SiroFAST
Fabric Assurance by Simple Testing

SiroFAST –
A System for Fabric Objective Measurement and its Application in Fabric and Garment Manufacture.

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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 pans 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 second pan of the report describes the use of SiroFAST in fabric and garment manufacture and gives case studies of its use by industry.
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.

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.

They 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 1.1.

<table>
<thead>
<tr>
<th>TABLE 1.1</th>
<th>FUNCTIONAL AND AESTHETIC PROPERTIES OF FABRICS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functional</strong></td>
<td>Tear strength</td>
</tr>
<tr>
<td></td>
<td>Abrasion resistance</td>
</tr>
<tr>
<td></td>
<td>Flammability</td>
</tr>
<tr>
<td></td>
<td>Handle - Firmness, Smoothness, etc.</td>
</tr>
<tr>
<td></td>
<td>Performance in Cutting, Sewing and Pressing</td>
</tr>
<tr>
<td></td>
<td>Shape distortion</td>
</tr>
<tr>
<td></td>
<td>Seam pucker</td>
</tr>
<tr>
<td></td>
<td>Pilling Resistance</td>
</tr>
</tbody>
</table>

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 (eg check, plain) and the requirements of the individual.

Extensive research in Sweden (7), Holland (8), Japan (9,13,16), the UK (12) and Australia (6,10,14,15,17) 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 1.2.

<table>
<thead>
<tr>
<th>TABLE 1.2</th>
<th>FABRIC PROPERTIES RELATED TO HANDLE, PERFORMANCE IN GARMENT MANUFACTURE, AND GARMENT APPEARANCE AFTER MANUFACTURE AND IN WEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Properties</strong></td>
<td>Performance in Manufacturing</td>
</tr>
<tr>
<td>* important</td>
<td>Physical Properties</td>
</tr>
<tr>
<td></td>
<td>Dimensional Stability</td>
</tr>
<tr>
<td></td>
<td>Mechanical Properties</td>
</tr>
</tbody>
</table>

- Extensive research in Sweden (7), Holland (8), Japan (9,13,16), the UK (12) and Australia (6,10,14,15,17) 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 1.2.
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 ‘fart 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 (16) and quantitatively predict performance in both garment manufacture and the appearance of garments.(9).

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 (11). The so-called dimensional stability of the fabric (perhaps more correctly called dimensional instability (12)) 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 light-weight clothing has resulted in the increased use of fabrics that are difficult to make-up and require new handling skills,1

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,

1.2.1 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 (7) and Dutch (8) 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 behavior of fabric. Those used to describe resistance to deformation are normally considered to be the most important and are defined in Table 1.3. The deformations involved are represented in Figure 1.
The work of the Swedish and Dutch groups has been confirmed by industrial users of objective measurement. Summarised in Table 1.4 is part of a Japanese report (I9) 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' (7). These properties are related to the tendency of a fabric to buckle when subjected to an in-plane compressive load (Fig 1.2). When a seam is sewn, the sewing thread and any overfeed applied to the components of the seam put enplane 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 mens’ suit jackets (b).
Table 1.4
Some Fabric Properties Related to Problems in Garment Manufacture (19)

<table>
<thead>
<tr>
<th>Region of Manufacturing Difficulties</th>
<th>Related Fabric Property</th>
<th>Problem Lone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting</td>
<td>Warp Extension</td>
<td>High</td>
</tr>
<tr>
<td>Sewing</td>
<td>Weft Extension</td>
<td>Low</td>
</tr>
<tr>
<td>Front-Back</td>
<td>Warp Extension</td>
<td>High</td>
</tr>
<tr>
<td>Arm Hole</td>
<td>Weft Extension</td>
<td>High</td>
</tr>
<tr>
<td>Arm Hole</td>
<td>Shear Rigidity*</td>
<td>Low</td>
</tr>
<tr>
<td>Canvas</td>
<td>Warp Extension</td>
<td>High</td>
</tr>
<tr>
<td>Shear Hysteresis*</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Side seam</td>
<td>Warp Extension</td>
<td>High or Low</td>
</tr>
<tr>
<td></td>
<td>Weft Extension &amp; Shear Hysteresis</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Shear Rigidity</td>
<td>High</td>
</tr>
<tr>
<td>Collar</td>
<td>Shear Rigidity</td>
<td>High or Low</td>
</tr>
<tr>
<td></td>
<td>Weft Extension</td>
<td>Low</td>
</tr>
<tr>
<td>Sleeve Setting</td>
<td>Shear Rigidity</td>
<td>High or Low</td>
</tr>
<tr>
<td></td>
<td>Shear Hysteresis*</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Bending Rigidity</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Bending Hysteresis*</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Weft Extension</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Warp Extension</td>
<td>High</td>
</tr>
</tbody>
</table>

* Sheaf and Bending hystereses are measures of energy loss in deformation.

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.

Formability = Bending Rigidity X Extensibility (at low loads)

1.2.2 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 (12):

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 1.5). 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 (12).

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) as well as 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).
<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>HIGH VALUE</th>
<th>LOW VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relaxation Shrinkage</td>
<td>Size Variation</td>
<td>Delamination of fusible interlining</td>
</tr>
<tr>
<td>Seam pucker</td>
<td></td>
<td>Seam Pucker</td>
</tr>
<tr>
<td>Excessive shrinkage</td>
<td></td>
<td>Moulding difficulties</td>
</tr>
<tr>
<td>Hygral Expansion</td>
<td>Excessive shrinkage</td>
<td>Poor garment appearance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delamination of fusible interlinings Seam pucker</td>
</tr>
</tbody>
</table>

### 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 rinsed 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 (25).
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 (21) 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 Tasting) was designed to meet the industrial need for a simple, robust system to predict fabric performance (25-27).

### 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 (25). The instruments were developed by the Australian CSIRO Division of Wool 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 x 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.
A schematic diagram of the instruments are shown in Fig 2.1, 2.2, and 2.3

Fig. 2.1 Schematic diagram of SiroFAST-1 compression meter

### 2.1 SiroFAST-1 Compression meter

The SiroFAST-I Compression meter thickness (28) is defined as the difference m accurately measures fabric thickness at loads thickness measured at the two loads, and is of 2 g/cm² and 100 g/cm². The surface layer 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).

Fig. 2.2 Schematic diagram of SiroF.45T-2 bending meter

### 2.2 SiroFAST-2 Bending meter

This instrument measures fabric bending length using the cantilever bending principle, us described in British Standard Method (BS:3356(1961)). From the 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).
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 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 (± 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 principle 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 (Table 2.2)

\[
\text{Formability} = \text{Bending Rigidity} \times \frac{(\text{Extension (20 g/cm)} - \text{Extension (5 g/cm)})}{14.7}
\]

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 (12) 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 to Fig 2.4. The properties measured directly are shown in Table 2.1. Those measurements derived or calculated from these measurements are shown in Table 2.2.

### 2.5 Sampling for SiroFAST tests

SiroFAST-1,2,3 test samples are 150 mm X 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 dimensional stability test (SiroFAST-4) requires a separate sample (300 X 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.

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### TABLE 2.1

<table>
<thead>
<tr>
<th>Properties measured</th>
<th>SiroFAST Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabric weight</td>
<td></td>
</tr>
<tr>
<td>Compression</td>
<td></td>
</tr>
<tr>
<td>Fabric thickness at 2 g/cm²</td>
<td>SiroFAST-1</td>
</tr>
<tr>
<td>Fabric thickness at 1110 g/cm²</td>
<td></td>
</tr>
<tr>
<td>Released thickness at 2 cm²</td>
<td></td>
</tr>
<tr>
<td>Released thickness at 100 g/cm²</td>
<td></td>
</tr>
<tr>
<td>Bending</td>
<td></td>
</tr>
<tr>
<td>Bending length</td>
<td>SiroFAST-2</td>
</tr>
<tr>
<td>Tensile</td>
<td></td>
</tr>
<tr>
<td>Warp extensibility</td>
<td>SiroFAST-3</td>
</tr>
<tr>
<td>Weft extensibility</td>
<td></td>
</tr>
<tr>
<td>Bias extensibility</td>
<td></td>
</tr>
<tr>
<td>Dimensional stability</td>
<td></td>
</tr>
<tr>
<td>Relaxation shrinkage</td>
<td>SiroFAST-4</td>
</tr>
<tr>
<td>Hygral expansion</td>
<td></td>
</tr>
</tbody>
</table>
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### TABLE 2.2

<table>
<thead>
<tr>
<th>Derived Properties</th>
<th>Calculated from</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Thickness</td>
<td>Thicknesses at 2 cm² and 100 cm²</td>
</tr>
<tr>
<td></td>
<td>Released Surface Thickness</td>
</tr>
<tr>
<td></td>
<td>Released thicknesses at 2 cm² and 100 cm²</td>
</tr>
<tr>
<td>Finish stability</td>
<td>Fabric surface thickness</td>
</tr>
<tr>
<td></td>
<td>Released surface thickness</td>
</tr>
<tr>
<td>Bending Rigidity</td>
<td>Bending length</td>
</tr>
<tr>
<td></td>
<td>Weight</td>
</tr>
<tr>
<td>Shear Rigidity</td>
<td>Bias extensibility</td>
</tr>
<tr>
<td>Formality</td>
<td>Bending Rigidity</td>
</tr>
<tr>
<td></td>
<td>Extensibility at low loads</td>
</tr>
</tbody>
</table>

### 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 SiroFAST control chart is shown to Fig 2.5.
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 fingerprints position in relation to the 'grey zones' on the SiroFAST chart.

The grey zones on the chart in Fig 2.5 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, dress goods or pleated skirts.

Higher skill levels In a factory, manufacturing a particular type of garment, would allows an increase in the range of fabrics and fabric properties that could be successful, handled.

Software is available for use with SiroFAST that allows users to adjust limits to meet changing garment designs and skill levels in their factor.

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 S.ro1-1S'1 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.

An example of actions that can he adopted when fabric properties fall within the grey cones is described in detail in Sec 4.2.
The use of a fabric fingerprint is preferred over alternative techniques for interpreting objective measurement data (9.10). 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.

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 (74, 75). 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 formal as earlier trials on the KES-F instruments. The results of these round trials are included as Appendix I of this report.

3. APPLICATION IN FABRIC MANUFACTURE AND FINISHING

The requirements of fabric manufacturers for an objective measurement system are broader than those of garment makers.

Firstly, 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.

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 needs good design and appropriate finishing practice.

3.1.1 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 on which fabric designers can use to predict the properties of loom state fabric from both 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 ICES-F system, the principles used are the same for SiroFAST. Table 3.1 demonstrates the way in which fabric design may be altered to prevent excessive warp extensibility in formal wear fabrics.

<table>
<thead>
<tr>
<th>Method</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change balance of ends and picks</td>
<td>large</td>
</tr>
<tr>
<td>Change fibre type</td>
<td>medium</td>
</tr>
<tr>
<td>Change spinning method</td>
<td>small</td>
</tr>
<tr>
<td>Blend synthetic fibres with wool</td>
<td>large</td>
</tr>
<tr>
<td>Use shrink resist yarn</td>
<td>medium</td>
</tr>
<tr>
<td>Change weave</td>
<td>n.a.</td>
</tr>
<tr>
<td>Use colour woven route</td>
<td>large</td>
</tr>
</tbody>
</table>

Derived from Mori (38)

### 3.1.2 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 (36,40).

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 (39).

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-slate fabric (40).

Many studies (39, 41-43) are now available which documents 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 3.2, and an example of the change in one such property during finishing is shown in Fig 3.1.
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). Stonier drying is the only operation in dry finishing where the dimensions of the fabric are directly controlled.

**TABLE 3.2**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Relaxation</th>
<th>Hygral Expansion</th>
<th>Extension</th>
<th>Bending</th>
<th>Shear</th>
<th>Compression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet setting</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Scouring</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Milling</td>
<td>X</td>
<td>X</td>
<td>M-X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Dyeing</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>M-X</td>
</tr>
<tr>
<td>Dr in</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cropping</td>
<td>M</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Singeing</td>
<td>M</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Damping</td>
<td>M</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relaxing</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Pressing</td>
<td>M-X</td>
<td>M-X</td>
<td>M</td>
<td>M</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Decatising</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Sponging</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>M</td>
</tr>
</tbody>
</table>

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.

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 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 present inadequate fabric extensibility are shown in Table 3.3. 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 into the fabric without significantly altering its other properties. This is achieved by controlling fabric dimensions, especially in the warp direction.

**TABLE 3.3**

<table>
<thead>
<tr>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet set the fabric (crabbing)</td>
</tr>
<tr>
<td>Increase severity of wet setting</td>
</tr>
<tr>
<td>Use hatch- rather than cone-crab</td>
</tr>
<tr>
<td>Use chemical assistant in conti-crab</td>
</tr>
<tr>
<td>Use a piece-dye route</td>
</tr>
<tr>
<td>Increase overfeed in drying</td>
</tr>
<tr>
<td>Reduce warp tension in dry finishing</td>
</tr>
<tr>
<td>Avoid rotary pressing</td>
</tr>
<tr>
<td>Pressure decatisse rather than ‘blow’</td>
</tr>
</tbody>
</table>

Derived from SiroFAST Users manual.
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 illustrated in Fig 3.2 (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.

SiroFAST CONTROL CHART

![SiroFAST CONTROL CHART](image)

Fig. 3.2 Fingerprints of fabrics finished by different routes before dyeing and after final finishing

--- shorter finishing route
-------- longer finishing route

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 3.3.

The objectively derived data shows 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 measurement system (such as SiroFAST), quantitative determination of the effectiveness and optimum level of milling is difficult.
The case studies, in Chapter 5 illustrate some of the other areas in which SiroFAST has been used to improve or optimise finishing routes.

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 Life to be autoclave pleated

A wool fabric that has no shrinkage call rarely be successfully autoclave pleated (12). Autoclave pleating of wool fabrics require, 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 team is introduced the fabric panel relaxes, as a result shrinkage can occur. At the same tone, the moisture content of the fibres increases so there is a tendency for the fabric to (hygrally) expand as shown m Fig 3 4. To form good pleats, the shrinkage in the fabric, both across and alone the 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.

![Fig. 3.4 Dimensional changes in pleated panels in the autoclave](image)

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.

Relaxation Shrinkage (required) = 1.0 + 0.33 X 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 auloelave (50). Light-weight 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 pleating 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 re-imposed 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.

4. APPLICATION OF SiroFAST IN GARMENT MANUFACTURE

4.1 Introduction

The trends toward increased use of lighter-weight fabrics and greater levels of automation by garment manufacturers, among other reasons, means that fabric objective measurement is becoming a necessary part of garment manufacturing.

The conversion of increasingly light-weight fabrics into high quality garments is more difficult because of the inherent properties of those fabrics. With decreasing operator intervention in automated garment manufacturing potential problems are compounded.

SiroFAST is used at various stages in garment manufacturing.

Evaluation of sample fabrics - Sample lengths can be evaluated for potential tailoring problems.

Checking bulk deliveries - The properties of bulk deliveries, particularly the first bulk delivery, can either be monitored or checked against specification.

Problem solving - SiroFAST can be used to locate the cause of fabric related difficulties in garment manufacture and garment appearance. In many cases, garment manufacturers can identify the symptoms of a problem, but for action to be taken it is essential that the cause of the problem (rather than the symptom) is determined.

Planning modified manufacturing techniques The range of dimensional and mechanical properties that can be imparted to a fabric by fabric manufacturers is limited by demands placed on fabric handle or required performance characteristics. This may mean that certain fabric properties are not optimised for desired garment appearance. In these situations consideration must be given to an acceptable compromise. Garment manufacturers must be able to identify the undesirable fabric property so that the appropriate care or process changes can be made.

4.2 Buying Control and Fabric Specification

SiroFAST is used by garment manufacturers to predict performance in garment manufacture and to compare the properties of incoming fabrics against specifications. Normally the major emphasis of testing is on identifying fabrics most likely to cause problems. This can only be done using experience gained from measurement of existing fabrics and by testing and categorising new fabrics (59,60).

When fabrics are tested to predict (heir performance, prior information about similar fabrics' use in related designs is of great assistance in determining appropriate SiroFAST limits. This is particularly important when the evaluation indicates that the garments require extra processes (and time) that must be included in costing.

In many cases, the limits applied to the SiroFAST measurements can result in different actions being taken by garment makers. The following examples from a Japanese garment maker (56) demonstrates actions that have been used in response to varying values of warp extensibility (Table 4.1). These values were originally measured using the KES-F system but have been converted to approximate values obtained using SiroFAST (25). Table 4.1 shows that there is a range in which no problems are created in garment manufacture. Above and below the problem free zone, appropriate warnings are issued to avoid problems when the fabric is made into garments.
TABLE 4.1
Actions used by Japanese Garment Maker in Response to Variation in Fabric Warp Extensibility

<table>
<thead>
<tr>
<th>Extensibility</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extensibility &gt; 5.4</td>
<td>Claim cost of refinishing against supplier</td>
</tr>
<tr>
<td>4.0 &lt; Extensibility &lt; 5.4</td>
<td>Do not use cloth's reading machine</td>
</tr>
<tr>
<td></td>
<td>Care not to stretch on ironing table</td>
</tr>
<tr>
<td></td>
<td>Confirm dimensions after evaporation</td>
</tr>
<tr>
<td>1.8 &lt; Extensibility &lt; 4.0</td>
<td>No action required</td>
</tr>
<tr>
<td>Extensibility &lt; 1.8</td>
<td>Puckering risk</td>
</tr>
<tr>
<td></td>
<td>Be careful not to shrink seam if differential feed mechanism is used</td>
</tr>
<tr>
<td></td>
<td>For curved seam panel, stretch the outer pan of the seam allowance by ironing</td>
</tr>
<tr>
<td></td>
<td>Confirm that no puckering has occurred 24 hours after pressing</td>
</tr>
</tbody>
</table>

 Derived from ref (56)

This company, outside of specified limits, has determined that with their level of operator expertise, types of machine, and garment designs, they are unable to construct a garment with the desired appearance or at the required price. The options available are to either reject the fabric or have the fabric sent back for refinishing.

4.3 Fabric Properties and Garment Design

Fabric properties should always be considered in conjunction with garment design and fashion requirements. Choice of the appropriate fabric for a given design depends on both the warp and weft properties.

Many garments are designed such that the values of fabric properties in one direction are more important than in others. For example, in structured jackets, properties such as formability are more important in the warp direction than the weft, simply because there are more seams in that detection.

SiroFAST's limits can be altered to recognise these different requirements. Three items of apparel, jackets, trousers, and skins, present different problems in manufacture and require different fabric properties. For example, limbs on trouser fabric that goes into a design with baggy legs, bras cut long seams and a gathered waist, can be different to a lightweight, patterned fabric intended for a high quality structured jacket.

The discussion of these garment types is generalised as there are a number of design variables within each item that will involve changes in the limits of different fabric properties.

4.3.1. Jacket

A structured jacket is probably the most of materials such as interlinings to obtain the complicated of apparel items. It has a variety desired shape and appearance. Figure 4.1 shows the of curved and straight seams and uses a variety general form of a jacket.

Fig 4.1 Exploded view of jacket panels
An important design consideration of a jacket is the three dimensional shapes associated with the shoulders and sleeve head. In order to form the smooth contours required in this complicated shape and create pucker-free seams when the sleeve is attached, the fabric will be deformed in shear, extension and bending. In addition it will be overfed into seams (52). The important fabric properties in these operations are shear rigidity, extensibility and formability.

At the sleeve head in a jacket, a small amount of relaxation shrinkage in the fabric is also an advantage. This enables the garment manufacturer to shrink out the extra fullness and distortions in the sleeve head during pressing. The side, back and sleeve seams in a jacket tend to run in the warp or off-warp direction and therefore will be affected by the warp formability to varying degrees.

The design of a jacket incorporates areas of localised stiffening where interlining is either sewn or fused. If the interlining is to be fused then both the relaxation shrinkage and hygral expansion of the shell fabric are important. As will be discussed further in Section 4.4, a degree of compatibility between the dimensional properties of the shell fabric and the interlining is required. This is such that a change in the dimensions of the shell fabric does not result in bubbling or delamination of the fusible interlining.

Table 4.2 shows the amount of shrinkage a fused fabric has undergone and also the same fabric that has not been through the fusing press (63,64). It is evident that fused panels behave differently to unfused fabric.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Fused with interlining</th>
<th>Fused without interlining (a)</th>
<th>Not fused</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fusing Press</td>
<td>0.5</td>
<td>3.3</td>
<td>-</td>
</tr>
<tr>
<td>Hoffman Press</td>
<td>0.5</td>
<td>0.7</td>
<td>3.0</td>
</tr>
<tr>
<td>Total shrinkage</td>
<td>1.0</td>
<td>4.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

(a) fabric panel passed through the fusing press without fusible interlining attached. Shrinkage to %.

Jackets made from fabric with excessive hygral expansion, and incorporating fused interlining, have other potential problems. As can be seen in Figure 4.2, in a high humidity environment, high hygral expansion in the fabric can impair the appearance of a jacket around areas where an interlining has been fused (14).

The rear view of this jacket shows an area next to the vent where an interlining has been fused. This region, which is less able to change its dimensions because of the fused interlining, shows considerable distortions as the surrounding fabric tries to expand in response to an increase in relative humidity. The same constraint on fabric dimensions and the resultant distortions can be seen in parts of the back and side seams. Ideally, the design of the jacket from a fabric with high hygral expansion should incorporate changes to avoid these appearance problems.

As a result of the critical nature of jacket dimensions, for example the chest, shoulder, sleeve and length of garment, the relaxation shrinkage of the fabric is important. However, in some casual styles a may be possible to use fabric with a higher level of relaxation shrinkage.
In summary, the following fabric properties must be taken into account in the design of jackets to avoid problems in manufacture and to ensure good appearance:

- Excessive shear rigidity
- Inadequate extensibility and formability
- Excessive hygralexpansion
- Excessive or inadequate relaxation shrinkage

While each of these situations would create problems or require extra care in the production of jackets, the list is not exhaustive and other examples of properties that can be important in jackets and other garments will be covered in section 4.3.2 and section 4.3.3.

4.3.2. Trousers

The most critical areas in trousers are the long seams down the leg, the crutch and the waistband area. In certain designs, the leg seams will run in the warp direction in a proportion of the length. In this case, the warp formability and extensibility of the fabric are important. However, if the seam is cut slightly on the bias then warp formability becomes less important because fabric extensibility increases when the direction of the seaming deviates from the yarn direction (2).

The waistband region is more dependent on the weft properties of the fabric (extensibility and formability). In trousers, high weft extensibility can enhance the comfort of the garment by providing an allowance for body movements. However, design features, such as gathering at the waist will affect the importance of the weft properties.

Trousers do not have the complicated three dimensional shapes of a jacket but tend to have simpler curves. For this reason, the shear rigidity is less important but can still influence the appearance of bias cut seams.

The limits for relaxation shrinkage of trouser fabric will depend on the sizing range. Warp relaxation shrinkage has a large effect on leg dimensions. An option for design using fabrics with high relaxation shrinkage is allowing for the extra shrinkage in pattern cutting. This can extend the acceptable limits of relaxation shrinkage if fabric width permits. In addition, excessive warp hygral expansion can create appearance problems along the leg seams. However, designs that incorporate baggy legs and gathered waist may be less sensitive to high weft relaxation shrinkage than more conventionally cut trousers.

4.3.3. Skirts

Skirts tend to have the simplest design of the three garments discussed but, due to the variation in styles, problems can still result from inappropriate values of critical fabric properties. As in the case of trousers there is often a long seam that runs in the warp direction and, therefore, the warp formability can be important. An example of the type of problems that can occur as a result of low formability in the side seams of a skin is seen in Figure 4.3. In this case, the seam pucker can be seen along the side seats and zipper.

Designs for skirts front fabric with low formability should avoid such seams, Weft formability rim influence the appearance of the waistband seam.

The warp extensibility of a fabric used for a skirt can influence the hem line. If the warp extensibility is excessive then the hem may hang unevenly. Problem hemlines may be even more serious for a skirt that is cut on the bias. This is because fabric is most extensible in the bias direction. In this case, the shear rigidity can be used to predict potential problems.
The effect of dimensional stability of skirting fabric is similar to that in trousers. The relaxation shrinkage affects length and waist size while hygral expansion will affect the appearance of seams when the garment is exposed to high humidity.

Dimensional stability of the fabric is most critical when the skirt panel is autoclave pleated. This is because there a requirement when producing either knife or box pleats for the fabric to shrink a small amount during the autoclave setting process (section 3.3).

It must be appreciated by the garment designer that in pleated skirt and jacket combinations, if the fabric has a hygral expansion greater than approximately 5%-6%, then the relaxation shrinkage requirements for pleating may be more than those needed (or good performance in the manufacture of jackets. In this case, there are conflicting requirements for the pleated skirt and the jacket.

The obvious design consideration for the pleated ensemble is to use only those fabrics where the hygral expansion of the fabric is less than 5%. This, however, excludes many piece-dyed pure wool fabrics. There are other options for both the fabric and garment manufacturer to resolve this dimensional stability conflict that are covered in Section 3 and Section 4.

4.4 Selection of Interlinings

Fusible interlinings tie widely used in the manufacture of structured garments. It is important that there is a degree of compatibility between the shell fabric and interlining to prevent distortion of the fused panel during garment storage or wear.

This is especially important (61-62) when an interlining as fused with a shell fabric of a jacket (eg. lapels, chest area, pocket flaps, vents etc). If the difference in dimensional stability is too great then surface distortions or even delamination can occur. If the shell fabric has a formability high enough to accommodate the shrinkage of the fusible, then surface distortion can be minimised. Generally we recommend that fusibles be selected that have less than 2% difference in shrinkage relative to the shell fabric (55).

The adverse effects associated with inappropriate matching of interlining and fabric may not be visible during the final assembly and pressing of the garment, but become apparent after dry cleaning when the dimensional changes of a wool fabric or interlining may reach a maximum.

Other investigations on fused composite performance have demonstrated that the bending properties of the fusible are important for garment appearance, and that the prediction of a suitable value for a given composite is possible (57,58). The shear rigidity of both fabric and interlining has also been found to be important during fusing. If the shear rigidities are too low it can be difficult to maintain the desired shape of the panel during the fusing operation (61).

4.5. Optimisation, Modification and Operations of Garment Manufacturing

The mechanical and dimensional properties measured by SiroFAST can, either individually or in combination, affect all major process stages involved in the production of garments. Table 4.3 shows some links between fabric properties and the garment process stages where problems may occur.

| TABLE 4.3 Operations in Garment manufacture affected by Fabric Properties |
|-----------------------------|------------------|------------------|------------------|------------------|------------------|
| FABRIC PROPERTIES          | Laying-up | Cutting | Fusing | Sewing | Pressing | Appearance |
| Relaxation Shrinkage        | X         |        | X      | X      |         | X          |
| Hygral Expansion            | X         | X      | X      | X      |         | X          |
| Formability                 | X         | X      | X      | X      |         | X          |
| Extensibility               | X         | X      | X      | X      |         | X          |
| Bending Rigidity            | X         | X      | X      | X      |         | X          |
| Shear Rigidity              | X         | X      |       | X      |         | X          |
| Thickness                   | X         |        |        |        |         | X          |

Note: Different designs and end uses can modify the range of appropriate values of a fabric property. This table is meant as a general indicator.
There are a number of options available to garment makers in modifying their manufacturing techniques to deal with difficult fabrics. These are listed below.

4.5.1 Relaxation Shrinkage

Some garment manufacturers, mainly in the USA, but also in fabrics to remove relaxation shrinkage. Sponging can have SiroFAST charts of Figure 4.4

![SiroFAST CONTROL CHART](image)

Chart A shows the desirable effect of sponging, namely, the reduction of a large relaxation shrinkage value. However, as can be seen in s. depending on the details of the processes used, sponging can be detrimental to fabric performance. Chart B shows a fabric that had more shrinkage after sponging than was originally present. Relaxation shrinkage was re-introduced by a subsequent atmospheric decatising operation. In addition the sponging operation can be so efficient that it removes all shrinkage. As mentioned earlier (Section 4.3), a small amount of shrinkage can be an asset in garment manufacture.

4.5.2 Hygral Expansion

To minimise the effect of hygral expansion a garment maker can construct the garment under conditions of high relative humidity as this will reduce the potential increase in dimensions during wear (13). The hygral expansion curve in Figure 4.5 shows the dimensional changes that occur between three different relative humidity values.

It can be seen from the curve in Fig 4.5 that for a fabric with a hygral expansion of 6.5 % the potential dimensional increase in an atmosphere of 90%, relative humidity can be more than halved if the garment is made up at 60% relative humidity (a in Fig. 4.5) rather than at 30% relative humidity to in Fig. 4.5). It is claimed that the progressive bundle method of garment manufacture allows more time for the fabric to absorb moisture after fusing because the fabric is in work for a longer time.
The pleating problems mentioned in 4.3.3, which result from inappropriate dimensional stability, can be reduced if the dimensional changes due to hygral expansion are limited. This is achieved by ensuring that the panel to be pleated is conditioned to a high relative humidity before it is put into the pleating papers and autoclave set. It is possible that differences in fabric moisture content are responsible for variations in the appearance of pleated panels from one day to another.

4.5.3 Formability

Inadequate formability increases the likelihood of seam pucker. However, because of the visco-elastic nature of the wool, the deformations may not appear immediately after sewing. A recent example (68) has shown that a jacket constructed from a 150 g/m² pure wool fabric with a warp formability of 0.2, did not pucker until after many weeks in storage.

If a garment manufacturer intends to modify sewing conditions to overcome the problem of seam pucker caused by low formability, the strategy must be either to reduce the in-plane compressive load on the fabric in the seam (53,54,65,67,69) or increase the stiffness of the seam (66). Five modifications to sewing that would help reduce in-plane compression have been suggested:

1. reduce the thread tension,
2. use an inextensible thread,
3. reduce the sewing thread diameter,
4. reduce the number of stitches, and
5. change the type of stitch used (chain or lock)

Another option to reduce seam pucker, in some garment designs, is to cut the panels slightly off the yarn axis. This would be most appropriate for garments made from a solid shade fabric and benefits from the fact that the extensibility of fabric increases when the direction of strain is not parallel to the warp or weft yarns.

4.5.4 Extensibility

Problems that are caused by excessive extensibility can often be avoided if the manufacturer is alerted that the fabric has high extensibility. Skills in handling stretch fabric must be used in laying-up and sewing highly extensible wool fabrics. Care is required to ensure that the fabric is neither distorted, stretched nor compressed as this can effect the final size of the cut panel, particularly in laying-up. An example of this problem is included in the case studies of Section 5.

The sewing of long seams in patterned highly extensible fabric can result in poor pattern matching unless additional care or suitable manufacturing techniques are used. This may be in the form of extra notches in the fabric for matching the panels or the use of fusible tapes on difficult seams. Whatever modification is made, it is usually at the expense of speed which may have to be costed into the garment.
If the problem is low extensibility, fewer options are available to the garment manufacturer. Low extensibility, as opposed to low formability, tends to affect those operations where the fabric has to be "eased" and moulded as in overfed seams. More care and time are normally required to form these fabrics.

It has been demonstrated (32) that automatic overfeed sewing machines cannot maintain constant levels of overfeed in a seam if there is a variation in fabric extensibility. As mentioned in the section on formability, where the garment design permits, the problem can be reduced by designing the seams slightly off the direction of warp and weft.

4.5.5 Bending Rigidity

Low bending rigidity is normally not a major problem to most garment manufacturers. However, fabric with low bending rigidity may also have low formability and as a result be prone to seam puckering. Problems when cutting fabrics with low bending rigidity can be overcome by using a vacuum table, as this effectively makes all fabrics more rigid. Problems may become more serious if the fabric is handled by automated machinery as both picking up and laying down of garment panels can be difficult with a fabric that bends easily. At present there is no viable solution to such problems.

4.5.6 Shear Rigidity

As shear rigidity has a large effect on fabric drape, it will affect garment appearance. Hence shear rigidity must be an important component of the garment design. However shear rigidity will also affect fabric performance in garment manufacturing.

Problems associated with inadequate shear rigidity are normally overcome with extra care requiring more time. Fabric with low shear rigidity may need special attention, for example pinning during laying up to stabilise the fabric. Extra care may also be required to avoid distortions when mounting shell fabric to fusible interlinings (61).

If the shear rigidity is too high then the fabric will not readily form smooth three dimensional shapes as required in a jacket around the shoulder and sleeve head (70). In many cases, problems in this area can be overcome with additional work and attention during pressing.

4.5.7 Surface Thickness and Released Surface Thickness

Poor finish stability can cause problems for the garment maker if distortions in the fabric, caused during finishing (e.g. rig and running marks), reemerge when the garment is pressed or stored. There is little a garment manufacturer can do with an unstable surface finish. Repressing cannot produce finishes that are stable to high relative humidity and dry cleaning.

5. CASE STUDIES OF THE USE OF SiroFAST IN FABRIC AND GARMENT MANUFACTURE

5.1. Evaluation of New or Alternative Finishing machinery or Technology

EXAMPLE 1. Comparison of alternative decatising machinery.

A large vertical fabric manufacturer was seeking to re-equip the finishing mill and replace the conventional batch decatising (open blowing) machines with the latest continuous decatising equipment. This would allow the mill to gain the economic advantages associated with the newer continuous technology.

There are two alternative types of continuous decatising machine, those that blow steam through the fabric and those that spray water onto fabric or an interleaved wrapper generating steam during the process. The finisher's greatest concern was to produce uniform fabric within tight specifications for relaxation shrinkage using a continuous decatising operation.

Samples of the contract cloth were finished using the alternative decatising machines and tested using SiroFAST. Evaluation of the fabric fingerprint obtained from the SiroFAST tests (shown in Fig 5.1), indicated that samples with the traditional batch-decatised finish and continuous process A had lower
relaxation shrinkage than fabric finished with continuous process B. Presumably the differences in the relaxation shrinkage reflected differences in tension control in the machines. As expected, the continuous processes had little effect on hygral expansion.

Comparison of the finished thicknesses of the fabric samples indicated that there was little difference in the amount of 'press' imparted by the different machines. The traditional batch decatising produced a slightly thinner fabric. However, comparison of overall and surface thickness of the variously-decatised fabrics, before and after release in steam, indicated that the stability of the finish imparted by the traditional batch process was greater than that imparted by either of the continuous processes (which were approximately equivalent).

In this particular instance, the fabric's dimensional stability and handle were considered to be the most important fabric properties. Using these criteria, there was little to choose between the batch and continuous decatised fabrics (A). Using the objective data, the finisher could choose one continuous decatising machine over the other and be confident that the economic advantages associated with the new machinery would not be offset by a significant deterioration in fabric quality.

In the United States, sponging is widely used to both control the relaxation shrinkage of fabrics and ensure that the fabrics delivered to the garment maker have appropriate dimensional stability. In this situation, the criteria for selecting new decatising machinery would have been different. In the United Kingdom, sponging is not widely practised and finishers have to meet much tighter requirements on fabric relaxation shrinkage.

EXAMPLE 2. Evaluation of the Merits of Chemical Setting

In Europe the aqueous chemical setting of wool in continuous crabbing machinery is widely practised to relax and flat set fabric during wet processing. Chemical setting can be used to stabilise loom state fabrics after weaving or to flat set fabric after rope processing in order to remove any running marks that may have formed. The process is not normally used on ecru fabrics since any unevenness in the setting may cause uneven dye uptake during piece dyeing.

SiroFAST was used to compare the effect of conventional continuous crabbing with a chemically assisted process (using Angra 338Rotta) on samples of melange flannel fabric that were subsequently dry finished by two alternative methods. When the fabric was finished by a method that did not impart further permanent set
to the fabric (dry, crop, semidecalise under mild conditions), there were significant differences between the differently crabbed fabrics (Fig. 5.2).

The chemically set fabric had superior flat stability and a softer handle, illustrated by the lower shear and bending rigidity of the fabric. Residual distortions (from the previous milling process) in the relaxed fabric were significantly reduced. Balanced against these improved properties was the higher hygral expansion and extensibility of the fabric in the weft direction, both of which remained within the limits normally recommended for a men's suiting fabric. The increase in hygral expansion (and extensibility), produced by permanent setting of wool fabric, has been known for many years and the mechanism has been explained in several publications (12).

When finished by a route that imparted some permanent set to the fabric (dry, crop, rotary press, pressure decatising), the differences between the differently prepared fabrics were dramatically reduced. The flat stability of all fabrics were high, as would be expected after pressure decatising (Table 5.2). The differences in relaxation shrinkage and mechanical properties were small. Only the differences in weft extensibility and hygral expansion remained the same. Obviously, the pressure decatising operation effectively masked most of the effects of prior processing.

SiroFAST can be used to quantify the differences associated with finishing routines and alert the garment maker to any potential problems associated with the fuller, softer finish produced by chemical setting. The information obtained using SiroFAST also warns the finisher that the softness imparted in chemical setting can be removed in later dry finishing operations.

### TABLE 5.2 Properties of a Chemically-set Wool Fabric

<table>
<thead>
<tr>
<th>Finish Setting</th>
<th>Wet Setting</th>
<th>Chemset</th>
<th>Contset</th>
<th>Pressure Decatised</th>
<th>Chemset</th>
<th>Contset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relaxation Shrinkage</td>
<td>- warp</td>
<td>2.1</td>
<td>2.1</td>
<td>1.7</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- weft</td>
<td>1.2</td>
<td>1.2</td>
<td>1.1</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>Hygral Expansion</td>
<td>- warp</td>
<td>3.2</td>
<td>4.1</td>
<td>3.0</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- weft</td>
<td>3.3</td>
<td>5.6</td>
<td>4.5</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>226</td>
<td>244</td>
<td>224</td>
<td>229</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formability</td>
<td>- warp</td>
<td>0.39</td>
<td>0.48</td>
<td>0.38</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- weft</td>
<td>0.63</td>
<td>0.97</td>
<td>0.75</td>
<td>1.02</td>
<td></td>
</tr>
<tr>
<td>Extensibility</td>
<td>- warp</td>
<td>2.1</td>
<td>2.4</td>
<td>1.4</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- weft</td>
<td>4.0</td>
<td>5.6</td>
<td>4.3</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td>Bending Rigidity</td>
<td>- warp</td>
<td>13.0</td>
<td>11.3</td>
<td>13.0</td>
<td>13.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- weft</td>
<td>10.6</td>
<td>10.2</td>
<td>9.8</td>
<td>9.7</td>
<td></td>
</tr>
<tr>
<td>Shear Rigidity</td>
<td>43</td>
<td>43</td>
<td>43</td>
<td>42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness</td>
<td>overall</td>
<td>0.89</td>
<td>0.83</td>
<td>0.51</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td></td>
<td>surface released</td>
<td>0.30</td>
<td>0.27</td>
<td>0.08</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>speed</td>
<td>1.15</td>
<td>1.04</td>
<td>1.04</td>
<td>0.63</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Contset - Crabbed in a Hemmer comfortab at 8 m/min, drum temperature 120°C
Chemset - As above including Angora 338 (Rotta) in the wetout bath
5.2 Optimising Finishing Operations


This case study concerns a major fabric producer who had been producing a lightweight (170 g/m), solid shade fabric by a piece-dyed route for many years. The decision was made to produce the fabric by a colour-woven route to avoid sending the fabric out for piece dyeing and to ensure continuity of shade.

This particular pure wool fabric was a popular style and would be associated with big runs. However, when the fabric was sent to the regular customers for men's jackets they found they could not make it up; the problem was puckering of the straight seams, puckering in the overfed side seams and difficulties in pressing.

SiroFASTI was used to determine the cause of the colour-woven fabric's tailoring difficulties (Fig 5.3). It was found that the colour-woven fabric had inadequate warp formability that was caused by very low warp extensibility. The piece-dyed fabric had, on the other hand, a much higher extensibility (and formability) in both warp and weft directions.

With the cause of the problem identified, it was simply a matter of implementing standard finishing practices to increase the warp extensibility of the colour-woven fabric. Extensibility was increased by increasing the amount of permanent set imparted to the fabric. This reduced yam interaction and increased the crimp in the warp yams of the fabric. Permanent setting of the fabric was increased by crabbing the fabric using a chemical setting assistant. Care was also required to minimise warp tension during the crabbing operation and in later dry finishing.

5.3 Engineering Fabrics to Customer Requirements

EXAMPLE 1. Engineering the properties of a wool-blend crepe to the requirements of the customer. The example of engineering a pleating finish on wool fabrics was given in chapter 3. This case study describes engineering fabric properties for another reason.

A manufacturer of medium to high quality fabric was trying to produce a wool-polyester crepe for the manufacturer of ladies dress goods that included jackets and both straight and pleated skins. A similar quality fabric from another fabric manufacturer was being used. When a sample was supplied, (a standard quality wool-blend crepe), the garment maker had difficulties with the fabric.
Aesthetically the garment from the new fabric was inferior to that produced from a competitive product. A comparison was made between the crepe that gave a ‘poor’ appearance and the acceptable crepe. SiroFAST was able to demonstrate that there were many differences between the fabrics.

The important difference seemed to be relaxation shrinkage. This property is known to be especially important for pleating, but also appeared to be contributing to the appearance of the unpleated garments as well. It was found that the problem fabric had very low relaxation shrinkage.

When the relaxation shrinkage of the fabric was increased the appearance of the garment improved dramatically. The production of a now acceptable fabric meant additional sales for the mill and demonstrated that, using SiroFAST, they were able to engineer particular fabric properties for their customer.

5.4 Problem Identification in Garment Manufacture

EXAMPLE 1. Identification of the cause of shrinkage during garment manufacture.

A European garment manufacturer ordered a new quality of fabric for men's jacketing from a UK fabric manufacturer. Problems were encountered with shrinkage during making up. The decision was taken by the garment manufacturer to send the first delivery of the fabric to a sponger on the assumption that the fabric could be put into work with minimal delay.

When the first delivery arrived after sponging it went straight into work and it was not until the first garments came off the line that it was noticed that shrinkage had still occurred. At this point the fabric manufacturer used SiroFAST to determine if there was excessive relaxation shrinkage in the fabric.

The chart created using SiroFAST (Fig. 5.4) showed that the fabric did not have excessive relaxation shrinkage and the only property that could have created problems during garment manufacturing was high warp extensibility.

This property may give the symptoms of high shrinkage if the fabric is stretched during laying up. As next order of the fabric was ready to go out, it was suggested that the fabric should be stretched in the warp direction and given an additional pressure decatising treatment to reduce the extensibility in the warp direction and stabilise the changed dimensions. The fabric processed with no problems.
For future production of this fabric it was necessary to change procedures to prevent fabric with high warp extensibility going to this particular customer, even though the same quality fabric with the same properties was being used with no complaints by other garment manufacturers. The causes of the high levels of warp extensibility was high weft extension and overfeed during drying. By weaving the fabric slightly wider, to reduce the need to pull the fabric out as much in the weft, and reducing the overfeed setting on the stenter, all future batches had the appropriate level of warp extensibility to satisfy the new customer.

This example demonstrates the importance of being able to identify the cause of a problem in garment manufacture and not just the symptom. This allowed a simple and quick remedy to be effected.

EXAMPLE 2. Identification of the cause of seam pucker in garments.

Due to supplier delays and delivery schedule a UK garment manufacturer was committed to an order of fabric for a ladies’ jacket. The first batch of jackets made up well and no problem was met with during construction. However, after final pressing and storage the garments developed severe seam pucker and were considered to be of seconds quality.

Further pressing did not remove the seam pucker and the garment manufacturer was unable to locate the cause of the pucker. The fabric was evaluated by SiroFAST to determine the cause of the seam pucker.

The SiroFAST chart in Fig. 5.5 shows the properties of the fabric.

It can be seen that there were borderline low values for weft formability, weft bending rigidity and shear rigidity, but the property that seemed most likely to cause the problem was the negative value of warp relaxation shrinkage. When it was relaxed during the final pressing, the fabric increased in warp dimensions. The expansion was evidently sufficient to exceed the ability of the fabric to contain the additional in-plane loads and the seams puckered.

The garment manufacturer addressed this problem by relaxing the fabric in steam before cutting and making up. Figure 5.5 also shows the SiroFAST chart of the steamed fabric in which the problem of negative relaxation shrinkage was corrected.

Other mechanical properties were also changed by steaming, but not in a way expected to impair seam performance. The fabric after atmospheric steaming was made up without seam pucker.
This is an example where the cause of a problem was not obvious, but after SiroFAST had been used to identify the problem, a simple corrective procedure could be implemented.

CONCLUSION

SiroFAST, or Fabric Assurance by Simple Testing, is a set of instruments and test methods for the measurement of those properties that relate to the performance of fabrics in garment manufacture and appearance of garments after manufacture and in wear. It was developed by the CSIRO Division of Wool Technology to meet industry's need for a simple, reliable method for predicting the performance of fabric before it is made up.

The SiroFAST system is simple to use, robust and gives a reliable prediction of performance. As the time required for testing is short, SiroFAST is highly suitable for use by fabric and garment manufacturers.

During its introduction into Europe and the US, SiroFAST has proved to be a valuable tool in many aspects of fabric and garment manufacture including quality control, problem solving and product development. However, it is finding an ever increasing range of applications in all aspects of fabric production and use.

The greatest value of the system may prove to be in encouraging communication between fabric and garment manufacturers by allowing the exchange of objective information on performance of fabrics and removing some of the subjectivity from discussions and disagreements.

ACKNOWLEDGMENTS

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Appendix I

To determine the repeatability (and reproducibility) of the SiroFAST instruments and the measurement procedures, a series of round trials were carried out (76,77). These trials took the same format as earlier trials on the KES-F instruments (71-73) where random samples of the same fabric were tested on different instruments.

The critical difference is the value above which the difference between separate fabrics is statistically significant (95% confidence). The data in the Table 2.3 is based on the number of samples recommended in the SiroFAST manuals.

The number in parenthesis is the critical difference expressed as a percentage of the mean value for the samples included in the trial (77).

The most recent round trial of the SiroFAST instruments, encompassing a greater range of fabric properties, achieved values similar to those in Table 2.3 (76). The results of this trial indicated there was a good correlation between the mean and standard deviation of some of the measurements. This means that the critical differences will be smaller for small values of some of the individual fabric mechanical properties.

Table 2.3 Critical Differences for Measurements on SiroFAST Instruments

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Measurement</th>
<th>Within Lab</th>
<th>Between Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thickness at 2 g/cm² (mm)</td>
<td>0.016 (3.2)</td>
<td>0.031 (6.2)</td>
</tr>
<tr>
<td>SiroFAST-1</td>
<td>Thickness at 100 g/cm² (mm)</td>
<td>0.008 (1.9)</td>
<td>0.024 (5.7)</td>
</tr>
<tr>
<td>ShroFAST-2</td>
<td>Bending Length (mm)</td>
<td>0.060 (3.5)</td>
<td>1.13 (6.7)</td>
</tr>
<tr>
<td>SiroFAST-3</td>
<td>Extensibility-warf/weft(%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>at 5 g/cm</td>
<td>0.13 (30.2)</td>
<td>0.35 (81.4)</td>
</tr>
<tr>
<td></td>
<td>at 20 g/cm</td>
<td>0.15 (13.0)</td>
<td>0.46 (40.0)</td>
</tr>
<tr>
<td></td>
<td>at 100 g/cm</td>
<td>0.2A (8.5)</td>
<td>0.61 (21.6)</td>
</tr>
<tr>
<td></td>
<td>Ext(20)-Ext(5)</td>
<td>1.09 (12.5)</td>
<td>0.17 (23.6)</td>
</tr>
<tr>
<td></td>
<td>Extensibility-bias (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>at 5 g/cm</td>
<td>0.27 (7.5)</td>
<td>0.84 (23.5)</td>
</tr>
<tr>
<td>SiroFAST-4</td>
<td>Relaxation Shrinkage (%)</td>
<td>0.38</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>Hygral Expansion (%)</td>
<td>0.60</td>
<td>0.91</td>
</tr>
</tbody>
</table>
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