seen from Table A.6, the greater part of the standard samples consisted of worsted fabrics and some woolen and textured yarn fabrics were selected as a supplement to them. This supplement will become useful when these kinds of fabrics are evaluated by using the standard samples.

Reproduction of the standard samples

It is very important that each of many companies and institutes possesses a copy of the set of standard samples for their hand evaluation and for use of the standardized hand values in order to use them in the technical or commercial communications between them.

The committee made a request for contributions from the leading textile companies in Japan for collecting the fabrics for the publication of 200 copies of the duplicated sets of the standard samples.

All of the requested companies whose names are listed on page 394, approved it and about 176 of the samples were collected.

The sub-committee, which is a group of experts, again evaluated all these samples based on the original standard samples, and decided their hand values for each of these samples.

In parallel with this work, another sub-committee was organized also in this committee for the purpose of measuring the mechanical and physical properties of the fabrics. In order to identify the former sub-committee from the new committee were named Sub-committee A for the former and Sub-committee C for the latter committee respectively. Based on the mechanical properties, the calculated hand value (CHV) was obtained by the translation formula (which will be described in Section A.4). These CHVs were used as the reference when sub-committee A picked up the samples for the reproduced set of the standard sample from the 176 samples.

In this duplicate set, the number of the supplement samples was reduced compared with the number in the original set. The reason is as follows. The committee considered that, for example, the hand values of two Koshi obtained from worsted fabric and from textured yarn fabric should be evaluated by essentially the same base and, for this reason, the set of standard samples must be simplified.

Based on this consideration, some of supplement samples were omitted from the set of standard samples. Finally the set shown in Table A.7 was obtained.

Table A.7 Reproduced standard for publication (first edition)

Winter	Hand value								
No. 1 Koshi									
worsted		2	3	4	5	6	7	8	9
textured			3		5		7		
No. 2 Numeri									
worsted	0.5	2	3	4	5	6	7		10
woolen		2	3	4	5.5				
No. 3 Fukurami									
worsted	0	2	3	4	5	6	7	8	9
woolen						6	7	8	9
Summer									
No. 4 Koshi-summer		2	3	4	5	6	7	8.5	
No. 5 Shari-summer		2	3	4	5	6	7	8	9

The second edition of The HESC Standard of Hand Evaluation

The publication of the second edition of *The HESC Standard of Hand Evaluation* was planned in 1979. This is also a faithfully reproduced set of the original of the standard.

A different feature from the first edition is that the layout of the samples is simplified compared with that of the first edition, that is, the layout of the sample is not continuous in order of the hand value but alternative in some portions such as 1, 3, 5 and so on. One reason of this simplification is the difficulty in getting enough samples, but another is that this simplified layout makes for easier understanding of the feeling intensity for many people who are not necessarily in professional positions.

The other different point is that the new standards, Fukurami-summer and Hari-summer, are added in this second edition; these expressions of hand were considered to be important for the quality judgement of summer-suit fabric and added as new standards recently as standard No. 6 and No. 7 respectively. The layout of the samples of the second edition is shown in Table A.8.

Table A.8 Reproduced standard for the second edition

Winter suit	Hand value								
No. 1 Koshi	1		3		5		7		9
No. 2 Numeri	1		3		5	6	7		9
No. 3 Fukurami	1		3		5	6	7		9
Summer suit									
No. 4 Koshi		2		4		6		8	
No. 5 Shari		2		4		6		8	
No. 6 Fukurami		2		4	5	6		8	
No. 7 Hari	1		3		5		7		9

A.2.2 Standard of the hand for women's dress fabrics

Classification of women's dress fabrics

The HESC started discussions on the primary hand expressions for women's dress fabrics for the purpose of standardizing in 1976 based on the HESC standard which had been established at that time.

A distinctive point of women's dresses is the diversity of style of a dress. For example, the thickness of these fabrics varies from about 0.1 mm to 2.5 mm. Therefore, the mechanical properties of these fabrics are also scattered over a very wide range.

The questions we asked were as follows.

(1) Is it possible to find some common expressions of hand for the women's fabric as we found in the men's suit fabric?
(2) Is there any requirement for standardization of these expressions if they exist?
(3) Is it possible to standardize such diverse types of fabrics?

Many discussions were repeated in the HESC, and questionnaires were given frequently to many people who were working at the women's dress manufacturer in Japan. Then we concluded that there were some hand-expressions commonly used; however, the understanding of these expressions was not so clear as in the case of men's suit fabrics. For example, Sofutosa (soft) is an expression used very frequently in fabric manufacturers and markets; however, this expression was not a professional or technical term as, for example, Numeri of men's suit fabric was. In other words, many expressions of hand are used by those people but there are almost no expressions used with clear understanding.

This was a strong reason why the standardization of hand expressions was necessary. This conclusion encouraged the committee members to begin working for standardization.

The first work the committee undertook was the classification of women's dress fabrics and they have been classified as follows.

(1) Thick fabric (overcoat)
(2) Medium thick fabric (suit)
(3) Thin fabric (blouse and one-piece dress)

Apparently, this classification is based on the fabric thickness, but also shows the use of the fabrics as shown in parentheses.

In fact, their thickness is overlapped as seen in Table A.9, in which their thickness ranges are shown as well as some of their mechanical properties. The data shown here were obtained from many samples collected from commercial products and classified by manufacturers for the purpose of hand analysis and standardization working.

Table A.9 Range of thickness and related properties

	Thin fabrics	Medium-thick fabrics
T	0.131~1.460 (0.445)	0.323~2.490 (0.974) mm
W	3.46~25.12 (10.2)	9.38~42.97 (23.6) mg/cm^2
B	0.0012~0.1693 (0.0267)	0.0160~0.3675 (0.1156) gf · cm^2/cm
B/w	1.03~16.91 (2.64)	0.70~25.18 (4.89) cm^3

T: thickness at 0.5 g/cm^2 pressure (mm)
W: weight (mg/cm^2)
B: bending rigidity per 1 cm width (gf · cm^2/cm)
w: weight (g/cm^2)

Reference data

	Summer – men's suit fabrics	Winter – men's suit fabrics
T	0.289~1.060 (0.504)	0.395~2.470 (0.802)
W	13.0~31.1 (19.5)	11.7~38.4 (26.4)
B	0.043~0.251 (0.104)	0.056~0.482 (0.150)
B/w	2.79~10.94 (5.3)	2.17~18.03 (5.6)

Selection of primary hand for women's dress fabric

The 'thick' fabrics were placed out of consideration and the 'medium thick' and the 'thin' fabrics were considered for their hand standardization. The selected hand expressions are shown in Table A.10 for the medium thick fabrics and Table A.11 for the thin fabrics respectively.

Table A.10 Primary hand expressions and their definitions for women's medium-thick fabrics

1.	Koshi	Stiffness	Same as Koshi in Table A.1
2.	Numeri	Smoothness	Same as Numeri in Table A.1
3.	Fukurami	Fullness and softness	Same as Fukurami in Table A.1
4.	Sofutosa[a]	Soft feeling	Soft feeling, a mixed feeling of bulky, flexible and smooth feelings

[a]This is not a primary hand. This expression was added as a semi-primary hand because this feeling was important for ladies' dress fabric.

Table A.11 Primary hand expressions and their definitions for women's thin-dress fabrics

1.	Koshi	Stiffness	Same as Koshi in Table A.1
2.	Hari	Anti-drape stiffness	Same as Hari in Table A.2
3.	Shari	Crispness	Same as Shari in Table A2
4.	Fukurami	Fullness and softness	Same as Fukurami in Table A.1
5.	Kishimi	Scrooping feeling	Scrooping feeling. A kind of silk fabric possesses this feeling strongly
6.	Shinayakasa[a]	Flexibility with soft feeling	Soft, flexible and smooth feeling

[a]This is not a primary hand but semi-primary hand. This hand is added because of its importance for the evaluation of ladies' thin fabrics.

Medium thick fabric

Many people manufacturing women's dresses were asked which expressions of hand were used frequently in their professional activities. Based on the answers from these professional people the expressions shown in Table A.10 were selected.

It is interesting that these expressions are the same as those for men's winter suit fabrics except Sofutosa. The committee discussed Sofutosa and has concluded that it is not a primary hand but a kind of mixed feeling of the other three primary hands. But this hand expression is used very frequently in markets and industries because of its importance as an intense expression.

Generally speaking, the expressions of hand are the same as those for men's suit fabrics, and we have concluded that the standard for men's suit fabrics can be used commonly in the case of the women's medium thin fabrics as their standards of hand evaluation. Only the standard of Sofutosa has been prepared as a reference of the evaluation of this expression.

Thin fabric

The hand expressions for this thin-fabric group are similar to the expressions of hand for men's summer suit fabrics and two expressions are added to the other primary hand expressions common with men's summer suit fabrics:

- Kishimi–scrooping feeling silk fabrics possess this feeling strongly.
- Shinayakasa–soft, flexible and smooth feeling.

These expressions are not a primary hand but a mixed feeling of the other primary hands. Also it is added because of its importance in the evaluation of the fabric properties of this kind of fabric and for its frequent use by professional people. These expressions and their definitions are shown in Table A.11.

These thin fabrics are quite different in mechanical properties and thickness divergency from those of men's summer fabrics. Therefore, it has been considered that the standard for men's summer fabrics cannot be applied to these thin fabrics and a new set of standards is necessary for the evaluation of their primary hand expressions.

The sub-committee C of the HESC has made the selection of fabrics for the standardization with a lot of help from sub-committee A. The layout of the original standard samples of the hand for the women's thin fabric is shown in Table A.12 and the layout of the samples published in the HESC Standard is shown in Table A.13.

Table A.12 The standard samples of the HESC Standard of Hand Evaluation for women's thin-dress fabrics, the original set

Women's thin dress	Hand value									
Koshi	1	2	3	4	5	6	7	8	9	
Hari	1	2	3	4	5	6	7	8	9	10
Shari	1	2	3	4	5	6	7	8	9	
Fukurami	1	2	3	4	5	6	7	8		
Kishimi		2		4		6		8		
Shinayakasa	1	2	3	4	5	6	7	8	9	10

Table A.13 Reproduced standard samples for publication of the HESC Standard of Hand Evaluation for women's thin-dress fabrics

Women's thin dress	Hand value										
No. 8 Koshi		1	2	3		5		7		9	
No. 9 Hari	0		2		4		6		8		10
No. 10 Shari		1		3		5		7		9	
No. 11 Fukurami			2		4		6		8	9	
No. 12 Kishimi		1		3		5		7	8		
No. 13 Shinayakasa		1	2		4		6		8		10

A.3 How to use the HESC Standard of Hand Evaluation

A.3.1 Evaluation of hand values (HV) using the standards

The HESC Standard of Hand Evaluation consists of two volumes; one is the standard for men's suit fabrics and consist of seven sets No. 1–7 and the other is that for women's thin-dress fabrics consists of six sets No. 8–13 as follows.

The sets for men's suit fabrics:

No. 1	Koshi	for winter suit fabrics
No. 2	Numeri	
No. 3	Fukurami	
No. 4	Koshi-summer	for summer suit fabrics
No. 5	Shari-summer	
No. 6	Fukurami-summer	
No. 7	Hari-summer	

The sets for women's thin-dress-fabrics:

No. 8 Koshi
No. 9 Hari
No. 10 Shari
No. 11 Fukurami
No. 12 Kishimi
No. 13 Shinayakasa

As described in section A.2, the hand value expresses the intensity of the hand feeling and a large value corresponds to 'strong' feeling. These values are based on the standards established by the Hand Evaluation and Standardization Committee.

If one intends to evaluate the hand value of a given sample, sets 1, 2 and 3 should be used when the sample is the fabric used for men's winter suit, and sets 4 to 7 for summer suit. For example, if 'Numeri' for the sample of the men's winter suit is evaluated, set 2 should be used to compare the sample with those of standard samples by hand touch and decide the hand value.

If the hand value of the sample lies between the values 5 and 6, the judge decides an appropriate value between 5 and 6 by his feeling. The error from this indefinite operation is not so large if the judge learns the intensity-gradient of the standard samples.

As an example, we can evaluate the hand values for a sample of men's winter suit fabric as follows.

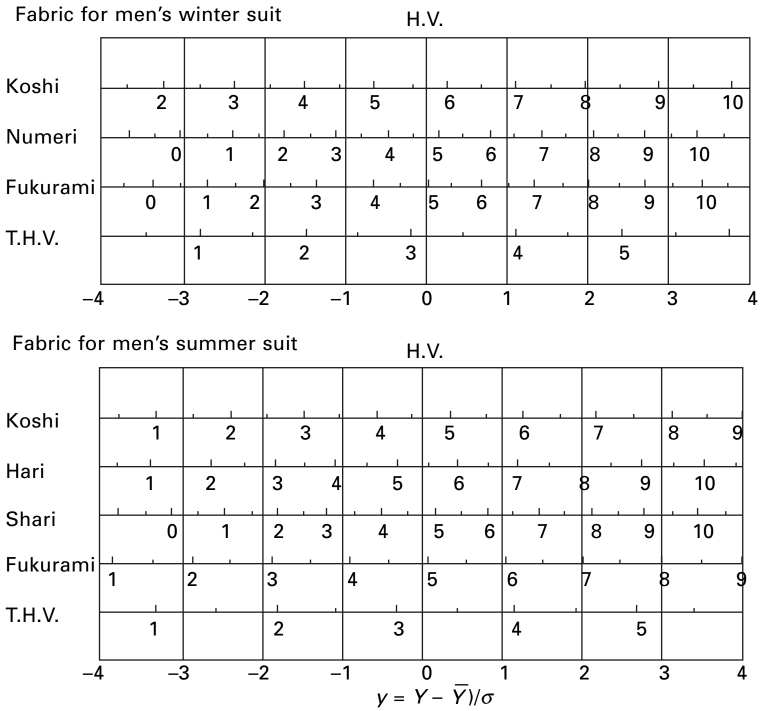
	Numeri	Koshi	Fukurami
Sample # 1	5.5	2	7.5

We recommend the following expression from, for example

HV-Numeri	5.5	
HV-Koshi-summer	3.5	
HV-Koshi-LDY*	5.0	(*LDY means 'for women's thin-dress fabrics')

We have not any specified operation for hand evaluation.

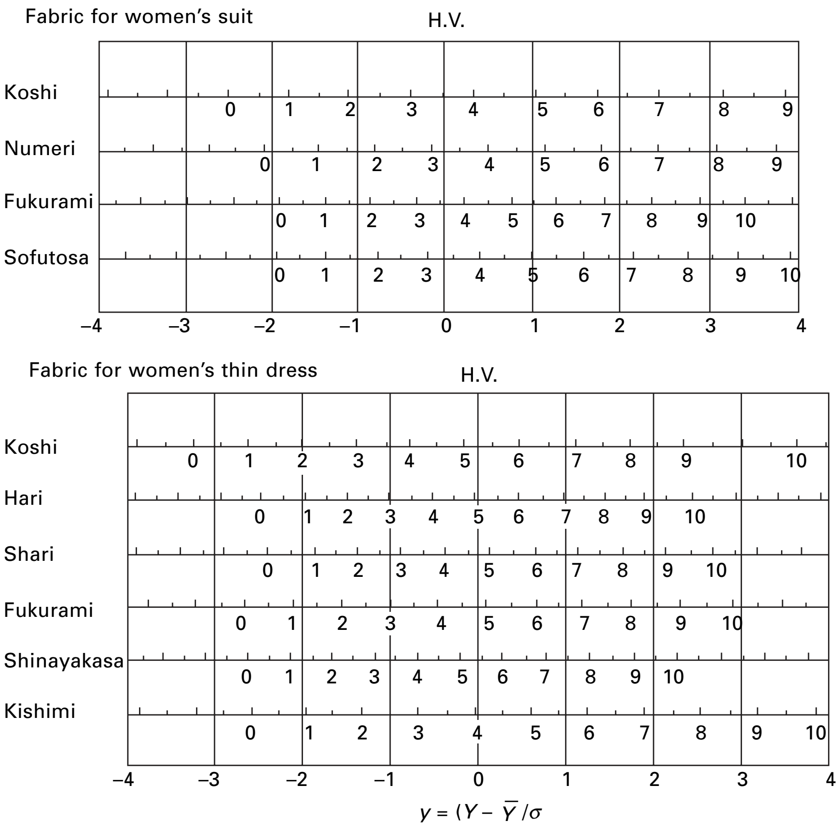
After the evaluation of the hand values, if you want to examine what kind of hand characteristic your sample has, you can plot the hand values on the normalized chart shown in Fig. A.9 or Fig. A10. The values required for this normalization were taken from Table A.3.



A.9 Charts for plotting the HV of men's suit fabrics. This chart is useful for examining the character of a fabric by plotting its HV on this chart. The common scale is normalized by the standard deviation, that is, $y = (Y - \bar{Y})/\sigma$. This normalizing was carried out by using the mean and the standard deviation of the samples which were collected for the development of the translation formula of basic mechanical properities into hand value, 214 samples of winter and 156 of summer.

A.3.2 Application of hand values

There are many possibilities of applications of the hand values. Firstly, the numerical expression of hand becomes a powerful tool for improving the



A.10 Charts for plotting the HV of women's medium-thick fabric (upper) and thin-dress fabric (bottom). The common scale is normalized by the standard deviation such as $y = (Y - \bar{Y})/\sigma$.

fabric quality. For example, if the temperature of a part of the finishing process is changed, its effect on hand of the fabric will be presented by recording the hand values before and after the change. Then we have a numerical correspondence between the temperature and the hand. This will be helpful to improve the process and produce the fabric having prescribed property.

The next example of the application is the communication of information about the hand among engineers and sales engineers. That is, a sales engineer calls his factory by telephone from a long distance and can discuss with an engineer the hand of fabric which is just finished at his factory by using the hand values.

Discussion about the property of a fabric by two engineers who belong to different companies will become possible. In this case, they can discuss the hand of the sample with the same understanding about the fabric hand and by the same scale of its feeling intensity.

Finally, the numerical expressions of hand can be used effectively in research on connecting the mechanical properties of fabrics with the hand evaluation by the experts. This will be shown in the next section.

A.3.3 Relation between the primary hand expressions and the 'good hand feeling'

The simplest but difficult expression of hand for our understanding is the expression 'good' hand or 'poor' hand. This expression, however, expresses the quality of fabric directly. In this case, we have only two expressions, good or poor.

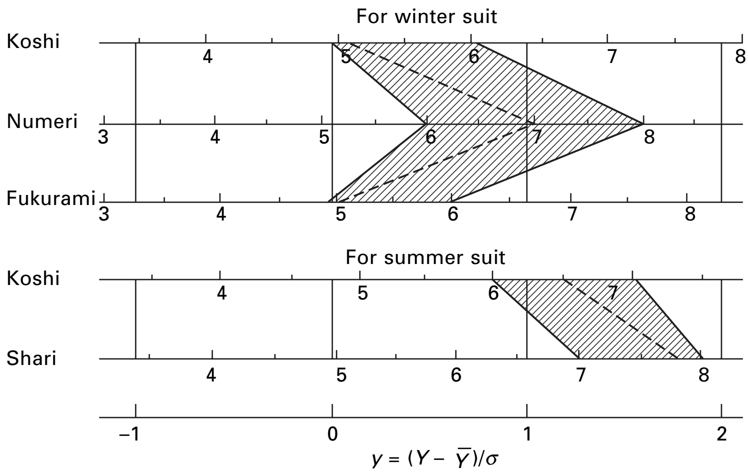
But if we ask an expert why it is said that the hand of that fabric is good, for example, the reply will be that the Numeri of this fabric is high and both the Koshi and the Fukurami are moderate.

This example can explain the relation between our primary hand expressions and the summarized hand expression, good or poor hand. We name this summarized expression 'Total Hand'. It is a very interesting and important problem to find out the relation between the primary hands and this total hand.

Experts on our committee have proposed their opinion based on their experience that the good total hand for men's winter suit is given by a combination of the primary hands such as HV-Numeri 7~8, Koshi 5~6 and Fukurami 5~6 as shown in Fig. A.11 as a 'good' range. The dotted line in this figure is also the combination of hand values which gives the maximum good hand. The combination given by the dotted line was obtained by the mathematical analysis of the data obtained by 20 experts, half of them experts on finishing and the other half in garment-making factories. However, this optimum combination has not been fixed yet.

After the analysis shown in Fig. A.11, a new assessment was carried out using different groups of fabrics which were collected for the development of the translation formula from mechanical properties to hand values. This group contains a relatively wide range of fabric grades, and we have obtained a different result as shown in section A.4.

Cooperation on the assessment of this Total Hand Value is now taking place with Professor R. Postle of the University of New South Wales, Australia and also with Professor S. Backer of MIT in the USA. Recently, Professor Postle obtained a quite different result from ours for summer suit fabrics. The correlation between the result in Australia and that of ours has a negative correlation coefficient, –0.35. This suggests to us that there is a difference between countries with respect to the evaluation of the Total Hand. It is noted that this cooperation was carried out applying the hand value.



A.11 'Good' hand is expressed by the compositions of hand values. Shadowed area is the good hand area based on experts' experience. The dotted line is obtained by the statistical analysis of the judgement of 20 experts. However, a small change of the optimum line has been obtained from the analysis of the new assessment as shown in section A.4.

A.3.4 Total hand value

The degree of 'good' hand has been expressed by the Total Hand Value (THV) as shown in Table A.14.

Table A.14 Total hand value

THV	Evaluation
5	excellent
4	good
3	average
2	below average
1	poor
0	out of use

These properties of fabric such as the resistance against wearing and washing are important; however, there is an essential quality of fabric beside them. This essential quality is expressed by the 'total hand'. Our concept on this quality is as follows.

'Good hand is an evaluation of the primary quality of fabrics, the quality is concerned with comfort and beautiful appearance in the silhouette of suit and is in conformity with function of garment and with human sense. A man who wears a suit made of such a fabric having good hand will become attached to it.'

214 samples of men's winter-suit fabrics and 156 of the summer-suit fabrics have been assesed by the HESC committee members who are experts on fabric finishing and evaluated their THV based on the definition of 'good' as shown before, then the present author and Dr Niwa have analyzed the evaluated data to obtain a translation formula from primary hands to the total hand. The obtained equations are as follows:

For winter-suit fabric:

$$\begin{aligned}\mathrm{THV} = -1.2293 + 0.5904Y_1 - 0.0441\,Y_1^2 - 0.1210Y_2 \\ + 0.0517\,Y_2^2 + 0.6317Y_3 - 0.0506\,Y_3^2\end{aligned} \tag{A.1}$$

where

Y_1 = HV of Koshi
Y_2 = HV of Numeri
Y_3 = HV of Fukurami.

For summer-suit fabric:

$$\begin{aligned}\mathrm{THV} = -1.3788 - 0.0004Y_1 + 0.0006\,Y_1^2 + 0.7501Y_2 - 0.0361\,Y_2^2 \\ + 0.5190Y_3 - 0.0369\,Y_3^2 + 0.2555Y_4 - 0.0352\,Y_4^2\end{aligned} \tag{A.2}$$

where

Y_1 = HV of Koshi-summer
Y_2 = HV of Shari-summer
Y_3 = HV of Fukurami-summer
Y_4 = HV of Hari-summer.

The contribution of each of the primary hands to the THV is shown graphically in Figs A.19 and A.20 on page 436.

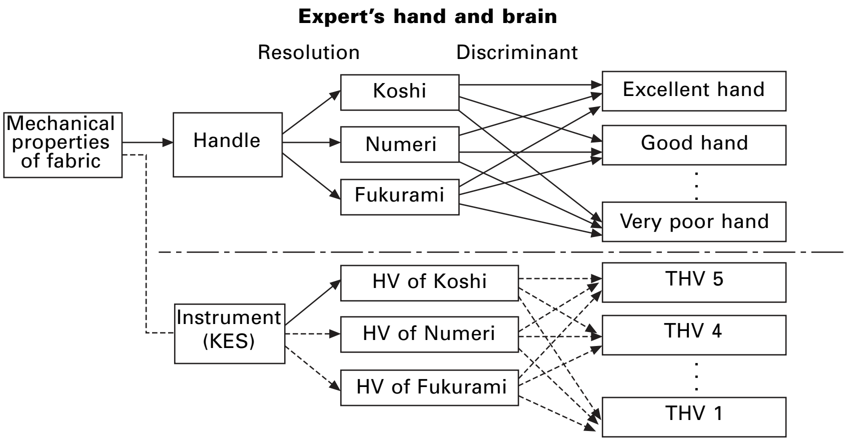
A.4 Analysis of hand evaluation

A.4.1 Translation formula from the characteristic values to the hand values

Preliminary researches

Figure A.12 is a schematic diagram of how experts judge the fabric quality by hand. Firstly, they examine the mechanical properties of fabric by hand to translate the feeling into the intensity of each of the primary hands and then judge the quality by the combination of these intensities of the primary hands. The route shown by a broken line in this figure is a simulation of this process by instrumentational and mathematical means; now we are going to develop this simulation method.

We have already defined the characteristic values of the mechanical properties of fabric and measured their values for each sample by the KES



A.12 The hand evaluation process by experts. The lower process is a simulation route by instrumentation and calculation. HV means the hand value and THV the total hand value.

system. The first problem is how to translate the characteristic values into the hand values. (Note that we have already defined hand value for each of the primary hands.)

The most simple equation predicting the hand value, Y, is the linear equation as follows:

$$Y = C_0' + \sum_{i=1}^{16} C_i' X_i \tag{A.3}$$

where Y = hand value
C_0' and C_i' = constant parameters
X_i = the ith characteristic value or its logarithm.

Equation (A.4) which is a modified form of equation (A.3) is a convenient form because the X_i is normalized by the mean and the standard deviation and, therefore, parameter C_i is proportional to the 'degree of influence' of X_i on the value of Y.

$$Y = C_0 + \sum_{i=1}^{16} C_i x_i \tag{A.4}$$

where

$$x_i \equiv \frac{X_i - \overline{X}_i}{\sigma_i}$$

C_i are constant parameters, $\overline{X}_i$ and σ_i are, respectively, the mean and the standard deviation of the ith characteristic values of the samples which were collected for the development of this translation equation as already mentioned above.

If we get the experimental values of Y of a primary hand and x_i for each of the many samples, we can use the statistical analysis such as regression analysis to determine the parameters C_o and C_i. As the first step of this determination, Kawabata and Niwa began the research to know how many samples were necessary at least for the determination of these parameters by using the multi-variable regression method. We have a set of data of hand values, for example, Numeri, for N samples given by matrix Y such as

$$\mathrm{Y} = \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_k \\ \vdots \\ Y_N \end{bmatrix} \tag{A.5}$$

Suffix k means the kth sample of the N samples, and also we have a set of data of the characteristic values corresponding to these Y_k for all samples.

For the N samples, we have a matrix of x_{ki} such that,

$$x = \begin{bmatrix} 1 & x_{11} & x_{12} & \cdots & \cdots & \cdots & x_{1p} \\ 1 & x_{21} & x_{22} & \cdots & \cdots & \cdots & x_{2p} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 1 & x_{k1} & x_{k2} & \cdots & x_{ki} & \cdots & x_{kp} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 1 & x_{N1} & x_{N2} & \cdots & x_{Ni} & \cdots & x_{Np} \end{bmatrix} \tag{A.6}$$

where N is the total number of samples and x_{ki} is the x value of the ith characteristic value of the kth sample, and p is the total number of characteristic values and is equal to 16 in our case. Now, let us consider a model given by equation (A.4) and determine their coefficients. The unknown parameters are also written by a matrix C such as

$$\mathrm{C} = \begin{bmatrix} C_0 \\ C_1 \\ \vdots \\ C_i \\ \vdots \\ C_p \end{bmatrix} \tag{A.7}$$

If we define ϕ as follows, where ε is error matrix:

$$\phi = \varepsilon^T \cdot \varepsilon = [\mathrm{Y} - \mathrm{x\ C}]^T\ [\mathrm{Y} - \mathrm{x\ C}] \tag{A.8}$$

and according to the least square method, solve next equation:

$$\frac{\partial \phi}{\partial \mathrm{C}} = O = -\,2\mathrm{x}^T\ [\mathrm{Y} - \mathrm{xC}] \tag{A.9}$$

that is,

$$2\mathrm{x}^T\mathrm{Y} = 2\mathrm{x}^T\ \mathrm{xC} \tag{A.10}$$

then we have

$$\mathrm{C} = [\mathrm{x}^T\mathrm{x}]^{-1}\ \mathrm{x}^T\mathrm{Y} \tag{A.11}$$

where *T* means the transpose and –1, the inverse of the matrix.

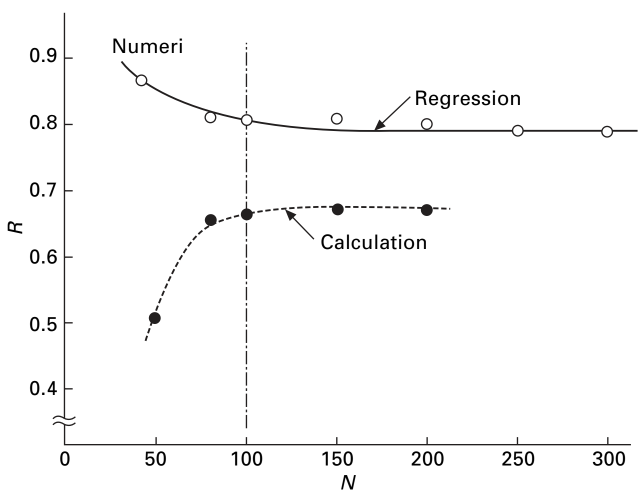
Thus we get the coefficient matrix C and, therefore, the translation equation. If we put $\tilde{Y}$ as the predicted value of *Y*, we have

$$\tilde{Y} = [1, x_1, x_2, \ldots, x_{16}]\ \mathrm{C},$$

or
$$\tilde{Y} = C_0 + C_1x_1 + C_2x_2 + C_3x_3 + \ldots + C_ix_i + \ldots + C_{16}x_{16} \tag{A.12}$$

If we calculate C from different number of *N*, the C obtained will be different. If *N* becomes larger, the accuracy of the regression will be decreased but the accuracy of the prediction by using the C obtained from large *N* will be increased.

To examine this, the correlation coefficient between the *Y* and the $\tilde{Y}$ was calculated using the samples which were used for the regression analysis. This correlation coefficient shows the regression accuracy in this case and shown by a solid line in Fig. A.13 as function of *N*.



A.13 Accuracy of the regression and the prediction.

On the other hand, the formulae were examined again for prediction accuracy by applying this formula to 100 fresh samples which were not included in the samples used for the regression analysis. The correlation coefficient between the Y and the $\tilde{Y}$ in this case is shown by a dotted line in Fig. A.13. The correlation coefficient increases with increasing N. This line will show the true accuracy of this prediction formula. As seen from Fig. A.13, the sufficient number of N for determining the coefficient matrix is about 150 in this case.

Development of the stepwise-block-regression method

Based on preliminary research, the determination of the parameters C_i of equation A.4 was carried out again.

After the research on this determination introduced in the first edition of *The HESC Standard of Hand Evaluation*, an extensive improvement has been carried out by Kawabata and Niwa with the cooperation of the HESC. The samples used for this analysis were selected from the many samples collected from commercially produced fabrics by the HESC. The selection has been made so as to distribute the hand values as widely as possible. Here the case of men's winter-suit fabrics will be introduced as an example.

Let us show the reason why we developed the stepwise-block-regression method. There are relatively high correlations between some pairs of the characteristic values, such as WT and WC, and B and $2HB$, etc. In such cases, the values of the coefficient C_i obtained by equation (A.11) are not necessarily proportional to the degree of importance of the contribution of x_i to the hand value Y.

Let us consider this problem using a simple example. Assume that Y is related with a variable x_1; on the other hand, x_2 is also related to with x_1 with a different category from the relation between Y and x_1. We assume that Y is related essentially with x_1 according to some physical reasons and not related with x_2. Now if we select two variables for predicting Y as follows:

$$\tilde{Y} = C_0 + C_1 x_1 + C_2 x_2 \tag{A.13}$$

then we may get the result by the multi-variable regression method such that $C_1 \cong C_2$ when x_1 and x_2 are normalized values and related to each other with close correlation. Instead of this multi-variable regession method, the stepwise regression method is adopted as follows. In this method, we examine the correlations between Y and x_1, and Y and x_2 separately. And if Y is directly related with x_1 and indirectly with x_2, the correlation coefficients $R(Y, x_1)$ and $R(Y, x_2)$ will become

$$R(Y, x_1) > R(Y, x_2) \tag{A.14}$$

Then we determine the regression equation with respect to x_1 such that

$$\tilde{Y} = \tilde{C}_0 + C_1 x_1 \quad \text{(A.15)}$$

Next, $\tilde{Y}$ is calculated by this equation for all samples and compared with experimental values, Y_k, in order to obtain the residuals such that

$$\varepsilon_k = Y_k - \tilde{Y}_k \quad \text{(A.16)}$$

Then we determine again the regression equation

$$\varepsilon = \tilde{\tilde{C}}_0 + C_2 x_2 \quad \text{(A.17)}$$

then we have

$$Y = \tilde{Y} + \varepsilon = \tilde{C}_0 + C_1 x_1 + \tilde{\tilde{C}}_0 + C_2 x_2 \quad \text{(A.18)}$$

or

$$Y = C_0 + C_1 x_1 + C_2 x_2 \quad \text{(A.19)}$$

If the x_2 is not truly non-correlated with Y, the value of C_2 should be very small or negligible.

In the case when the variables are more than two, the same procedure may be taken stepwise.[56] We applied this method to determine the translation formula, and developed a modified method, stepwise-block-regression method for this purpose.[57] This method is as follows.

We have already six blocks of the characteristic values as shown in Table A.15.

Table A.15 Six blocks and characteristic values

Block	Property	Characteristic values, X_i
1	Tensile	LT, log WT, RT
2	Bending	log B, log 2HB
3	Surface	log MIU, log MMD, log SMD
4	Shearing	log G, log 2HG, log 2HG5
5	Compression	LC, log WC, RC
6	Weight and thickness	log W, log T_0

First step: By applying multi-variable regression method to each of the blocks, the six regression equations are determined such that:

1st Block: $\tilde{Y} = \tilde{C}_0 + C_1 [LT] + C_2 [WT] + C_3 [RT]$

2nd Block: $\tilde{Y} = \tilde{C}_0 + C_4 [B] + C_5 [2HB]$

3rd Block: $\tilde{Y} = \tilde{C}_0 + C_6 [MIU] + C_7 [MMD] + C_8 [SMD]$ (A.20)

⋮ ⋮

where [] means the normalized value of the characteristic value or of a logarithm of the characteristic value.

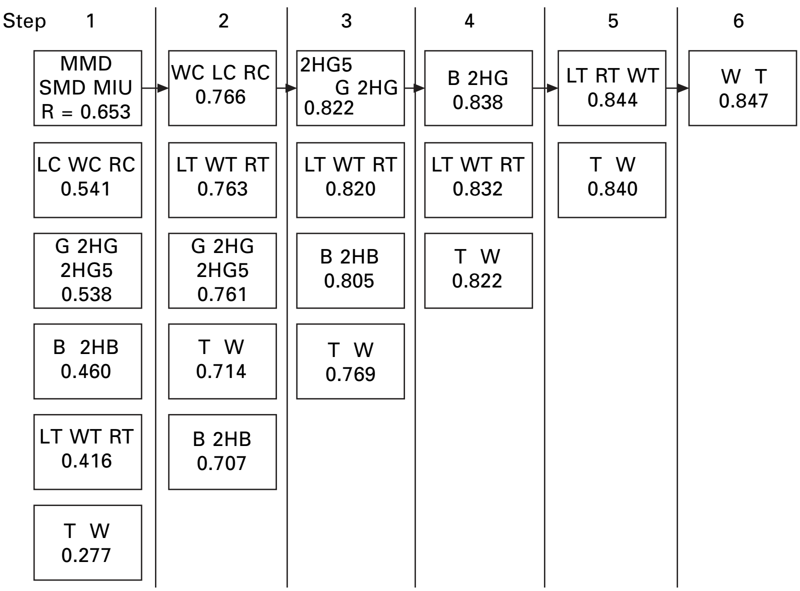
Thus the six equations are obtained with respect to each of the six blocks separately. The $\tilde{Y}$ are calculated using the each of these equations.

Second step: The block which has the highest correlation between the experimental values Y and the calculated $\tilde{Y}$ is picked up and named as the first block.

Third step: The residual $Y - \tilde{Y}$ of this first block are regressed to each of the remaining blocks separately by the same procedure as the first step, and we can determine the second block in the same manner as the second step. Thus, the regressions are continued stepwise. Figure A.14 shows an example of this stepwise-block-regression method.

Fourth step: As shown in Fig. A.14, we obtain an order of the blocks following the stepwise regression. Following this order, the stepwise regression is again repeated for each characteristic value in each of these blocks. The order of the block subjected to this procedure is conserved.

Fifth step: Finally we obtain a linear equation for predicting Y.

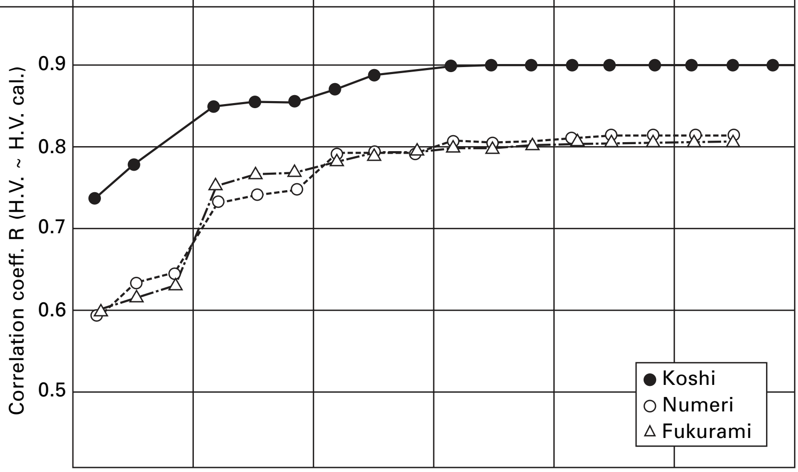


A.14 An example of stepwise block-regression applied to the analysis of Numeri.

The strong point of this method is firstly that the order of the blocks indicates the importance of the blocks to hand value Y. This is very useful to analyze the expert's hand feeling and to find out the interrelation between the expert's hand and the physical or the mechanical properties of fabrics.

Secondly, we can use a short equation in which the blocks of no importance can be omitted without injuring the accuracy of the regression equation. Figures A.15 and A.16 show these relations for winter-suit fabrics and for summer-suit fabrics respectively. The correlation coefficient between Y and $\tilde{Y}$ is increased with the increasing number of terms of characteristic value as shown in the figure and also the saturation of R is observed. After the curve is saturated we can omit the blocks or the characteristic values which continue behind for the calculation of Y. Final equations obtained are as follows.

	1	2	3	4	5	6
Koshi	B 2HB	C 2HG 2 HC5	T W	WT RT LT	WC LC RC	MMD MIU SMD
Numeri	MMD SMD MIU	WC LC RC	2HG G 2HG	B 2 HB	LT RT WT	W T
Fukurami	WC LC RC	MMD SMD MIU	LT WT RT	2 HC5 C 2HG	T W	2HB B



A.15 The prediction accuracy with increasing number of characteristic values (winter suit).

The translation equations developed recently are 10 equations, each equation named as shown in Table A.16. The KN is the initials of Kawabata and Niwa who have developed these equations. All equations have the form:

$$Y = C_0 + \sum_{i=1}^{16} C_i \frac{X_i - \overline{X}_i}{\sigma_i} \qquad \text{(A.21)}$$

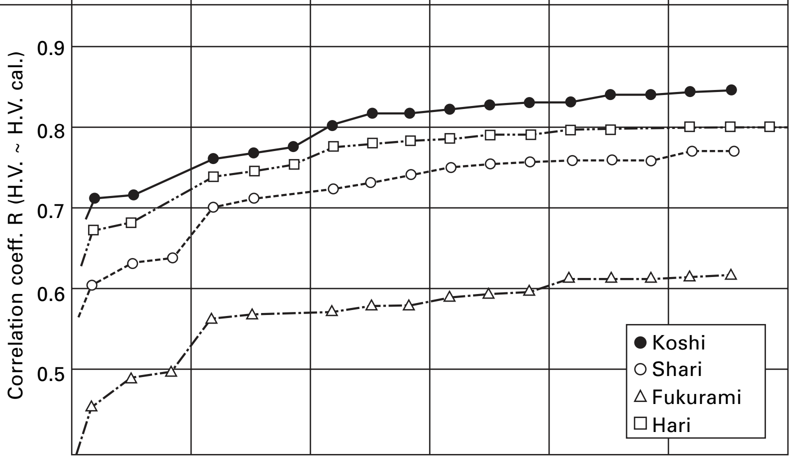
where

Y = hand value

X_i = ith characteristic value or its logarithm (refer to Table A.17 to see which characteristic values are taken or their logarithms)

$\overline{X}_i$, σ_i = mean value and the standard deviation of the ith characteristic value. See Table A.17(a) for men's winter suit fabric, Table A.18(a)

	1	2	3	4	5	6
Koshi	B 2HB	C 2HG 2 HG5	MIU SMD MMD	WC RC LC	WT RT LT	W T
Shari	SMD MIU MMD	B 2 HB	LT WT RT	RC LC WC	2 HG5 2HG G	W T
Fukurami	LT WT RT	W T	G 2 HG5 2HG	MIU SMD MMD	WC RC LC	B 2 HB
Hari	B 2 HB	MIU MMD SMD	2 HG5 2HG G	LC WC RC	W T	WT LT RT



A.16 The prediction accuracy with increasing number of characteristic values (summer suit).

Table A.16 Designation of the mechanical properties – hand values translation formulae developed by Kawabata and Niwa[58,60]

Name of equation	Predicted hand	Fabrics
KN-101-Wintr-Koshi	Koshi	Men's winter suit fabrics
KN-101-Winter-Numeri	Numeri	
KN-101-Winter-Fukurami	Fukurami	
KN-101-Summer-Koshi	Koshi	Men's summer suit fabrics
KN-101-Summer-Shari	Shari	
KN-101-Summer-Fukurami	Fukurami	
KN-101-Summer-Hari	Hari	
KN-201-LDY-Koshi	Koshi	Women's thin dress fabrics
KN-201-LDY-Hari	Hari	
KN-2011-LDY-Fukurami	Fukurami	
KN-201-LDY-Shari	Shari	
KN-201-LDY-Kishimi	Kishimi	
KN-201-LDY-Shinayakasa	Shinayakasa	
KN-201-LDYM-Sofutosa	Sofutosa	Women's medium thick fabrics

for men's summer suit fabric and Table A.19(a), for women's thin fabric for the $\overline{X}_i$ and the σ_i.

C_0, C_i = parameters (constant coefficient). See Table A.17(b) for women's thin fabric.

The order of X_i corresponding to $i = 1, 2, \ldots$ is not common for all the equations because this follows in order of importance of blocks and also of characteristic values in their blocks to each primary hand. For example, in case of Koshi of men's winter fabric, the KN-101-winter-Koshi is applied. From Table A.17, we can write as follows:

$$Y = 5.7093 + 0.8459 \frac{\log B - (-1.0084)}{0.1267} - 0.2104 \frac{\log 2HB - (-1.3476)}{0.1801} + \ldots \quad \text{(A.22)}$$

In Tables A.17(b), A.18(b) and Table A.19(b), the correlation coefficient between experimental and calculated Y is also shown as R for each stage of calculation. As seen in these tables, R saturates with increasing steps and we can see how many steps are enough for the calculation of Y. In general, three blocks are enough for the actual application. The first three blocks also indicate their importance of these properties to Y value. It is noted that the translation equations for women's medium thick fabrics are not necessary because we can use equations for men's suit fabrics except Sofutosa in this case. For only the Sofutosa, the equation is shown in Table A.20.

As mentioned earlier (page 408), the HESC Committee discussed Sofutosa and concluded that it is not a primary hand, but a kind of mixed feeling of the other primary hands. So it is possible for it to be composed of a combination of primary hands such as Koshi, Numeri and Fukurani. Equation (A.23) is the equation for calculating Sofutosa by this means. The accuracy of this equation is better than the equation calculating it from the characteristic values; the R of regression is 0.945 and the RMS is 0.585.

The Shinayakasa of women's thin fabric is also not a primary hand, and may be calculated from the primary hands as shown in equation (A.24). The R is 0.933 and the RMS is 0.737. This value has higher accuracy than the value of the equation translating the characteristic values.

$$\text{Sofutosa} = 2.1495 - 1.0014Y_1 + 0.0735\,Y_1^2 + 0.5576Y_2 + 0.0111\,Y_2^2 + 0.5444Y_3 - 0.0167\,Y_3^2 \quad \text{(A.23)}$$

where Y_1 = HV of Koshi (HV means hand value)
Y_2 = HV of Numeri
Y_3 = HV of Fukurami.

$$\text{Shinayakasa} = 10.3921 - 1.1328Y_1 + 0.1277\,Y_1^2 - 0.6043Y_2 - 0.0339\,Y_2^2 + 0.0913Y_3 - 0.0144\,Y_3^2 - 0.4146Y_4 + 0.0373\,Y_4^2 + 0.6539Y_5 - 0.0296\,Y_5^2 \quad \text{(A.24)}$$

Table A.17 Parameters of equations KN-101-Winter for translating mechanical values into hand values of men's winter suit fabric
(a) X_i, $\overline{X}_i$, σ_i table[a,b]

Block	i		X_i	Winter suit N = 214	
				$\overline{X}_i$	σ_i
	0				
1	1		LT	0.6082	0.0611
	2	log	WT	0.9621	0.1270
	3		RT	62.1894	4.4380
2	4	log	B	−1.0084	0.1267
	5	log	2HB	−1.3476	0.1801
3	6	log	G	−0.0143	0.1287
	7	log	2HG	0.0807	0.1642
	8	log	2HG5	0.4094	0.1441
4	9		LC	0.3703	0.0745
	10	log	WC	−0.7080	0.1427
	11		RC	56.2709	8.7927
5	12		MIU	0.2085	0.0215
	13	log	MMD	−1.8105	0.1233
	14	log	SMD	0.6037	0.2063
6	15	log	T	−0.1272	0.0797
	16	log	W	1.4208	0.0591

(b) C_i table

Koshi			Numeri			Fukurami		
i	C_i	R	i	C_i	R	i	C_i	R
0	5.7093		0	4.7533		0	4.9799	
4	0.8459	.740	13	−0.9270	.595	10	0.8845	.600
5	−0.2104	.780	14	−0.3031	.633	9	−0.2042	.616
6	0.4268	.849	12	−0.1539	.645	11	0.1879	.630
7	−0.0793	.854	10	0.5278	.734	13	−0.5964	.754
8	0.0625	.854	9	−0.1703	.742	14	−0.1702	.768
15	−0.1714	.868	11	0.0972	.749	12	−0.0569	.770
16	0.2232	.889	8	−0.3702	.794	1	−0.1558	.782
2	−0.1345	.896	6	−0.0263	.794	2	0.2241	.793
3	0.0676	.898	7	0.0667	.792	3	−0.0897	.795
1	−0.0317	.899	4	−0.1658	.807	8	−0.0657	.799
10	−0.646	.900	5	0.1083	.803	6	0.0960	.800
9	0.0073	.900	1	−0.0686	.808	7	−0.0538	.802
11	−0.0041	.901	3	−0.1619	.812	15	−0.0837	.807
13	0.0307	.901	2	0.0735	.813	16	−0.1810	.805
12	−0.0254	.901	16	−0.0122	.813	5	0.0848	.805
14	0.0009	.901	15	−0.1358	.812	4	−0.0337	.806

[a] log means $\log_{10}$.
[b] Each of these characteristic values which belongs to blocks 1, 2, 3 and 5 is the mean value of those of warp and weft directions. After mean value is calculated from the characteristic values of both directions then the mean value is transformed into its logarithm to obtain X_i, for each sample.

where Y_1 = HV of Koshi
Y_2 = HV of Hari
Y_3 = HV of Fukurami
Y_4 = HV of Shari
Y_5 = HV of Kishimi.

A.4.2 Comparison between the calculated and experimental hand values

In order to examine the accuracy of the prediction of these equations, Y and $\tilde{Y}$ are shown in Fig. A.17 for Koshi of men's winter-suit fabric where $\tilde{Y}$ is the predicted value by the translation equation. The predicted $\tilde{Y}$ of the tested samples, all of which are fresh samples and have not been used for the regression analysis, were calculated and compared with the mean value of the Y evaluated by eight experts by hand evaluation.

The examinations for the other hand translation equations are summarized in Table A.21. The correlation coefficient is not always correct for evaluating

Table A.18 Parameters of equations KN-101-Summer for translating mechanical values into hand values of men's summer suit fabrics
(a) X_i, $\overline{X}_i$, σ_i table[a]

Block	i	X_i		Winter suit N = 156	
				$\overline{X}_i$	σ_i
	0				
	1		LT	0.6286	0.0496
1	2	log	WT	0.8713	0.0977
	3		RT	66.4557	5.4242
2	4	log	B	–1.1052	0.1081
	5	log	2HB	–1.5561	0.1635
	6	log	G	–0.0662	0.1079
3	7	log	2HG	–0.0533	0.1769
	8	log	2HG5	0.3536	0.1678
	9		LC	0.3271	0.0660
4	10	log	WC	–0.9552	0.1163
	11		RC	51.5427	8.8275
	12		MIU	0.2033	0.0181
5	13	log	MMD	–1.3923	0.1707
	14	log	SMD	0.9155	0.1208
6	15	log	T	–0.3042	0.0791
	16	log	W	1.2757	0.0615

[a]log means $\log_{10}$.

Table A.18 (b) C_i table

Koshi			Shari			Fukurami			Hari		
i	C_i	R	i	C_i	R	i	C_i	R	i	C_i	R
0	4.6089		0	4.7480		0	4.9217		0	5.3929	
4	0.7727	.712	14	0.9162	.605	1	–0.4652	.455	4	0.8702	.672
5	0.0610	.714	12	–0.2712	.631	2	–0.1793	.489	5	0.1494	.681
6	0.2802	.760	13	0.1304	.637	3	0.0852	.495	12	–0.3662	.738
7	–0.1172	.767	4	0.4260	.702	16	0.2770	.564	13	0.1592	.747
8	0.1110	.774	5	–0.1917	.711	15	–0.0591	.567	14	0.1347	.755
12	–0.2272	.804	1	0.2012	.723	6	0.0567	.570	8	0.2345	.776
14	0.1208	.817	2	0.1632	.731	8	–0.0944	.577	7	–0.0938	.779
13	0.0472	.816	3	0.1385	.739	7	0.0361	.578	6	0.0643	.781
10	–0.1139	.823	11	–0.2252	.751	12	–0.1157	.589	9	–0.1153	.786
11	–0.1164	.828	9	0.0828	.753	14	–0.0560	.592	10	–0.0846	.789
9	–0.0193	.828	10	–0.0486	.754	13	–0.0635	.595	11	–0.0506	.790
2	0.1154	.833	8	0.1237	.757	10	0.1411	.611	16	0.0918	.796
3	0.0955	.839	7	–0.0573	.759	11	0.0440	.612	15	0.0067	.796
1	–0.0031	.839	6	0.0400	.759	9	–0.0388	.613	2	–0.1115	.802
16	0.0549	.844	16	0.0824	.764	4	–0.0209	.614	1	0.0156	.803
15	0.0245	.845	15	0.0001	.764	5	0.0201	.614	3	0.0194	.803

[b]Each of these characteristic values which belong to blocks 1, 2, 3 and 5 is the mean value of those of warp and weft directions. After mean value is calculated from the characteristic values of both directions then the mean value is transformed into its logarithm to obtain X_i, for each sample.

the accuracy, because the range of the hand values of the samples examined influences remarkably the coefficient. The root mean square error, RMS, between experimental and calculated hand values is useful for the evaluation. Agreement between experimental and calculated values is good and, in fact, the calculated value falls in the scatter zone of the data evaluated by experts as seen in Fig. A.17. As seen in Table A.21, the accuracy is not so high in the case of Fukurami of men's summer suit.

This is caused by the difficulty in the experts' judgement for this primary hand. The scatter in the data obtained by the experts is very large in this case. Kishimi is also a problem for the same reason as summer's Fukurami. These are now improving with the cooperation of HESC.

In Japan, many companies have already begun the use of these equations for their research works on quality control and the development of new materials. And recently, the translation equations for the specific use knitted fabrics (outerwear use) have been obtained by the committee with the cooperation of the Wool Knit Association Japan.

Table A.19 Parameters of equations KN-201-LDY for translating mechanical values into hand values of women's thin dress fabrics

(a) X_i, $\overline{X}_i$, σ_i table[a]

Block	i		X_i	Ladies dress N = 120	
				$\overline{X}_i$	σ_i
	0				
1	1		LT	0.5906	0.0939
	2	log	WT	1.0551	0.2728
	3		RT	43.6828	12.0448
2	4	log	B	–1.7749	0.3592
	5	log	2HB	–2.0351	0.5126
3	6	log	G	–0.3731	0.3044
	7	log	2HG	–0.2733	0.5586
	8	log	2HG5	0.0295	0.4506
4	9		LC	0.4483	0.1109
	10	log	WC	–0.9951	0.3174
	11		RC	49.4168	11.6778
5	12		MIU	0.2258	0.0452
	13	log	MMD	–1.6832	0.2191
	14	log	SMD	0.4892	0.3999
6	15	log	T	–0.4253	0.2209
	16	log	W	0.9623	0.1768

[a] log means $\log_{10}$.

Table A.19 (b) C_i table

Koshi			Hari			Shinayakasa			Fukurami			Shari			Kishimi		
i	C_i	R	i	C_i	R	i	C_i	R	i	C_i	R	i	C_i	R	i	C_i	R
0	5.1991		0	5.0816		0	5.3474		0	4.7891		0	4.6833		0	4.0158	
4	1.2622	.794	4	1.8527	.906	4	–1.6807	.821	13	–0.6889	.384	13	1.0850	.550	7	–0.8711	.560
5	–0.3961	.870	5	0.0462	.906	5	–0.2870	.839	12	0.5535	.516	14	0.3082	.578	8	0.1120	.570
7	–0.4317	.906	6	0.2238	.914	13	–0.3788	.862	14	–0.1246	.513	12	–0.1014	.577	6	–0.1765	.576
8	0.1781	.920	7	–0.1366	.916	14	0.2827	.869	10	0.4589	.581	6	–1.1854	.832	14	–0.4783	.653
6	–0.0247	.920	8	0.1281	.919	12	0.0648	.869	9	–0.2820	.603	7	–0.0112	.832	13	–0.1089	.659
15	–0.2405	.933	2	–0.2409	.931	6	–0.3688	.895	11	–0.1401	.601	8	0.0012	.832	12	0.0834	.660
16	0.0281	.933	3	0.1212	.933	7	–0.0826	.898	16	0.3154	.616	11	0.2745	.845	2	–0.4831	.738
13	0.1760	.937	1	0.1272	.934	8	0.0784	.896	15	–0.1367	.629	9	0.0674	.846	1	0.0205	.738
14	–0.0537	.940	13	0.0999	.936	1	–0.1810	.898	3	0.1264	.641	10	0.0469	.847	3	–0.0557	.736
12	–0.0596	.940	14	–0.1379	.938	3	0.0795	.899	1	0.0399	.642	2	–0.1181	.848	10	0.1902	.739
1	0.0003	.940	12	–0.0119	.938	2	–0.0263	.899	2	0.1015	.644	3	–0.0982	.849	9	–0.0504	.740
2	–0.3688	.936	15	–0.0990	.938	9	–0.0203	.898	6	–0.0018	.644	1	0.0189	.849	11	0.0314	.741
3	0.0242	.935	16	0.0332	.938	10	0.1411	.898	7	0.0134	.643	16	0.1958	.854	16	–0.0041	.741
10	0.1096	.939	9	0.1163	.938	11	–0.0382	.897	8	0.0104	.642	15	–0.0748	.854	15	0.0044	.741
9	0.0561	.941	11	0.0164	.938	16	0.1019	.897	4	0.0474	.641	4	0.0770	.855	5	0.1018	.743
11	0.0285	.941	10	–0.0361	.938	15	–0.0534	.898	5	0.0199	.639	5	–0.0602	.856	4	–0.0218	.743

[b] Each of these characteristic values which belong to blocks 1, 2, 3 and 5 is the mean value of those of warp and weft directions. After mean value is calculated from the characteristic values of both directions then the mean value is transformed into its logarithm to obtain X_i, for each sample.

Table A.20 Parameters of equation KN-201-LDYM for translating mechanical values into hand values of women's medium thick fabric

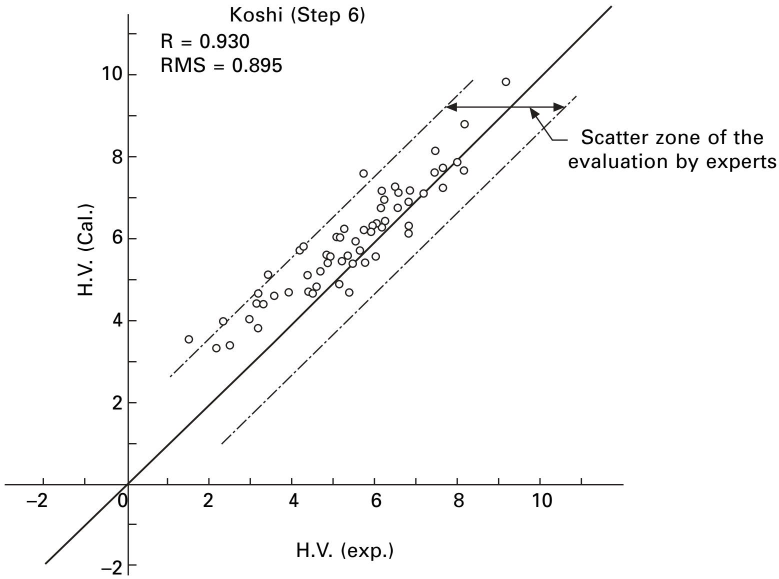
(a) X_i, $\overline{X}_i$, σ_i table[a]

Block	i		X_i	Ladies dress N = 220 $\overline{X}_i$	σ_i
	0				
1	1		LT	0.6177	0.0823
	2	log	WT	1.1511	0.2166
	3		RT	42.0564	6.9586
2	4	log	B	−1.0133	0.2565
	5	log	2HB	−1.2855	0.3473
3	6	log	G	−0.0745	0.2099
	7	log	2HG	0.1312	0.2966
	8	log	2HG5	0.4217	0.2596
4	9		LC	0.4070	0.1061
	10	log	WC	−0.6211	0.2380
	11		RC	52.2626	9.1288
5	12		MIU	0.2416	0.0431
	13	log	MMD	−1.7248	0.1926
	14	log	SMD	0.5696	0.3521
6	15	log	T	−0.0446	0.1693
	16	log	W	1.3550	0.1270

(b) C_i table

i	Sofutosa C_i	R
0	3.2881	
13	−0.9211	.541
14	0.3479	.604
12	−0.2159	.605
10	0.5641	.680
11	0.4741	.734
9	−0.0472	.734
6	−0.4214	.775
8	−0.0326	.775
7	0.0146	.775
3	−0.3573	.803
1	−0.1783	.811
2	0.0102	.811
4	−0.3073	.831
5	0.0159	.831
15	−0.0657	.831
16	0.0340	.831

[a]log means $\log_{10}$.
[b]Each of these characteristic vlaues which belong to blocks 1, 2, 3 and 5 is the mean value of those of warp and weft directions. After mean value is calculated from the characteristic values of both directions then the mean value is transformed into its logarithm to obtain X_i, for each sample.



A.17 Correlation between the hand values of Koshi evaluated by experts (experimental hand value) and those calculated from mechanical properties using the regression equation. Samples used here are the new samples prepared for examination of the accuracy of the regression equation.

Table A.21 Accuracies of the prediction by the translation formulae

(a) Men's winter suit fabrics (N = 66)

	Koshi	Numeri	Fukurami
Correlation between experimental and calculated hand values, R	0.930	0.793	0.783
Root mean square of errors, RMS	0.895	1.126	1.018

(b) Men's summer suit fabrics (N = 44)

	Koshi	Shari	Fukurami	Hari
Correlation between experimental and calculated hand values R	0.803	0.716	0.392	0.688
Root mean square of errors, RMS	1.006	0.978	1.328	0.960

Note: The correlation coefficient is sensitive to the distribution of the hand values of the samples selected. The RMS is rather more reliable than the R in case of practical-use testing

A.4.3 Analysis of the hand evaluation of the experts

The coefficients obtained by the stepwise-block-regression method give interesting information about the primary hands. The order of the blocks in the equation is considered as a presentation of the extent of the contribution of the block against the hand value. The following conclusions can be obtained. Corresponding to the experts' conception about the hand expressions shown in section A.2, we ask again same questions:

(a) What kind of feeling do you feel for its hand expression?
(b) Which properties are related mainly with its hand feeling?

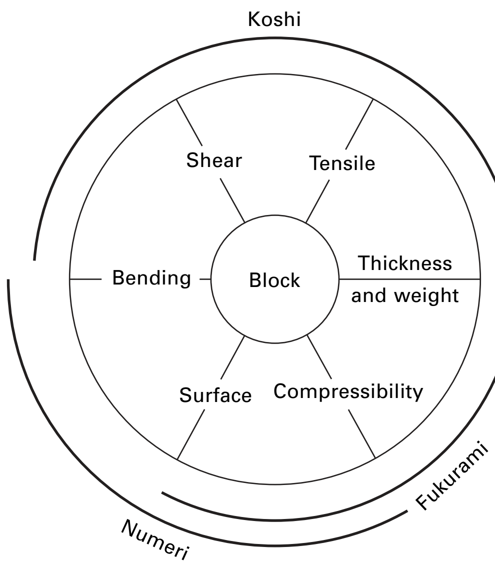
The answers obtained by the mathematical analysis are as follows.

1. Numeri
   (a) Smoothness which comes from smaller variation of frictional force and smooth surface. The bending, shearing and compressional properties have small rigidity and are springy.
   (b) 1st block: surface
   2nd block: compressional
   3rd block: shearing
2. Koshi
   (a) Stiff and springy property in bending. Stiff in the shearing and the compressional properties. Thin fabric in proportion to its weight increases Koshi.
   (b) 1st block: bending
   2nd block: shearing
   3rd block: weight and thickness
3. Fukurami
   (a) Softness in the compressional property. Smooth surface and soft extensibility.
   (b) 1st block: compression
   2nd block: surface
   3rd block: tensile
4. Koshi for summer
   (a) Stiff in bending. Rough surface and high shearing resistance.
   (b) 1st block: bending
   2nd block: shearing
   3rd block: surface
5. Shari for summer
   (a) Rough surface. Stiff and springy in the bending property.
   (b) 2nd block: bending
   3rd block: tensile
6. Hari for summer
   (a) Stiff in bending. Higher hysteresis also increases Hari. Rough surface and high shearing rigidity, especially high 2HG5.

   (b) 1st block: bending
       2nd block: surface
       3rd block; shearing
7. Fukurami for summer
   (a) Extensible, especially in the relatively small tensile strain.
   (b) 1st block: tensile
       2nd block: weight and thickness
       3rd block: shearing.

It is interesting to compare these results with the feelings about the hand by experts, which are shown in section A.2.

As shown in Fig. A.18, these three hands, Koshi, Numeri and Fukurami, cover the blocks of the properties as shown in this figure. And it is seen that Fukurami and Numeri are feelings near each other. Table A.22 gives the correlation coefficients between these three hands. This table also shows this relation. If we compose both Fukurami and Numeri together, then the composed feeling is considered as a soft and smooth feeling, and the Koshi covers the opposite, stiff and springy feeling.



A.18 Relation between the three primary hands and mechanical properties. The related properties are covered by a line of the corresponding hand.

The correlation coefficients between each hand are shown in Tables A.22–A.25, for men's winter suit fabric, men's summer suit fabric, women's thin dress fabric and women's medium thick fabric respectively.

Table A.22 Correlation between three primary hands of men's winter suit fabrics (*N* = 214)

	Koshi	Numeri	Fukurami	T.H.V.
Koshi	1.0000	–0.4390	–0.2515	–0.2237
Numeri	–0.4390	1.0000	0.9040[a]	0.8661
Fukurami	–0.2515	0.9040[a]	1.0000	0.8378
T.H.V.	–0.2237	0.8661	0.8378	1.0000

[a]This value is quite different from the value obtained by the 448 fabrics sampled randomly from commercially produced fabrics in Japan, probably because this new selected fabric assembly shown in this table contains many high grade fabrics compared with the distribution as seen in the randomly sampled fabrics.

Table A.23 Correlation between primary hands of men's summer suit fabrics (*N* = 156)

	Koshi	Hari	Shari	Fukurami	T.H.V.
Koshi	1.0000	0.8488	0.8024	–0.0079	0.5129
Hari	0.8488	1.0000	0.6917	0.0212	0.4328
Shari	0.8024	0.6917	1.0000	–0.0704	0.7360
Fukurami	–0.0079	0.0212	–0.0704	1.0000	0.2495
T.H.V.	0.5129	0.4328	0.7360	0.2495	1.0000

Table A.24 Correlation between primary hands of women's medium thick fabrics (*N* = 220)

	Koshi	Numeri	Fukurami	Sofutosa
Koshi	1.0000	0.1745	0.4435	–0.0869
Numeri	0.1745	1.0000	0.7417	0.8628
Fukurami	0.4435	0.7417	1.0000	0.7297
Sofutosa	–0.0869	0.8628	0.7299	1.0000

Table A.25 Correlation between primary hands of women's thin dress fabrics (*N* = 120)

	Koshi	Hari	Shari	Fukurami	Kishimi	Shina-yakasa
Koshi	1.0000	0.8183	0.2051	–0.1849	0.3217	–0.6195
Hari	0.8183	1.0000	–0.0567	–0.0482	0.0042	–0.8790
Shari	0.2051	–0.0567	1.0000	–0.6531	–0.0110	0.0365
Fukurami	–0.1849	–0.0482	–0.6531	1.0000	0.1867	0.1298
Kishimi	0.3217	0.0042	–0.0110	0.1867	1.0000	0.2520
Shinayakasa	–0.6195	–0.8790	0.0365	0.1298	0.2520	1.0000

A.4.4 Calculation of THV

As introduced in section A.3, the translation equation from HV to THV, as seen in Fig. A.12, has been developed for men's suit fabrics.

The equation is as follows.

$$\mathrm{THV} = C_0 + \sum_{i=1}^{k} Z_i$$

where

$$Z_i = C_{i1}\left(\frac{Y_i - M_{i1}}{\sigma_{i1}}\right) + C_{i2}\left(\frac{Y_i^2 - M_{i2}}{\sigma_{i2}}\right) \quad \text{(A.25)}$$

Y_i = primary hand values as shown in Table A.26

M_{i1}, M_{i2}, σ_{i1}, σ_{i2} = mean values of Y and Y^2, standard deviation of Y and Y^2 respectively.

C_{i1}, C_{i2} = constant parameters shown in Table A.26.

Figures A.19 and A.20 express the Z_i value as function of Y_i for winter and summer suit fabrics respectively. The optimum combination of the primary

Table A.26 Parameters of the HV-THV translation equations shown in equation (A.25). This equation is useful for understanding the influence of each primary hand on the THV (a) KN-301-Winter-THV, the equation for winter suit fabrics (C_0 = 3.1466)

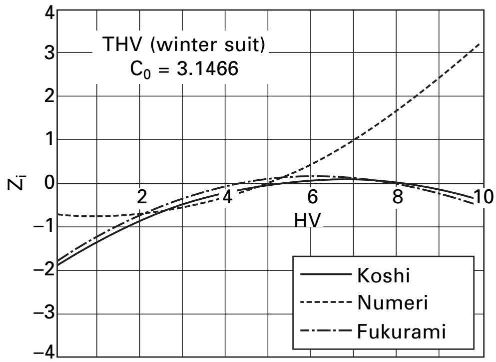
i	Y_i	C_{i1}	C_{i2}	M_{i1}	M_{i2}	σ_{i1}	σ_{i2}
1	Koshi	0.6750	–0.5341	5.7093	33.9032	1.1434	12.1127
2	Numeri	–0.1887	0.8041	4.7537	25.0295	1.5594	15.5621
3	Fukurami	0.9312	–0.7703	4.9798	26.9720	1.4741	15.2341
RMS[a]		0.333					
R[b]		0.900					

[a]Root mean square of regression error
[b]Correlation coefficient between regressed and experimental values.

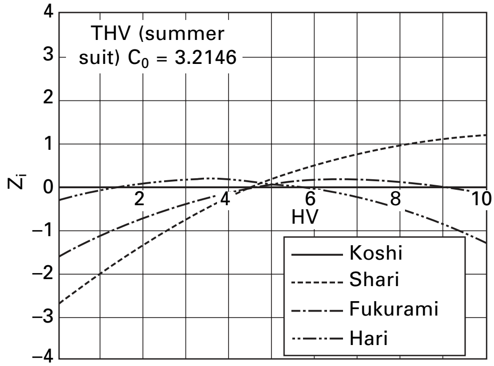
(b) KN-301-Summer-THV, the equation for summer suit fabrics (C_0 = 3.2146)

i	Y_i	C_{i1}	C_{i2}	M_{i1}	M_{i2}	σ_{i1}	σ_{i2}
1	Koshi	–0.0004	0.0066	4.6089	22.4220	1.0860	11.1468
2	Shari	1.1368	–0.5395	4.7480	24.8412	1.5156	14.9493
3	Fukurami	0.5309	–0.3741	4.9217	25.2704	1.0230	10.1442
4	Hari	0.3316	–0.4977	5.3929	30.7671	1.2975	14.1273
RMS[a]		0.354					
R[b]		0.849					

[a]Root mean square of regression error.
[b]Correlation coefficient between regressed and experimental values.



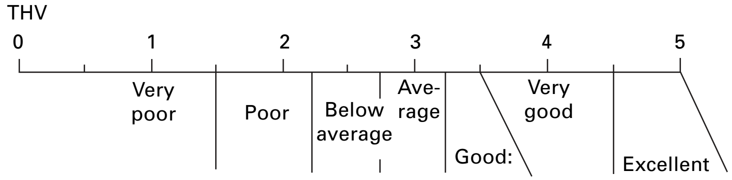
A.19 The influence of each primary hand to the total hand value is shown separately for men's winter suit fabric.



A.20 The influence of each primary hand to the total hand value is shown separately for men's summer suit fabric.

hands can be estimated from these figures. The results shown in these figures are little different from the results shown in Fig. A.11. This is probably caused by the considerable number of high quality samples added to the samples used for this analysis.

From the distribution of THV calculated from these equations, a new grading of fabrics by THV is estimated in Fig. A.21.



A.21 Grading of men's suit fabrics by THV estimated by the distribution of the calculated THV.

As mentioned before, research on total hand is now carried out with the cooperation of HESC and countries such as Australia and the USA.

A.4.5 Discriminant analysis

The total hand value which has been introduced in this chapter is one of generic hand expressions. Another example of the generic hand expression is an assortment hand such as silk-like hand, cotton-like hand, etc. Let us assume that this type of hand can be discriminated by using the primary hands such as Koshi, Hari, etc. Consider two groups of the samples:

Group A: silk fabrics
Group B: cotton fabrics

and assume that these two groups are discriminated by the value of Z given by the equation[61]

$$Z = \sum_{i=1}^{6} C_i Y_i \tag{A.26}$$

where Y_i = hand values of primary hands such that
Y_1 = HV of Koshi
Y_2 = HV of Hari
Y_3 = HV of Fukurami
Y_4 = HV of Shari
Y_5 = HV of Kishimi
Y_6 = HV of Shinayakasa
C_0, C_i = parameters determined so as to maximize the ϕ defined by

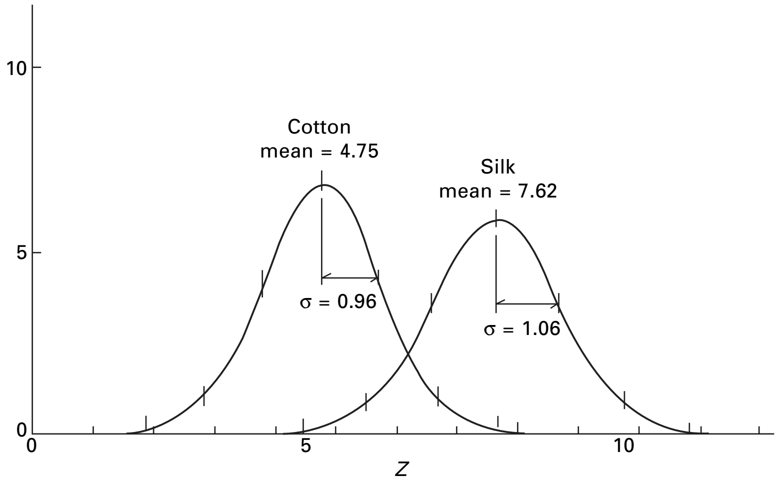
$$\phi = \frac{|\bar{Z}_A - \bar{Z}_B|}{\sqrt{\sigma_A^2 + \sigma_B^2}} \tag{A.27}$$

where $\bar{Z}_A$ and $\bar{Z}_B$ are mean values of Z_A and Z_B, respectively, which are calculated by equation (A.26) for the samples of group A and group B respectively
σ_A, σ_B = standard deviation of Z_A and A_B respectively.

For example, the following equation is obtained from 33 samples of cotton fabric and 31 samples of silk fabric for women's thin-dress fabrics:

$$Z = Y_1 - 0.481\ Y_2 - 0.096\ Y_3 + 0.069\ Y_4 + 0.583\ Y_5 + 0.155\ Y_6 \tag{A.28}$$

Figure A.22 shows how the two groups are discriminated by this Z value, in other words, by a combination of primary hands. In this figure, the distributions of the Z_A and the Z_B are shown and it is seen that separation of both groups is good.



A.22 Discrimination of silk and cotton fabrics by *Z* values.

When we examine a sample, regardless whether the sample is silk, cotton or another fabric, being silk-like or cotton-like, we substitute the primary hand values of this sample into equation (A.28) to obtain the Z value. If the Z value is larger than the boundary value between two groups shown in Fig. A.22, the sample may have silk-like hand.

We can expand this method to the discrimination of three groups, A, B and C. In this case, we have two discriminant equations such that[59]

$$Z_1 = \sum_{i=1}^{6} C_i Y_i$$

$$Z_2 = \sum_{i=1}^{6} C_i' Y_i \qquad \text{(A.29)}$$

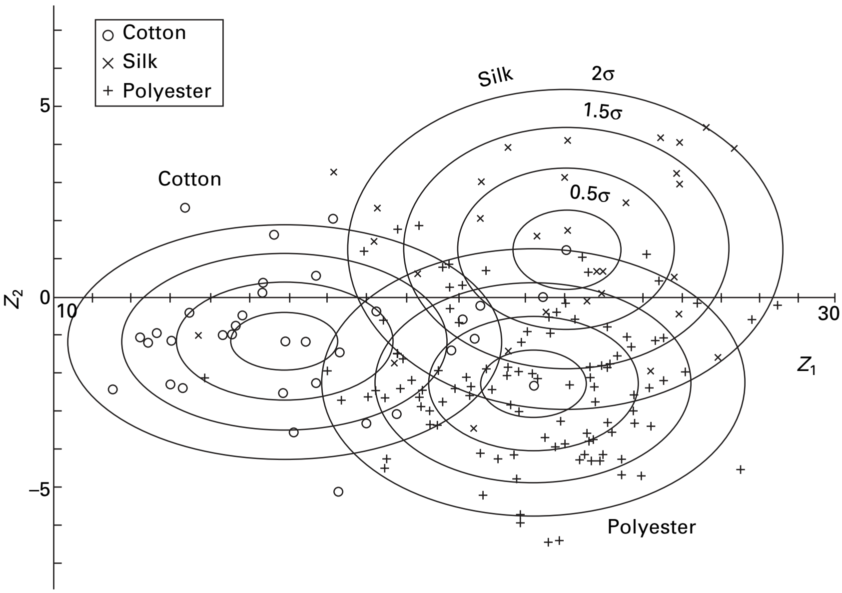
C_i and C_i' are also determined following the same principle as shown in the case of two groups. Figure A.23 shows the discriminant area and

zone A = silk-like hand
zone B = cotton-like hand
zone C = polyester-like hand

and lines shown in the figure are contour lines of distribution density presented by the scale of standard deviation of corresponding distribution.

$$Z_1 = 1.9473\ Y_1 - 05433\ Y_2 - 0.3183\ Y_3 + 0.6725\ Y_4 + Y_5 + 1.2677\ Y_6$$

$$Z_2 = 1.4027\ Y_1 - 1.1520\ Y_2 + 0.1413\ Y_3 - 0.7693\ Y_4 + Y_5 - 0.8543\ Y_6 \qquad \text{(A.30)}$$



A.23 Discrimination of three groups of fabric, silk, cotton and polyester groups by Z_1 and Z_2. The Z values are calculated from the hand values of primary hands of these samples.

A.5 Hand evaluation in the future

The primary hands selected here are essentially the experts' hands. Each of these experts in the textile factories, especially in the finishing process, has studied his evaluating technique by himself but, as mentioned before, his judgement is based on information which has been gathered from many people including consumers, concerned with clothing materials for a long time.

From such a situation, Kawabata thinks that we must appreciate these hand expressions to be a precise expression of the property required for our clothing materials.

The author also considers that all these hand expressions with respect to the fabric quality will be replaced by some mechanical or physical properties of the fabric in future. Our committee has also started this research already as mentioned in section A.3 and these primary hands, which have been brought up by the experts, will become an important guiding principle for the progress of this research.

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Appendix B
SiroFAST – fabric assurance by simple testing*

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B.1 Introduction

SiroFAST (Fabric Assurance by Simple Testing) is the most recently developed integrated set of instruments and test methods available for fabric objective measurement. SiroFAST measures the mechanical and dimensional properties of fabric that can be used to predict performance in garment manufacture and the appearance of the garments in wear.

SiroFAST was developed in Australia by the CSIRO Division of Wool Technology to meet industry's need for a simple, reliable method of predicting fabric performance. Despite SiroFAST's simple appearance, it is based on considerable research into the relationships between measured fabric properties and fabric performance. Fabric objective measurement, in particular SiroFAST, is currently being used by fabric and garment manufacturers in many parts of the world in a wide variety of applications.

The first part of this report is a description of the background developments in fabric objective measurement that form the basis of SiroFAST. This section includes a description of the SiroFAST system, its instruments, test methods, and the methods used to display and use SiroFAST results.

The principles of fabric objective measurement are common to all measurement systems, such that the information contained in this report could be obtained using alternative systems. The applications illustrated here show the value of fabric objective measurement in general, and SiroFAST in particular, to both fabric and garment manufacturers.

* This appendix has been adapted for this publication by Professor H. Behery. With great thanks to CSIRO Textile and Fibre Technology for allowing the use and inclusion of this information.

B.1.1 The properties of fabrics

The properties of fabrics can be loosely described as either functional or aesthetic.

- Functional properties relate to the failure (normally mechanical) of the fibres or yarns that make up the fabric during use.
- Aesthetic properties are the most highly subjective and complex features of fabrics.

Properties include appearance and handle, and involve visual or tactile aspects of the fabric, rather than simply the nature of fabric, yarns or fibres. Most aspects of fabric performance fall into one or other of these categories; some of these are listed in Table B.1.

Table B.1 Functional and aesthetic properties of fabrics

Functional	Tear strength Tensile strength Abrasion resistance Shrink resistance Flammability
Aesthetic	Handle – firmness, smoothness, etc. Performance in garment manufacture Performance in cutting, sewing and pressing Appearance of garment after manufacture and in wear Shape distortion Panel distortion Seam pucker Wrinkle recovery Pilling resistance

Since the aesthetic properties of fabrics are subjective, their description and measurement can be quite complex. For example, the attractiveness of a given fabric's handle will depend on its end use as well as possible cultural and individual preferences of the wearer [1]. The properties of each fabric will also influence the style of the garment that can be made and the level of skill required of the garment makers [2]. Finally, there are many aspects to the appearance of garments in wear. These include seam pucker [3], panel distortion, wrinkling [4] and pilling [5]. Concern over appearance after manufacture, and in wear, will depend on the garment, the design of the fabric (e.g. check, plain) and the requirements of the individual.

Extensive research in Sweden [6], the Netherlands [7], Japan [8–10], the UK [11] and Australia [12–16] has identified many of those mechanical, dimensional and other properties of fabrics that affect handle, performance in garment manufacture and the appearance of garments in wear. Some of the most important properties are shown in Table B.2.

Table B.2 Fabric properties related to handle, performance in garment manufacture, and garment appearance after manufacture and in wear

Properties (*important)	Performance in manufacturing	Handle	Appearance in wear
Physical properties			
Thickness		*	
Weight	*	*	*
Dimensional stability			
Relaxation shrinkage	*		*
Hygral expansion	*		*
Mechanical properties			
Extensibility	*	*	*
Bending properties	*	*	*
Shear properties	*	*	*
In-plane compression		*	*
Surface properties			
Compression		*	
Friction		*	
Surface irregularity		*	
Optical properties			
Lustre			*
Performance properties			
Pilling			*
Wrinkling			*
Surface abrasion			*

B.1.2 Objective measurement and fabric aesthetics

The idea of using the objective measurement of properties to predict fabric performance is not new. Measurements have been used to predict some aspects of fabric performance for many years. However, fabric objective measurement in the context of this report involves quite different objective measurements. The tests described in this report are designed to predict the success or failure of a fabric to 'make up well', to feel 'good', or for garments to look 'good' after manufacture and 'in wear'. This requires very subtle measurements that are much more accurate than those required to cause fabric to 'fail' in the normally accepted sense. The difference between the testing referred to in this report and that previously required to predict functional performance is that testing to assess aesthetic properties involves measurement at low deformations.

Recently, techniques have been developed to measure the mechanical properties of fabrics and use these measurements to quantify handle [10] and quantitatively predict performance in both garment manufacture and the appearance of garments [8]. However, mechanical properties are not the only properties that determine fabric aesthetics. Thermal properties, such as insulation and the warm–cool touch sensation, also play an important part in determining fabric handle [17]. The so-called dimensional stability of the fabric (perhaps more correctly called dimensional instability [11]) is also critical, not only in the manufacturing process but also to the subsequent appearance of the garment in wear.

The need for tests to predict or assess subjective aspects of fabric aesthetics has increased in recent years for three main reasons:

1. The trend towards lightweight clothing has resulted in the increased use of fabrics that are difficult to make up and require new handling skills.
2. The trend towards shorter 'seasons' and the use of rapid systems (such as just-in-time manufacturing) have meant that the delivery of fabrics that are difficult to make up will disrupt production schedules. For this reason it is even more important that garment makers are able to predict fabric performance.
3. The increased use of automation in garment manufacture removes the opportunity for skilled operators to correct for difficult or variable fabrics.

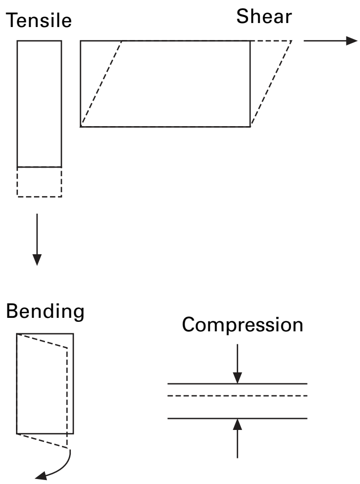
Mechanical properties

The first experimental work on the objective measurement of fabric mechanical properties dates back to the 1930s [18]. The prediction of fabric performance in garment manufacturing from mechanical properties was first extensively examined by Swedish [6] and Dutch [7] research teams in the 1960s. These teams identified many properties of fabric associated with performance in garment manufacture. These included extensibility, bending and shear properties as well as fabric weight. Several measurements are required to fully describe tensile, shear or bending behaviour of fabric. Those used to describe resistance to deformation are normally considered to be the most important and are defined in Table B.3.The deformations involved are represented in Fig. B.1.

Table B.3 Properties describing resistance to deformation

Deformation	Property	Definition
Tensile	Extensibility	Extension of a fabric under a predefined load
Bending	Bending rigidity	Couple required to bend unit width of fabric to unit curvature
Shear	Shear rigidity	Shear load required to deform unit width of fabric to unit strain

The work of the Swedish and Dutch groups has been confirmed by industrial users of objective measurement. Summarised in Table B.4 is part of a Japanese



B.1 Schematic diagram of deformations important in garment manufacture.

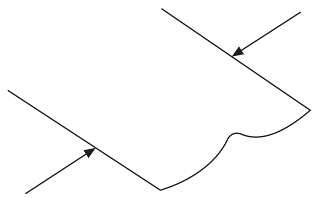
Table B.4 Some fabric properties related to problems in garment manufacture [19]

Region of manufacturing difficulties	Related fabric property	Problem zone
Cutting Sewing	Warp extension	High
Front-back	Warp extension Weft extension	High Low
Arm hole	Warp extension Weft extension Shear rigidity Shear hysteresis[a]	High High Low Low
Canvas	Warp extension Weft extension Shear rigidity	High Low High
Side seam	Warp extension Weft extension, shear hysteresis Shear rigidity	High or low Low High
Collar	Shear rigidity Weft extension	High or low Low
Sleeve setting	Shear rigidity Shear hysteresis Bending rigidity Bending hysteresis[a] Weft extension Warp extension	High or low Low Low High High High

[a]Shear and bending hystereses are measures of energy loss in deformation

report [19] on the relationship between problems in garment making and the mechanical properties of fabrics. This work demonstrated that there are optimum ranges for fabric mechanical properties, notably extensibility and shear rigidity.

The Swedish research team also identified two extra properties of fabrics termed 'compressibility' and 'formability' [6]. These properties are related to the tendency of a fabric to buckle when subjected to an in-plane compressive load (Fig. B.2). When a seam is sewn, the sewing thread and any overfeed applied to the components of the seam put in-plane compression on the fabric. If the formability is too low, the fabric will buckle and the seam will pucker. If the formability is high, the fabric will accept the compression without buckling and the seam will usually have a good appearance. Formability has also been shown to influence the overall appearance of men's suit jackets [12].



B.2 Behaviour of fabric in longitudinal compression.

Formability is defined using the in-plane compressibility of fabric, but because this is difficult to measure, fabric extensibility at low loads (typically 10–50 g/cm width) is often used to obtain an approximate measure of compressibility [2]. An alternative equation is normally used to calculate formability. For most purposes, this is an adequate approximation.

$$\text{Formability} = \text{bending rigidity} \times \text{extensibility (at low loads)}$$

Dimensional stability

The dimensional stability of wool fabrics has two components, both of which contribute to the shrinkage or growth of fabrics in garment manufacture [11]:

1. Relaxation shrinkage, the irreversible change in dimensions that occurs when a fabric is relaxed in steam or water.
2. Hygral expansion, the reversible change in fabric dimensions that occurs when the moisture content of the fibres is altered.

The importance of these properties in garment making, and on the appearance of garments, depends on the particular garment-making operation or conditions of wearing (Table B.5). The importance of fabric shrinkage is relatively familiar to garment makers, but hygral expansion is just as important. A simple test is available that separates these two components of dimensional stability of wool fabrics [11].

Table B.5 Problems often associated with poor dimensional stability

Property	High value	Low value
Relaxation shrinkage	Size variation	Delamination of fusible interlining
	Seam pucker	Seam pucker
	Excessive shrinkage	Moulding difficulties
Hygral expansion	Excessive shrinkage	
	Poor garment appearance	
	Delamination of fusible interlinings	
	Seam pucker	

There are many alternative test procedures used to measure fabric dimensional stability [20]. These procedures include the DIN test [21], the WIRA cylinder, the locked-press shrinkage test [22] and a large number of in-house procedures designed to simulate the conditions met in the garment-making process. However, some of these tests measure only one component of dimensional stability and, in other cases, give a complex mixture of both which can give a misleading impression of potential fabric performance [20].

B.1.3 Instrumentation for objective measurement

Measurement of all the properties that determine important aesthetic characteristics of fabrics is not feasible for industrial users. However, fabric or garment makers require a system that measures only the necessary properties to achieve satisfactory quality control [23].

Simple instruments have been used for many years by research workers to measure individual fabric properties, such as thickness and extensibility. Until recently, the use of these separate instruments to predict fabric performance was not sufficiently coordinated to be widely used except by a small sector of the fabric and garment manufacturing industries.

Two developments have raised the status of fabric objective measurement from a research instrument to a tool suitable for use in industry:

1. The availability of a set of instruments that are relatively inexpensive and simple to use [24].

2. The coordination of background information needed to interpret the large amount of data produced by the instruments and use it to predict fabric performance.

The first coherent set of instruments for this type of fabric objective measurement was developed by Kawabata [25] in Japan. While these instruments are accurate, comprehensive and effective, they are also relatively complex, difficult to use and too expensive for all but the largest textile companies. The most recently developed set of instruments (SiroFAST – Fabric Assurance by Simple Testing) was designed to meet the industrial need for a simple, robust system to predict fabric performance [24, 26, 27].

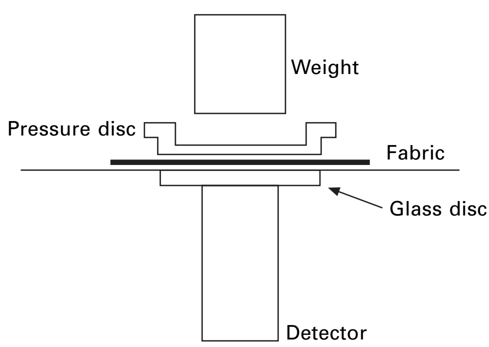
B.2 SiroFAST – fabric assurance by simple testing

SiroFAST is a set of instruments and test methods for measuring mechanical and dimensional properties of wool fabrics. These measurements allow the prediction of fabric performance in garment manufacture and the appearance of the garment during wear [24]. The instruments were developed by the Australian CSIRO Textile Fibre and Technology. The system was designed to be relatively inexpensive, reliable, accurate, robust and simple to operate. A simple method of interpreting the data to predict fabric performance is an integral part of the system.

SiroFAST consists of three instruments and a test method:

- SiroFAST-1 is a compression meter that measures fabric thickness.
- SiroFAST-2 is a bending meter that measures the fabric bending length.
- SiroFAST-3 is an extension meter that measures fabric extensibility.
- SiroFAST-4 is a test procedure for measuring dimensional properties of fabric.

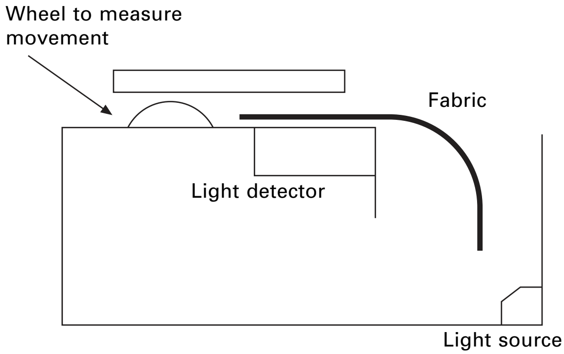
Schematic diagrams of the instruments are shown in Figs B.3, B.4 and B.5.



B.3 Schematic diagram of SiroFAST-1 compression meter.

B.2.1 SiroFAST-1 Compression meter

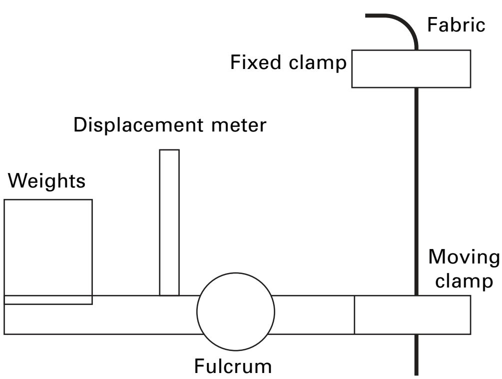
The SiroFAST-1 Compression meter accurately measures fabric thickness at loads of 2 g/cm^2 and 100 g/cm^2. The surface layer thickness [28] is defined as the difference in thickness measured at the two loads, and is calculated from these measurements. The measurements are normally made on the (conditioned) fabric and then repeated after the fabric has been relaxed in steam. From these measurements the released thickness and released surface layer thickness are obtained. Comparison of the original surface thickness and the released surface thickness can be used to assess the stability of the finish on the fabric under the conditions of garment manufacture, such as pressing and steaming [29].



B.4 Schematic diagram of SiroFAST-2 bending meter.

B.2.2 SiroFAST-2 Bending meter

This instrument measures fabric bending length using the cantilever bending principle, as described in British Standard Method BS:3356(1961). From the



B.5 Schematic diagram of SiroFAST-3 extension meter.

values of bending length obtained, the bending rigidity of the fabric is calculated. Bending rigidity is a measure of the stiffness of a fabric and is related to handling in garment making. SiroFAST-2 uses a photocell to detect the leading edge of the sample, which is done by eye in some other test methods. The elimination of this source of operator error makes the SiroFAST bending meter more reliable and simpler to use than alternative instruments [26].

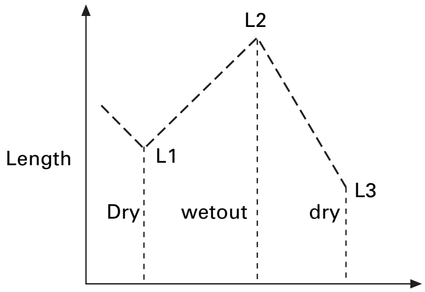
B.2.3 SiroFAST-3 Extensibility meter

The SiroFAST-3 extensibility meter measures the extensibility of a fabric under three different loads (5, 20 and 100 g/cm of width). The loads are chosen to simulate the level of deformation the fabric is likely to undergo during garment manufacture. SiroFAST-3 is also used to measure the bias extensibility of the fabric (at 45° to the warp direction) under a low load (5 g/cm width). Bias extensibility is not used directly but instead is used to calculate shear rigidity [30]. Shear rigidity is one of the principal determinants of the ease, which is a measure of the ease with which a fabric can be deformed into a three-dimensional shape. Formability is derived from measurements made using SiroFAST-3 in combination with data from SiroFAST-2 (see Table B.7 on page 454).

$$\text{Formability} = \text{bending rigidity} \times \left(\frac{\text{extension (20 g/cm)} - \text{extension (5 g/cm)}}{14.7} \right)$$

B.2.4 SiroFAST-4 Dimensional stability test

SiroFAST-4 is a test method for measuring the hygral expansion and relaxation shrinkage of fabric. SiroFAST-4 is a modification of the conventional 'wet–dry' test [11] and can be completed in under two hours [31]. Another advantage of SiroFAST-4 is that the fabric does not require conditioning. With SiroFAST-4 the fabric is dried in a convection oven at 105°C and its dry dimensions measured. The fabric is then relaxed by wetting in water and its wet dimensions measured. Lastly, the fabric is dried again at 105°C and its final dry dimensions are measured. The method for calculating relaxation shrinkage, hygral expansion and a schematic diagram of the SiroFAST-4 procedure is shown in Fig. B.6. The properties measured directly are shown in Table B.6. Those measurements derived or calculated from these measurements are shown in Table B.7.



$$RS = \frac{L1 - L3}{L1} \times 100\%$$

$$HE = \frac{L2 - L3}{L3} \times 100\%$$

B.6 Schematic diagram of SiroFAST-4 dimensional stability test.

Table B.6 List of fabric properties measured using SiroFAST

Properties measured	SiroFAST instrument
Fabric weight	
Compression	
Fabric thickness at 2 g/cm^2	SiroFAST-1
Fabric thickness at 100 g/cm^2	
Released thickness at 2 g/cm^2	
Released thickness at 100 g/cm^2	
Bending	
Bending length	SiroFAST-2
Tensile	
Warp extensibility	SiroFAST-3
Weft extensibility	
Bias extensibility	
Dimensional stability	
Relaxation shrinkage	SiroFAST-4
Hygral expansion	

B.2.5 Sampling for SiroFAST tests

SiroFAST-1, 2, 3 test samples are 150 mm × 50 mm. The tests are performed in the order SiroFAST-1, SiroFAST-2, SiroFAST-3. This avoids deformations that would affect later results. The SiroFAST manual recommends:

- SiroFAST-1 Compression – 5 replicates
- SiroFAST-2 Bending – 3 warp and 3 weft replicates
- SiroFAST-3 Extension – 3 warp, 3 weft, and 6 bias replicates (3 left-bias and 3 right-bias).

The samples are then steam released and the SiroFAST-1 tests repeated. The

Table B.7 List of fabric properties which can be derived from measurements made using SiroFAST

Derived properties	Calculated from
Surface thickness	Thicknesses at 2 g/cm^2 and 100 g/cm^2
Released surface thickness	Released thicknesses at 2 g/cm^2 and 100 g/cm^2
Finish stability	Fabric surface thickness Released surface thickness
Bending rigidity	Bending length Weight
Shear rigidity	Bias extensibility
Formability	Bending rigidity Extensibility at low loads

dimensional stability test (SiroFAST-4) requires a separate sample (300 × 300 mm).

In practice, about half a metre of fabric at full width is required to carry out the whole range of tests and allow reasonable sampling across the piece. Results for about 6–10 fabrics can be obtained within one working day. The SiroFAST instruments are interfaced with a computer which does the data handling automatically.

B.2.6 Interpretation of SiroFAST data

Measurement of fabric properties using SiroFAST is a relatively simple process, but interpretation of the data to assess the potential performance of the fabric in garment manufacture is much more difficult. The SiroFAST system uses a control chart as an aid to interpreting the data. This approach is not new and has been recommended for other objective measurement systems [32, 33]. The fingerprint is formed by plotting properties of the fabric on the appropriate scales and then joining the points. Computer software is available that performs this task automatically. A wide range of information can be obtained from direct observation of the fingerprint's position in relation to the 'grey zones' on the SiroFAST chart. These grey zones indicate where potential problems can be anticipated in the manufacture of suits or structured jackets. Slightly different zones would be used for other applications, such as women's dress goods or pleated skirts.

Higher skill levels in a factory manufacturing a particular type of garment would allow an increase in the range of fabrics and fabric properties that could be successfully handled. Software is available for use with SiroFAST that allows users to adjust limits to meet changing garment designs and skill levels in their factory. The limits shown on the SiroFAST chart are derived from published information, research at CSIRO during the development of SiroFAST, the experience of users of SiroFAST and other forms of fabric objective measurement.

The warnings listed indicate the potential problems associated with fabrics with properties outside the recommended limits. The first section of this report detailed some of the problems associated with inappropriate dimensional and mechanical properties; the chart lists just a few. The 'grey zones' on the SiroFAST chart are not intended for use only as 'accept or reject' zones; they should be used as indicators that forewarn the garment maker that problems can be anticipated and these problems should be considered in garment manufacture.

The use of a fabric fingerprint is preferred over alternative techniques for interpreting objective measurement data [8,13]. This is because the fingerprint makes it easier for the garment maker to categorise different garment-making problems and to identify, and possibly correct (by re-finishing for example), the property or properties associated with poor fabric performance.

B.2.7 Repeatability and reproducibility of the SiroFAST system

It is essential for the effective commercial use of fabric objective measurement that all instruments provide the same answer for a given property on the same fabric. This enables the measurements to be used as a common language between supplier and customer, regardless of location. There are two aspects ensuring good repeatability and reproducibility of fabric objective measurements:

1. The conditions of measurement.
2. The instrumentation and measurement procedure.

The conditions for the measurement of textile properties have been set by various testing organisations such as ISO and IWTO at 20°C and 65% RH. This is necessary when testing wool fabrics because the properties change with variations in the moisture content of the constituent fibres. If the measurements are to form a basis of communication or specification, then standard testing conditions must be used. The SiroFAST instruments and the measurement procedures have been tested in a series of round trials carried out using the same format as earlier trials on the KES-F instruments.

B.3 Application in fabric manufacture and finishing

The requirements of fabric manufacturers for an objective measurement system are broader than those of garment makers. First, fabric manufacturers require a quality control system that can be used to ensure fabrics are 'to specification'. This means that they meet the requirements of customers. Secondly, fabric designers need a system that will predict the performance of new fabrics in garment manufacture and the appearance of the garment after manufacture and in wear. Finally, fabric manufacturers require a tool that will optimise fabric design and finishing so that required properties can be engineered into each fabric, with a minimum number of operations and at minimum cost.

Although it has only been available for a relatively short time, SiroFAST has been used in a wide variety of applications in fabric manufacture and finishing [34]. Many of the applications described here apply equally to SiroFAST as to other systems for fabric objective measurement. The principles are the same in each case.

B.3.1 Producing fabric 'to specification'

The most obvious application of SiroFAST for fabric manufacturers and finishers is the avoidance of problem fabrics or the choice of the correct balance of fabric properties so that garment maker's problems are minimised. Customers use SiroFAST to select fabrics. This effectively means that fabric producers will be required to ensure that the fabric supplied meets the 'specifications' of the customer, in both absolute values and consistency. Production of fabrics of known properties need good design and appropriate finishing practice.

Fabric design

The construction of a fabric on the loom (weave, cover factor, etc.) affects its final properties [35, 36] and ultimately its suitability for a particular use. There are aspects of fabric design which can have little or no effect on later processes in finishing. These include fibre diameter and distribution, yarn count and twist as well as fabric weave and, to a large extent, cover factor.

At present there is relatively little quantitative information available which fabric designers can use to predict the properties of loom state fabric both from the properties of the yarn and the fabric design. Some research [37] has been undertaken to relate construction parameters to the final properties of the fabric, but the relationship is inevitably complicated by the effect of finishing.

Nevertheless, some Japanese companies have published information on the design criteria used to produce fabrics consistent with the requirements of apparel company engineers [38]. Although these criteria were based on objective measurements made using the KCES-F system, the principles used are the same for SiroFAST. Table B.8 demonstrates the way in which fabric design may be altered to prevent excessive warp extensibility in formal wear fabrics.

Table B.8 Design changes used to avoid excessive warp extensibility in formal wear fabrics

Method	Effect
Change balance of ends and picks	Large
Change fibre type	Medium
Change spinning method	Small
Blend synthetic fibres with wool	Large
Use shrink resist yarn	Medium
Change weave	n.a.
Use colour woven route	Large

Source: Derived from Mori [38].

Finishing

Although garment makers were the first to adopt objective measurement technology, the responsibility for avoiding, or correcting, problem fabrics at this stage remains primarily with the finisher. This is appropriate in many instances, since the effect of changes in finishing on certain important fabric properties is greater than can be achieved by modifying the fabric on the loom [36, 39].

Finishing is an extremely complex subject because of the large number of changes that occur in fabric properties during a finishing sequence. The effects of many finishing operations are interactive; the total effect of a sequence of operations is not the sum of the individual operations [40]. There is an interaction between fabric construction and finishing such that the effect of finishing on fabric properties will depend on both the finishing route and the construction of the loom-state fabric [39]. Many studies [40–43] are now available which document the effect of individual, and sequenced [44, 45], finishing operations on the properties of fabrics.

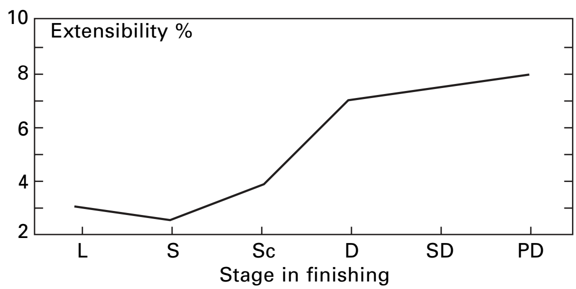
A summary of the most important changes in wool fabrics is shown in Table B.9, and an example of the change in one such property during finishing is shown in Fig. B.7. The properties of wool fabrics are significantly modified by those operations that permanently set the fibres [41] such as wet setting (crabbing), piece dyeing and pressure decatising. Milling and stenter drying are also critical operations for determining the properties of wool fabric. Milling increases yarn and fibre interaction whilst modifying the surface [44]. Stenter drying is the only operation in dry finishing where the dimensions of the fabric are directly controlled.

Information is available to assist finishers in modifying fabric properties, correcting faults in fabrics, avoiding the production of problem fabrics and producing fabrics to the specifications of their customers [46]. However, at this stage little of this information is quantitative. SiroFAST gives the finisher the tool by which the properties of the fabric can be monitored to ensure that

Table B.9 Effect of finishing operations on the properties of wool fabric

Operation	Fabric property					
	Relaxation shrinkage	Hygral expansion	Extension	Bending	Shear	Compression
Wet setting	X	X	X	X	X	X
Scouring	M	M	M	M	M	M
Milling	X	X	M–X	X	X	X
Dyeing	X	X	X	X	X	M–X
Drying	X		X			
Cropping	M		M			M
Singeing						M
Damping						M
Relaxing	X		X			X
Pressing	M–X		M–X	M	M	X
Decatising	X	X	X	X	X	X
Sponging	X		X			M

X indicates a large effect. M indicates a small but significant effect. M–X indicates that while the effects are normally small, under the appropriate conditions the effect can be large.



B.7 Change in fabric extensibility during finishing.

they are 'on track' to meet the final specifications. As finishers gain experience of these measurements they can considerably reduce the time needed for new fabric development.

Lack of adequate formability in the warp direction (caused by lack of adequate extensibility) is the single biggest problem in the manufacture of lightweight men's suiting in Europe. Control of warp formability and extensibility is critical for the production of lightweight fabrics that make up well. Some of the techniques used to prevent inadequate fabric extensibility are shown in Table B.10. All lightweight fabrics have low bending rigidity which cannot be altered without affecting fabric handle. To ensure that a fabric has adequate formability, finishers must engineer appropriate extensibility

Table B.10 Methods used in finishing to ensure adequate warp extensibility in wool fabrics

Wet set the fabric (crabbing)
Increase severity of wet setting
Use batch- rather than conti-crab
Use chemical assistant in conti-crab
Use a piece-dye route
Increase overfeed in drying
Reduce warp tension in dry finishing
Avoid rotary pressing
Pressure decatise rather than 'blow'

Source: Derived from 'SiroFAST Users' Manual'.

into the fabric, without significantly altering its other properties. This is achieved by controlling fabric dimensions, especially in the warp direction.

B.3.2 Optimisation of finishing

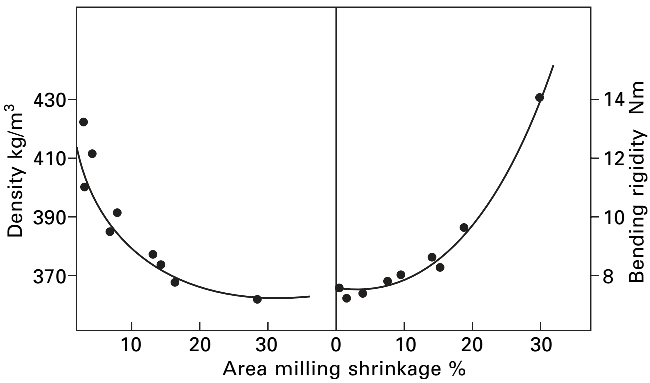
Because of the critical position of finishers in fabric production, they are able to derive maximum benefit from SiroFAST. Finishers have used SiroFAST to:

- Optimise individual and sequences of processes
- Ascertain the relevance of current practice
- Evaluate new alternative finishing machinery
- Evaluate new auxiliaries or chemical processes.

The use of SiroFAST to ascertain the value of a change in finishing sequence is described in ref. 51. The effect of two extra setting processes on the potential performance of the fabric was evaluated. These extra processes made the finishing more expensive but were expected to improve the quality of the fabric.

When a comparison of fabric properties was made before dyeing, there were significant differences that indicated that the quality was improved by the extra processes. However, in the finished fabric the differences were small, suggesting that the longer finishing route had no significant effect on the properties of the finished fabric and was simply a waste of money. Without an objective measurement system such as SiroFAST, quantitative proof of this would have been impossible. The effect of a milling on the properties of a wool fabric is shown in Fig. B.8.

The objectively derived data show the effect of milling on the properties of wool fabric is inconsistent. This means that an optimum level of milling is required to maximise changes in some properties (e.g. fabric density), while minimising changes in others (e.g. bending rigidity). Without an objective



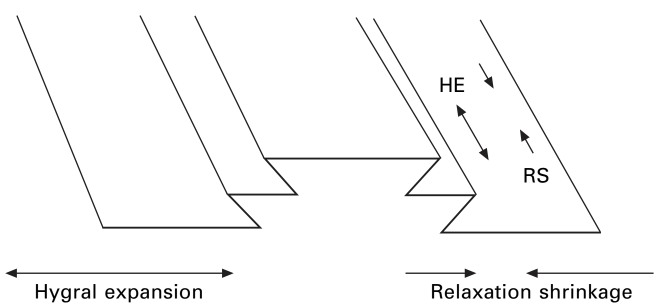
B.8 The effect of milling on the properties of wool fabric.

measurement system (such as SiroFAST), quantitative determination of the effectiveness and optimum level of milling is difficult.

B.3.3 Engineering special finishes

There are special finishes applied to wool fabrics which require engineering of fabric properties. This may be necessary to produce a certain 'look' [47], performance in the garment or to avoid problems in later processes. The best known example of these finishes is that required for wool fabrics that are to be autoclave pleated. A wool fabric that has no shrinkage can rarely be successfully autoclave pleated [11]. Autoclave pleating of wool fabrics requires an engineered balance of both relaxation shrinkage and hygral expansion. The reason for this is found in the changes that occur in fabric dimensions in the autoclave.

When steam is introduced the fabric panel relaxes, and as a result shrinkage can occur. At the same time, the moisture content of the fibres increases so there is a tendency for the fabric to (hygrally) expand as shown in Fig. B.9. To form good pleats, the shrinkage in the fabric, both across and along the



B.9 Dimensional changes in pleated panels in the autoclave.

pleats, must exceed the expansion, otherwise the fabric will buckle, creating puckered pleats. Like the pleats, the buckling will then be permanently set into the fabric.

The amount of relaxation shrinkage that must be present in the fabric depends on the hygral expansion. Equations have been derived [48, 49] to indicate the amount of relaxation shrinkage required to prevent puckering of pleated panels.

$$\text{Relaxation shrinkage (required)} = 1.0 + 0.33 \times \text{hygral expansion}$$

The amount of relaxation shrinkage required will also depend on fabric weight, style of pleat, regain of the fabric and conditions in the auloclave [50]. Lightweight fabrics (for example) buckle more readily than heavier fabrics and consequently require more relaxation shrinkage [50]. Without a reliable technique for measuring both components of dimensional stability (relaxation shrinkage and hygral expansion), such as SiroFAST-4, engineering a pleated finish is impossible.

Once the requirements for a fabric are established in quantitative form, there are several finishing routes available to achieve the required result. The simplest and most reliable is to wet out the fabric and re-dry it in the stenter to dimensions that will give the required relaxation shrinkage. Naturally this procedure will remove any temporary surface finish on the fabric but this can be reimposed with a light decatising. However, as such a temporary finish would be removed during autoclave pleating, decatising does not affect the properties of the pleated panel.

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