6

Fabric properties related to clothing appearance and fit

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6.1 Introduction

Discerning and quality conscious consumers require that their clothing satisfy their requirements and expectations in terms of appearance, fit and comfort, both when new and for an acceptable wear period thereafter. The clothing manufacturer, on the other hand, requires that the fabric is easy to tailor, passes through the making-up (garment manufacturing) process easily and without undue problems and that the finished garment has a good appearance (see Table 6.1[1]).

Table 6.1 Assessment of fabric performance in apparel

For Consumer		
Aesthetic impression	visual	colour and pattern * drape
	tactile	* feel
	audible	rustle etc
Cover	light transmission body shape (obscure or enhance)	
Comfort	permeability, heat, moisture, air	
	skin contact	* feel (local and distributed)
Strength and durability	breakage and loss of fibre * damage-prone sharp folds	
Appearance retention	* wrinkling and creasing change of aesthetics ease-of-care	
For Clothing Manufacturer		
Handling characteristics	* laying down, cutting, * transporting, * sewing manipulation, needle and stitch action, * forming and pressing	

* all involve complex buckling of fabrics related to fabric hand.
Source: Hearle, 1993.[1]

Many aspects, notably garment type, style, cut and sizing are involved in 'fit', but this chapter will basically cover changes in fit, and the fabric properties which play a role in such changes, notably dimensional stability and deformation, as well as fabric appearance and those fabric properties which affect garment appearance, quality and performance during cutting, sewing and making-up. Appearance, within the context of this chapter, chiefly refers to the visual appearance of the garment *per se*, as opposed to that of the fabric, covering aspects such as puckering, bagging and fit. Fabric-specific appearance factors, such as wrinkling, pilling, abrasion (also shine), fuzzing and colour changes, as well as aspects relating to garment comfort, are therefore not covered. These aspects are well covered in other chapters or relevant reviews (see section 6.2).

Essentially the wear behaviour, performance and appearance of a garment depend upon the following factors:

- fibre structure and properties
- yarn structure
- fabric structure
- garment construction and fit
- wear conditions

Traditionally, the quality of fabrics and 'fitness for purpose', including their performance during making-up (tailoring) and in the garment, were assessed subjectively in terms of the fabric handle (referred to as fabric handle or hand), by experts (judges) in the clothing industry (see Fig. 6.1).[3] In assessing the fabric, these experts used sensory characteristics, such as surface friction, bending stiffness, compression, thickness and small-scale extension and shear, all of which play a role in determining garment making-up (tailorability) and appearance during wear. Such experts, who were frequently highly skilled, assessed the fabrics using their hands to perform certain physical actions on the fabric, such as rubbing, bending, shearing and extension (stretching). They expressed what they felt (i.e. their perceptions) in terms of subjective sensations, such as stiffness, limpness, hardness, softness, fullness, smoothness and roughness, which then formed the basis for the fabric selection.[2] Because of the way this was assessed, i.e. by tactile/touch/feel, and

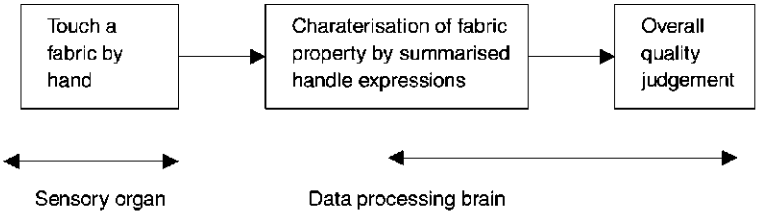

Figure 6.1 Process used by experts in the subjective evaluation of fabric handle. Source: Kawabata, 2000.[3]

Table 6.2 Fabric properties that are related to tailoring performance, appearance in wear, and handle

Property	Test	Tailoring performance	Wear appearance	Handle
Physical	Thickness	–	–	+
	Mass per unit area	+	+	+
Dimensional Shrinkage	Relaxation	+	+	–
	Hygral expansion	+	+	–
Mechanical	Extensibility	+	+	+
	Bending properties	+	+	+
	Shear properties	+	+	+
Surface	Compression properties	–	–	+
	Friction	–	–	+
	Surface irregularity	–	–	+
Optical	Lustre	–	+	–
Thermal	Conductivity	–	–	+
Performance	Pilling	–	+	–
	Wrinkling	–	+	–
	Surface abrasion	–	+	–

+ Important; – Less important
Source: De Boos, 1997.[4]

the terminology used, i.e. 'fabric handle or hand', it is sometimes incorrectly assumed that the assessment was purely aimed at arriving at a subjective measure of the fabric tactile-related properties (i.e. handle). In fact, in reality, the fabric handle, when so assessed by experts, provided a 'composite' measure of the overall garment-related quality of the fabric, including garment making-up, comfort, aesthetics, appearance and other functional characteristics (see Table 6.2). Nevertheless, although such experts were highly skilled and their judgement sensitive and reliable, the end result was still subjective and qualitative by nature and suffered from the inherent weakness of all subjective assessments, being amongst other things dependent upon the skills, training, background (cultural and other) of the evaluator. In the light of the above, the need to develop an objective (i.e. instrument) measurement system for assessing fabric quality became apparent, fabric objective measurement (FOM) being such an integrated system of measurement. The FOM instruments were designed so as to measure the low deformation forces encountered when the fabric is manipulated by hand and also during the garment making-up (tailoring) process and removes much of the guesswork from garment manufacturing.

Figure 6.2, taken from Kawabata and Niwa,[5] presents the development in textile science and engineering, including fabric objective measurement and the engineering of fabric quality and properties, during the past century.

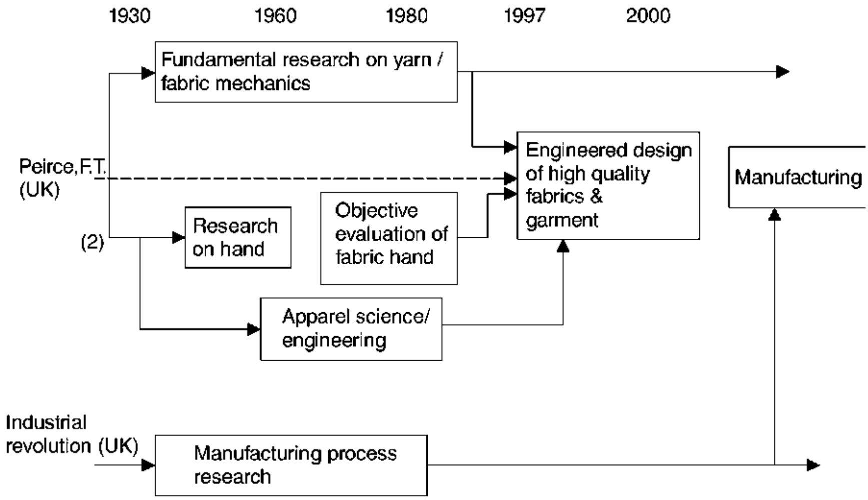

Figure 6.2 A history of the textile technology of the twentieth century. Source: Kawabata and Niwa, 1998.[5]

6.2 Reviews

There are various reviews on the topic covered by this chapter, as well as related topics. These include the following:

- The design logic of textile products[6]
- Clothing, textiles and human performance[7]
- Protective clothing[8]
- The thermal-insulation properties of fabrics[9]
- Science of clothing comfort[10]
- Apparel sizing and fit[11]
- Fabric objective measurement[12–25]
- Fabric handle[26]
- Modelling fabric mechanics[27]

6.3 Fabric objective measurement (FOM)

6.3.1 Background

Fabric objective measurement (FOM) provides a scientific means of quantifying the quality and performance characteristics of fabrics. Two issues need to be addressed in fabric objective measurement, namely what to measure and how to interpret the results. Niwa[28] stated that three criteria are used for the objective evaluation of fabric performance: good handle, good garment appearance and garment comfort, and that an ideal fabric should satisfy all three criteria.

Comfort generally comprises thermal comfort and mechanical comfort, the former being assessed from the permeability of the fabric to air, water and heat, and mechanical comfort being evaluated by the subjective assessment of handle, assessed visually and by tactile means.

According to Kawabata and Niwa,[5] clothing fabric performance needs to be assessed according to the following three requirements:

- Category A: utility performance (strength, etc.)
- Category B: comfort performance (fitting to the human body)
  - – mechanical comfort
  - – thermal comfort
- Category C: Fabric performance for the engineering of clothing manufacture.

Tests for the objective measurement of fabrics may be broadly classified as follows:[2]

- High-stress mechanical tests to measure properties, such as tensile strength, tear strength and abrasion, such tests normally being conducted until the fabric fails.
- Low-stress mechanical tests which reflect the range of stresses a fabric undergoes during normal use and which determine fabric handle (as well as making-up or tailoring performance and garment appearance).

At the present time, and as used here, FOM refers to the instrument measurement of those fabric properties (i.e. quality) which affect the tactile, making-up/tailorability and appearance-related properties of fabrics in garment applications, and generally involves the following characteristics: mostly small-scale deformation characteristics (bending, shear, compression and extension) as well as dimensional stability-related characteristics, such as hygral expansion and relaxation shrinkage.

In its broadest sense, fabric objective measurement of finished fabric has three main uses for quality control:[4]

- to ensure fabrics are easy to tailor
- to ensure garments keep their shape during wear
- to provide information on fabric handle.

The above factors are interrelated and, in many cases, are dependent upon the same, or similar, fabric properties (see Table 6.2). Tables 6.2 and 6.3 contain a list of fabric properties which are believed to be related to these quality control objectives. Test methods related to the fabric properties are also listed. The tests have been rated according to their importance for assessing the relevant property.

Based upon extensive research, it has been well established that the garment quality and appearance and its making-up processing and performance are determined by the fabric mechanical and surface properties.[2,23] The quality of

Table 6.3 Basic fabric mechanical properties and related quality and performance attributes of fabrics and garments

Fabric mechanical properties	Quality and mechanical performance
Uniaxial and biaxial tension	Fabric handle and drape
	Fabric formability and tailoring properties
Shear under tension	Garment appearance and seam pucker
Pure bending	Mechanical stability and shape retention
Lateral compression	Relaxation shrinkage, dimensional stability and hygral expansion
Longitudinal compression and buckling	Wrinkle recovery and crease retention
	Abrasion and pilling resistance
Surface roughness and friction	Mechanical and physiological comfort

Source: Postle, 1983.[24,29]

fabrics, their (tailorability and the subsequent appearance and performance of garments) can, in fact, be related to six basic fabric mechanical properties as shown in Table 6.3, with the quality and mechanical performance characteristics to which they relate[24,29] together with the fabric dimensional properties.

Fabric objective measurement is widely recognised as a key component for the success of the textile and clothing industries in the highly competitive environment and quality conscious and demanding consumers of the twenty-first century. Table 6.4 lists the various areas of application of FOM. Fabric objective measurement technology provides the key whereby the extensive experimental and theoretical research of the previous century may be implemented by the textile and clothing industries,[23] the underlying concept

Table 6.4 Application of fabric objective measurement technology

1.	Objective measurement of fabric quality and handle and their primary components for various textile products.
2.	Design and production of a diverse range of high quality yarns and fabrics using objective mechanical and surface-property data.
3.	Objective evaluation and control of textile processing and finishing sequences for the production of high quality yarns and fabrics.
4.	Objective evaluation of fabric tailorability and finished garment quality and appearance.
5.	Objective specifications by tailoring companies for fabric selection, production planning, process control and quality assurance, using fabric mechanical and dimensional property data.
6.	Measurement and control of the comfort, performance and stability of fabrics and clothing during use.
7.*	Evaluation of the effect of changes in fabric finishing routines, including decatising, on fabric tailorability.

* Author's addition
Source: Postle, 1983, 1989.[23,29]

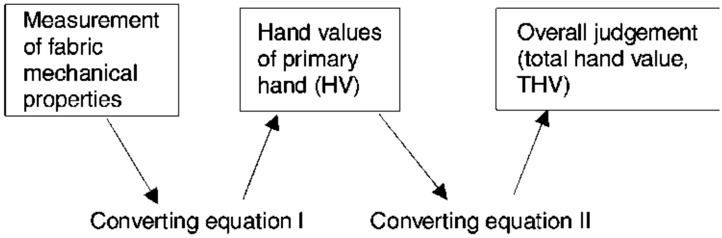

Figure 6.3 System for the objective evaluation of fabric handle. Source: Kawabata, 2000.[3]

being that a necessary and sufficient set of instrumental measurements be made on fabrics in order to specify and control the quality, tailorability and ultimate performance of an apparel fabric (see Table 6.4, Ref. 23). It also establishes an objective basis and language for communication between researchers, industry sectors (notably between fabric and garment manufacturers) and traders in fabrics and garments.

Although an important step towards the objective or quantitative assessment of fabric 'handle' and quality was the work of Peirce,[30] the most significant advance occurred early in the 1970s when Kawabata and Niwa organised the Hand Evaluation and Standardisation Committee in 1972[31] as a research committee of the Textile Machinery Society in Japan, inviting a number of experts in handle evaluation to join the committee. Through extensive research, involving experts from the clothing industry, the committee selected and defined the 'primary fabric handle' expressions and related these to the mechanical properties of the fabric[32] (Figs 6.1 and 6.3). This will be discussed in more detail later. An integrated system of FOM, the Kawabata Evaluation System for Fabrics (KES-F, later to become the KES-FB system), was the most important outcome of this work. This pioneering work laid a solid foundation for the accurate and routine measurement of those fabric properties which determine fabric handle and garment making-up and appearance and will be discussed in more detail later. Along similar, but greatly simplified lines, the CSIRO in Australia, developed the FAST (Fabric Assurance by Simple Testing) system many years later, for measuring the main fabric properties affecting garment making. The FAST system will also be discussed in more detail later.

The Kawabata and FAST systems measure similar low-stress fabric mechanical properties (compression, bending, extension and shear) and their results are generally in good agreement, although they differ somewhat in the measurement principles which they use, there being good correlation between similar parameters measured on the two systems and also on other systems. The results obtained on the two systems are plotted on control charts, sometimes called 'fingerprints', and comparisons between fabrics as well as diagnosis of tailoring problems can be made more easily when information is presented in this way. Originally the Kawabata system was essentially aimed at predicting the feel, handle and appearance of fabrics, whereas the FAST was essentially aimed at predicting fabric tailorability.[15] The KES-F system measures fabric surface characteristics and recovery properties which the FAST system does not, whereas the FAST also measures relaxation shrinkage and hygral expansion and calculates formability which the KES-F system does not. Sule and Bardhan[15] have summarised the differences between the two systems with respect to predicting tailorability as follows: the KES-F system does not consider relaxation shrinkage or hygral expansion in adjudging tailorability, while the FAST system ignores linearity of tensile as well as tensile bending and shear hysteresis, to which the Kawabata system attaches considerable importance.

Discriminant and neural network analyses,[33] utilising KES-F and FAST fabric measurements, have been used to develop models to classify cotton, linen, wool and silk fabrics. The models based upon neural network analysis classified the fabrics better than did those based upon discriminant analysis.

Although the Kawabata and FAST systems dominate the fabric objective measurement market, various alternative or complementary systems have been developed,[15,34] such as a portable system,[34] the Instron,[35] a polymeric human finger sensor (artificial finger), to measure fabric handle and frictional properties,[36,37] as well as a system of on-line measurement of fabric compressional behaviour.[38] Work is also under way to develop a haptic simulation model of fabric forces on the fingers and hand associated with feeling a fabric via highly sensitive touch response transducers,[39] enabling users to evaluate fabric handle without actually touching the fabric.

6.3.2 Typical fabric properties measured in FOM

Compression

Fabric compression normally refers to the difference in fabric thickness under different loads, also termed the thickness of the surface layer and provides a measure of fabric softness or fullness.[40] The surface released thickness, i.e. difference between the surface layer thickness before and after steaming, provides a measure of how stable the fabric finish is.

Dimensional stability

Generally there are the following three main types of dimensional change resulting from changes in the environment:[4]

- relaxation
- hygral
- thermal.

In practice, only the first two are generally considered important and measured.

The stability tests provide a measure of the potential change in fabric dimensions when exposed to changes in moisture, and normally consist of relaxation shrinkage and hygral expansion.[40] During finishing, most fabrics are dried under tension, which is not released until the fabric is exposed to moisture, typically during final pressing, at which stage the fabric undergoes relaxation and returns to its original dimensions, this being termed relaxation shrinkage. Some relaxation shrinkage is beneficial to avoid bubbling in the pleat formation process and to shrink out any residual fullness in the garment during final pressing,[40] while excessive shrinkage creates problems which will be discussed later.

Hygral expansion refers to reversible changes in fabric dimensions when the fabric is exposed to changing moisture, and excessive hygral expansion results in a change in appearance, seam pucker, bubbling and even delamination of fused panels. Excessive hygral expansion can also cause problems in pleating.[40] Problems relating to hygral expansion typically occur when the garments are made under low humidity conditions and then exposed to conditions of high humidity.[40]

Together with relaxation shrinkage, hygral expansion can cause problems with sizing, seam appearance, waviness, pucker, pattern matching at seams and the balance or appearance of the finished garment after making-up and during wear.[41]

Tensile and shear

Fabric tensile, and sometimes also recovery and hysteresis (energy loss) properties, are measured under low deformation forces, these also being used to calculate properties such as deformability.

Low fabric extensibility can lead to difficulties in producing overfeed seams, leading to problems in moulding and seam pucker.[40] High extensibility can lead to the fabric being stretched during laying-up, causing the cut panels to shrink when they are removed from the cutting table, this often being mistaken for relaxation shrinkage. Fusible tape can be used to stabilise fabrics with excessive extensibility. Shear rigidity can be calculated from the bias extensibility, while formability is calculated from the extension at 5 gf/cm and 20 gf/cm, together with fabric bending rigidity, being the product of fabric bending rigidity and initial fabric extensibility.[40] Inadequate warp formability necessitates refinishing of the fabric to increase warp extensibility. For wool fabrics, hygral expansion, relaxation shrinkage and extensibility are often related.

Friction and roughness

A measure of fabric friction and roughness can be obtained by measuring either fabric-against-fabric or fabric-against-metal static and dynamic friction.[40] This property is related to fabric handle.

Bending rigidity

Fabric bending length is generally measured and used to calculate the fabric rigidity. Fabrics with relatively high values of bending rigidity will feel stiffer but will not generally cause problems in making-up. Fabrics with low values can lead to problems during making-up (tailoring), for example distortion during cutting as well as seam pucker during sewing.[40]

6.3.3 Kawabata system

A detailed description of the Kawabata system and instruments is given in Ref. 42. The Kawabata System for Fabrics (KES-F, later renamed as the KES-FB) consists of the following four instruments[2] (see Figs 6.4 and 6.5 and Table 6.5).

1. *Tensile and shear tester (KES-FB1)*. A tensile test is conducted by clamping the sample between chucks. A shear test is conducted under a constant tension, provided by a dead weight attached to the fabric sample.
2. *Bending tester (KES-FB2)*. A fabric sample is mounted in a vertical plane and a pure curvature is applied to record moment-curvature relationships.

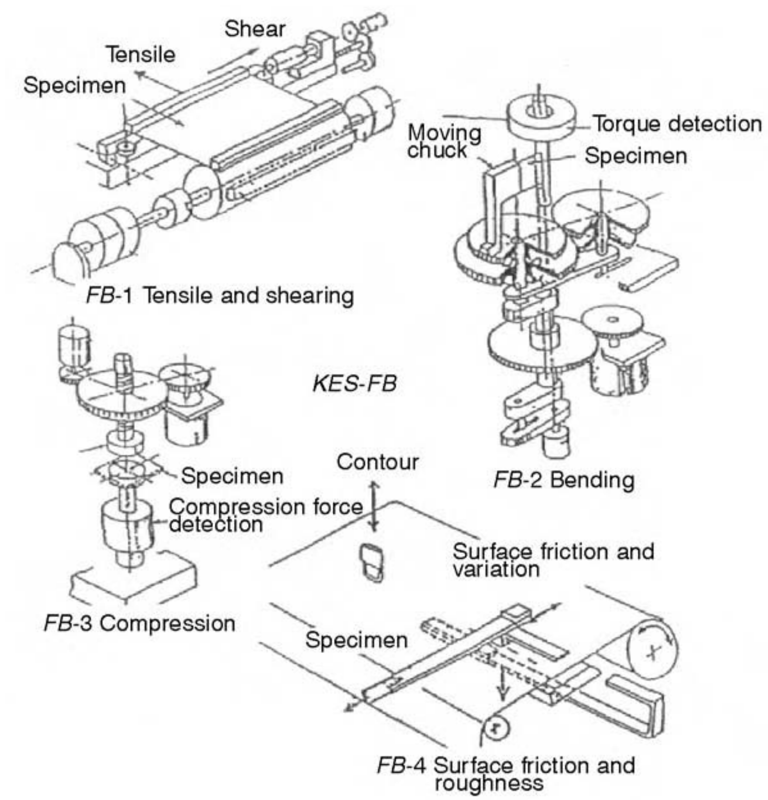

Figure 6.4 The KES-F system for measuring fabric mechanical properties. Source: Kawabata and Niwa, 1991.[43]

3. *Compression tester (KES-FB3).* A fabric sample is compressed in the thickness (lateral) direction, using a compression head, and the load-deformation curve is recorded.
4. *Surface tester (KES-FB4).* Surface roughness and the coefficient of friction are measured using two contact sensors, one for measuring thickness variation and the other for measuring frictional force. The fabric sample is moved, relative to the sensors, under a constant tension.

These instruments can test fabrics automatically and provide continuous stress-strain curves. Load and deformation are measured using sensors and recorded using an *X-Y* plotter.

Figure 6.5 shows the principles used in the measurement of fabric properties by the four KES-F instruments.[24,29] Figure 6.6[29] shows typical graphical outputs (deformation-recovery curves) of the KES-F instruments, which illustrate the non-linearity and hysteresis of the curves, and the need to select the maximum values for the recovery part of the cycle in accordance with the values experienced in the performance of the garment. The hysteresis (losses) of the curves are due to interfibre friction and the visco-elastic properties of the fibres.[24] Typical bending/shear deformations are reversible, i.e. they can be deformed in either direction to give positive or negative curvatures. Tensile deformations are not reversible since the fabric tends to buckle under logitudinal compressive loads. For small deformations, the shear and bending rigidities, as defined by the gradients of the graphs, are linear,[24] these together with hysteresis, being important in determining the ease with which fabrics drape and can be forced into complex three-dimensional shapes without puckering. Hysteresis behaviour is important in terms of fabric resilience or springiness.

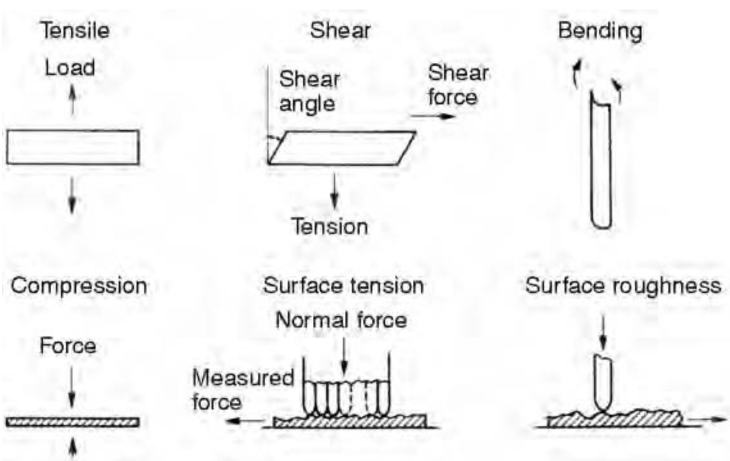

Figure 6.5 Principles used in the KES-F instruments for the objective measurement of fabric mechanical and surface properties. Source: Postle, 1983, 1989.[24,29]

Table 6.5 The sixteen parameters describing fabric mechanical and surface properties

Tensile	(KES-FB1)	LT	Linearity of load/extension curve
		WT	Tensile energy (gf. cm/cm^2)
		RT	Tensile resilience (%)
		EM	Extensibility, strain at 500gf/cm tensile load
Shear	(KES-FB1)	G	Shear rigidity (gf. cm/deg)
		2HG	Hysteresis of shear force at 0.5° shear angle
		2HG5	Hysteresis of shear force at 5° shear angle
Bending	(KES-FB2)	B	Bending rigidity
		2HB	Hysteresis of bending moment
Lateral compression	(KES-FB3)	LC	Linearity of compression/thickness Curve
		WC	Compressional energy (gf. cm/cm^2)
		RC	Compressional resilience (%)
Surface characteristics	(KES-FB4)	MIU	Coefficient of friction
		MMD	Mean deviation of MIU
		SMD	Geometrical roughness (μm)
Fabric construction		W	Fabric weight per unit area (mg/cm^2)
		T_o	Fabric thickness (mm)

Source: Postle, 1983.[24,29]

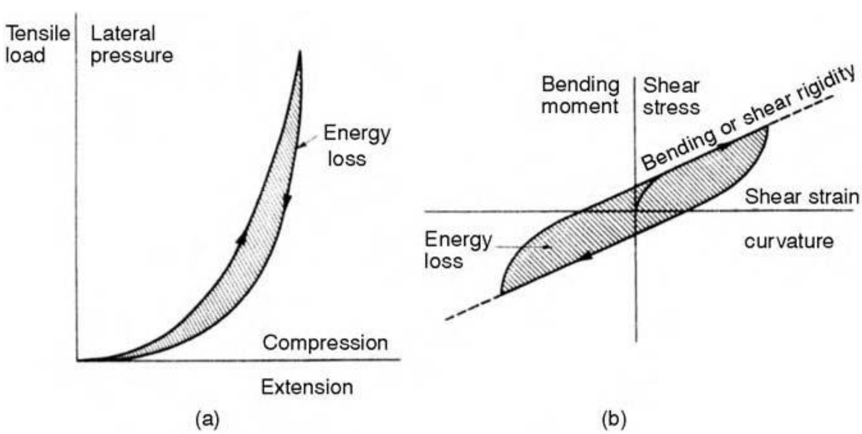

Figure 6.6 Typical deformation-recovery curves for (a) fabric extension or lateral compression, and (b) fabric bending or shear, showing the energy loss during a complete cycle as the shaded area. Source: Postle, 1983.[29]

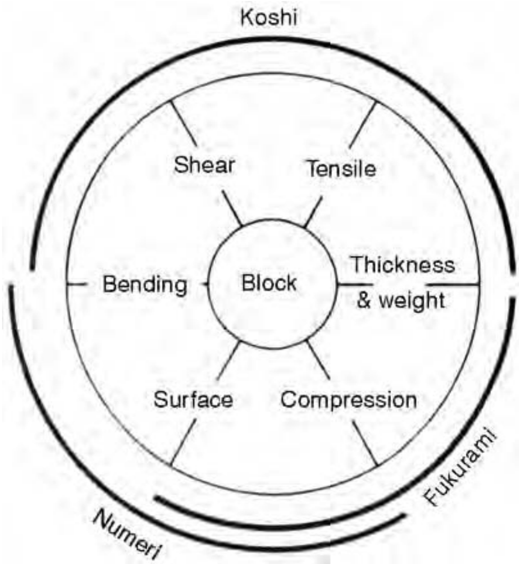

Figure 6.7 Relation between the three primary hands and the mechanical properties. The related properties are covered by a line of the corresponding hand. Source: Hand Evaluation and Standardization Committee, 1972–1975.[31]

The three primary handle values (PHV) arrived at were Koshi (stiffness), Numeri (smoothness) and Fukurami (fullness) and were related to the KES-F measured fabric properties as illustrated in Fig. 6.7, using elaborate statistical analysis. Further handle values, Shari (crispness) and Hari ('anti-drape stiffness') were added for men's summer suitings and women's fabrics (see Table 6.6).

An outcome of the above development is that fabric handle can be objectively graded in terms of the 'Total Handle Value' (THV), and garment (suit) appearance in terms of the Total Appearance Value (TAV).[3] See Fig. 6.8 and Table 6.7[14] for the interpretation of the values, TAV providing a measure of tailorability and drape/suit appearance.

Table 6.6 Primary hands

KOSHI	'Stiffness'	A measure of crispness in bending; springy flexural rigidity
NUMERI	'Smoothness'	A measure of smooth, supple and soft feel
FUKURAMI	'Fullness and softness	A measure of bulk, with springiness in comparison; rich and warm
SHARI	'Crispness'	A measure of a crisp rigid fabric surface, with a cool feel
HARI	'Anti-drape stiffness'	A measure of flare, the opposite of limp conformability

Source: Hearle, 1993.[44]

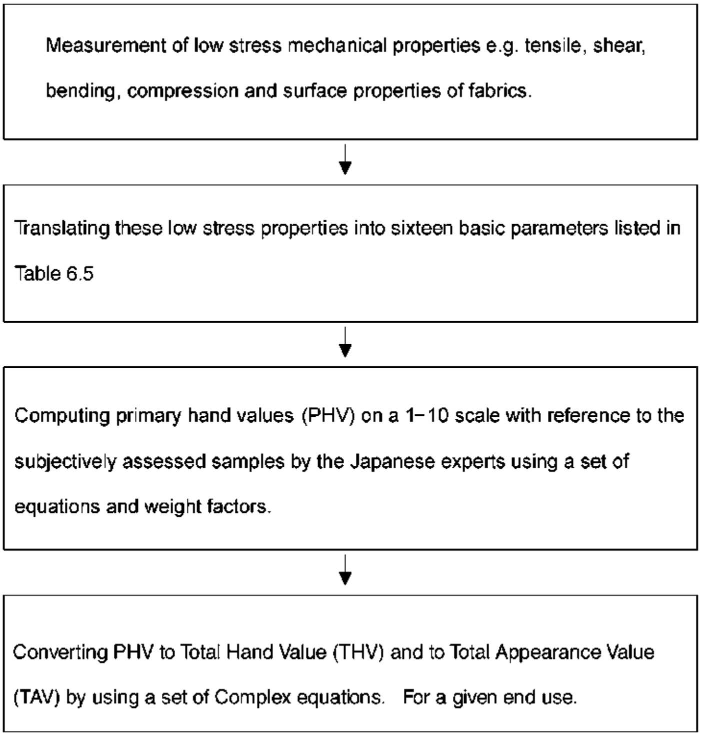

Figure 6.8 Basis of objective evaluation of KES-FB system. Source: Kawabata and Niwa, 1989.[46]

Experience over many years has suggested that the KES-F measurements may be standardised in terms of the 16 parameters listed in Table 6.5:[29] In the Kawabata (KES) system, the quality, tailoring and appearance performance of fabrics can be related to six basic fabric mechanical properties[45] (see Table 6.3). The relationship between KES-F measured properties and tailorability and appearance is illustrated in Tables 6.8, 6.9 and 6.10[46] and Figs 6.9 and 6.10.[47]

Table 6.7 Influence of measured parameters on PHV

PHV	Measurable parameter
Smoothness (Numeri)	Surface, compression and shear
Stiffness (Koshi)	Bending rigidity, weight, thickness, shear and surface
Fullness and softness (Fukurami)	Compression surface, thickness, shear
Crispness (Shari)	Surface, bending and tensile
Antidrape/Spread (Hari)	Shear, surface and bending

Source: Sule and Bardhan, 1999.[13]

Table 6.8 The desirable range of mechanical properties for high-quality suit production

Mechanical parameter	Range for good appearance and good tailorability	Range for especially good appearance
EM_1 (%)	4–6	4–6
EM_2/EM_1 (%)	>1	>2
RT (%)	65–76	72–78
G (gf. cm/deg)	0.5–0.7	0.5–0.7
2HG5 (gf/cm)	0.8–1.7	0.6–1.5

Source: Kawabata and Niwa, 1989.[46]

Table 6.9 The range of mechanical properties for fabric to be rejected

Mechanical parameter	Range for rejection
EM_1 (%)	>9 or <3
EM_2 (%)	<4
2HG5 (gf/cm)	<4

Source: Kawabata and Niwa, 1989.[46]

Mori[48] lists the following requirements for apparel fabrics:

- Relaxation shrinkage of fabric must be less than 2% and hygral expansion less than 7% for both warp and weft directions. Specifications for steam-press shrinkage are also being formulated.

Table 6.10 Interrelation between difficulties in sewing process and ranges of mechanical parameters

Range of parameters	Difficulty predicted in:
LT<0.55 or >0.7	Overfeed operations
RT>70	Cutting process
RT<55	Steam-press operations
LT<0.55 and RT>73 or LT<0.55 and RT <55	Especially difficult in overfeed operations
EM_1<3 or >8	Overfeed operations
EM,>5	Cutting operations
EM_2<4	Overfeed operations
EM_2/EM_1>3	Sewing operations and steam-press operations
G<0.6 or >0.95	Overfeed operations
2HG5>3	Overfeed operations

Source: Kawabara and Niwa, 1989.[46]

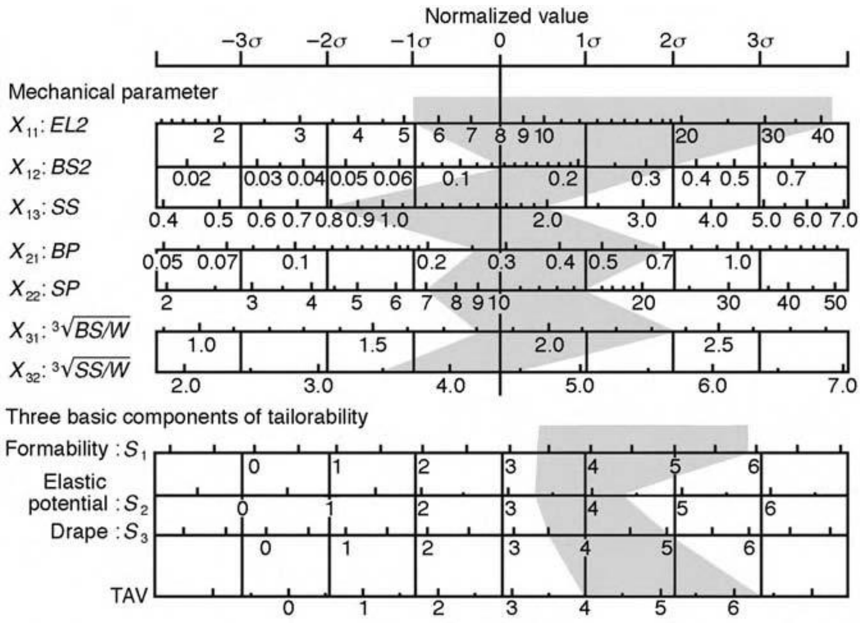

Figure 6.9 High TAV zone for suit expressed by the three components. Source: Kawabata and Niwa, 1994.[47]

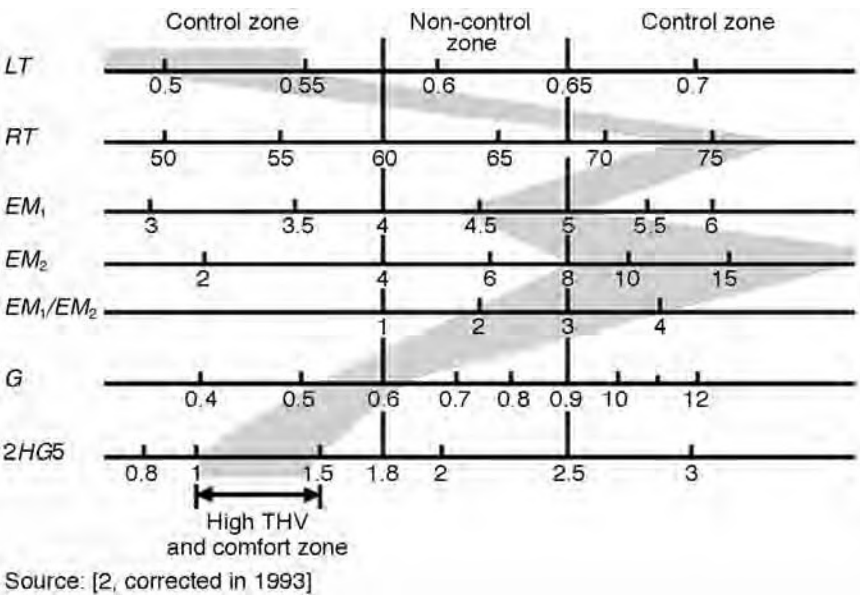

Figure 6.10 'Tailoring Control Chart' and high quality zone from wear comfort. Source: Kawabata and Niwa, 1994.[47]

- Extensibility of polyester/wool/mohair blended fabrics for summer suits should be greater than 4% (KES-F, standard testing condition) in the weft direction (EM2 $\geq$ 4%).
- The extensibility of wool gaberdine, polyester/wool tussah and polyester/wool tropical must be between 4% and 8% in the warp direction (4% $\leq$ EM1 $\leq$ 8%).
- Shear hysteresis (at shear angle 5°) must be less than 2.5 gf/cm (KES-F, standard testing condition) for suit and jacket fabrics (2HG5 $\leq$ 2.5 gf/cm).

Furthermore, the criteria for high-quality fabrics, termed ideal fabrics, were created. It is now required to inter-link fibre science to enable a more accurate engineering design of fabrics (see Fig. 6.2). The test results from the Kawabata system, although primarily aimed at defining handle, will show which fabrics will go through a clothing factory easily and efficiently, which will need special care, with indicated adjustments of machine settings and which will cause serious problems.[44]

Kawabata and Niwa[5] stated that an ideal suiting fabric should satisfy the following three conditions:

1. Good handle (high THV)
2. Good suit appearance (high TAV)
3. Mechanical comfort conditions (shaded zone on control chart)

For example, warp and weft extension at a load of 500 g/cm should preferably be 4% or higher for wool fabrics.

Table 6.11 gives the proposed criteria which a fabric needs to satisfy if it is to be considered a 'perfect' or 'ideal' fabric.[5]

Table 6.11 The criteria for ideal fabric

	Type of suiting		Remarks
	Winter-autumn	Mid-summer	
1 Total Hand Value (THV)	*THV* $\geq$ *4.0*	*THV* $\geq$ *3.5*	*THV:* 1 (poor)–5 (excellent)
2 Total Appearance Value (TAV)	*TAV* $\geq$ 4.0	TAV $\geq$ *4.0*	*TAV:* 1 (poor)–5 (excellent)
3 Mechanical comfort (must be inside the snake zone)	0.58$\geq$ LT$\geq$0.50 78$\geq$RT$\geq$73 5.1 $\geq EM_1 \geq$4.3 18$\geq EM_2 \geq$7.5 3.0$\geq$EM2/EM1 $\geq$1.3 0.65$\geq$G$\geq$0.50 1.5$\geq$2HG5$\geq$0.8	0.60$\geq$ LT$\geq$0.50 78$\geq$RT$\geq$73 5.1 $\geq EM_1 \geq$4.3 18$\geq EM_2 \geq$7.5 3.0$\geq$EM2/EM1 $\geq$1.3 0.65$\geq$G$\geq$0.50 1.5$\geq$2HG5$\geq$0.8	LT: Average of LT_1 and LT_2 RT: Average of RT_1 and RT_2

Suffix 1; warp direction, 2; weft direction
Source: Kawabata and Niwa, 1998[5]

Shishoo[49] also presents a table indicating the relationship between KES measured mechanical properties and tailoring properties. The KES system is also able to distinguish differences in finish, for example differences between classes of silicone finishes[50] on polyester/cotton fabrics, and has been applied to evaluating the quality of ladies' garments.[51]

Chen *et al.*[52] used a method of fuzzy comprehensive evaluation to solve the problem of grading fabric softness as a measure on the Kawabata KES-FB instruments. Based upon the KES-FB measurements, Chen *et al.*[53] proposed a neural network computing technique to predict fabric end use.

6.3.4 FAST system

The Fabric Assurance by Simple Testing (FAST) system was developed in the 1980s by the CSIRO Division of Wool Technology, Australia, as a simpler alternative to the more sophisticated Kawabata system, and consists of three individual instruments (FAST-1, FAST-2 and FAST-3)[2] as well as a test method (FAST-4). The FAST instruments are similar in operation to conventional measuring instruments, except that measurement is carried out using sensors, and the test results are displayed digitally.

FAST-1

Compression meter (FAST-1), measures:

- fabric thickness (T)
- fabric surface thickness ($ST = T_2 - T_{100}$)
- released (relaxed) surface thickness.

The compression meter[54] measures the thickness of fabrics at two loads 2 gf/cm^2 (0.196 kPa) and 100 gf/cm^2 (9.81 kPa). This allows the calculation of the fabric surface thickness, the difference in thickness between the two loads which is a measure of the amount of compressible fibre or pile on the surface of the fabric and can be used to ascertain the extent and consistency of fabric surface processes, such as singeing, cropping, raising, pressing, etc. A further measurement of the fabric surface thickness, after release in steam (or even water), provides a measure of the stability of the finish of the fabric; the larger the difference, the less stable the finish. This measurement is important in determining the extent of subsequent changes in appearance and handle of the fabric after garment pressing and can indicate the potential re-emergence of such things as running marks.[54]

FAST-2

Bending meter (FAST-2), measures:

- bending length (BL in mm – measured at an angle of 41.5°)

- bending rigidity (BR in μN/m) = $9.8 \times 10^{-6}\ W\ (BL)^3$
  (where W = fabric weight (g/m^2)).

The bending meter measures[54] the bending length of fabric from which the bending rigidity can be calculated. This is an important property for the handle of the fabric and also influences the cutting performance and the ease with which the fabric can be processed by automated handling equipment.[54] Too stiff a fabric can lead to problems in moulding the fabric, whereas too limp a fabric can be difficult to cut as it will easily distort and can also lead to seam pucker.

FAST-3
Extension meter (FAST-3), measures:

- warp extensibility
- weft extensibility
- bias (45º) extensibility
- shear rigidity (N/m) = 123/EB5 (% bias extension).

The extension meter[54] measures the extensibility of the fabric at three loads, 5 gf/cm (4.9 N/m), 20 gf/cm (19.6 N/m) and 100 gf/cm (98.1 N/m), in the warp and weft direction to indicate potential problems in the laying up of the fabric and in seams that require overfeed. This information is also combined with the bending rigidity to determine the fabric 'formability' which is a measure of the fabric's propensity to pucker when it is compressed along seams, a possibility along with seam blowing, when formability is low. The extensibility is also measured on samples that are cut on the bias (45º to the warp) to determine fabric shear rigidity. This measurement indicates potential problems in laying up and in the fabric's ability to form smooth three-dimensional shapes, such as are needed around the sleeve head and shoulder region in a structured jacket.[54] Low shear rigidity indicates that the fabric will be easily distorted in laying up, marking and cutting, whereas a high value indicates that the fabric will be difficult to form into smooth three-dimensional shapes, causing problems in moulding and sleeve insertion. Too low a shear rigidity could indicate that the fabric will be difficult to lay up and may require pinning, whereas too high a value could indicate problems with moulding the fabric and inserting sleeves. Low extensibility can lead to difficulties in producing overfeed seams, problems in moulding and seam pucker. High extensibility can lead to the fabric being stretched during laying up, causing the fabric panels to shrink when removed from the cutting table.

FAST-4
Dimensional stability test method (FAST-4), measures:

- relaxation shrinkage (RS) = $(L_o - L_D)/L_o$
- hygral expansion (HE) = $(L_w - L_D)/L_D$

where L_o = the original length, L_D = the dried length, and L_W = the relaxed length in water.

The dimensional stability test enables both the relaxation shrinkage and the hygral expansion of the fabric to be determined.[54] Relaxation shrinkage is the once only change in fabric dimensions associated with the release of strains set up in the fabric during spinning, weaving and finishing (e.g. if a fabric is dried under a high tension during finishing). This change can be brought on by exposure of the fabric to steam, water or high humidity. Depending upon which stage during garment manufacture this change manifests itself, the problem can range from one of incorrect sizing to poor appearance on and around fusibles and seams. This is also a critical fabric property for processes, such as pleating, where there are certain minimum requirements for sharp, smooth pleats.

Hygral expansion is the reversible change in fabric dimensions associated with the absorption and desorption of moisture by hygroscopic fibres such as wool. The appearance of garments can deteriorate when exposed to high humidity if the hygral expansion is high, especially those that were made up under conditions of low relative humidity.[54]

From the above measured properties, other properties, such as 'formability' ($F(mm^2)$ = BR (E2O − E5)/14.7) and 'finish stability', can be calculated. For example, if the ratio of surface thickness after and before relaxation is over 2.0, it indicates improper finishing or 'definishing'.[13] Formability (compressibility × bending rigidity or extensibility at low loads × bending rigidity, the latter being used on the FAST) is a measure of the ability of fabric to accommodate 'in-plane' compression without buckling, such as that encountered during tailoring, and is a direct measure of seam puckering, low formability indicating a tendency to pucker.

Table 6.12 Summary of CSIRO's FAST system

Instrument and test	Measures	Predicts problems in:
FAST-1	Thickness	Pressing
	Compression	Finish stability
FAST-2	Bending	Cutting, automated handling
FAST-3	Extensibility	Laying up, pattern matching, overfed seams, moulding
	Shear	Laying up, moulding, sleeve insertion
FAST-2 & 3	Formability	Seam pucker
FAST-4	Relaxation shrinkage	Size, seam pucker and pleating
	Hygral expansion	Looks, pleating

Source: Sule and Bardhan, 1999.[13]

Table 6.13 Fabric properties associated with problems in garment making

Property	Potential problem
Low relaxation shrinkage	Bubbling of fused panels Delamination of fused panels Bubbling in pleating Difficulty shrinking out fullness
High relaxation shrinkage	Excessive fusing press shrinkage Excessive steam press shrinkage Variation in size of cut panels
Excessive hygral expansion	Excessive shrinkage during manufacture Bubbling of fused panels Bubbling of pleated panels
Low formability	Difficulty in sleeve setting
Low extensibility	Difficulty with sewing overfed seam Difficulty in pressing Difficulty shrinking out fullness
High extensibility	Difficulty matching checks Difficulty sewing unsupported seams (Warp) Easy to stretch in laying up leading to shrinkage problems
Low bending rigidity	Difficult to cut and sew Automated handling problems
High bending rigidity	Difficult to mould and press
Low shear rigidity	Easy to distort in laying up, marking and cutting
High shear rigidity	Difficulty in garment moulding Difficult to form smooth 3D shapes

Source: Anon.[56]

Table 6.14 Fabric properties associated with potential poor garment appearance in wear

Property	Potential problem
Low relaxation shrinkage	Bubbling/waviness in fused panels Delamination of fused panels Seam pucker
High relaxation shrinkage	Size variation Seam pucker
Excessive hygral expansion	Bubbling/waviness in fused panels Poor shape retention Seam pucker
Low formability	Puckering of seams Difficulty in pressing
Low bending rigidity	Poor shape retention Soft drape of sleeves
Low shear rigidity	Poor garment shape retention Soft drape of sleeves
Excessive increase in surface thickness	Poor appearance retention (fabric) Re-emergence of running marks or cracking and distortion of fabric

Source: Anon.[56]

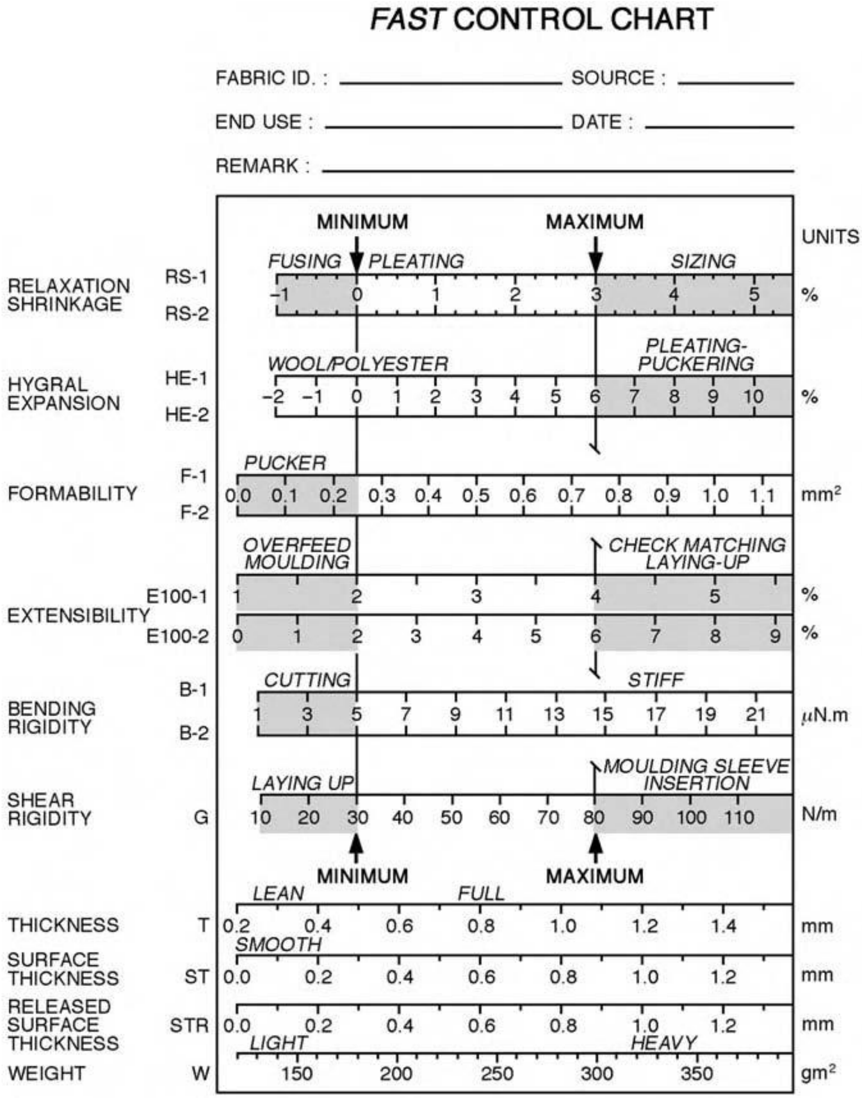

Figure 6.11 The FAST control chart for light-weight suiting fabrics. Source: Anon.[57]

In addition to the above properties, 'seam pressing performance' (PP) can also be predicted, using the crease pressing performance test which involves inserting a crease in a sample and then measuring the recovery of the crease under standard atmospheric conditions. It enables the propensity of a fabric to produce blown seams (i.e. seams which do not remain flat) after pressing, to be predicted.[55]

Table 6.12[13] provides a summary of the FAST system. Table 6.13 summarises the FAST fabric properties associated with problems in garment making[56] while Table 6.14 lists those FAST fabric properties associated with potentially poor garment appearance.[56] Figure 6.11 shows the FAST control chart on which measured fabric properties are plotted as a 'fingerprint', for easy diagnosis and corrective action.

6.4 References

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