Part III

Effect of processing on fabric hand

9
Effect of wet processing and chemical finishing on fabric hand

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9.1 Introduction

Hand or handle is an elusive quality of fabric that is usually defined as the subjective assessment of a textile material obtained from the sense of touch. For subjective assessments, the terms silky, soft and smooth are the most frequently used descriptors. Among other descriptors are scroopy, beefy, bouncy, lively and dead. These subjective descriptors have evolved from people's attempts to describe the feel of the fabric on their hand. Techniques for objectively quantifying hand have been developed from measurement of an array of physical properties and correlation of these objective measurements with human subjective assessments. These techniques are discussed in detail in other chapters of this book. Many factors contribute to hand, for example the influence of fiber, yarn and fabric construction, and dyeing and finishing. The fiber, yarn and fabric construction factors are covered in other chapters, so the effect of dyeing and finishing will be the focus of this chapter.

The hand of most greige woven and knitted fabrics will not resemble the final hand of the dyed and finished end product; they must be wet processed before they are suitable for their intended use. The hand of greige fabric is the product of the woven or knitted construction plus the presence of non-fibrous materials. Subsequent wet processing steps remove the non-fibrous materials and alter the construction. The basic steps in wet processing are preparation, dyeing and finishing. The sum total of all wet processing steps will impact the final hand of the fabric. In many cases, process conditions are chosen to achieve the desired final hand.

9.2 Dyeing and finishing

Wet processing is the term used to describe the post web formation steps required to produce finished fabrics. The term dyeing and finishing is synonymous with wet processing and incorporates fabric preparation under its umbrella.

9.2.1 Fabric preparation

Preparation is the wet processing steps that ready a fabric for dyeing and finishing. The purpose is to remove all of the non-fiber materials that interfere with dyeing and finishing. The contaminates range from fiber spin lubricants, waxes, pectin, and wool grease to warp size, machine lubricants and mill dirt. Inadequate removal will adversely affect the quality of dyeing and finishing. In many cases, the cause of poor quality dyed goods can be traced back to poor preparation.

Desizing, scouring, and bleaching are the steps used to prepare most woven fabrics. The desizing step is designed to remove the polymeric warp size. Many woven fabrics, especially those made from spun yarns, require a warp size for efficient weaving. The size is a protective coating applied to the warp yarns and is a usually a combination of film forming polymers and waxes. The most commonly used film formers are starch and/or polyvinyl alcohol. Desizing is accomplished in three stages: apply the appropriate chemicals, provide time and temperature to promote chemical reaction, and finally, wash away the soluble by-products.

Scouring removes waxes, oils, grease and dirt. Cotton yarns contain waxes and pectin, wool yarns contain wool grease, and synthetic yarns contain fiber spin finishes. Additionally the rolls of fabric may be soiled by the way they are handled in the mill. The scouring step involves applying a detergent composition, providing time and temperature to loosen the soil, and finally washing away the contamination.

The bleaching step is designed to chemically degrade color bodies inherent in the fiber. Bleach chemicals can also cause fiber degradation so the choice of bleach, time and temperature will be a balance between desired whiteness and minimizing fabric strength loss. The most widely used bleach is hydrogen peroxide because it is much milder to both wool and cellulosic fibers. Full bleach is the goal for fabrics to be sold as white goods. For dyeing pastel shades, partial bleaching is often enough because it is important to have a consistent white base, to minimize shade variations between dye lots.

Knitted fabrics differ from woven fabrics in that they do not contain warp size, therefore scouring and bleaching alone will be sufficient. Fiber spin lubricants, knitting machine oils and mill dirt are the major components of the contamination to be dealt with.

Fabric handling

The way fabrics are handled in wet processing will have an effect on fabric hand. There are batch machines and continuous ranges that are used to prepare and/or dye fabrics. Additionally, these machines are specifically designed to process the fabric in open-width or rope form. Lot size, final fabric properties and costs are some of the criteria used to decide which method to use. In terms of fabric properties, fabrics processed open-width are under tension in both the warp and filling directions, so shrinking is minimized. Fabrics processed in rope form, especially in batch machines, are more relaxed, so shrinking can occur. This phenomenon is used to develop bulk in fabrics made from textured yarns and in certain woolen fabrics.

9.2.2 Dyeing

There are two ways of coloring textiles – dyeing (getting the colorant into the interior of the fiber) or pigment dyeing (anchoring the colorant onto the fiber surface). There are many technical details to consider when deciding how to dye a fabric. Some of these are the fiber(s) to be dyed, shade, fastness properties, reproducibility and cost. This chapter will focus on only those details affecting fabric hand. In general, the dyestuffs and auxiliaries used in conventional dyeing have little or no impact on fabric hand. These dyes penetrate the fiber cross-section and the auxiliaries are rinsed away. However, colorants used in pigment dyeing or printing require a binder for fixing them onto the fiber surface. The binder will stiffen the hand. For conventional dyeing, the biggest impact on hand is brought about by how the fabrics are handled during the dyeing process.

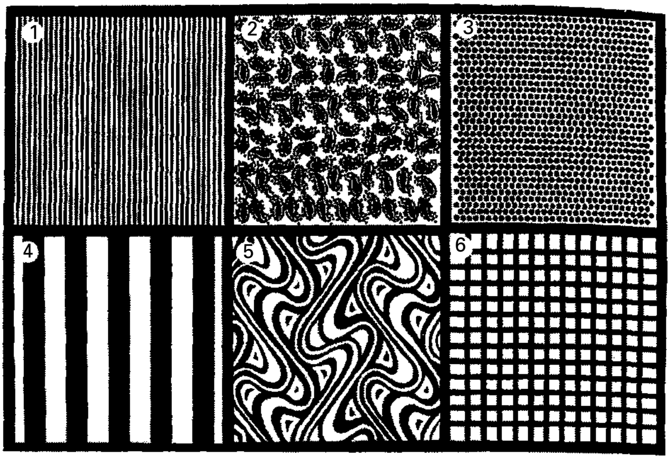
Robinson *et al.* [1] studied the effect of pattern design and fabric type on the hand characteristics of pigment prints. The study was conducted on two cotton fabrics printed with two pigment types in six designs. The analyses of the hand characteristics were evaluated by a trained descriptive panel to evaluate the effects of pattern design, color, and fabric type.

Fabrics used in the study

Two bleached 100% cotton fabrics were selected for this study – an Egyptian shirting fabric and an interlock knit. The shirting had a fabric count of 78 ends × 72 picks per 2.5 cm (or 25 mm), a thickness of 0.188 mm (0.0094 in), and a weight of 111.53 g/m^2 (3.29 oz/yd^2). The knit fabric had 36 wale and course loops per 2.5 cm, a thickness of 0.656 mm (0.0328 in), and a weight of 195.93 g/m^2 (5.78 oz/yd^2). Samples of the shirting and knit fabrics were cut to 35 cm × 67.5 cm with the long dimension parallel to the warp direction.

Pattern design

The six 25 cm × 25 cm pattern designs we developed for this study are shown in Fig. 9.1. All patterns had 50% coverage of the printed area, except for the paisley design, which had 40% coverage. Flatbed screens containing



9.1 Patterns (25 × 25 cm) used in study: (1) 3.2 mm wide stripes, (2) paisley, (3) 6.4 mm diameter dots, (4) 25.4 mm wide stripes, (5) swirl, and (6) checks with 6.4 mm wide crossed stripes. *Source:* 'Influence of pattern design and fabric type on the hand characteristics of pigment prints', by K.J. Robinson, E. Chambers and B.M. Galewood, from *Textile Research Journal,* vol. 67, no. 11, p. 837, 1997. Copyright Sage Publications.

a 109-mesh polyester fabric were prepared for each of the designs using Ulano® water resistant screen emulsion coating.

Print paste preparation, printing, and curing

Preliminary experiments with a variety of pigment print pastes led to the selection of two print paste formulations containing either C.I. Pigment Blue 15:3 or C.I. Pigment White 6 (see Table 9.1). White and blue print pastes were selected to examine the influence of print color on the panelists' evaluation of hand. C.I. Pigment White 6 contained dioxide (TiO_2), which is a harder, more crystalline compound than C.I. Pigment Blue 15:3, a commercially important phthalocyanine pigment. Compared to the blue pigment, a higher concentration of the white print pigment was needed to obtain adequate cover.

The print pastes were prepared by placing water in a 600 ml beaker and slowly adding the thickener while mixing with a high speed mechanical mixer for 10 minutes. Next, the auxiliary crosslinker was slowly added, followed by the binder and pigment, with a 10-minute mixing period after each addition, giving a total mixing time of 40 minutes. The viscosities of the white and blue print pastes ranged from 23,120 to 23,360 cps and from 20,240 to 20,400 cps, respectively.

The cotton fabric specimens were printed on a flatbed machine, using one

Table 9.1 Print paste formulation

Components	Amount (g)	
	Print paste 1 (white)	Print paste 2 (blue)
Distilled water	419.80	426.00
Highfast carrier 06-59287[a] (thickener)	25.00	25.00
Highfast fixative 06-50251[a] (binder)	22.50	22.50
Inmount auxiliary binder 06-50627[a] (crosslinker)	4.00	4.00
Tiona TiO_2[b] (C.I. Pigment White 6)	28.70	
Highfast n. conc. Blue 3GB-61460[a] (C.I. Pigment Blue 15:3)		11.25
Total	500.00	488.75

[a]BASF Corporation
[b]SCM Chemicals.
Source: 'Influence of pattern design and fabric type on the hand characteristics of pigment prints', by K.J. Robinson, E. Chambers and B.M. Gatewood, from *Textile Research Journal,* vol. 67, no. 11, p. 837, 1997. Copyright Sage Publications.

pass with a 1.0 cm (width) × 50 cm (length) magnetic squeegee. Fifteen prints were made with each screen before washing to prevent screen logging. The printed fabrics were air dried at ambient temperature (~21°C), then assigned randomly to groups of 30 for curing. The samples were sewn together in a continuous chain with the warp in the lengthwise direction, attached to a leader fabric, then cured with dry heat at 160°C for 3 minutes. The printed fabrics were cut into 25 cm squares with the design in the center and conditioned in a standard atmosphere for textile testing (21 ± 1°C and 65 ± 2% RH).

Panel selection and orientation

In preparation for this study, the panelists received four hours of orientation to reacquaint them with the hand analysis procedures and fabric types. Orientation samples were taken from preliminary print paste experiments. During orientation, the panel members examined two unprinted fabrics and established consensus intensities for the measured attributes to be used as internal reference samples that provided panelists with a basis for consistent and reproducible evaluations. A complete set of previously evaluated fabric standards representing the realm of fabric types was also available to the panelists as a reference for attribute intensities requiring further delineation.

The 17 hand attributes evaluated in this study are given in Table 9.2. The definitions, methods of evaluating the attributes (except surface texture), and attribute categories were developed by Civille and Dus [2]. Geometric

Table 9.2 Definition of fabric hand attributes by Civille and Dus [2]

Attributes	Definition
Geometric characteristics	
Fuzziness	Amount of pile, fiber, fuzz on the surface
Graininess	Amount of small, rounded particles in the sample
Grittiness	Amount of small abrasive picky particles in the surface of the sample
Surface texture [a]	Impact of tactile awareness of a random or non-random pattern
Thickness	Perceived distance between thumb and fingers
Mechanical characteristics	
Force to gather	Amount of force required to collect/gather the sample in the palm
Force to compress	Amount of force to compress the gathered sample into the palm
Stiffness	Degree to which the sample feels pointed, ridged, and cracked, not pliable, round, and curved
Depression depth	Amount the sample depresses when downward force is applied
Fullness	Amount of material felt in the hand during manipulation
Compression resilience	Force with which the sample presses against cupped hands
Springiness	Rate at which the sample returns to its original position after depression is removed
Tensile stretch	Degree to which the sample stretches from its original shape
Hand friction	Force required to move the hand across the surface
Fabric friction	Force required to move the fabric over itself
Sound characteristics	
Noise intensity	Loudness of the noise
Noise pitch	Sound frequency of the noise

[a]Developed by The Sensory Analysis Center Panelists Kansas State University
Source: 'Development of terminology to describe the hand-feel properties of paper and fabrics', by G.V. Civille and C.A. Dos, from *Textile Research Journal* vol. 5, pp. 10–32+319, 1990. Reproduced with permission from *Textile Research Journal.*

characteristics included four attributes related to the feel of the fabric surface (fuzzy, grainy, gritty, and surface texture) and fabric thickness. Surface texture was measured by positioning the hand flat on the fabric and moving the hand back and forth over the surface, focusing awareness on the first three fingers.

The mechanical characteristics included 10 attributes related to compressibility (force to gather, force to compress, stiffness, and depression depth), fullness, resiliency (compression resilience and springiness), stretchability, and frictional properties of the fabrics. The third attribute category was sound properties and included the intensity and pitch of the noise made when rotating the sample gently in the palm held next to the ear. More extensive descriptions of the techniques for assessing each of the attributes are given by Civille and Dus [2]. A ballot containing 17 attributes was developed and the trained panelists were instructed to rate the degree to which each attribute was present in the printed fabric specimens on a scale from 0 (none) to 15 (high).

Results and discussion

The mean intensity scores for the 17 attributes on each of the six designs for the pigment printed cotton knit and shirting fabrics are shown in Tables 9.3 and 9.4, respectively. Figures 9.2–9.5 show the grand means for the four fabric–pigment combinations within each of the attributes. Overall, fabric type had a significant influence on the intensity scores for the 17 hand attributes; it also influenced the differences in the intensity scores among the six pattern designs and two print pastes.

Influence of geometric characteristics

Fabric type followed by print paste composition (pigment type) appeared to have a greater influence on the intensity ratings for the geometric characteristics of the printed specimens than did the design of the print. These findings agree with a previous study [2], which showed that the kind of fabric used in hand evaluations can have a tremendous influence on perceived differences due to treatments.

Overall, the knit fabric was perceived as being fuzzier (grand means = 5.79 (knit) versus 2.18 (shirting) and thicker (means = 7.45 (knit) and 3.18 (shirting) than the shirting fabric. This was expected because the knit was almost twice as thick as the shirting, and in addition it had a lofty appearance in contrast to the flat, smooth shirting fabric. All the fabric–print paste combinations had similar and fairly low intensity values for graininess (small, rounded particles) and surface texture (tactile awareness). The particles on the knitted and woven fabrics were too small to be considered grainy. Conversely, the pigment prints had higher intensity scores for grittiness (small abrasion pick particles), especially on the woven fabrics (means = 9.25 (white prints) and 6.70 (blue prints)). For both fabric types, the intensity values for grittiness were significantly higher on the white pigment prints than on the blue. This was attributed to the higher solids contents and larger,

Table 9.3 Mean scores for hand attributes of cotton shirting

	Intensity based on scale from 0 to15						
Hand attribute	Pattern 1 (small stripe)	Pattern 2 (paisley)	Pattern 3 (dots)	Pattern 4 (large stripe)	Pattern 5 (swirl)	Pattern 6 (checks)	*p* value[a]
White pigment print							
Geometric characteristics							
Fuzziness	1.98	2.03	2.11	2.07	2.15	2.12	ns
Graininess	2.11	2.54	2.55	2.51	2.45	2.30	ns
Grittiness	9.93	8.76	9.68	8.98	9.63	8.49	ns
Surface texture	2.33	1.48	1.94	2.98	2.03	2.45	ns
Thickness	3.17	3.37	3.19	3.11	3.11	3.13	ns
Mechanical characteristics							
Force to gather	6.00	5.89	6.33	5.58	5.93	5.85	ns
Force to compress	6.43	6.47	6.59	6.17	6.41	6.39	ns
Stiffness	8.80a	8.09b	8.79a	7.93b	8.13b	8.03b	<0.05
Depression depth	1.56	1.53	1.61	1.49	1.48	1.49	ns
Fullness	5.49	5.46	5.67	5.69	5.49	5.51	ns
Compression resilience	6.39	6.16	6.64	5.81	6.34	6.17	ns
Springiness	1.47	1.53	1.57	1.51	1.49	1.51	ns
Tensile stretch	1.21	1.18	1.21	1.21	1.17	1.21	ns
Hand friction	8.61	7.85	8.10	8.19	8.57	7.94	ns
Fabric friction	13.59a	12.74ab	12.65abc	9.81d	12.02bc	11.37c	<0.01
Sound characteristics							
Noise intensity	4.55a	4.48ab	4.54a	4.34b	4.41ab	4.39b	<0.05
Noise pitch	4.54ab	4.50abc	4.56a	4.37c	4.43abc	4.41bc	<0.05
Blue pigment print							
Geometric characteristics							
Fuzziness	2.13	2.17	2.33	2.39	2.59	2.11	ns

Table 9.3 Continued

Hand attribute	Intensity based on scale from 0 to15						
	Pattern 1 (small stripe)	Pattern 2 (paisley)	Pattern 3 (dots)	Pattern 4 (large stripe)	Pattern 5 (swirl)	Pattern 6 (checks)	*p* value[a]
Graininess	2.29	2.31	2.54	2.15	2.56	2.14	ns
Grittiness	6.24	7.23	7.89	6.10	6.73	6.04	ns
Surface texture	3.12a	1.07c	1.27c	1.85bc	1.12c	2.19b	<0.01
Thickness	3.31a	3.09bc	3.29ab	3.05c	3.21abc	3.12abc	<0.05
Mechanical characteristics							
Force to gather	5.33b	5.45b	5.90a	5.09b	5.35b	5.10b	<0.001
Force to compress	5.70bc	5.79bc	6.15a	5.49c	5.84ab	5.67bc	<0.01
Stiffness	7.21	7.18	7.51	6.65	7.13	6.91	ns
Depression depth	1.52	1.45	1.54	1.39	1.45	1.48	ns
Fullness	5.05	5.20	5.38	4.97	5.37	5.03	ns
Compression resilience	5.79	5.78	5.91	5.31	6.13	5.81	ns
Springiness	1.53	1.51	1.56	1.43	1.66	1.52	ns
Tensile stretch	1.19	1.16	1.18	1.19	1.16	1.17	ns
Hand friction	6.80	6.97	7.99	7.00	7.01	6.69	ns
Fabric friction	10.57ab	9.24a	11.27a	9.15c	9.82bc	9.47bc	<0.05
Sound characteristics							
Noise intensity	4.11	4.20	4.20	4.16	4.23	4.14	ns
Noise pitch	4.13	4.22	4.22	4.18	4.26	4.16	ns

[a]Within a significant attribute only, means with the same letter are not significantly different.

Source: 'Influence of pattern design and fabric type on the hand characteristics of pigment prints', by K.J. Robinson, E. Chambers and B.M. Gatewood, from *Textile Research Journal,* vol. 67, no. 11, p. 837, 1997.

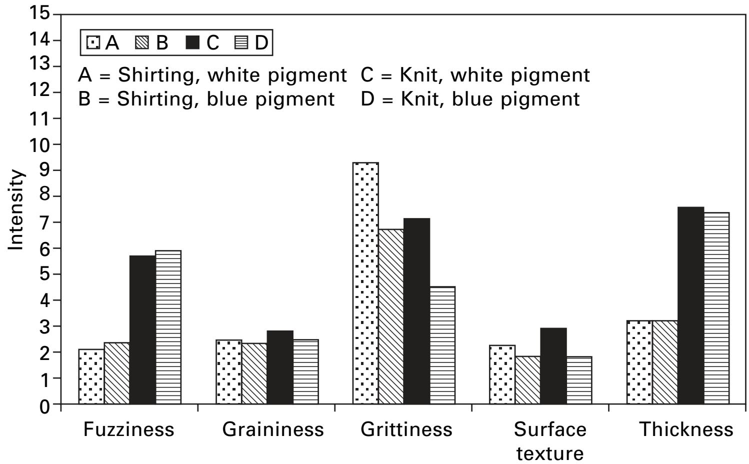
Table 9.4 Mean scores for hand attributes of cotton knit

	Intensity based on scale from 0 to 15						
Hand attribute	Pattern 1 (small stripe)	Pattern 2 (paisley)	Pattern 3 (dots)	Pattern 4 (large stripe)	Pattern 5 (swirl)	Pattern 6 (checks)	*p* value[a]
White pigment print							
Geometric characteristics							
Fuzziness	5.57	5.21	5.73	5.87	5.72	5.95	ns
Graininess	2.97	2.83	2.93	2.46	2.68	2.68	ns
Grittiness	7.81a	7.50a	7.77a	5.71b	6.92a	6.97a	<0.05
Surface texture	2.72bc	2.65bc	2.14c	4.15a	3.11b	2.47bc	<0.01
Thickness	7.61	7.75	7.59	7.45	7.55	7.35	ns
Mechanical characteristics							
Force to gather	5.69a	5.68a	5.46a	5.15b	5.59a	5.15b	<0.01
Force to compress	6.36a	6.31a	6.22a	5.80b	6.16a	5.83b	<0.01
Stiffness	5.78	5.89	5.91	5.63	5.77	5.51	ns
Depression depth	7.10	7.28	7.11	6.99	7.09	6.96	ns
Fullness	8.50	8.59	8.56	8.37	8.53	8.35	ns
Compression resilience	4.48	4.53	4.65	4.44	4.62	4.35	ns
Springiness	5.27	5.27	5.38	5.22	5.17	5.19	ns
Tensile stretch	14.24	14.22	14.22	14.25	14.15	14.20	ns
Hand friction	8.50	8.21	8.20	7.74	8.15	7.81	ns
Fabric friction	14.70a	14.74a	14.74a	13.88b	17.37a	14.55a	<0.05
Sound characteristics							
Noise intensity	2.94	2.88	2.92	2.80	2.85	2.73	ns
Noise pitch	2.94	2.88	2.92	2.80	2.85	2.73	ns
Blue pigment print							
Geometric characteristics							
Fuzziness	5.82	5.88	5.95	5.96	5.72	6.09	ns

Table 9.4 Continued

Hand attribute	Intensity based on scale from 0 to 15						
	Pattern 1 (small stripe)	Pattern 2 (paisley)	Pattern 3 (dots)	Pattern 4 (large stripe)	Pattern 5 (swirl)	Pattern 6 (checks)	*p* value[a]
Graininess	2.49	2.38	2.65	2.34	2.64	2.50	ns
Grittiness	4.88	4.27	4.77	4.15	4.58	4.69	ns
Surface texture	2.06ab	1.58bc	1.07c	2.71a	1.75bc	1.38bc	<0.01
Thickness	7.43	7.32	7.43	7.20	7.42	7.29	ns
Mechanical characteristics							
Force to gather	4.95	4.96	5.08	4.98	4.92	4.91	ns
Force to compress	5.53	5.59	5.55	5.47	5.53	5.51	ns
Stiffness	4.97	5.05	5.17	4.95	5.03	5.01	ns
Depression depth	6.98	6.99	6.97	6.93	6.94	6.96	ns
Fullness	8.19	8.18	8.26	8.23	8.19	8.25	ns
Compression resilience	4.03	4.29	4.32	4.21	4.29	4.14	ns
Springiness	5.11	5.18	5.14	5.07	5.21	5.11	ns
Tensile stretch	14.29	14.21	14.26	14.21	14.19	14.22	ns
Hand friction	7.29	7.19	7.07	7.22	7.24	7.00	ns
Fabric friction	14.17	12.56	13.55	13.63	13.23	13.57	ns
Sound characteristics							
Noise intensity	2.72	2.76	2.69	2.67	2.72	2.69	ns
Noise pitch	2.72	2.75	2.71	2.67	2.72	2.69	ns

[a]Within a significant attribute only, means with the same letter are not significantly different.
Source: 'Influence of pattern design and fabric type on the hand characteristics of pigment prints', by K.J. Robinson, E. Chambers and B.M. Gatewood, from *Textile Research Journal,* vol. 67, no. 11, p. 837, 1997. Copyright Sage Publications.



9.2 Mean scores for geometric attributes. *Source*: 'Influence of pattern design and fabric type on the hand characteristics of pigment prints', by K.J. Robinson, E. Chambers and B.M. Galewood, from *Textile Research Journal,* vol. 67, no. 11, p. 837, 1997. Copyright Sage Publications.

more crystalline particle size of the TiO_2. The panelists may have perceived the blue prints as being less harsh because a blue color is often associated with softness; however, the panelists are trained to disregard color.

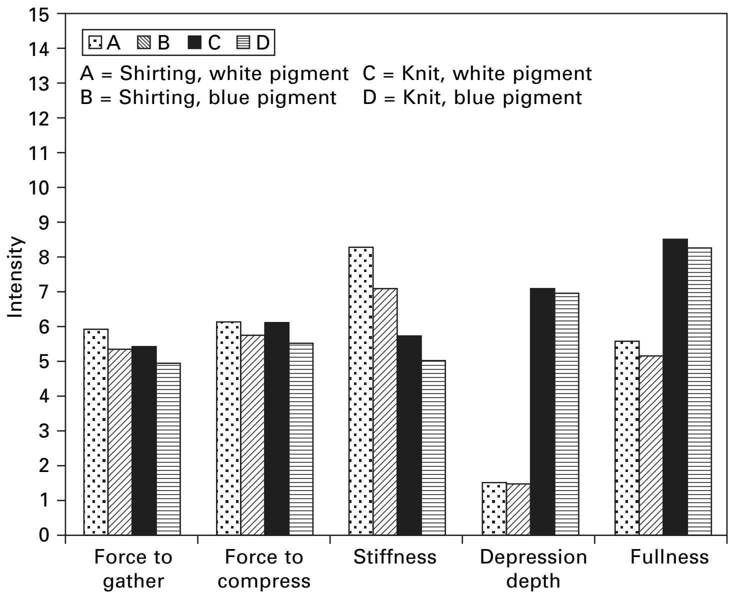
The pattern designs had some influence on the intensity ratings for the five geometric attributes, but their effects were often confounded by fabric and pigment type. Overall, the designs appeared to have little influence on the panelists' perception of fuzziness and graininess. On the cotton shirting fabrics printed with the white pigment, there were no significant differences in the intensity scores for any of the geometric attributes within the six designs. However, there were some differences in the six designs for the shirting fabric printed with the blue pigment. Specifically, design had an influence on the surface texture and thickness scores for the shirting fabric printed with the blue pigment.

The shirting fabric with the small stripe design was perceived as having more surface texture than the other white prints. Conversely, the larger stripe had the highest value for surface texture overall, and on the knits printed with both pigments and the shirting fabric with the white print. The wider stripe enables one to feel the pigmented and non-pigmented areas more distinctly as the fingers move across the surface, whereas with the smaller pattern, the fingers are constantly touching both the pigmented and non-pigmented areas.

On the knit fabrics, unlike the woven fabrics, the pattern design also had a significant influence on the intensity rating for grittiness (small abrasive picky particles). The large stripe was rated as being significantly less gritty compared to the other designs. Grittiness and surface texture seem to be closely related attributes, but the intensity ratings assigned by the panelists differed considerably, as did the influence of the design on these geometric characteristics. This implies that surface texture is a composite of many textural sensations, including grittiness.

Effect of mechanical characteristics

Figure 9.3 shows the mean intensity scores of the four fabric–pigment combinations for the mechanical attributes of hand related to compressibility (force to gather, force to compress, stiffness, depression depth) and fullness. In general, both fabric type and pigment type had a greater influence on most of these attributes than print design. Within a specific print paste type, the shirting fabric had a slightly higher force to gather and force to compress and was significantly stiffer, whereas the knit fabric had a significantly higher depression depth and fullness, which was expected based on the inherent characteristics of the two fabrics. For both fabric types, the white pigment prints were perceived as having a lightly greater force to gather, force to



9.3 Mean scores for mechanical attributes related to compressibility and fullness. *Source*: 'Influence of pattern design and fabric type on the hand characteristics of pigment prints', by K.J. Robinson, E. Chambers and B.M. Galewood, from *Textile Research Journal,* vol. 67, no. 11, p. 837, 1997. Copyright Sage Publications.

compress, stiffness, depression depth, and fullness, which coincided with the results obtained for the geometric attributes. The fabric type had the greatest influence on the intensity values for stiffness, depression depth, and fullness, whereas it had only a slight influence on force to gather and force to compress.

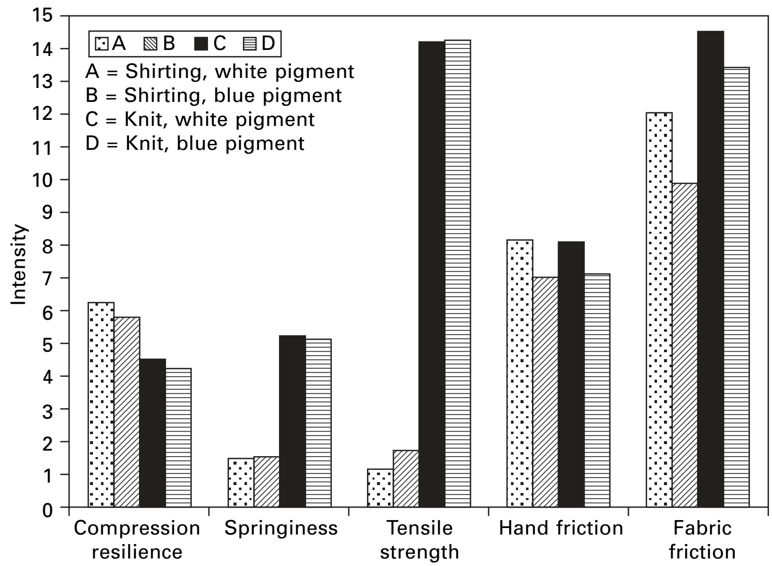
As mentioned before, the influence of pattern design on the compressibility/fullness mechanical characteristics was confounded by the fabric–print paste combination (see Tables 9.3 and 9.4). For example, pattern design had a significant influence on the intensity ratings for the white pigment on the cotton knit and the blue pigment on the shirting, but not on the blue pigment on the knit or the white pigment on the shirting.

In addition, there were few consistencies between the fabric-print paste combinations in terms of the rank order of the intensity values associated with the size designs, except for the large stripe and dotted patterns. Furthermore, the range of values was quite small, even though some of the differences were significant based on the statistical tests. In general, the dotted design (pattern 3) had the highest intensity rating, and the larger stripes (pattern 4) had the lowest overall, and within most of the fabric–print paste combinations for force to gather, force to compress, and stiffness. Therefore, the design of a print, such as small discontinuous dots versus wide continuous stripes, may influence the bending ability of the fabrics, thus influencing the stiffness-related attributes that are important in evaluating the quality of pigment prints.

Similar results were obtained for the hand attributes related to resiliency, stretchability, and frictional properties, in that fabric type and pigment paste formulation had a greater influence on intensity values assigned by the trained panelists than did the design of the print (see Fig. 9.4). Overall, the knit fabrics had significantly greater springiness (rate at which the sample returns to the original position after the depression is removed), tensile stretch, and fabric friction, whereas the shirting fabric had significantly higher compression resilience (force with which the compressed sample presses against the hand). No appreciable differences were detected in hand friction due to fabric type.

Within a fabric type, differences were also seen in the intensity values between pigment types; e.g., the white pigment had slightly higher compression resilience and hand and frictional properties. However, the white prints were perceived as having a slightly lower tensile stretch. The pigment type had no appreciable effect on springiness.

The pattern designs had no significant effects on the resiliency, stretchability, or frictional properties of the fabrics, except fabric friction. For most of the fabric–print paste combinations, the larger stripes had the lowest intensity values for fabric friction (force required to move the fabric over itself). Perhaps the larger stripe was perceived as being more efficient in reducing fabric friction, especially on the fuzzier knits.



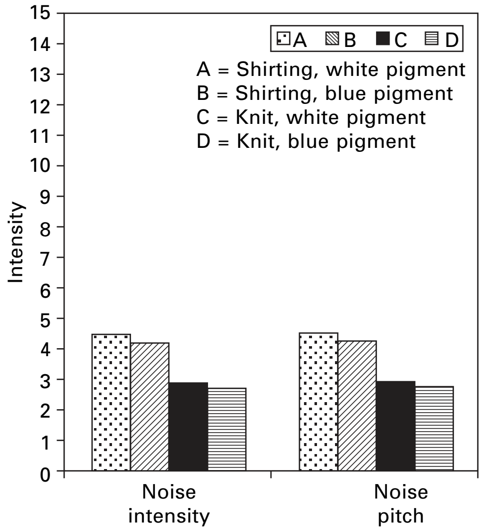
9.4 Mean scores for mechanical attributes related to resilience, stretchability, and frictional properties. *Source*: 'Influence of pattern design and fabric type on the hand characteristics of pigment prints', by K.J. Robinson, E. Chambers and B.M. Galewood, from *Textile Research Journal,* vol. 67, no. 11, p. 837, 1997. Copyright Sage Publications.

Influence of noise characteristics

As shown in Fig. 9.5 fabric type had an influence on the sound characteristics of the printed fabrics, with the woven fabric exhibiting higher noise intensity (loudness) and noise pitch (frequency) values. This was expected because a smooth, woven fabric usually makes more noise than a softer knit when rotated in the palm of the hand. The trained panelists also detected slightly higher noise values for the white pigment print with the TiO_2 particles compared to blue phthalocyanine pigment. The pattern design had no significant effect on the sound characteristics of the fabric, except for white print on the cotton shirting, but the ranges in the intensity values for noise intensity and pitch for the six designs were so small they would have little practical value.

Conclusions

The results of this study on the hand attributes of pigment prints show that fabric type has a greater influence on the geometric, mechanical, and sound properties than pigment type or pattern design. Overall, the printed knitted fabrics were fuzzier, thicker, softer, fuller, springier, and stretchier and had more surface texture and fabric friction than the shirting fabrics. These findings



9.5 Mean scores for sound properties. *Source*: 'Influence of pattern design and fabric type on the hand characteristics of pigment prints', by K.J. Robinson, E. Chambers and B.M. Galewood, from *Textile Research Journal,* vol. 67, no. 11, p. 837, 1997. Copyright Sage Publications.

parallel typical characteristics of cotton knits and flat, plain, woven shirting fabrics. Likewise, the woven cotton shirting fabric was stiffer and had a slightly higher force to gather, force to compress, compression resilience, and noise intensity and pitch. Hence the panelists were able to detect differences between the two fabrics in the 17 hand attributes, based on the terms, definitions, and techniques developed by Civille and Dus [2].

The print paste composition had some influence on the perceived hand of the printed fabrics, but the results were often confounded by fabric type and the attribute being evaluated. Differences between the print pastes were slightly more apparent on the knit fabric, whereas differences between designs were slightly more apparent on the woven fabrics. Pigment type had the greatest influence on grittiness, hand and fabric friction, surface texture, stiffness, force to gather, and force to compress for the woven and knit fabrics, and on the tensile stretch of the knit. For most of the other attributes, there were few differences between the two print paste formulations. This was not unexpected because the print pastes differed only in pigment type. Changes in binders, crosslinkers, thickeners, viscosities, add-ons, and curing conditions would have a greater influence on the geometric, mechanical, and sound properties than pigment type alone.

Pattern design had a significant effect on nine of the 17 hand attributes evaluated in this study, i.e., grittiness, surface texture, thickness, force to gather, force to compress, stiffness, fabric friction, noise intensity, and noise pitch. However, its influence was often confounded by pigment and fabric type, and the range in values was often quite small, thus limiting their practical value. For many of the attributes, no one design had intensity ratings that were significantly higher or lower than the others for all fabrics and print paste formulations. Among the geometric attributes, however, the larger stripe had the lowest graininess and grittiness values but the highest surface texture values compared to the other designs. There were also some consistencies in the panelists' ratings of the six designs on mechanical characteristics. The dotted design had the highest mean intensity values overall for force to gather, force to compress, stiffness, depression depth, fullness, compressional resiliency, and springiness, whereas the 2.54 cm stripe had the lowest mean intensity values for most of these attributes. Differences between print patterns were often more apparent on the shirting fabrics. Conversely, the knit fabrics showed greater differences between the print pases. Therefore, this research indicates that more than one pattern, print paste, and fabric construction should be included in studies on the influence of pigment print pastes on fabric hand. All these factors may have an impact on the hand of pigment prints, so each must be considered when assessing the overall hand characteristics of any print.

How the dyeing process affects the hand

The wet process encountered in fabric preparation holds true during the dyeing process. As an example of how the dyeing process affects the hand, consider polyester fabrics. Polyester fibers are dyed with disperse dyes requiring thermal energy to transfer the molecules into the fiber cross-section. The fabric can be dyed either in a pressure beck which supplies the thermal energy in the presence of water, or by the thermosol process. The thermosol process relies on dry heat to activate the dye molecules to the energy level needed for diffusion into the fiber cross-section. The thermosol process is carried out on a tenter frame to maintain the desired width. Either process can obtain the same shade, but the fabric hand will be noticeably different. The beck-dyed fabric will be soft and supple whereas the thermosol-dyed fabric will be stiffer. Post-dyeing finishing treatments may alter this stiffness, but the hands of the two will never approach each other.

9.2.3 Functional finishes

Finishing can be defined as any operation that imparts the final qualities to a fabric. It can encompass drying, applying chemical auxiliaries, or mechanical finishing. The latter will be covered in more detail in Chapter 10. Two categories of functional finishes, softeners and hand builders, are specifically aimed at modifying the fabric hand. For sake of simplicity, each category will be discussed as a stand-alone subject. In practice however, all of the required chemical auxiliaries are mixed into a single bath and applied simultaneously.

Wrinkle-free finishes

Wrinkle-free finishes, also known as crease resistant finishes, durable-press finishes, permanent press finishes, no-iron finishes, and shrink resist finishes, are reactants applied to cellulosic fabrics that chemically cross-link the cellulose polymer chains. In so doing, the fiber becomes more hydrophobic and resilient, resulting in a fabric that is wrinkle resistant, shrink resistant and smooth drying, and in garments with better shape retention.

Glyoxal based resins (DMDHEU) have become the resin of choice and the newer resins have dramatically reduced problems associated with formaldehyde release. The desired properties (DP rating, shrinkage reduction, etc.) are improved with increasing resin add-on, hence greater cross-linking of the cellulose polymer chains. However, cross-linking is responsible for reducing tensile strength, tear strength and abrasion resistance. As the add-on (cross-linking) increases, the greater will be the losses of these physical properties. In practice, a compromise is reached by balancing the degree of improved performance against the loss of physical properties. In terms of effect on fabric hand, cross-linking stiffens the fiber so the fabric becomes less limp.

Water repellent finishes

Repellent finishes fall into two categories: water repellent and anti-stain finishes. Chemical auxiliaries capable of accomplishing these goals fall into three categories: hydrocarbon waxes, silicones and fluorochemicals. As hydrophobes, all three will function as water repellents. The wax types give good initial repellency, are the least expensive and are the least durable to washing. They are not durable to dry-cleaning. The silicones also give good initial repellency. They are more durable to washing and dry-cleaning but are slightly more expensive than the wax types. The fluorochemicals give excellent initial repellency, are the most durable to washing, dry-cleaning and physical abrasion.

As chemical auxiliaries, they are the most expensive. Fortunately, less add-on is required so the added cost is not prohibitive. All three are effective in resisting water-borne stains but only the fluorochemicals have the added feature of holding out oil-borne stains.

Durable water repellent (DWR) finishes are formulations that combine resin wax water repellents with fluorochemical repellents. This combination was developed by the Army Quartermaster Corp. and is often referred to as Quarpel. It has proven to be effective for use on protective outerwear and foul weather gear and is durable to multiple field laundering cycles.

Water resistant fabrics are also known as 'water repellent' or 'waterproof' and it is important to distinguish between these terms. The term water repellent is used to describe a water resistant fabric where water droplets bounce off without clinging to the surface. AATCC Test Method 22 is used to rate this quality. The better the spray rating, the less water clings to the fabric surface. When the term waterproof is used, the fabric must also resist the passage of water through it. The ability of water to pass through is a function of the number and size of pores and openings. For example, DWR-finished tightly constructed fabrics, such as poplins, are more waterproof than are more open-weave fabrics even though the spray ratings may be the same. Coating the fabric is another way of reducing the openings and pores. As the coating coverage increases, water resistance increases and the greatest resistance is achieved whenever the coating becomes a continuous film. Performance requirement for water resistant fabrics must take into account the force of the water striking the fabric. It is obvious that a raincoat suitable for light to moderate rain will offer little protection in a driving rainstorm. A number of tests address the relationship between the force of the water and the threat level protection. AATCC test methods, ASTM test methods and Mil Spec provide more details.

Stain repellent finishes

Most fabric stains are the result of liquid spills from water-borne or oil-borne soils. Stain repellent finishes offer a degree of protection by resisting the penetration of the liquids into the fabric. Examples of water-borne stains are coffee, wine, tea and colas; oil-borne stains include food oils, fats and greases, and motor oil. The silicone and fluorochemical water repellent finishes also function as stain repellents. The silicones provide protection against water-borne stains but not against oil-borne stains. On the other hand, the fluorochemicals resist both. Water repellency tests are an effective way to assess water-borne stain resistance, but they do not address oily stains. The most widely used method for measuring oil repellency is AATCC Test Method 118. A series of test oils differing in their surface tension makes up the test kit. A drop of each test oil is placed on the fabric surface and allowed to sit for five minutes. The oil repellency rating corresponds to the highest numbered oil that does not penetrate into the fabric. The higher the number, the lower the surface tension and this signifies that the finish is a better barrier to oil stains. The same test is repeated after multiple laundering and dry-cleaning to assess the durability of the finish.

In terms of effect on fabric hand, the fluorochemicals are less likely to alter the finished hand, mainly because of the low add-on. The silicones will impart a slippery feel and some resilience or bounce to the fabric. The wax types, because of the resin plus the higher add-on level, will make the fabric feel 'beefier' and more robust. Since these chemicals are applied with other finish components, the hand will be more affected by the other components.

Soil release finishes

The introduction of polyester fibers into apparel fabrics created a problem in the removal of oil stains by laundering. The polyester fiber tends to tenaciously hold on to the stain. This was especially true for polyester/cotton fabrics finished with DP finishes. The problem is exacerbated by the soil repellent finishes mentioned above because once the soil is ground in, it becomes even more difficult to remove the stain by laundering. To address this, several types of soil release finishes are available. One type is specifically for DP fabrics and another for 100% polyester fabrics. Two different chemistries are available for DP finishes. One is based on copolymers of methacrylic acid and ethyl acrylate and is applied together with the DP resins. This chemical type forms a hydrophilic coating on the surface of the fibers. Under laundering conditions, the coating swells and this swelling action dislodges the soil from the fiber surface and allows the detergents to carry it away. It is quite effective in removing dirty motor oil stains. The amount of finish plus the stiffness of the polymer causes the hand to become stiff and boardy. The second, Dual Action, was developed by 3M and consists of block copolymer containing fluorochemical blocks and hydrophilic blocks along the polymer backbone. This finish in effect combines the features of oil repellency with soil release. When dry, the fluorochemical blocks function as a conventional oil repellent finish; under laundering conditions, the hydrophilic blocks absorb water, causing the polymer backbone to flip. Now the fiber surface is hydrophilic and the coating functions as a soil release agent. It too is applied together with DP resins. The effect on fabric hand is negligible because low add-ons are needed and the cured polymer is not as stiff as the methacrylic acid/ethyl acrylate finish.

A totally hydrophilic family of block copolymer finishes that impart both water wick-ability and soil release is available for 100% polyester fabrics. These finishes can be applied as a part of the dye cycle where they exhaust onto the surface or by padding. They are permanently attached. One segment of the copolymer serves as an anchor while the other provides hydrophilicity. When applied to fabrics made from textured yarns, oily soil release is noticeably enhanced. The soil release property is not as effective on fabrics containing either spun or continuous flat filament yarns. Even though the fiber surfaces are modified, the compactness of fibers in the yarn cross-section interferes with the dislodgement of the soil and its transport out of the fabric.

In terms of effect on fabric hand, the treated fabrics may experience a slightly softer hand as some of these finishes have lubricating qualities.

Moisture management, and comfort finishes

An important property associated with fabric comfort is moisture management. Moisture management deals with the ability of a fabric to transmit moisture away from the body. The mechanism of movement can be either by wicking or by passage of water vapor through the fabric. Breathability is a term often used to describe this property. Hydrophilic fibers such as cotton or wool are perceived to be comfortable because of their breathability. Hydrophobic fibers such as nylon, polyester, polypropylene are not. The ability of soil release finishes to improve water wicking also serves to improve moisture management and is often promoted as finishes for improved comfort.

Flame retardant finishes

Flame retardant finishes are designed to reduce a fabric's ability to sustain combustion. Combustion requires that three elements be present: fuel, oxygen and heat. If any one of these elements is removed, the flame will extinguish. For a solid material to ignite, it must be first heated to a temperature where it is pyrolyzed into flammable gaseous by-products (fuel). The temperature to do this is known as the pyrolysis temperature (T_p) and differs for the various fibers. Hence wool, Nomex and Kevlar are inherently more resistant to ignition than are cellulose, polyester, and acetate. Thermoplastic fibers such as nylon and polyester have low melting points so they are able to melt and withdraw from the flame source. In so doing, the melt temperature does not reach T_p so no flammable gases are produced and ignition does not occur. This is the mechanism that allows 100% polyester fabrics to pass the children sleepwear test. If thermoplastic fibers are blended with cellulosic, wool or even fiberglass, the melt does not recede from the heat source so T_p will be reached and these fabrics will ignite.

Flame retardant finishes are based on chemistries that interrupt the flammability cycle. For example, the elements phosphorus and nitrogen in flame retardants for cellulose fibers alter the combustion chemistry and prevent the formation of flammable fuel. Self-propagation cannot be sustained without flammable gaseous fuel. Another way of dousing the flame is to remove the heat source or reduce the temperature of the burning solid. The obvious way to do this is to pour water on the fire. Another way is to interrupt the chain reactions in the flame. Intercepting any of the exothermic reactions in the sequence reduces the heat output to the point that the solid no longer decomposes into gaseous fuel. Halogens such as chlorine and bromine operate in this manner and flame retardant finishes that operate in this mode are highly brominated or chlorinated compounds. They decompose with heat and release chlorine or bromine radicals. Since this mechanism operates in the flame, these retardants are useful for a broad range of fibers. A fourth method of extinguishing a flame is to suffocate it by keeping oxygen out, much like throwing dirt or a blanket over a fire. Flame retardants that work on this principle contain elements such as boron that form a non-flammable coating on the fiber. This restricts the oxygen supply.

Most flame retardant compositions will stiffen the hand of fabrics. There are a few exceptions. Usually high loading of the finish will be needed because the percentage of the active elements with respect to the total weight of the finish is low. Durability is also an issue. Some of the finishes are polymer formers, some react with the fiber, while others are pigments that are encapsulated in a binder on the fiber surface.

Hand modifiers

Softeners and hand builders are the functional finishes that have the greatest impact on fabric hand. These are the tools available to a finisher to try to tailor a hand. They too will be incorporated in the final finish bath along with all of the other ingredients. Almost all finish formulations will include a softener as a component. Softeners are lubricants that provide functional properties as well as hand qualities. From a physical property point of view, they improve tear strength and abrasion resistance and reduce frictional heat build-up on cutting knives and sewing needles in cutting and sewing operations. Hand builders are applied on limp or fragile fabrics so they can more easily be handled in cutting and sewing.

Hand builders

Hand builders are film-forming polymers that coat fiber surfaces. They add weight, body and stiffness to fabrics. Some are identical to the binders used to durablize pigments as mentioned in a previous section. Hand builders fall into two major categories: non-durable and durable. The durable ones are further divided into thermosetting and thermoplastic polymers. The effect on hand depends on add-on and the inherent stiffness of the polymer film. As can be imagined, the amount of a stiff polymer needed to achieve a certain hand is less than that of a soft polymer. Similarly when added weight and bulk is the target, higher amounts of softer polymers can be used without over-stiffening the fabric. A negative aspect regarding increased stiffness is the corresponding loss of tear strength. Fortunately, tensile strength is not affected. The reason for this is that the yarns are immobilized and are not free to slide when the fabric is subjected to tearing stresses. In a stiff fabric, each yarn along the tear line individually bears the entire brunt of the force;

therefore it takes less force to initiate the tear. If the yarns are mobile such as in pliable fabrics, they can slide and can bunch up at the point of stress. The yarns slip and the brunt of the force is met with a greater fiber mass.

Non-durable hand builders

For some fabrics, a crisp, smooth appearance is a desirable attribute. The consumer expects men's dress shirts to have a crisp smooth hand for over-the-counter appeal. Denim jeans traditionally are expected to have weight and body. Quality and toughness attributes have been equated to heavier fabrics so traditionally the weight of the fabric in ounces per square yard has been the barometer of quality. The consumer has come to expect the hand to break down and the color loss that occurs when the garment is laundered. In fact this is a revered quality because the garment becomes softer and more comfortable. The degree of color loss is a visible indicator of wash down, and the more faded and worn the garment becomes, the more comfortable the garment is perceived to be. Pre-washed jeans have become a hot fashion item and the topic will be discussed in greater detail later in this chapter. Non-durable or hand builders with limited durability are used for these applications and water-soluble polymers such as starch, carboxymethyl cellulose and polyvinyl alcohol make up this category.

Durable hand-builders

Durable hand-builders fall into two major categories: thermosetting and thermoplastic. Melamine resins are the most widely used thermosetting hand-builders and are the reaction product of melamine and formaldehyde. The resins are water soluble and stable for a period of time. When formulated with a catalyst, they cure into a three-dimensional cross-linked polymer with some reactivity to cellulose fibers. The cured resin holds up well to multiple washing and can be used on a wide range of fibers. Fabrics made from cellulose, polyester, nylon, acrylic and wool fibers are candidates for this finish. They are also used on blended fabrics.

Thermoplastic polymers are another type of durable hand builders. A wide range of latex polymers is available, made from monomers like vinyl acetate, acrylates, methacrylates, styrene, butadiene and urethanes. This array exists because latexes are used for a broad range of coating applications other than textiles. The physical nature of cured latex films is reflected by its glass transition temperature (T_g). This is the temperature at which a polymer transforms from the glassy state to the rubbery state and is a measure of the stiffness of the film. The lower the T_g, the softer the coating; conversely the higher the T_g, the stiffer the coating. The monomers selected to make the polymer largely control the T_g so the polymer chemist has a wide range at his or her disposal. In addition to T_g considerations, reactive monomers can be incorporated in the composition to provide secondary reactive sites capable of cross-linking the polymer chains after the film is formed. Cross-linking improves the durability of the coating. This wide range of products allows the textile chemist to tailor the hand of the fabric to match a given target.

Softeners

Softeners are the most important class of functional finishes that impact fabric hand. Nearly every finished fabric will have a softener in the finish formulation. Softeners improve tear strength and abrasion resistance and improve the efficiency of cutting and sewing in addition to providing tactile qualities. Softeners are lubricants and the purpose of a lubricant is to lower friction between mating objects, for example fibers against fibers, yarns against guides, fabric against sliding objects, and fabric against skin. Lubricants accomplish their goal by reducing the coefficient of friction and a lubricant's ability to do this depends on two qualities – the polar nature of the molecules and the viscosity. Non-polar compounds such as hydrocarbons and silicones are more effective than polar compounds. Within a given class, for example hydrocarbons, low viscosity fluids give a lower coefficient of friction than paraffin wax. From a practical point of view, the lower hydrocarbons are volatile so their effectiveness as a softener is negated. Mineral oil and paraffin waxes, on the other hand, can be used as softeners. Some other important factors in softener selection are color, dye lightfastness, odor, smoke point and water dispersability. Some potential softeners are dark in color or discolor with heat and age. These would not be suitable on white or pastel shades. Others will alter the dye shade and/or affect the dye's light fastness. Still others have a characteristic unpleasant odor or develop odor on aging. Smoke point is related to volatile components that vaporize as smoke during drying and condense to drip back on the fabric as grease spots downgrading the quality of the finished fabric. Water dispersability is important because softeners are applied from a water bath along with all the other finishing components. Some surfactants also function as softeners and are desirable because they readily disperse in water. Others like silicones, polyethylene and paraffin waxes must be emulsified before they can be used.

Anionic softeners

Anionic softeners are surfactants derived from fatty acids that come from the hydrolysis of triglycerides. Triglycerides are naturally occurring esters found in animal fats and vegetable oils. Fatty acids are the starting materials for making anionic, cationic and non-ionic surfactants. Because of the long hydrocarbon chain, they also serve as softeners. Anionic surfactants contain water-loving groups such as carboxylic acid, sulfonic acid and phosphoric acid. When in contact with water, these groups ionize and develop a negative charge, which is why they are termed anionic. Similarly, most fibers in contact with water will develop a negative zeta potential on the surface. The net effect is that the charged species act to repel each other so there is no attraction between the fiber surface and anionic surfactants. Nonetheless, these materials can be applied from water and will remain on the surface after the water evaporates. As a softener, anionic surfactants require higher add-on because the repulsive forces on the fiber surface must be overcome. The hand developed with anionic softeners is a greasy feel with little or no improvement in fabric suppleness. Anionic softeners are used as napping and Sanforizing lubricants to protect the fabric against the rigors of the machine surfaces. A good napping lubricant will offer the fabric some protection against the napping wires, while at the same time not being so lubricious as to allow the wires to completely pull fibers out of the yarn. While most softeners are hydrophobic and resist water, anionic softeners retain their hydrophilicity and become the softener of choice for applications such as bath towels or moisture management fabrics where water wicking is important.

Cationic softeners

Excluding the silicones, cationic softeners provide the greatest softening effect unmatched by any of the others. Cationic softeners are molecules that have a positive charge on the hydrophilic end which are amines and quaternary ammonium salts. In contrast with the anionics, the positive end of a cationic softener is attracted to the fiber surface and orients the molecule so that the hydrophobic portion is away from the fiber surface, creating an enriched hydrocarbon outer layer. This attraction is also the reason why cationics exhaust out of the bath onto the fiber. This leads to efficient use of the softener with maximum surface coverage and optimum lubrication. Quaternary ammonium cationic softeners are used as home laundry softeners. Cationic softeners are the ones of choice when a soft, pliable and silk-like hand is the target. Because of the low add-on, softness is achieved without a greasy feel. In addition to softening, a cationic softener renders the fabric hydrophobic. Drawbacks associated with cationic softeners are that some of them will discolor with age and some will have a negative impact on the lightfastness of certain dyes. Aminosilicones can also be considered cationic softeners, but they will be discussed in the section dealing with silicone softeners.

Non-ionic softeners

Polyethylene

There are several classes of materials that fall under the heading of non-ionic softeners. Fatty acid derivatives fall into the surfactant category while polyethylene and silicone do not. Hydrocarbon softeners are based on petroleum and include polyethylene and paraffin wax. They have little effect on fabric hand because they are semisolid materials at ambient temperatures. However, at elevated temperature, they melt and become good lubricants. This condition occurs when fabrics are subjected to frictional heating, so polyethylene is widely used whenever protection against abrasive forces, tearing forces and cutting and sewing is needed.

Ethoxylates

Ethoxylated fatty acid derivatives are the reaction product of a fatty hydrophobe with ethylene oxide. There are a number of hydrophobes that can be ethoxylated, e.g. fatty acids, fatty alcohols, fatty amines and alkylphenols, The degree of ethoxylation can be controlled to give a wide range of products ranging from oils to semisolid waxes. The ethoxylated portion imparts water solubility and remains a neutral molecule when in water, so is non-ionic. The number of different hydrophobes coupled with varying the degree of ethoxylation (moles of e.o.) creates a large menu of products from which to choose. As softeners, the effect on hand will depend on which combination is chosen. The ones that are oils will develop a pliable hand while those that are semisolid waxes will not noticeably affect the hand at all. These softeners are also used when re-wetting is desirable.

Silicones

Silicones as a group are considered the premium softeners. The family of silicone softeners is based on polydimethylsiloxane and includes neutral fluids, fluids with reactive side groups and aminofunctional silicones. The silicone fluids are capped at both ends of the linear chain with non-reactive end groups to provide a series of fluids with viscosity ranging from low viscosity fluids like sewing machine oil to high viscosity fluids like mineral oil. These water-clear fluids are emulsified and come as milk-white dispersions at about 30% solids. They do not discolor on aging and do an excellent job of lubricating as they develop a pliable, luxurious, silky hand. The fabric also becomes water resistant and the finishes are durable through a number of washes. This can present a problem to the finisher when it becomes necessary to rework the fabric. Fabric must be readily wettable to successfully strip, re-dye and finish off quality fabrics.

A more lasting effect can be accomplished by using silicone fluids modified with side reactive groups. Epoxy functionality can be introduced into the polymer backbone and these modified silicones can self cross-link or react with the fiber surface, making them more durable. These softeners are also used to enhance the resilience of wrinkle-free fabrics by adding bounce to the wrinkle recovery process.

A more recent addition to the silicone family softeners is the aminofunctional silicone microemulsions. The amine functionality confers several useful properties. First of all it greatly assists the emulsification process by acting as an internal emulsifier. The amine group acts as an internal emulsifier, making it much easier to produce stable micro emulsions. The emulsions are translucent rather than milky, indicating that the dispersed particles are much smaller, allowing the finish to be more uniformly distributed throughout the fabric structure. Secondly, the polymer molecule will have cationic sites along the backbone. As in the case for the other cationic softeners, these sites are attracted to the surface of the fiber, ensuring better surface coverage and orientation of the non-polar groups to the outer layer. These features are responsible for putting the aminosilicones at the top of the list as hand softeners. One interesting feature is that the cationic nature is neutralized under laundry conditions, making them less water-soluble and thereby improving their durability.

9.3 Special topics

9.3.1 Dryers and ovens

The equipment used to dry and cure fabrics will impact fabric hand. Tenter frames and dry cans are fabric transport mechanisms that use tension to convey the fabric. Fabric is restrained from shrinking so it will have a stiffer hand. Tumbling dryers, loop ovens and relax dryers have mechanisms that move the fabric in a relaxed state and result in a much softer hand. Relax dryers are preferred for knit fabrics as they allow the loops to rearrange into a stable configuration. Stable loop formation is important for controlling the wash shrinkage of knit fabrics.

9.3.2 Heat setting

The purpose of heat setting is to stabilize fabrics containing thermoplastic fibers. Fabrics from polyester and nylon yarns benefit from heat setting because the thermoplastic fibers acquire a new memory after they are fashioned into fabrics. When heated above the fibers' prior heat history, the geometry of the yarn crimp becomes locked in as the fibers acquire a new memory. This serves to stabilize the fabric by providing a new stable state and resistance to distortion and wrinkling. Polyester, nylon, spandex and blends with cellulose and wool benefit from heat setting. Heat setting can be done on greige fabrics as well as finished fabrics. Greige heat setting is done to stabilize fabric and prevent it from being distorted during wet processing. Greige heat setting becomes necessary for those fabrics where wet wrinkles cannot be pulled out during drying. Final heat setting can be done at any stage of dyeing and finishing but preferably at the end.

Heat setting is usually done on a tenter frame. Time and temperature parameters are selected to achieve the degree of stabilization needed without overstiffening the fabric. The setting process does stiffen fabric hand and the closer the temperature gets to the fiber's melting point, the stiffer the fabric becomes. Because of the fiber mass, heavyweight fabrics require more exposure time than do lightweight fabrics. Another heat setting issue of concern is dyeing. Heat-set fibers are more difficult to dye because they become more crystalline, making it more difficult for dye molecules to penetrate. Ideally, heat setting should be done after the fabric is dyed to the correct shade.

Setting processes are also used at several stages in the production of wool and wool-blend fabrics and garments. Such processes, which induce stress relaxation in the fibres and yarns, result in major modifications to the properties of the fabrics and thereby form the basis of the operations used to develop hand and other characteristics of wool-containing fabrics. The principles of setting wool and synthetic fibers are well understood and a wide range of techniques are available to exploit the more recent advances in setting technology.

Setting is also an important function of the final pressing operations (dry finishing). Final pressing routines are very important in determining the physical and mechanical properties of fabrics which in turn determine fabric hand [3]: luster, making-up characteristics (tailorability) [4] and the appearance of the garment. Traditionally, final pressing has consisted of a series of batch operations designed to impart the required aesthetic properties to the fabrics and render those properties stable to release under mild conditions. More recently, higher costs have necessitated the increased use of continuous or semi-continuous pressing processes [5]. Moreover, the requirements of fabric stability have increased so that more severe setting conditions are needed.

Fabric may also be set after the garment has been manufactured. Pleated skirts or skirt panels are often set in a vacuum autoclave using high temperature saturated steam, whereas skirts and trousers can be set using chemical assistants (e.g. Siroset). Such processes will also modify hand and other characteristics of the fabric.

A number of studies of the effect of setting and pressing operations on the mechanical properties and dimensional stability have been reported. Many of these studies have measured properties important in the assessment of fabric hand, such as fabric thickness and compressibility, ending stiffness, surfae friction, and wrinkle recovery. Measurements of these properties during finishing of wool and wool-blend fabrics demonstrated that many of the changes in mechanical properties of the fabrics can be attributed to changes in frictional effects within the fabric. Such changes are brought about by a reduction in the normal force between adjacent fibers and yarns as a result of stress relaxation of the fibers at constant length or by shrinkage of the fabric. The surface frictional properties of the fabric, however, appeared to vary with each operation: friction increased in operations which the fabric was unconstrained and become smaller in pressing operations.

Several studies of final pressing operations, which include many of the above measurements, have demonstrated that differences in fabric mechanical properties are also achieved by modifying the final pressing conditions. However, few studies have considered whether the changes that occur during setting operations in wet finishing (before, during or after dyeing) are still observable in the finally pressed fabric and whether their effect can be compensated for by suitable modification of the dry-finishng routine.

The results of a study into the effect of set-inducing finishing processes on those mechanical properties of worsted suiting-type fabrics relevant to hand and tailoring properties were reported by DeBoos *et al.* [5], as presented in the following sections.

Experimental

Suiting fabrics

A. Pure-wool, plain-weave, yarn-dyed (~244 g/m^2)
B. 70/30 wool-polyester, plain-weave, undyed (~188 g/m^2)
C. 55/45 wool-polyester, plain weave, undyed (~227 g/m^2)
D. Pure-wool, 2/2 hopsack, undyed (~278 g/m^2)
E. Pure-wool, twill, yarn-dyed (~279 g/m^2)
F. Filament polyester, plain-weave (~197 g/m^2).

All fabrics were obtained in the loom-state and finished as specified below.

Finishing methods

The fabrics were finished using the following methods:

(1) Semidecatizing (loom state). Steamed for 3 minutes in a Bailey machine.
(2) Crabbing. Laboratory beam dyeing machine. 1 hour at the boil. These conditions were selected so as to produce the same amount of set as produced by heat-setting fabric.
(3) Scouring. Open width in a pilot scale dyeing winch, 30 minutes, 50°C (1 g/1 Diadavin DWN (Bayer) and 2 g/1 sodium sulphate).
(4) Heat setting. Benz laboratory stenter, 180°C, 30 seconds. The fabrics were unconstrained during setting.
(5) Dyeing. Open width in a laboratory winch, pH = 4.8, 100°C, 60 minutes.
(6) Semidecatizing (final pressing). Bailey machine for 2 minutes.
(7) Pressure decatizing. Biella KD-matic, 3 minutes, 120°C.

All fabrics were conditioned overnight between operations.

Testing

Duplicate samples of all treated fabrics were tested under the standard conditions recommended for the KES-F instrumentation (Kato-Tekko). All fabrics were aged for at least 28 days prior to testing.

Results: change in properties of pure-wool fabrics in setting

Fabric shrinkage

Fabric shrinkage during processing is one of the most important factors affecting fabric mechanical properties. The amount of shrinkage that occurs during setting depends on both the method used and the amount of set imparted. The pure wool fabrics tested (Table 9.5) shrank little during stress setting (semi- or pressure decatizing) but by a larger amount during crabbing in boiling water (where the dimensions were only partially controlled) and even more during dyeing where the fabric was unconstrained. Overall shrinkage was least when the fabrics were heavily preset under constrained conditions, i.e. crabbing.

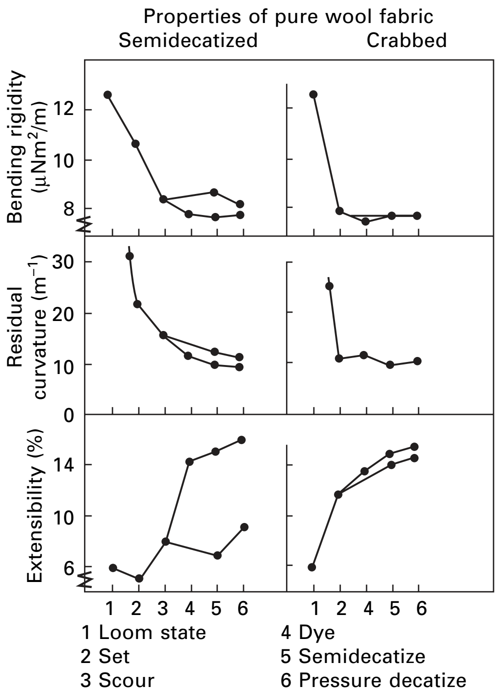
Table 9.5 Shrinkage during setting of loom-state wool fabric and subsequent dyeing

	Area shrinkage (%)[a]		
	Plain weave (A)	Hopsack (D)	Twill (E)
1. Semidecatize	0	1	0.5
2. Pressure decatize	2.2	2.5	1.9
3. Crab	6.9	5.7	6.2
Dyeing of 1	10.8 (14.0)	6.1 (9.6)	7.2 (10.3)
Dyeing of 2	7.3 (12.9)	4.0 (9.4)	5.0 (9.1)
Dyeing of 3	4.0 (11.1)	2.4 (9.0)	2.1 (8.0)

[a]Total shrinkage after dyeing is shown in parentheses.
Source: 'Objective assessment of the effect of setting processes on the properties of wool-containing fabrics', by A.G. DeBoos, F.J. Harigan and M.A. White, from *Proc. 2nd Australian–Japanese Bitaleral Science Tech. Symposium,* p. 318, 1983. Reproduced with permission from the Textile Machinery Society of Japan.

Bending properties

The greatest reduction in bending rigidity and residual curvature of the fabrics occurred in presetting and scouring (Fig. 9.6). Residual curvature depends on the frictional interaction between fibers in a fabric and measures the ability of the fabric to recover from the imposed strain. Treatments which



9.6 Changes in bending properties and extensibility of fabric A (plain weave wool) during processing. *Source*: 'Development of terminology to describe the hand-feel properties of paper and fabrics', by G.V Civille, and C.A Dos, from *Textile Research Journal,* vol. 5, pp. 10–32, 319, 1990. Reproduced with permission from *Textile Research Journal.*

reduce frictional interactions between fibers will reduce residual curvature in bending. The more effective the setting treatment, the greater was the change in bending rigidity and residual curvature. After dyeing, the fabric was completely relaxed whether or not it had been set in the loom state. However, where a mild setting treatment was used on the look-state yarn-dyed fabric (Fabric A), and this was followed by a mild scour and a mild final press, some differences in final bending properties were observed. The differences were minimized if the fabrics were subsequently set more effectively by pressure decatizing, implying that the initial mild treatments did not fully relax the fabric.

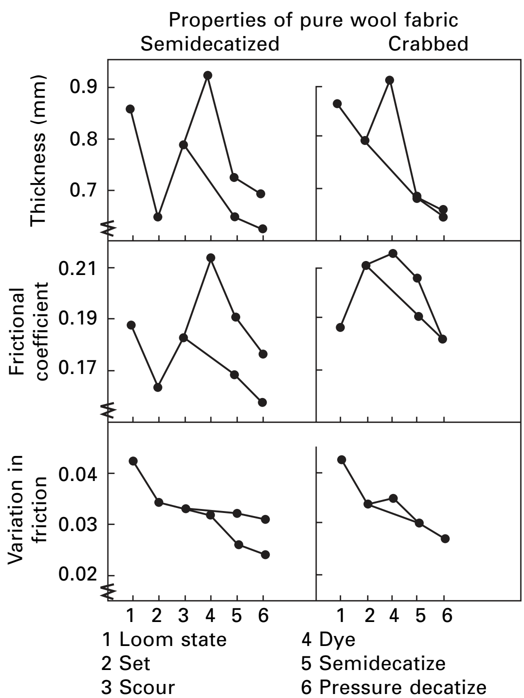
Fabric extensibility

Fabric extensibility is an important determinant of the making-up characteristics of worsted fabrics, particularly for men's suitings. Many garment manufacturers now impose limits on warp and weft extensibility of fabrics. Consequently, the changes in fabric extensibility that occur in finishing should be understood and monitored.

Piece-dyeing caused the greatest increase in the extensibility of the pure wool fabric. In large part, this was the result of the shrinkage that occurred during dyeing.

Fabric thickness

As expected, setting of wool fabrics constrained by a wrapper cloth (e.g. decatizing) reduced fabric thickness, whereas setting of unconstrained wool fabric (e.g. dyeing) increased fabric thickness (Fig. 9.7). Although setting operations during final pressing, including pressure decatizing, tended to reduce the difference in thickness between dyed and undyed fabrics (simulating piece and yarn- or top-dyed fabrics respectively), the latter remained thinner than piece-dyed fabrics. Pressing treatments vary considerably in their effect on fabric thickness but generally the more effective the setting treatments the thinner the resultant fabric.



9.7 Changes in thickness and surface properties of fabric A (plain weave wool) during processing. *Source*: 'Development of terminology to describe the hand-feel properties of paper and fabrics', by G.V Civille, and C.A Dos, from *Textile Research Journal,* vol. 5, pp. 10–32, 319, 1990. Reproduced with permission from *Textile Research Journal.*

Surface properties

When lightly preset wool was set unconstrained (e.g. piece dyeing), the frictional coefficient of the fabric surface increased substantially. Crabbing also increased surface friction but after piece dyeing the frictional coefficient was largely independent of the presetting method. The frictional coefficients of fabrics that were not dyed (as would be the case in yarn-dyed fabrics) were considerably less than those of the piece-dyed fabrics. Setting of wool in pressing operations reduced the coefficient of surface friction of fabrics, the greater reduction resulting from the more effective setting treatments. Previous studies have shown excellent correlation between fabric thickness and the coefficient of surface friction.

The variation in the frictional force is important in determining fabric hand. This property has a large effect on fabric smoothness (*numeri*) [3] which is an important determinant of the overall hand of winter weight fabrics. The variation in surface friction was reduced by steam pressing operations, particularly on piece-dyed fabrics. After final pressing the variability of surface friction of dyed (or crabbed) fabric was significantly less than that of the equivalent undyed fabrics.

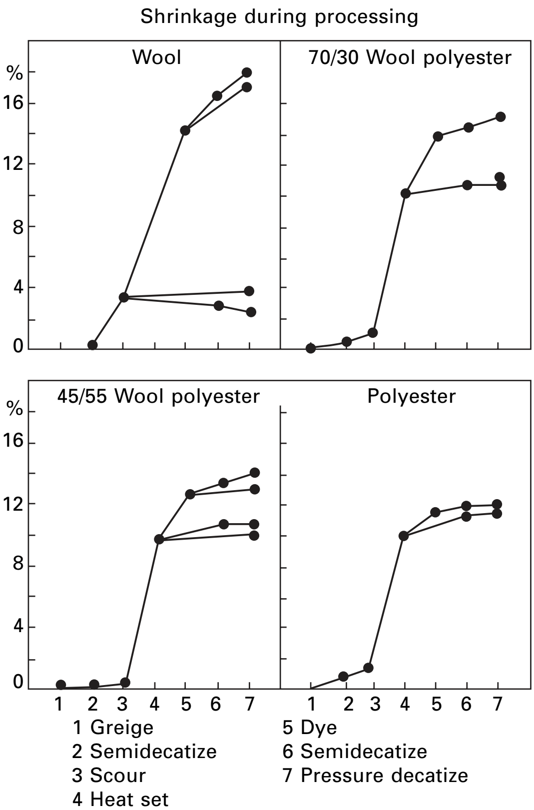
Results: changes in the properties of wool-polyester blends

Unlike pure wool fabrics, wool-polyester blend fabrics are normally heat set, usually before dyeing and sometimes in the loom state. Top- and yarn-dyed fabrics are also heat set and the operation, which sets only the polyester component, improves the wrinkle recovery and flat stability of the blend fabric. Although blend fabrics tend to shrink during heat setting, in a stenter positive dimensional control of the fabric is possible and shrinkage can be controlled or minimized. By controlling shrinkage during heat setting, the finisher can control the weight of the fabric but at the same time will modify the fabric mechanical properties.

The effect of the various setting operations on the shrinkage and mechanical and physical properties of a 70/30 wool-polyester blend fabric is shown in Figs 9.8 and 9.9. Fabric shrinkage occurred primarily in the heat setting operation for the polyester bled fabrics as opposed to dyeing for pure wool cloth. Minimal warp and weft tension was applied to the fabric so that shrinkage was not impeded.

Bending properties

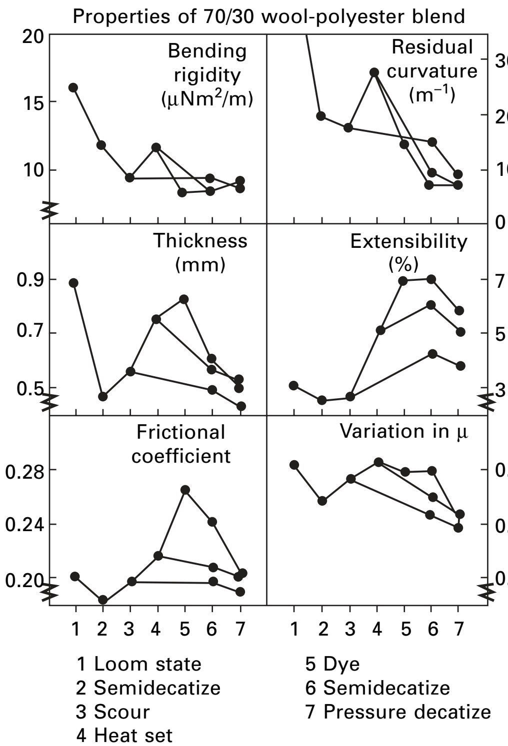
Heat setting increased the fabric bending rigidity and residual curvature in bending (Figure 9.9). This increased stiffness has been attributed to the formation of spot welds between the rubbery surfaces of the fibers. Subsequent



9.8 Shrinkage during processing of wool and blend fabrics (A, B, C, F). *Source*: 'Development of terminology to describe the hand-feel properties of paper and fabrics', by G.V Civille, and C.A Dos, from *Textile Research Journal,* vol. 5, pp. 10–32, 319, 1990. Reproduced with permission from *Textile Research Journal.*

dyeing or pressing removed the effect and it was presumed that the welds are destroyed by mechanical action during dyeing and pressing. However, the increase in stiffness was most readily observed in blend fabrics rather than in a filament polyester fabric. Increased frictional interaction between wool and polyester fibers occurring as result of dimensional changes in the polyester fibers would produce similar effects and may provide a simpler explanation of the observed phenomena. Heat setting had little effect on the ultimate bending rigidity of the pressed fabric, especially after pressure decatizing.

As with pure wool fabrics, the bending properties of wool-polyester blend fabrics may be modified by variations in the final pressing procedure [4]. Again these effects are small compared to the overall changes in bending properties that occur in processing.



9.9 Change in mechanical properties of fabric B (plain weave 70/30 blend) during processing. *Source*: 'Development of terminology to describe the hand-feel properties of paper and fabrics', by G.V Civille, and C.A Dos, from *Textile Research Journal,* vol. 5, pp. 10–32, 319, 1990. Reproduced with permission from *Textile Research Journal.*

Fabric thickness

As in the treatment of pure wool fabrics, setting of constrained fabrics reduced thickness whereas setting of the unconstrained fabric increased thickness. Heat setting under minimal tension had the greatest effect on thickness and, whereas dyeing produced further increases, the additional effect was lost when the fabric was pressed. Omission of both heat setting and dyeing produced a thinner fabric, presumably because shrinkage during processing was reduced.

Fabric extensibility

As with pure wool fabrics, the extensibility of blends is important in determining the tailorability of the fabric. In blends, the behavior of both fibers is important in determining the subsequent extensibility of the fabric.

Heat setting and dyeing both increased the extensibility of the 70/30 wool polyester blend fabrics, again, in part, reflecting the shrinkage that occurred during these setting operations. Where shrinkage was prevented during heat setting, fabric extensibility was not as great.

Surface properties

Heat setting and, more particularly, dyeing increased the coefficient of surface friction in the fabrics. After final pressing the surface friction of fabric that had been heat set and dyed remained greater than that in which both of these operations were omitted (Fig. 9.9). Similarly, heat setting increased the variability of the frictional force. Pressure decatizing in final processing removed the differences between the variously processed fabrics.

9.3.3 Denier reduction

Polyester fibers are subject to hydrolysis in hot caustic solutions. Under severe conditions, the fiber will dissolve. Because the fiber is hydrophobic and resists the penetration of aqueous solution into its structure, the hydrolysis reaction occurs at the fiber surface and works inward toward the core. Under controlled condition, this phenomenon can be used advantageously to impart desirable properties to 100% polyester fabrics. First of all, the hydrolyzed fiber surface will become more hydrophilic and result in a fabric with better wetting characteristics. Secondly, the weight of the fabric is reduced and the diameter of the fiber cross-section becomes smaller, thus the term denier reduction. The net result is finer, more flexible fibers under less physical constraint. This gives rise to more pleasing fabric that has a soft and silky hand. The process conditions are selected to achieve a targeted weight reduction because strength loss will accompany weight loss.

9.3.4 Mercerizing

Mercerizing is the treatment of cotton fabrics with concentrated sodium hydroxide. The treatment usually follows bleaching and profoundly changes fiber properties. The fiber swells and the cross-sectional shape changes from collapsed to round. The round cross-section is retained after the caustic is rinsed away. Mercerized fabrics become more water absorbent and easier to dye and give a greater color yield per unit of dye. Additionally, the round cross-section improves fabric luster, giving it a silk-like sheen. Liquid ammonia mercerization will create similar effects to cotton fibers, but not to the same degree as caustic solutions.

9.3.5 Wool shrink resist

Scales on the surface of wool fibers are the cause of felting shrinkage. The surface scales allow the fibers to slip in only one direction when wool fabrics are washed. Under the mechanical action of washing, this one-way slippage causes the fabric to felt or compact. It shrinks in width and length and grows in thickness. To prevent this, shrink resist treatments alter the scale structure and smooth the surface. This is done either by chemically removing the scales or by covering them with a polymeric coating.

9.3.6 Garment wet processing

Garment wet processing has become a well-established process for creating a wide range of garments with unique and desirable properties. For example, it is ideal for pre-shrinking garments. It can create a washed-down look and produce a garment that is soft and pliable. It can start with undyed garments and end up with dyed, fully finished and shaped garments. Garment processing fits well with the 'just-in-time' delivery concept of supply and is an economical way of producing small lots on a timely basis.

Garment wet processing as a fully fledged manufacturing process blossomed with the introduction of stone-washed denim. Prior to this, it was used to dye and finish items such as full-fashioned sweaters, hosiery and socks. Traditional indigo-dyed denim jeans were one of the staples in work clothing. The qualities of ruggedness, toughness and durability were requirements, and fabric weight, bulk and stiffness were equated to better quality. It was common practice to finish denim with 15% starch and then run it through a Sanforizer to reduce wash shrinkage. The consumer was aware that in use, initial color would fade and the starch hand would soften when the garment was washed repeatedly. The consumer accepted this because the garment became softer and more pliable, therefore more comfortable. Attempts to market jeans with colorfast dyes failed because they did not match the consumer's perception of quality – the worn faded look. In fact, the more faded and worn the garment became, the more the consumer prized its comfort quality.

Historical lore has it that the idea for pre-washed denim arose from a mill trying to salvage rolls of warehoused fabric that had become water damaged and mildewed. Attempts to salvage the goods by wet processing with chlorine bleach effectively removed the mildew; however, it also removed the starch, and the bleach caused the indigo dye to fade in a random, streaky pattern. Samples were shown to the marketplace and the idea became an immediate hit, appealing to both consumers and fashion designers. The original mill wash-down process was difficult to reproduce, so the idea of washing the garments in an industrial washing machine was pursued. Many developments followed in an effort to reproduce the wash-down effect. Among some of the procedures tried were stone wash, acid wash, enzyme wash, chlorine bleach, permanganate bleach and more. Each set of conditions produced uniquely different effects, giving designers a broad menu of washed-down effects from which to choose.

The rise of the casual look, driven by the desire for comfort, extended the range of garments amenable for garment washing. The wrinkled look of pure finished 100% cotton garments became the fashion rage and this quality could only be accomplished by garment laundering. Garments coming out of the dryer were softer, more pliable and somewhat faded in color. Garment wet processing was further broadened to include a dye cycle. As with all fads, public taste changes and the desire for the neat look, i.e. freshly pressed garments, became the next fashion rage. The garment wet processing cycle was eventually expanded to encompass the entire process of desizing, scouring, bleaching, dyeing and finishing by starting with undyed garments. The finishing step required the use of the same finishing chemicals as were applied at the mill, so machine modifications were necessary to control the add-on and to ensure even distribution of chemicals over the entire load. Also the drying step required careful control to prevent finish migration.

How does garment wet processing affect fabric hand? The major contribution is pre-shrinking the garment. This allows the finisher to reduce the amounts of chemicals needed to give shape retention. Less cross-linking equates to better retention of physical properties, therefore bringing 100% cotton into the wrinkle-free arena. The relaxed state of the fabric plus added softeners results in softer, more pliable and more comfortable garments.

9.4 Literature review

9.4.1 Enzyme finishing

Cellulase treatment is commonly used to improve the hand of cotton fabrics and is one of the most important processes in fabric manufacturing.

Cellulase enzymes will hydrolyze cellulose fibers and cause weight loss and alter fabric hand. These treatments also remove surface hairs and pills, making the surface smoother. Mori *et al.* [6] used the KES system to evaluate the effect of cellulase hydrolysis of seven cotton fabrics. The induced weight loss was approximately 5%. This study confirmed that the hydrolysis of the cotton fabric by cellulase took place in the interior of the fibers. Changes in primary hand qualities were the same silk-like trends shown by a polyester filament fabric treated with sodium hydroxide.

Experimental

Commercially available fabrics were scoured and bleached in a conventional technical manner. No differences were detected in the surfaces of the cotton fibers through SEM observation. The amount of damage caused, especially by bleaching, was almost the same for all the cottons used. Additionally, the materials were washed with an aqueous solution of 0.2% nonionic surfactant at 40°C and then rinsed several times with pure water. The original fabric characteristics after washing are summarized in Table 9.6.

Cellulase treatment occurred in a 0.2% (v/v) aqueous solution at a temperature of 40°C, a liquor to-sample ratio of 1:100, and a pH of 4.5. Alkali treatment involved a 10% (w/v) aqueous sodium hydroxide solution at 60°C. Strokes were 3.5 cm at 82 rpm for both treatments. Weight loss was obtained from weights before and after cellulase and alkali treatments. Weight loss and treatment time for each treatment are also shown in Table 9.6.

Fabric properties were measured with a KES-FB instrument (Kato Tech Co.). Property definitions and measurement conditions based on KES are listed in Table 9.7.

Bending rigidity B and shear rigidity G represent the elastic components. In contrast, hysteresis of bending moment 2HB and hysteresis of shear force 2HG and 2HG5 represent the inelastic components of the properties.

Residual curvature is defined as 2HB/B and is the equivalent of deformation at zero fabric bending moment. Also, residual shear strains of 2HG/G and 2HG5/G represent the extent to which a fabric recovers from shear deformation. 2HG at a smaller shear angle than 2HG5, as described in Table 9.7, was also measured.

Results and discussion

Comparing cottons and polyester

Cellulase treatment of the cotton fabrics and alkali treatment of the polyester staple fabric decreased both the bending rigidity and the hysteresis of the bending moment. Figure 9.10 shows that the decrease in residual curvature of the polyester fabric following alkali treatment was more marked than that of the cotton fabrics following cellulase treatment in both warp and weft measurements, ragardless of the cotton weave structures.

Positive changes in residual curvature appeared in the shirting

Change in elongation measured at 5 N/cm based on KES [7] might be a useful indication of fabric relaxation caused by the treatments. Relaxation during the treatments is thought to cause fiber entanglement, which is one factor influencing residual curvature. The average change in elongation of the seven cotton fabrics was 16.7% for the warp measurement and 11.5% for the weft measurement. The average value of the elongation change of the warp in the cottons was much smaller than the warp elongation change in the

Table 9.6 Characteristics of the staple used. Cotton and polyester fabrics were treated with cellulase and sodium chloride, respectively, for treatment times given

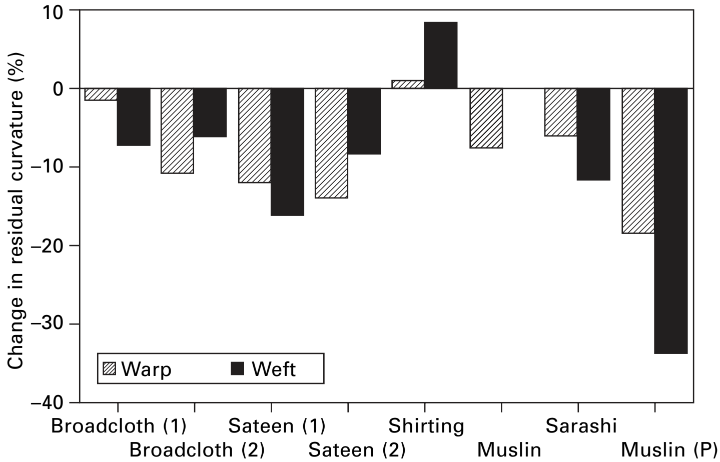
No.	Fabric	Fiber	Weave	Weight loss (%)	Treatment time (hours)	Density (cm^{-1})		Count (tex)		Mass/area (g/m^2)
						Ends	Picks	Warp	Weft	
1	Broadcloth (40/1)	Cotton	Plain	6.5	5.00	54	27	14	14	121
2	Broadcloth (100/2)	Cotton	Plain	6.2	4.50	61	30	12	11	118
3	Sateen (1)[a]	Cotton	Satin	4.8	4.50	36	52	14	14	130
4	Sateen (2)[b]	Cotton	Satin	6.7	4.25	70	44	9	10	119
5	Shirting	Cotton	Plain	5.0	1.00	31	26	19	18	108
7	Muslin	Cotton	Plain	6.0	2.38	31	27	17	19	112
8	Sarashi[c]	Cotton	Plain	6.5	3.08	20	20	28	29	118
9	Muslin	Polyester	Plain	4.5	1.50	28	26	30	31	158

[a] 5 Harness (5 picks, base of 2).
[b] Harness (8 picks, base of 3).
[c] Japanese traditional fabric.
Source: 'Mechanical properties and fabric hand of action fabrics subjected to cellulose treatment', by R. Man, T. Haga and T. Takagishi, from *Journal of the Society of Fiber Science and Technology*, Japan, vol. 55, no. 10, p. 488, 1999. Reproduced with permission from the Society of Fiber Science and Technology, Japan.

Table 9.7 Definition of properties, parameters and measuring conditions based on KES

Property	Abbreviation	Description	Measuring conditions
Bending	B	Bending rigidity obtained from linearity between curvature and bending moment	Pure bending, bending rate, 0.5 cm^{-1}/s
	2HB	hysteresis of bending moment at ± 0.5 cm^{-1} of curvature	Maximum curvature + 2.5 cm, sample size (W × L) 20 × 1 cm
Shear	G	Shear rigidity obtained from linearity between shear deformation and shear force	Shear deformation, shearing rate 0.417 mm/s
	2HG	Hysteresis of shear force at 8.7 mrad	Maximum shear angle ± 40 mrad
	2HG5	Hysteresis of shear force at 87 mrad	Tension on sample 0.1 N/cm, sample size (W ×L) 20 × 5 cm

Source: 'Mechanical properties and fabric hand of action fabrics subjected to cellulose treatment', by R. Mari, T. Haga and T. Takagishi, from *Journal of the Society of Fiber Science and Technology*, Japan, vol. 55, no. 10, p. 488, 1999. Reproduced with permission from the Society of Fiber Science and Technology, Japan.



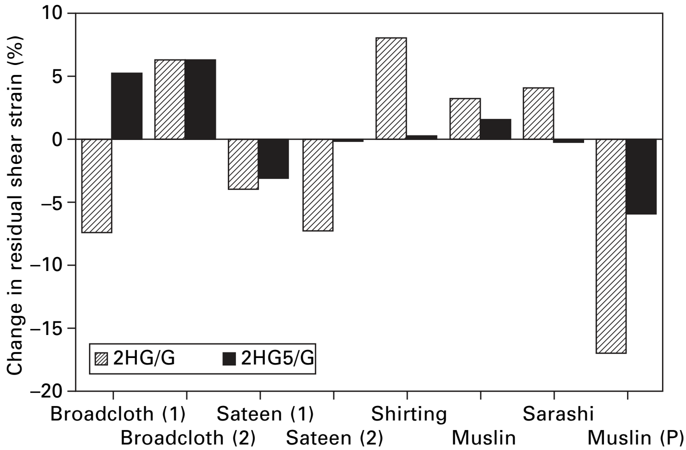
9.10 Percent change in residual curvature for cottons treated with cellulase and polyester staple fabric treated with sodium hydroxide. Muslin (P) means muslin woven of polyester staple fibers (no. 9 in Table 9.6). *Source*: 'Bending and shear properties of cotton fabrics subjected to cellulase treatment', by R. Mori, T. Haga and T. Takagishi, from *Textile Research Journal,* vol. 69, no. 10, 1999. Copyright Sage Publications.

polyester (130%), but the average value of the weft change was comparable to that of the polyester (10.5%). Thus, the work suggests that the residual curvature of the polyester is reduced to a greater extent than that of the cottons as a result of the treatments, especially in the weft direction, as shown in Fig. 9.10.

Shear rigidity and hysteresis of shear force, as well as bending rigidity and hysteresis of bending moment, of all fabrics tested decreased with the respective treatments. Because of the comparable extent of presumed relaxation in the weft direction between the cellulase and alkali treatments, we focused on the residual shear strain of 2HG/G and 2HG5/G in the weft measurements, as displayed in Fig. 9.11. The polyester fabric exhibited the most extensive decrease in residual shear strain of both 2HG/G and 2HG5/G for all fabrics tested. The cotton fabrics displayed positive or small negative changes in residual shear strain.

The reduction in fiber fineness caused by the treatments is thought to have contributed more strongly to the decreased residual shear strain than the decreased residual curvature, because the maximum deformation of the fibers is smaller for the shear measurement than for the bending measurement in KES.

The reduction in frictional force accompanied by the reduction in fiber fineness might enhance recovery from shear deformation and lessen the inelastic shear component of the shear property. Nevertheless an increase in residual shear strain was observed for several cellulase-treated cotton fabrics



9.11 Percent change in residual shear strain in weft measurements for cottons treated with cellulase and polyester treated sodium hydroxide. 2HG/G and 2HG5/G are residual shear strain introduced at 8.7 mrad and 87 mrad, respectively. Muslin (P) means muslin woven of polyester staple fibers (no. 9 in Table 9.6). *Source*: 'Bending and shear properties of cotton fabrics subjected to cellulase treatment', by R. Mori, T. Haga and T. Takagishi, from *Textile Research Journal,* vol. 69, no. 10, 1999. Copyright Sage Publications.

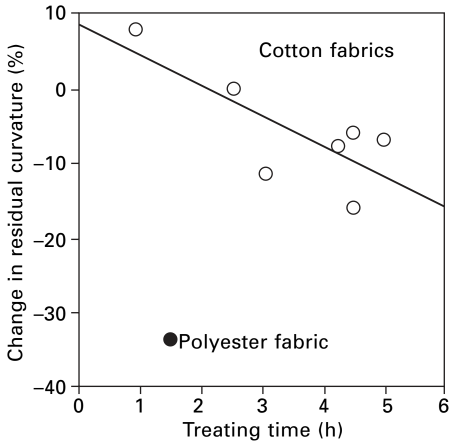
in both 2HG/G and 2HG5/G. The change in residual shear strain was consistent with the fact that the hydrolysis of the cotton fibers took place not only on the fiber surface, but also in the interior of the fibers.

Bending strongly depends on fiber properties. The cellulase treatment weakened the cotton fibers and caused a decrease in both the elastic and inelastic components of bending. However, the inelastic component of hysteresis of the bending moment did not decrease to as great an extent as the elastic component of bending rigidity, due to the degradation within the cotton fibers during cellulase treatment. Because of this internal degradation, the decrease in residual curvature of the cotton fabrics was smaller than that of the polyester fibers, where hydrolysis by alkali treatment took place only on the fiber surface.

Effect of fabric construction on properties

The changes in residual curvature and residual shear strain induced by cellulase treatment are possibly influenced by the original fabric characteristics (Table 9.6). Numerical values were set of 1 and 2 for plain and sateen weaves, respectively, in order to make single correlation analyses for the other quantitative factors. The analyses demonstrated that residual curvature in weft measurement was significantly related to two factors, treatment time and mass/area, at a confidence level of over 95%.

The relationship between residual curvature and treatment time for the cotton fabrics was linear, as shown in Fig. 9.12. In contrast, the relationship between residual curvature and mass/area for the cotton fabrics was described better by an elliptical curve (Fig. 9.13).



9.12 Changes in residual curvature in weft measurements plotted against treatment time for cottons and polyester treated with aqueous cellulase and sodium chloride solutions, respectively. A linear equation is optimized for the plots of the cottons. *Source*: 'Bending and shear properties of cotton fabrics subjected to cellulase treatment', by R. Mori, T. Haga and T. Takagishi, from *Textile Research Journal,* vol. 69, no. 10, 1999. Copyright Sage Publications.

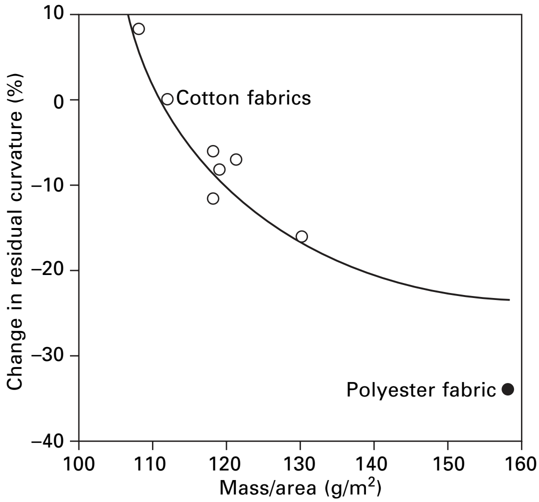
The change in residual curvature in the weft direction for the cottons decreased as expected with both treatment time and mass/area. This was because relaxation increased with treatment time, and larger fiber density worked more efficiently to decrease residual curvature.

Given the treatment time for the polyester fabric, the decrease in residual curvature in the weft measurement was much smaller for the cotton fabrics than for the polyester. In addition, the decrease in residual curvature in the weft direction of the cotton fabrics was definitely smaller compared to that of the polyester at the mass/area given by the polyester.

These results suggest that the reduction in the inelastic component is less marked for the cotton fabrics than for the polyester when considering both bending and shear properties.

Conclusions

The cotton fabrics treated with cellulase have a tendency to decrease to a lesser extent in residual curvature and residual shear strain than does a polyester staple fabric treated with alkali, especially in the weft direction.



9.13 Changes in residual curvature in weft measurements plotted against treatment time for cottons and polyester treated with aqueous cellulase and sodium chloride solutions, respectively. An elliptical equation is optimized for the plots of the cottons.
Source: 'Bending and shear properties of cotton fabrics subjected to cellulase treatment', by R. Mori, T. Haga and T. Takagishi, from *Textile Research Journal,* vol. 69, no. 10, 1999. Copyright Sage Publications.

The inelastic component is reduced less efficiently for the cotton fabrics than for the polyester in bending and shear properties, because the hydrolysis of the cotton fabrics with cellulase takes place, not only on the fiber surface, but also within the fiber. In contrast, the hydrolysis of the polyester fabric takes place only on the fiber surface. Residual curvature in weft direction of the cotton fabrics decreases with increasing treatment time and mass/area less efficiently than that of the polyester. This is consistent with the fact that the inner structure of the cotton fibers is degraded by cellulase treatment.

Karimde *et al.* [8] subjected fabrics made from cuprammonium rayon fabrics to cellulose enzymatic hydrolysis. Variations in time, processing condition (immersion versus pad-roll) and temperature yielded varying degrees of hydrolysis. The physical properties decreased with increase in hydrolysis. A 10% hydrolyzed fabric by the immersion process and a 15% hydrolyzed fabric by the pad-roll process gave the silkiest hand. Kumar and Harnden [9] studied the performance of various cellulase enzymes in garment processing of Tencel and its blend with cotton and linen. Marked differences in hand were observed between whole cellulase and engineered component cellulases and were directly related to the enzyme composition. Mechanical action from the garment processing equipment played a more significant role in removing the fibrillation overriding the effect of the enzyme composition.

Chikkodi and Khan Sand Mehta [10] studied the effect of biofinishing on cotton/wool-blended fabric. Both cellulase and protease enzymes were applied. The enzyme treatment reduced protruding fibers and had a significant effect on physical and aesthetic properties of the blended fabrics. Chattopadhyay *et al.* [11] finished pure jute fabrics with cellulase enzyme and analyzed the changes in fabric hand by the KES system. It was observed that the treatment caused considerable reduction in protruding surface hairs and improvement of fabric hand. The total hand value increased more than 15%.

9.4.2 Bleaching and mercerization

Kotakemori *et al.* [12] evaluated the hand of cotton weaves treated by enzyme bleaching agents. A mixture of horseradish peroxidase and hydrogen peroxide bleaching system reduced hairiness and protected the disordering of intra-yarn, reflecting the high performance of handle values. Wakida *et al.* [13] compared mercerizing desized, scoured ramie fabric with liquid ammonia and sodium hydroxide. Initial dyeing rate was increased with NaOH but greatly decreased with NH_3. As a measure of hand evaluated with KES, shearing modulus and bending modulus were decreased by the NH_3 treatments. Ohshima *et al.* [14] used the KES system to evaluate the effect of high pressure steaming on the hand of cellulose fabrics. Shearing and bending parameters decreased by high pressure steaming except for cotton, concluding that high pressure steaming is effective to improve hand as well as washing shrinkage.

9.4.3 Wool and silk

Marmer *et al.* [15] evaluated the fabric hand of worsted challis fabrics after oxidative/reductive bleaching using the KES system. This study showed greater softness, flexibility and smooth feeling for the two-step process. Karakawa *et al.* [16] compared the hand of fabric made from wool top sliver that had been shrink-resist processed. Ozone verses persulfate oxidation continuous processes were compared. The treated fabric hand and fiber friction were generally the same as for the untreated control fabrics. Jian and Yuan [17] used the KES system to measure the effect of low temperature plasma on the hand of treated wool fabrics. Kim *et al.* [18] investigated the garment performance and mechanical properties of thin worsted fabrics under various wet processing conditions and finishing processes. The effect of rope scouring in wet finishing and pressing and of decatizing in dry finishing on crease recovery, formability, drape and hand were studied. The hand of fabrics processed on semi decators showed better results than on pressing machines. Chopra *et al.* [19] used the KES system to evaluate silk fabrics degummed by different methods. Methods utilizing soap, alkali or triethyl amine scored over acid and enzyme in terms of handle properties.

9.4.4 Finishing

Oh [20] studied various methods to achieve the optimum balance of improved wrinkle recovery of ramie fabrics without losses of mechanical properties and with improved hand. Pre-mercerization and two techniques of applying DP treatment – pad-dry-cure and wet-fixation – were investigated. The contribution of silicone softeners was also explored. The results showed that the wet-fixation process provided a better balance of DP performance versus losses in mechanical properties. This was attributed to the difference in distribution of the resin monomer. Wet fixation promoted better diffusion of the reactant into the fiber interior, resulting in a structure with better stress distribution and a more pliable hand. Furthermore, the inclusion of a silicone softener in the pad-dry-cure method enhanced wrinkle recovery of the ramie fabric with a significant improvement in strength retention as well as a softer hand.

Castelvetro *et al.* [21] evaluated fluorochemical latices such as water and oil-repellent finishes. Three fluoropolymer latices were applied by pad-dry-cure to wool, cotton and polyester fabrics and their performance evaluated for water repellence, oil repellence, fabric hand and mechanical properties. The fluorinated coating did not significantly alter the fabric hand. Czech *et al.* [22] presented data comparing the performance of finish formulations based on fluorocarbon soil release finishes and various types of silicones. The silicone softener contained both amino and hydrophilic moieties and provided substantially improved fabric hand without degrading the soil release properties provided by the fluorochemical treatment. Kim *et al.* [23] evaluated instrumental methods for measuring the surface frictional properties of six fabrics finished with different softeners. Two evaluations were quantitative, based on the KES system, and the third was a human panel evaluation. Statistical analysis of the results showed that the fabric-on-fabric probe provided a superior discrimination in surface frictional behavior compared to the standard probe or the human panel.

Robinson *et al.* [24] reported the influence of pattern design and fabric type on the hand characteristics of pigment prints. Two cotton fabrics printed with two pigment types in six designs were analyzed by a trained descriptive panel to evaluate the effects of pattern design, color and fabric type on 17 hand characteristics. Results showed that fabric and pigment type had a greater influence on hand characteristics than did the design of the print. Pattern design had a significant influence on eight of the 17 hand components. These results were reported earlier in the chapter. Anon [25] investigated the effect of softeners in pigment printing. Two softeners – one based on fatty esters and the other based on silicone microemulsion – were evaluated. The softener based on a silicone microemulsion provided more stable films with improved elasticity, which reflected in fabric hand.

Barndt *et al.* [26] evaluated the effect of silicone finishes on 100% cotton denim for softness using both the KES system and a hand panel. The KES descriptors were capable of distinguishing small changes in fabric hand and the values correlated well with the hand panel ratings. The study showed that only one or two of the 16 KES fabric mechanical properties were necessary to accurately describe the effects of the finishes on fabric. Lautenschlager *et al.* [27] explored the structure activity relationship between the arrangement of pendant aminofunctional side change in silicone finishes and finish response such as hand, whiteness, water absorbency and soil release. Dramatic effects were observed, suggesting that optimizing the aminofunctional side chain could lead to a substantially improved finish.

Beal *et al.* [28] studied the sorption of a cationic surfactant, distearyl dimethyl ammonium bromide onto fabrics made of 100% cotton, 100% polyester, and a 50/50 cotton/polyester blend with and without functional finishes. Finishes chosen were a DMDHEU durable press finish and a polyacrylic acid soil release finish. The results showed that unfinished 100% cotton picked up more softener than did unfinished 100% polyester. DMDHEU finished fabrics picked up less than their corresponding untreated controls. The polyacrylic acid finished fabrics picked up more softener than the unfinished controls. Perceived fabric softness was generally improved for all cationic softened test fabrics. Both 100% cotton and 50/50 cotton/polyester fabrics finished with DMDHEU durable press finish were perceived to be less soft than their unfinished counterparts; however, sorption of the cationic softener onto the DP finished fabrics restored the softness level back to that of the unfinished fabrics. The stiffness of both cotton and polyester fabrics was greatly increased by the acrylic finish. Even the presence of large amounts of softener did not restore the softness ratings to levels comparable to the unfinished controls.

Paek [29] evaluated the fabric hand and absorbency of three types of children's flame-retardant sleepwear fabrics. Fabric hand was determined by measurements of flexural rigidity, coefficient of friction and compactness and subjective hand ratings by a test panel. The analysis of response profile indicated that roughness and openness was preferred to smoothness and compactness for the sleepwear fabrics evaluated. Absorbency was mainly influenced by fiber content and not by the flame retardant finishes or additives. Mukhopadhyay [30] measured the general characteristics of eight fabric groups divided by fiber content, fabric construction and special finishing treatment by the KES-F system. Using silk as a reference, caustic-reduced polyester fabrics exhibited strong silk-like characteristics except in their surface properties. Liquid ammonia-treated cotton fabrics also possessed a certain silky hand. Micro-fiber fabrics are soft and smooth but do not have the high *kishimi* hand typical of silk fabrics. Fabric construction has some influence on fabric stiffness, but not on hysteresis. Polyester lining fabrics have high bending stiffness and polyester/cotton fabrics have very high shear stiffness and hysteresis. These two groups are the least silk-like. Shear properties and bending hysteresis appear to be the most important factors affecting the hand of the fabrics studied. Matsudaira and Matsui [31] followed the changes of mechanical properties and fabric hand of polyester fabrics through wet processing and the finishing stages using the KES system. Relax processing, including desizing, shrinking and denier reduction, softened the polyester fabric in all its mechanical properties and fabric hand. The weight reduction stage, because of the effective gap between fibers, was largely responsible for the increase in softness. However, the effects of dyeing and raising were small.

Csiszár and Somlai [32] characterized the hand and mechanical properties of linen, cotton/linen and polyester/linen blends taken step by step from greige fabric through final finishing. Combinations of chemical–mechanical and enzymatic–chemical–mechanical finishing technologies were used. The most noticeable effect on hand was obtained on 100% linen fabric, which was the stiffest of the three. Physical test results indicated that the major contributor to fabric softness was mainly due to mechanical treatment and not enzymatic or chemical finishing. However subjective assessment indicated that the enzymatic treatment within the applied finishing line resulted in fabrics with better appearance and luxurious hand.

9.5 Future trends

The trend of producing textiles in low-wage-labor countries has changed the responsibilities of the parties along the supply chain. The retailers must assume the responsibility not only for creating new products, but also for sourcing and quality assurance. The technical support once provided by the domestic manufacturers involved in vertical manufacturing is shrinking as jobs flow to low-wage countries. The retailers must now turn to their global suppliers, upgrade their technical staff or contract the work out to a third party. It was one thing when all parties in the vertical chain were in close proximity. Now it is a new game and to work effectively, information must be transmitted in unambiguous terms. When it comes to fabric hand, subjective descriptors are fraught with language translation and individual interpretation, so it becomes important to factor out the human element and develop reliable methods for accurately quantifying hand properties. The information also must be in a universal language and formatted in a form that can be transmitted electronically.

A good example of this is management of fabric color. Traditionally, the human eye was used to evaluate color. All decisions and communications were based on these evaluations. Color science has advanced to the point where the attributes that describe color can be measured by a spectrophotometer.

Software has been developed that allows the use of this information for all aspects of color management, and for communicating this information electronically. It has taken many years to get the technology to this stage; however, it has reached a state of maturity that allows it to be quickly implemented as globalization becomes more widespread.

Another trend on the horizon is the potential rise of businesses aimed at niche markets. Fashion, fads and new products are as important as price in satisfying consumer needs. The void created by the disappearance of the traditional domestic manufacturers creates an opportunity for creative individuals to step in.

9.6 Sources of further information and advice

Additional information regarding the chemistry of the finishes discussed in this chapter can be found in Tomasino [33]. This book provides a review of the chemistry and technology of fabric preparation and finishing. Vigo [34] provides details on textile processing and properties, and Lewin and Sello [35] delve deeply into functional finishes. Product bulletins provided by suppliers of chemical auxiliaries are another good source of information. A compilation of products and suppliers can be found in the annual buyers' guide edition of the *AATCC Review*.

The constant flow of new products to the retailers' shelves is the lifeblood of the textile industry. Fashion designers and product developers are the ones who initiate this flow. Since the hand of the final fabric largely depends on the starting greige fabric, factors discussed in other parts of this book, such as fiber, yarn and fabric construction, have a profound influence on the final hand. Usually fabric designers are concerned with manufacturing the greige fabric and give little or no thought to what happens in wet processing. While the finisher does have some tools at his disposal to fine tune the hand, they may not be enough to satisfy the fashion designer. If there is a specific hand target in mind, the fabric designer and the finisher should work together. Having a greige construction that can accommodate the changes that occur in dyeing and finishing is the best approach. Therefore as advice, the designer, greige manufacturer and finisher must work together at the onset stage rather than in isolation.

Further information can be obtained from References 37–44.

9.7 References

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10
Effect of mechanical finishing on fabric hand

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10.1 Introduction

Mechanical finishing is defined as the use of mechanical devices to manipulate fabrics to enhance their functional and aesthetic properties [1]. Herard [2] has referred to mechanical finishing as 'yesterday's finishing techniques applied to today's fabrics'. It has also been stated [6] that mechanical finishing is not an exact practice, but in many ways an art. It takes skilled operators to control the operating parameters to compensate for equipment wear to produce finished goods with consistent quality. The term 'surface finishing' is also used to describe the effect produced by some of the devices. This chapter will describe the mechanical devices, what they do and how the tactile properties and appearance are altered. Topics included in this chapter are calendering, compacting, napping, sueding, shearing, polishing and pressing.

10.2 Calendering

Calendering by definition is mechanical finishing processes for fabrics or webs to produce special effects such as luster, cover, glaze, moiré, Schreiner and embossed patterns [6]. Fabrics are compressed between two or more rolls under controlled conditions of time, temperature and pressure. A calender is a machine consisting of two or more massive rolls compressed against each other by means of hydraulic cylinders applying pressure at the journals. One roll is considered the pattern roll and is responsible for the finished appearance of the fabric, while the other roll (the filled roll) serves as pressure back-up for the pattern roll and also to transport fabric through the machine.

There are many types of calenders, each designed to impart specific effects to cloth. The composition of the rolls, number of passes, temperature control, moisture control and pressure can vary to fit the desired effect. For example, the pattern roll can be engraved to emboss a three-dimensional pattern into the fabric. The engravings can be shallow or deep depending on the desired effect. The pattern roll can be smooth, made of steel or nylon, to give the fabric a high luster and sheen. The backing rolls can be made from corn husks, kraft paper, or hard or soft rubber, and deform to receive the pressure of the pattern roll. In calendering, the yarns are flattened and become more oval in shape. This causes them to spread in two dimensions, closing up the fabric structure and leaving less open spaces between the yarn crossovers. The surface becomes smoother and more lustrous and the fabric becomes thinner and more compact. The reason fabrics are calendered is to improve aesthetics. The major fabric changes are reduced fabric thickness, increased fabric luster, increased fabric cover, smooth silky surface feel, reduced air porosity and reduced yarn slippage.

10.2.1 Types of calenders

Rolling calender

The function of a rolling calender is to provide a smooth or glossy fabric surface as well as to improve hand. It is used on all types of cloth but is predominately used on woven fabrics or cotton knits. Normally rolling calenders consist of three rolls with alternate steel and filled backing rolls. The filled backing rolls can be of wool felt paper, cotton, resilient wool and cotton blends. There are others that may contain two, four or five rolls to accommodate multiple pressing in a single run through the machine. The nip pressures are very high and can range from 300 to 500 PLI kg per linear cm. When required, the steel roll can be heated by gas, hot oil, electricity or steam up to 210°C.

Silk finishing calender

The main function of a silk finishing calender is to provide a smooth fabric surface with improved hand and light luster. It can be used on all types of fabrics but is used mostly for high content cotton and coated or impregnated webs. The silk finishing calender has a three-roll configuration with a top and bottom filled roll and a steel middle roll. The filled rolls are made from cotton/wool blends. The main steel roll can be heated by gas or steam to a surface temperature of 177°C. The nip pressure is 80–139 kg/cm compared to the 300–500 kg/cm linear for roller calenders. The major difference between the rolling calender and the silk finishing calender is the lower nip pressure. This parameter is responsible for the lighter surface luster and fabric silk-like hand.

Friction calender

The main function of a friction calender is to polish fabric surfaces to a very high gloss or to reduce the porosity of the fabric to the minimum. The ‘down proofness' and 'water resistance' of a fabric are greatly enhanced by friction calendering. Accordingly, the fabric hand becomes stiffer and crisp. The calender is used on woven fabrics of cotton or linen and these fabrics must be very strong to withstand tremendous tension in the calendering nip. The friction calender is a three-roll design with the intermediate roll filled with heat resistant cotton. The top roll is the polishing roll and is driven faster than the support rolls at speed differentials ranging from 5% to 100%. The line speed of the fabric traveling through the calender is determined by the speed of the cotton filled intermediate roll and the bottom support roll. The coefficient of friction between the fabric and these rolls is similar so the fabric sticks to these surfaces. The top roll, because of the nature of the steel surface, can slide by at twice the speed, creating a frictional polishing action. The top roll can be heated to 177–218°C and the bottom roll to a maximum of 66–121°C. Frictioning produces a high degree of luster on one side.

Schreiner calender

The function of a Schreiner calender is to texture the surface of a fabric to obtain controlled opacity, desirable softness, luster and translucency. For knits, a Schreiner calender provides improved hand, surface texture and more cover, while for woven goods it offers more texture and drape. It has also been used to soften latex impregnated non-wovens. The pattern roll has from 100 to 140 lines per cm, etched at 26.5° from the vertical and at a depth of 0.025–0.050 mm. These lines are lightly embossed onto the fabric surface and, being regular, reflect light so as to give the surface a high luster. When mercerized cotton fabrics are Schreiner calendered, the fabrics develop a silk-like luster and brilliance.

The calender is normally a two- or three-roll machine and operates with a nip load at about 214–300 kg/linear cm. The top pattern roll is chrome-plated forged steel and the resilient roll is wool felt paper. In a three-roll calender, the bottom roll is forged steel. Both the top and bottom steel rolls can be heated to 177°C.

Embossing calender

The function of an embossing calender is to impart texture or a three-dimensional pattern to the surface of the fabric. All types of fabrics including woven, non-woven and knitted fabrics can be embossed. Embossing calenders are two-roll machines using a forged steel engraved top roll and a filled bottom roll with filling of wool felt paper, resilient wool/cotton, or in the case of 'Kiss' embossing where a slight glaze or luster is preferred, a higher content cotton filling. A synthetic shelled bottom roll can be used in lieu of a fiber roll. The top roll can be heated by high-pressure steam or hot oil. For natural fibers such as cotton and cotton blends, the roll can be heated to 177°C, while for synthetic woven goods or knits, to 232°C. Engraved pattern rolls range from polished to very deep floral patterns. For example, the moiré effect, a watered appearance that resembles paper after it has been wetted with water, can be obtained by using a moiré pattern embossing roll. Thermoplastic fabrics can be permanently embossed with heated rolls and the effect can withstand repeated laundering. Natural fibers are more difficult to emboss and usually starch is needed for the embossing to take; however, this effect is not durable to laundering. Certain melamine resins can be added prior to embossing and, when properly cured, the embossing effect is more durable.

Cire calender

The Cire calender is used for glazing and glossing fabric surfaces. Some porosity reduction and fabric compaction also occurs but not to the degree obtainable by a friction calender. All types of fabrics can be processed but usually they are 100% synthetic fiber or fabrics with a high synthetic fiber content. The units are operated at 300–600 kg/linear cm and the top roll can be heated to 177–242°C. The filling roll is usually cotton.

10.2.2 Construction of the rolls

Pattern rolls

Pattern rolls are turned from solid steel billets. The pattern is engraved onto the roll surface and the roll is heat treated to harden it and make the pattern more durable. The rolls are chromed which also increases wear resistance and protects them from rusting on storage. The center of these rolls is bored out to accommodate various heating systems. Steam, electrical heaters, natural gas and recirculating hot oil systems have been used to heat these rolls.

Resilient rolls

Resilient rolls are steel cores filled with cotton, or a combination of wool and cotton. The diameter of the steel core is approximately 50% of the final filled roll. Cotton is used to produce very hard, dense surfaces. These are not very resilient and are susceptible to being marked or scarred should hard objects inadvertently pass through with the cloth. Wool or wool/cotton is used because the surface will be more resilient and less likely to be damaged if a seam passes through. A disadvantage of wool is that the scales on the fiber tend to pick certain fabrics and create surface defects. Paper is also used to fill bowls. The latest in bowl design is nylon bowls – a 2.5 cm thick nylon shell fitted over a roll. The advantage of nylon is its resiliency; it is more resistant to being marked than are the other surfaces. Seams and wrinkles can run through without having to refurbish them all the time. Cloth having selvages thicker than the body of the fabric can be run through without problems.

Auxiliary equipment

Other devices are necessary for running the calender. Let-off and take-up rolls geared-in with the calender rolls are important. Proper tensions must be maintained to produce a consistent product. Edge guides and spreader bars are necessary to keep wrinkles from developing and being permanently pressed into the fabric. Seam detectors signaling the machine to prepare to jump the seam are necessary, otherwise the seam will mark the bowl. A marked-up bowl will spoil many yards of cloth.

10.3 Compacting

Compactors are mechanical devices that physically rearrange the geometrical relationship of yarns in a fabric. For example, in woven fabrics, the filling yarns can be forced closer together, thus pre-shrinking the fabric. In knit fabrics, the loops can be rearranged to overcome distortion in the length versus width caused by stretching tensions. Knit compactors balance the length to width loop ratio, thereby stabilizing the residual shrinkage in laundering. Controlled residual shrinkage is an important quality parameter for many fabrics to be made into garments. These fabrics need to meet specifications of less than 2%.

10.3.1 Why fabrics shrink

Woven and knitted goods are three-dimensional arrays of crimped or looped yarns. Fabric forming processes take straight lengths of yarns and force them into three-dimensional arrays. In a woven fabric, the degree of crimp is a function of the yarn size and fabric construction. When fabric is completely relaxed as is the case after washing, the crossing yarns will move around in relation to each other until a stable configuration is reached. This stable arrangement, the point where the relaxed fabric no longer shrinks in width and length, is also related to yarn sizes and fabric construction. When stretching tensions are applied to the fabric, the crimped amplitude decreases and the fabric grows in the direction of the stress. Later when the tensions are relieved and the fabric is allowed to relax, the crimp amplitude returns to its stable configuration and the fabric shrinks. Many fabrics are stretched during wet processing as they are pulled from one operation to another. This is the major cause of fabric shrinkage.

10.3.2 Types of compactors

Sanforizer

The Sanforizer is a fabric compactor developed by Cluett Peabody; the term 'Sanforized®' is their registered trademark and is used to market fabrics that meet certain shrinkage specifications. 'Sanforized' is now generally accepted to mean a fabric that has low residual shrinkage and the term 'sanforizing' is used to describe a particular method of compacting. The process consists of a multi-step operation where the fabric is first moistened with steam, run through a short tenter frame (pup tenter) to straighten and smooth out wrinkles, through the compressive shrinkage head and then through a Palmer drying unit to set the fabric. The fabric is wound into large rolls under minimum winding tensions. Usually, a lubricant is added in preceding operations to facilitate yarn movement. Selection of the proper lubricant is critical.

Compactor head

The compactor head is where force is applied to move parallel yarns closer together, causing the length to shrink. More fabric must be fed in than is taken off. A thick rubber blanket running against a steam-heated cylinder provides the compacting force. The rubber blanket is pre-stretched at the entry end where the fabric enters the compactor. The fabric and blanket together come in contact with a large diameter steam-heated cylinder. At this point, the stretching tensions on the rubber blanket are released, causing it to contract to its original length. Since the fabric is non-elastic, something must happen to the extra length of fabric trapped between the conveyor and the restraining drum. The frictional forces imposed on the fabric cause adjacent yarns to move closer together and the unit length of fabric becomes equal to the unit length of rubber blanket it rests on. If the fabric construction does not allow the yarns to move, the extra fabric will buckle, developing creases and wrinkles. Constant stretching and relaxing of the rubber blanket generates heat, so it is sprayed with water to cool it at the exit end. The degree of shrinkage can be controlled by the thickness of the blanket. The thicker the blanket, the greater is the stretched length at the entry end, allowing more fabric to be fed in and resulting in greater fabric compaction. Conversely if the blanket is thinner, less compacting will occur. Blanket thickness can be adjusted by means of a pinch roll compressing the rubber blanket allowing for 'dialing in' the desired degree of compacting. To be effective, the required degree of compacting should be predetermined ahead of time. This is done by first laundering the fabric to determine its shrinkage behavior. The degree of compacting should not exceed the degree determined by laundering, otherwise over-compacting will cause the fabric to grow when relaxed. This is as much a disadvantage as is shrinkage.

Friction calender compactors

Another method of compacting fabrics is with calender rolls. The fabric passes between two metal cylinders, one cylinder rotating faster than the other. Shoes positioned against the cylinders prevent buckling of the fabric. The fabric delivery cylinder rotates faster than the take-off cylinder and the frictional forces against the fabric cause filling yarns to move closer together, thus pre-shrinking it. The degree of compacting can be controlled by the differential speeds of the two calender rolls. Tubular knits fabrics can be calendered by machines designed to operate simultaneously on both layers of the fabric in tube form.

10.4 Raising (napping, sueding)

Raising is the term used to describe the creation of pile surface on a fabric [8]. In napping, single loops of fibers are engaged by wire hooks, lifted and released or lifted, and stressed beyond the loop's tensile strength to break the loop. The surface of the fabric is now populated with raised loops or single fiber ends with a soft surface texture. Napping, sueding and shearing are techniques for developing surface pile. In conjunction with calendering, these processes fall into the category of 'surface finishing'. Surface finishing effects, especially raising, have been used for years to enhance the appearance and hand of fabric. Many of the finest wool and cashmere fabrics are still mechanically finished – not only to improve their hand and appearance but to increase their bulk, to impart the feeling of warmth, to increase the number of fiber ends on the surface of the fabric, to provide improved adhesion for laminating purposes and to improve the profit margin per yard sold. While originally developed for finishing fabrics made from natural fibers (yesterday's technology), the same processes are used to finish today's woven and knitted goods made from synthetic and synthetic blends. Sueding and napping machines are used on both filament and spun constructions, while shears, polishers, calenders and decatizers are used singly or in combination to create specific surface effects.

10.4.1 Sueding (sanding)

The objective of sueding, also known as sanding, is to degrade fiber bundles, allowing exposure of a portion of filament ends. The strategy behind sueding is to expose the surface of the web to an abrasive medium at high velocity, providing a surface populated with extremely short filament ends. No pile effect is desired in this process. The machine consists of one or more rolls covered with an abrasive. Fabrics traveling over these rolls develop a soft hand and the material's surface can be made to feel like suede leather. The hand will depend on the fiber composition, the filament count in the yarn and the intensity with which the fabric is worked. Filament fabrics can be made to feel like a spun fabric and, generally speaking, all fabrics will have a softer hand. Another purpose of sueding is to alter the optical property of the surface by hiding or blending the fabric construction.

Multi-cylinder sueders

Multi-cylinder machines are usually five rotating cylinders, each independently driven. They can be rotated clockwise or counter-clockwise to the travel of the cloth. Cylinder construction can vary between machines made by different manufacturers. Some machines are sandpaper-covered abrasive rolls, either free standing or as rolls mounted around the periphery of a larger rotating cylinder shaft. Other types of abrasives are also used, for example, flexible bristle abrasives (silicon carbide impregnated filaments) or specially treated wires. Ahead and behind each cylinder are adjustable idle rolls that control the pressure of the fabric against the abrasive cylinder. Entry and exit drive rolls transport and control the fabric tension as it progresses through the machine.

Single-cylinder sueder

The single-cylinder sueder has one abrasive-covered metallic roll and one rubber-covered pressure roll. Water is circulated through the cylinder interior to control the heat generated from friction. The pressure roll presses the fabric against the abrasive cylinder and is set by means of a micrometer. The abrasion of the fibers on the surface of the fabric takes place in the nip between the pressure roll and the abrasive cylinder.

Abrasive covered rolls

The quality of sueding will depend on fabric construction and selection of abrasive grit. Over-sanding may weaken woven fabrics or perforate knit fabrics. Abrasive material deteriorates with use so it must be changed on a regular basis to guarantee consistent product.

Advantages and disadvantages

Both machine designs perform very well and produce acceptable products. However, one machine may have advantages over the other on a specific style. For example, fabrics with knots or slubs on their reverse sides, or fabrics with selvages thicker than the body, are best run on a multi-cylinder machine. Knot holes or over-sanded selvages may occur on the single cylinder machine because the fabric is compressed against the abrasive cylinder. A single roll sueder is more effective on fabrics with terry loops on the face that must be broken. Also, difficult styles that require shaving the face to develop a surface effect are more effectively and efficiently sanded on a single cylinder machine. Some fabrics tend to develop a directional pile when sanded on a single cylinder machine. The multi-roll machine may be operated with the cylinders rotating in opposing directions, eliminating this effect.

10.4.2 Napping

Nappers in contrast to sueders change the aesthetics of fabrics by developing pile on the surface of the fabric. The pile can be either raised unbroken loops or raised loops where the filaments are broken in the process. The depth of pile developed on a napper can be significant compared to sueding. Pile finishes such as high-pile fur-like effect, fleece, velour, flannel and bed blanket are produced by napping. Proper fabric construction is a prerequisite to napping. It is important that the yarns acted on by the napper are not the ones responsible for the strength and integrity of the fabric, because the napped yarns are weakened by the napping action. Fabric to be napped should have a napping lubricant or softener applied prior to napping to allow the fibers in the yarn to slide more freely during the napping operation.

Nappers

Wire nappers, known as planetary nappers, are the most common machines in the industry. The basic design of a wire napper is 24 to 36 small pile wire-clad rolls (worker rolls) mounted on the periphery of a large main cylinder. The large napper cylinder rotates in the same direction as the flow of the fabric at a constant speed, while the worker rolls rotate on their own axis in a direction opposite to the rotation of the main cylinder. Cleaning rolls or brushes below the main cylinder remove lint and entangled pile to keep the wires at high efficiency. The speed of the worker rolls, the type of wire and the angled direction of the wire all influence the degree of nap. There are many arrangements of these components, each designed for their individual specialty.

Double acting nappers

The double acting napper is the most commonly used machine in the industry. The main cylinder carries 24, 30, or 36 napper rolls. Every other worker roll (the pile worker roll) has hooked wire points angled in the same direction as the rotation of the cylinder. The alternating worker roll (the counter-pile roll) has hooked wire points angled in the opposite direction. The relative speed between the fabric travel and the speed of the worker rolls determines the amount of napping energy imposed on the fabric. Neutral energy is defined as the point at which the surface speed of counter-rotating worker rolls matches the surface speed of the fabric, so that no napping takes place. The napping action is such that the counter-pile rolls dig into the yarn to pull out fibers while the pile roll felts or tucks the fiber ends into the base of the fabric. The double acting napper develops a dense, tangled nap which is very desirable on many fabrics.

Knit goods napper

Knit goods nappers are designed for use almost exclusively by the knit industry. Machines designed for tubular fabrics as well as open-width fabrics are available. A knit goods napper differs in that the main cylinder rotates on its own axis in a direction opposite to the flow of the cloth. Half of the worker rolls are covered with straight wire called traveler wire, and the other half are covered with hooked wire whose points face the rear of the machine. While it looks like pile wire, it acts like counter-pile wire because of the direction of rotation of the main cylinder. Both sets of worker rolls rotate on their own axis in a direction opposite to the cylinder rotation. Fourteen to 24 worker rolls are mounted on the main cylinder. The hooked wire roll does the napping, and the traveler wire roll speed is adjusted to control the tension of the fabric on the cylinder. Correct speeds prevent wrinkles from forming in tubular goods and longitudinal wrinkles in flat goods.

Single acting napper

While the double acting and knit nappers generally develop a directional nap with parallel fibers that can be lofty or flat, the purpose of the single acting napper is to untangle and comb the fibers parallel. The single acting napper's main cylinder rotates in the same direction as the flow of the cloth. There are 20 to 24 pile worker rolls in the cylinder whose wire points face the rear of the machine. The pile worker rolls rotate in a direction opposite to the main cylinder. A distinguishing feature of this machine is the way the cloth is fed to contact the main cylinder. The cloth is fed over contact rolls that permit two to four tangential contacts. If the cloth hugged the entire cylinder, the wire ends all pointing in the same direction would tear it to shreds.

Napper wire

The characteristics of the napper wire are just as important as the machine design. Most wires have a 45° bend at the knee and are ground needle sharp. The wire protrudes through a tough flexible backing, built up and reinforced to securely hold the wires. The backing and wire are wound spirally over a hollow supporting roll to become the worker roll. For certain fabrics, e.g., tricot warp knits, it has been found that a bumped or mushroomed wire point with tiny barbs underneath will develop a denser nap in fewer runs. As the wire point withdraws from the yarn bundle, the minute barbs will raise more fiber than a single-needle point, producing more fiber coverage per napping run. Wires with less severe knee bends can be used to raise unbroken loops from filament yarns. In this instance, the wire raises the filament from the yarn and drops it off without breaking the filaments.

10.5 Shearing

Shearing is a process where raised fibers are cut to a uniform height [7]. Some spun fabrics are sheared close to the fabric surface as a means of removing the raised hairs, giving the fabric a clear, smooth surface. Shearing can be used as an alternative to singeing. More often, however, shearing follows napping to clear out random lengths of fibers and produce a uniform and level pile. Shearing is used to reduce pilling, to produce a certain hand, to improve color and appearance and to produce sculptured effects. Knitted and woven fabrics with loops on the face or back are not necessarily napped first – they can be sheared directly to cut off the tops of the loop and produce plushy velours such as knit velours and plush towels. Terry looped bath towels can be sheared on one or both faces to produce a plush pile surface.

10.5.1 Shearers

The shearer head consists of a spiral blade revolving on its own axis in contact with a ledger blade. This creates a shearing action similar to that produced by a pair of scissors. When fibers are presented to this cutting head, they will contact the ledger blade and be cut off by the rotating blade. The fabric travels over a cloth rest (bed) in front of the ledger blade and the design is such that the fabric forms an acute angle. This sharp angle causes the pile to stand erect and be more easily cut. The distance between the bed and the ledger blade is adjustable, so the height of the pile can be regulated. Most shearers are equipped with expander rolls to straighten and flatten the fabric as it approaches the bed and a vacuum system to remove the lint produced at the cutter. Specially designed support beds are available for producing sculptured patterns on high-pile fabrics. Variations can produce stripes, zig-zag, checks, etc. Very often the fabric is brushed prior to shearing. The object of brushing is to lay the fibers in one direction and thus facilitate the cutting process.

10.6 Polishing

Polishers are primarily used on synthetic pile fabrics when either an erect lustrous pile or a laid-down pile is required. The machine consists of a fluted heated cylinder driven by a variable speed motor and an endless felt blanket. The fabric passes over the endless blanket that is adjustable and brings the fabric face in contact with the heated cylinder. The serrations on the cylinder draw through the fibers to raise and parallelize them. Heat facilitates the straightening process and sets the fibers. Polished fabrics appear more lustrous because the parallel fibers result in more uniform light reflection. By running the cylinder so that the edges of the serrations revolve against the fabric flow, the pile will be made to stand more erect; however, if the edges of the serrations run in the same direction as the cloth, the pile will lie flat.

10.7 Corduroy cutters

Corduroy fabrics are distinguished from other fabrics by parallel pile ribs running lengthwise in the warp direction. The pile ribs, called wales, are produced by passing the fabric through a cutter that slits specific filling yarns across the face of the fabric. The design of the fabric is such that the filling consists of ground yarns and pile yarns. The ground yarns provide fabric strength and integrity while the pile yarns form the rib or wale when cut and brushed. The principle of raising the pile is relatively simple; the filling yarn is slit in two places, creating two legs anchored by warp yarns. The two legs become erect when the fabric is brushed in the filling direction. The brushing action also causes the individual fibers in the two legs to disentangle and become a single rib.

The cutter is a simple device consisting of circular knife blades positioned over slotted base plates. The slotted base plates resemble thin needles inserted under the floating filling yarns to be cut. Each wale requires two cutters so the number of cutters will depend on the number of wales per inch. Once the fabric is threaded onto each base plate, the fabric is pulled through the machine at an angle. Fine wale fabric requires multiple passes because of physical limitations as to how close the cutters can be placed together. Brushing following the cutting operation is necessary to stand the pile. Some styles require an adhesive back coat to anchor the pile because the pile can be pulled out unless it is bonded to the back.

10.8 Decatizing

Decatizing is a method of steaming fabric between two layers of cotton press cloth and can be the last finishing process for some fabrics. The effect on the fabric is similar to steam pressing garments under a press-cloth. The process is used to improve the hand and drape, to brighten colors and enhance natural luster, to assist in setting the finish, or to refinish fabrics after sponging or cold-water shrinking. Decatizing is a normal finishing step for many wool and wool blend fabrics. Wool fiber from different animals will have varying shrinking characteristics. Fabrics made from wool from different regions of the world will develop a cockled surface appearance when exposed to high humidity. The differential shrinking behavior can be evened out by decatizing the fabric and allowing the high temperature steam pressing to reset the fibers. Decatizing is also an effective mechanical softening treatment resulting in a luxurious, soft, smooth hand. The process can also be used on fabrics containing other fibers such as acetate, acrylic, rayon, spun polyester and other synthetic blends.

10.8.1 Semi-decatizing

Semi-decatizing is a batch process where fabric is wound onto a perforated drum between interleaving cotton blankets. Steam is forced through the roll (inside-out) for several minutes to provide moisture and heat. Compressed air is then blown through the roll to remove some of the moisture and cool it down. The fabric and blanket are rewound onto another perforated drum so that the outside layers become the inside layers and the cycle is repeated to ensure uniformity. At the end of the cycle, the fabric and blanket are separated and wound into individual rolls. Controlling time, pressure, heat, moisture and cooling are prerequisites for quality results.

10.8.2 Continuous decatizing

The continuous decatizer has one steaming cylinder and one cooling cylinder. An endless apron carries the fabric around both the steaming and the cooling cylinders. Fabric continuously moves through, so the exposure time depends on the speed of the machine and is less than in batch semi-decatizing. Nonetheless, excellent results are obtained on many fabrics.

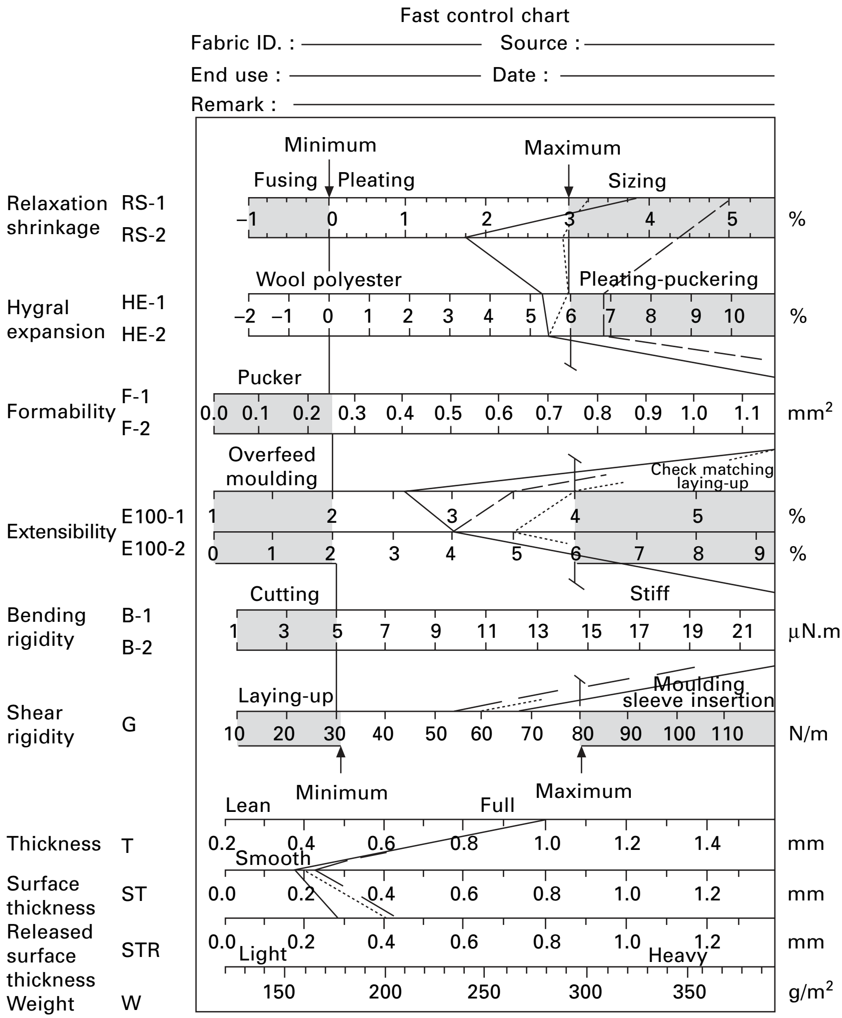
10.8.3 Comparison of alternative decatizing equipment

DeBoos *et al.* [9] reported a study on the comparison of alternative decatizing equipment. The study included conventional decatizing (open blowing) machines with the continuous decatizing equipment. Two types of continuous decatizing machines were evaluated:

A. One that used a wrapper cloth to hold the fabric against a perforated drum and, in sequence, blew steam then sucked cold air through the fabric and wrapper.
B. One that sprayed water onto the fabric (or an interleaved wrapper) and

then used an impermeable belt to hold the cloth against a heated drum and generate the steam during the process.

Samples of cloth were finished using the two types of continuous decatizer and tested using FAST. The data were compared with those obtained from fabric finished using a traditional batch decatizer. Evaluation of the fabric fingerprints obtained using FAST (shown in Fig. 10.1), indicated that fabric



10.1 FAST fingerprints of fabrics decatized in: ——— batch decatizer; – – – continuous decatizer A; ········ continuous decatizer B. *Source*: 'Objective evaluation of wool fabric finishing', by A.G. DeBoos and A.M. Wemyss, from *Journal of the Textile Institute*, vol. 84. no. 4, p. 506, 1993. Reproduced with permission from *Journal of the Textile Institute*.

with the traditional batch-decatized finish and continuous process B had better dimensional stability than fabric finished with continuous process A.

Comparison of the finished thickness of the fabric samples indicated that there was little difference in the amount of press imparted by the different machines; the traditional batch decatizing method was marginally more effective. However, when the overall and surface thickness of the variously decatized fabrics were compared before and after release in steam, it was found 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).

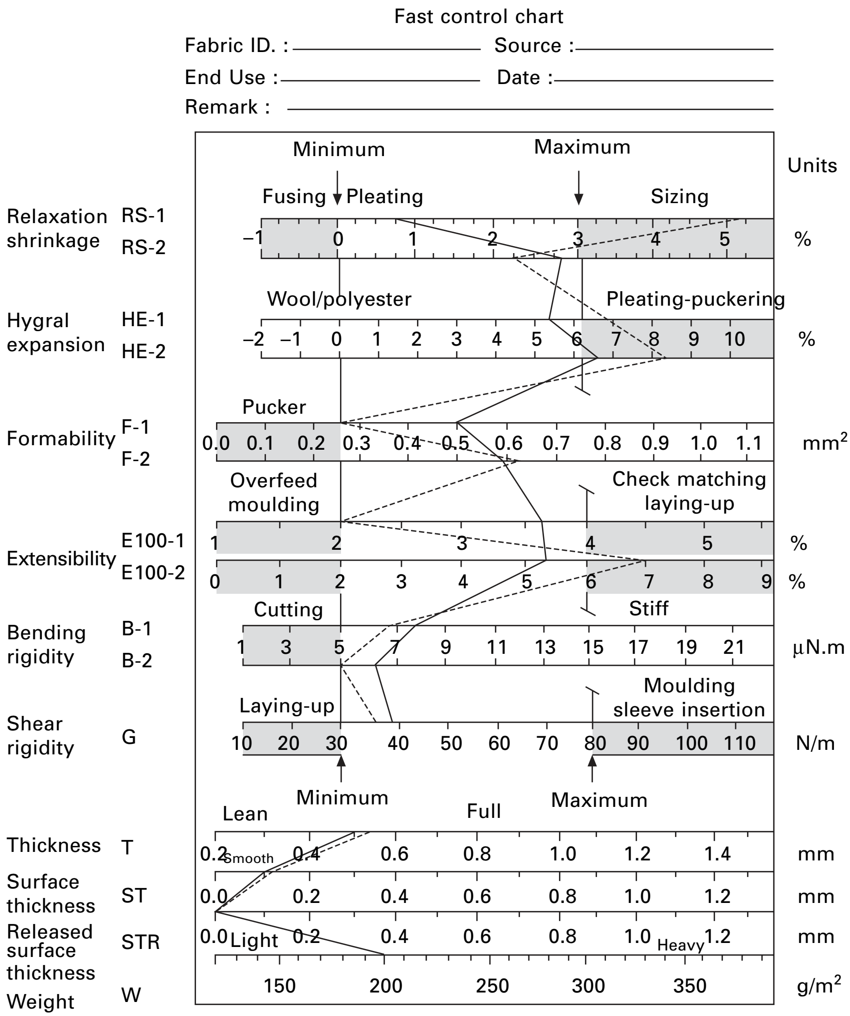
In the particular mill situation, fabric dimensional stability and hand were considered to be of greatest importance. Using these criteria, there was little to choose between the batch and continuous B-decatized fabrics. On the basis of the objective data, the finisher could reject one continuous decatizer in favor of the other and be confident that the economic advantages associated with the new machinery would not be offset by a deterioration in the most important aspects of fabric quality.

In the United States and Japan, sponging is widely used to control the relaxation shrinkage of fabrics and to ensure that fabrics delivered to the garment maker have adequate dimensional stability. In this situation, the criteria of selecting new decatizing machinery would be different from those in the United Kingdom, where sponging is not as widely practiced and finishers are generally required to meet much tighter tolerances on fabric dimensional stability.

The decatizing process could also be used to improve fabric properties as shown in Fig. 10.2. This takes place when faulty pieces are corrected by reversing the crimp interchange that has taken place during the finishing process. The new configuration has to be stabilized by permanent setting in a pressure decatizer.

10.8.4 Effect of finishing stages

In another study, by Dhingra *et al.* [11], the effects of finishing stages, including pressure decatizing in the finished state, were investigated. Three wool and wool/polyester suiting fabrics were sampled after the following stages of a commercial finishing operation: weaving – loom or grey state, heat setting (wool/polyester fabrics only), scouring, blowing and paper pressing (hydraulic flat press), and pressure decatizing in the finished state. The construction and finishing details for these fabrics are given in Table 10.1. Measurements were made on the fabric mechanical and surface properties of the samples taken after each of the finishing stages. The effect of fabric finishing on each of the mechanical properties tested using the KESF instruments is discussed below.



10.2 FAST fingerprint of the original (– – –) and re-finished fabrics (———). *Source*: 'Objective evaluation of wool fabric finishing', by A.G. DeBoos and A.M. Wemyss, from *Journal of the Textile Institute*, vol. 84. no. 4, p. 506, 1993. Reproduced with permission from *Journal of the Textile Institute*.

Fabric properties relating to hand

Tensile properties

Fabric extensibility (EM) after the various finishing stages is shown in Fig. 10.3. For the pure wool fabric, there is a large increase in fabric extensibility after scouring in both principal or thread directions, that is, from 5.6% to 11.6% in the warp and from 3.2% to 6.6% in the weft direction. This is

Table 10.1 Construction and finishing details for the three fabrics used in the fabrics finishing experiment

	Fabric 1	Fabric 2	Fabric 3
Wool fiber diameter, nominal average	22.5 μm	22.5 μm	22.5 μm
Polyester linear density	–	3 denier	3 denier
Yarn count, tex	R44/2	R 40/2	R 52/2
Singles twist, tpm	600	650	550
Folding twist, tpm	560	728	630
Finished fabric sett			
Ends/cm	25	35	17
Picks/cm	21	25	18
Weave	2 × 2 twill	3 × 1 satin	plain
Weight, g/m^2	275	290	212
Finishing	Soap milling	Heat set	
	–	Singe	
	Scour	Scour	
	Brush/crop	Brush/crop	
	Open decatize	Open decatize	
	Paper press	Paper press	
	Pressure decatize	Pressure decatize	

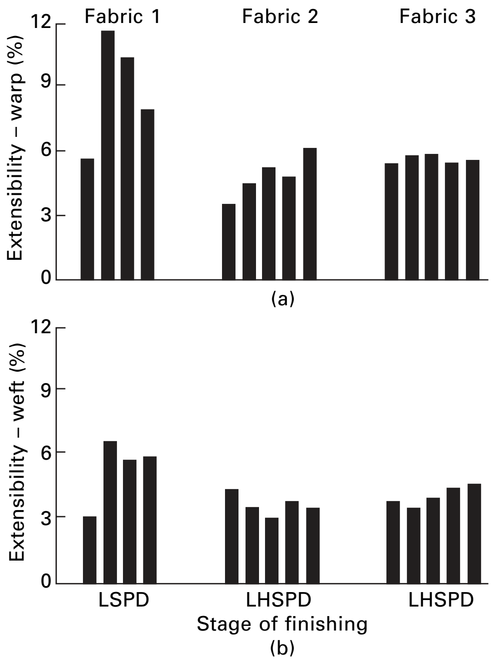
The fabric is lapped between specially glazed cardboard sheets and heated to approximately 40 °C under a pressure of 2800 kPa. The operation is done twice to even out the treatment, especially on the folds.

followed by much smaller decreases in extensibility in subsequent finishing steps. Since the overall increase in extensibility is common to both principal fabric directions, it must be explained in terms of the relaxation shrinkage in both warp and weft directions occurring during scouring rather than a simple interchange of warp and weft yarn crimp.

The increase in extensibility that occurs during finishing of the wool fabrics could improve tailorability, especially from the viewpoint of shaping and sewing. Very high levels of extensibility, however, may result in excessive hygral expansion for the finished wool fabrics, which could result in puckering problems in the tailored garment as a result of changes in ambient relative humidity conditions.

For the wool/polyester satin fabric, the increase in warp extensibility after heat setting and scouring was accompanied by a corresponding decrease in the weft extensibility: this result could be attributed to crimp interchange from the weft to the warp yarns during heat setting and scouring.

Tensile resilience (RT) increases during finishing much more for the two polyester/wool fabrics than for the pure wool fabric. For example, tensile resilience in the warp direction increases from 49% (loom state) to 63% (finished state) for the satin fabric and from 51% (loom state) to 66% (finished

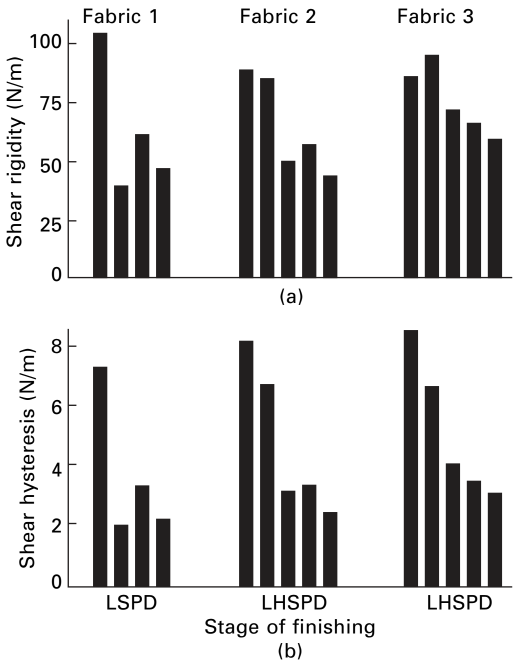


10.3 Fabric extensibility, EM, in (a) the warp and (b) the weft directions after various stages of fabric finishing: L = loom state, H = after heat setting, S = after scouring, P = after pressing, D = after pressure decatizing. *Source*: 'Measuring and interpreting low-stress fabric mechanical and surface properties', by R.C. Dhingra, D. Liu and R. Postle, from *Textile Research Journal*, vol. 59, 1989. Copyright Sage Publications.

state) for the plain weave fabric. The corresponding increase in tensile resilience for the pure wool fabric was from an initial relatively high value of 58% (loom state) to 63% (finished state). Similar results also apply in the weft direction.

Shear properties

Figure 10.4 demonstrates the shear rigidity (G) and shear hysteresis (2HG5) measured with tension applied in the warp direction after the various finishing stages. For the wool fabric, there is a very marked reduction after scouring in both the rigidity and hysteresis in shear. For example, the reduction in shear rigidity is 62% of the original value; the reduction in the shear hysteresis parameter 2HG5 is 76% of the original value. The corresponding reductions in the shear hysteresis 2HG and residual shear strain SG after scouring are 85% and 60%, respectively. Similar results also apply to the shear measurements made with tension applied in the weft direction. These results are indicative



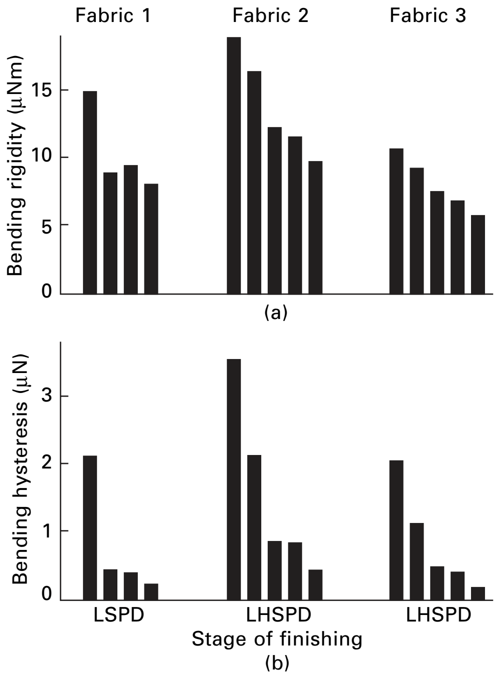
10.4 (a) Fabric shear rigidity, G, and (b) shear hysteresis, 2HG5 in the warp direction after various stages of fabric finishing: L = loom state, H = after heat setting, S = after scouring, P = after pressing, D = after pressure decatizing. *Source*: 'Measuring and interpreting low-stress fabric mechanical and surface properties', by R.C. Dhingra, D. Liu and R. Postle, from *Textile Research Journal*, vol. 59, 1989. Copyright Sage Publications.

of the greatly reduced inter-yarn pressures in wool fabrics after scouring. For the wool/polyester blended fabrics, the effects noted above are almost equally divided between heat setting and scouring.

These very large reductions in fabric shear rigidity and shear hysteresis represent one of the major effects of fabric finishing. The unfinished fabric has very high shear rigidity, which means that draping and three-dimensional forming (as required in tailoring) would be very difficult. Furthermore, the unfinished fabric exhibits a high degree of inelasticity in shear as measured by the large values of shear hysteresis. The unfinished fabric that exhibits this inelastic paper-like behavior is transformed largely by scouring (for pure wool fabrics) or scouring/heat setting (for wool/polyester blend fabrics) into the finished fabric that exhibits the classical three-dimensional elastic draping and fabric forming qualities necessary for successful tailoring and garment wear.

Bending properties

Similar dramatic changes in the values of fabric bending parameters are also evident after scouring (pure wool fabric) or heat setting/scouring (wool/polyester fabrics), as shown in Fig. 10.5. Both the bending rigidity (B) and bending hysteresis (2HB) are greatly reduced during scouring or heat setting/scouring, e.g., the reductions in bending rigidity and bending hysteresis (in both principal directions) after scouring are 42% and 79%, respectively, of the pre-scour values for the pure wool fabric.

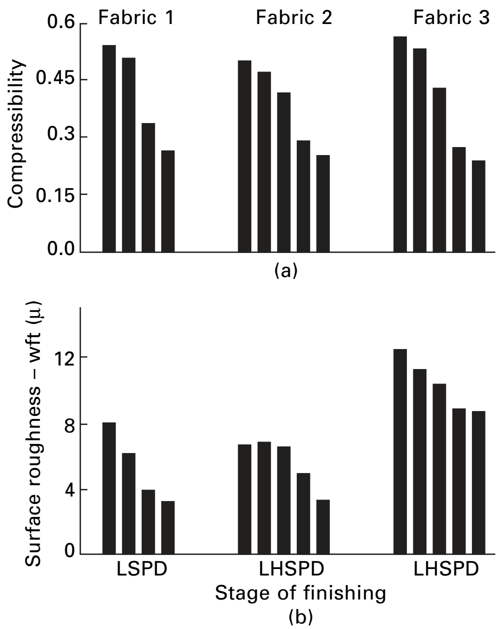


10.5 (a) Fabric bending rigidity, B, and (b) bending hysteresis, 2HB measured in the warp direction after various stages of fabric finishing: L = loom state, H = after heat setting, S = after scouring, P = after pressing, D = after pressure decatizing. *Source*: 'Measuring and interpreting low-stress fabric mechanical and surface properties', by R.C. Dhingra, D. Liu and R. Postle, from *Textile Research Journal*, vol. 59, 1989. Copyright Sage Publications.

The reduction in residual curvature (KB) due to scouring for the pure wool fabric and due to the combined effects of heat setting and scouring for the wool/polyester fabrics is 53–64% in both directions of fabric bending. Again, the finishing processes, especially scouring and heat setting (in the case of wool/polyester blends), greatly increase the fabric flexibility and elastic recovery from bending as required by fabric tailoring, draping, and wear.

Compression properties

The variation in fabric compressibility (CM) with finishing stage is shown in Fig. 10.6(a). The compressibility of each fabric decreases as the fabric progresses through the finishing routine. Figure 10.6(a) shows that the greatest decrease in fabric compressibility occurs during fabric pressing, where we see reductions in compressibility of 32–38% (compared with the post-scoured value) for both wool and wool/polyester fabrics.



10.6 (a) Fabric compressibility and (b) surface roughness in the weft direction after stages of fabric finishing. L: = loom state, H = after heat setting, S = after scouring, P = after pressing, D = after pressure decatizing. *Source*: 'Measuring and interpreting low-stress fabric mechanical and surface properties', by R.C. Dhingra, D. Liu and R. Postle, from *Textile Research Journal*, vol. 59, 1989. Copyright Sage Publications.

The overall reduction in fabric compressibility due to the combined effects of scouring, pressing, and decatizing for the pure wool fabric is 52% of the loom state value. The corresponding reduction in compressibility due to the combined effects of heat setting, scouring, pressing, and decatizing for the two wool/polyester fabrics is 50–58% of the loom state value.

There was also a large increase in compressional resilience (RC) for the pure wool fabric during finishing: the compression resilience increased from 45% for the loom state fabric to 58% for the finished fabric. The compressional resilience for the wool/polyester fabrics was relatively unchanged, varying between 41% and 46% during finishing.

Fabric thickness (T) and specific volume (V) are also greatly affected by pressing for each of the three fabrics. For the pure wool fabric, there was an approximately 20% increase in fabric thickness after scouring, followed by a dramatic decrease (46%) after pressing (compared with the post-scoured value) and a further small decrease after decatizing. The thickness of both wool/polyester fabrics decreased progressively through the finishing routine. Once again, the greatest decrease in fabric thickness occurred during fabric pressing, where we observed a reduction in thickness of 31–35% compared with the value before pressing.

Fabric specific volume decreased progressively through the finishing routine for each of the three fabrics. The greatest decrease occurred during fabric pressing, where reductions were seen in fabric specific volume of 31–45% compared to the corresponding value before pressing. The overall reduction in fabric specific volume due to the combined finishing operations is between 52% and 60% of the loom state value for the three fabrics investigated. The characteristic bulkiness of pure wool fabrics was evident from the slightly higher specific volume of the finished pure wool fabric, 2.7 cm^3/g, compared to the value for the two wool/polyester fabrics, 2.3 cm^3/g in each case. These differences occur despite the different weave construction of each fabric.

Surface properties

The variation in fabric surface roughness along the weft direction is depicted in Fig. 10.6(b). Here again, fabric pressing has the greatest effect when compared to the other finishing operations. These results quantify the effect of pressing on the surface roughness of the three different fabrics. Figure 10.6(b) also highlights the much greater surface roughness of the finished plain weave fabric, 8.9 μm, compared with 3.3 μm for the 2/2 twill and 3.5 μm for the 3/1 satin. Results were similar in the warp direction, too. The geometrical roughness of the finished plain weave wool/polyester fabric was 9.9 μm compared with 3.8 μm for the 2/2 twill wool fabric and 2.3 μm for 3/1 satin fabric. These results are attributable to the larger number of yarn interlacings for the plain weave fabric compared to the twill and stain constructions.

General remarks

The remarkably large influence of finishing on the low-stress fabric mechanical and surface properties can be specified quantitatively by the objective mechanical data obtained using the KESF instruments.

For the wool fabrics, there is a marked reduction after scouring in both the rigidity and hysteresis in shear and bending properties. For the wool/polyester blended fabrics, these effects are almost equally divided between scouring and heat setting. There was an overall increase in both warp and weft fabric extensibilities during finishing for the wool fabric, arising entirely from the scouring operation (after which there was a small reduction in extensibility for subsequent finishing operations). For the wool/polyester blended fabrics, however, a crimp interchange process from weft to warp during heat setting/ scouring operations resulted in increasing warp extensibility and decreasing weft extensibility. The tensile resilience of the unfinished wool fabric was relatively high compared with that of the unfinished wool/polyester materials, but after finishing, the tensile resilience of all fabrics increased to a similar value of approximately 63–66%. Furthermore, there was a marked reduction after paper pressing in compressibility, thickness, and surface roughness for both wool and wool/polyester blended fabrics.

The overall effect of these changes in mechanical/surface properties due to finishing results in a progressive improvement of elastic recovery properties, surface hand feeling, and the desirable fabric aesthetic attributes. This study demonstrates the scope of applying the principles of engineering design (using low-stress fabric mechanical/surface property measurements) to the production of apparel fabrics with aesthetic properties acceptable for particular markets and end products.

10.9 Mechanical hand breaking (softening)

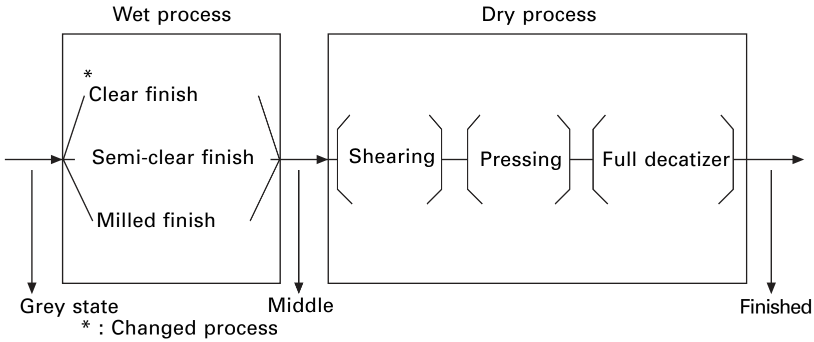
When a fabric is mechanically manipulated the hand will break down and become soft. Physical manipulation will disrupt cohesive forces between fibers and yarns and the fabric becomes more flexible. There are many causes of fabric stiffness; for example, line-dried towels are boardy and stiff compared to tumble-dried towels. However, this stiffness can be overcome by flexing or tumbling them. Similarly, starched fabrics and certain chemical finishes also cause fabric stiffness. They too can be softened by physical manipulation.

There are several machines that can be used to break down the hand of roll goods. The compressive shrinking machine discussed earlier is one. There are also several machines designed specifically for the purpose of mechanically working the fabric. A button breaker is one. The button breaker is a mechanical device where a number of paired rotating rolls studded with protruding buttons are positioned on a non-rotating cylinder. The fabric is pulled through under tension and the force of the buttons working against the fabric causes the hand to break down. Another version utilizes scroll rolls arranged in pairs of opposing helical spirals. The action of the opposing spirals applies stresses to the fabric, resulting in a softer fabric.

10.10 Interrelation between fabric mechanical properties and finishing process

There are different combinations of finishing processes for fabric finishing. A study was conducted by Matsui [10] using the most representative processes to investigate changes in the fabric mechanical properties by finishing processes, using the KES-FB system.

The finishing process of worsted weaves was divided into two stages: wet process and dry process. The wet process was changed by three methods called clear, semi-clear, and milled, as shown in Fig. 10.7.



10.7 A most representative sequence of the finishing process; the wet process is changed in three ways. *Source*: 'Fabric finishing on the basis of objective measurement of fabric mechanical properties by cooperation with apparel company engineers', by Y. Matsui, from *Objective Evaluation of Apparel Fabrics*, (ed. R. Postle, S. Kawabata and M. Niwa). Reproduced with permission of the Textile Machinery Society of Japan.

Samples of fabrics were taken at the grey state, after the wet process (middle) and in finished state for measurement. The mechanical properties of these fabrics were measured for the three finishing methods and the results of fall/winter men's suit fabric are shown in Table 10.2, as well as those of summer men's suit fabrics – at clear finish only. The results are plotted on the HESC Data Chart and shown in Figs 10.8(a)–(d).

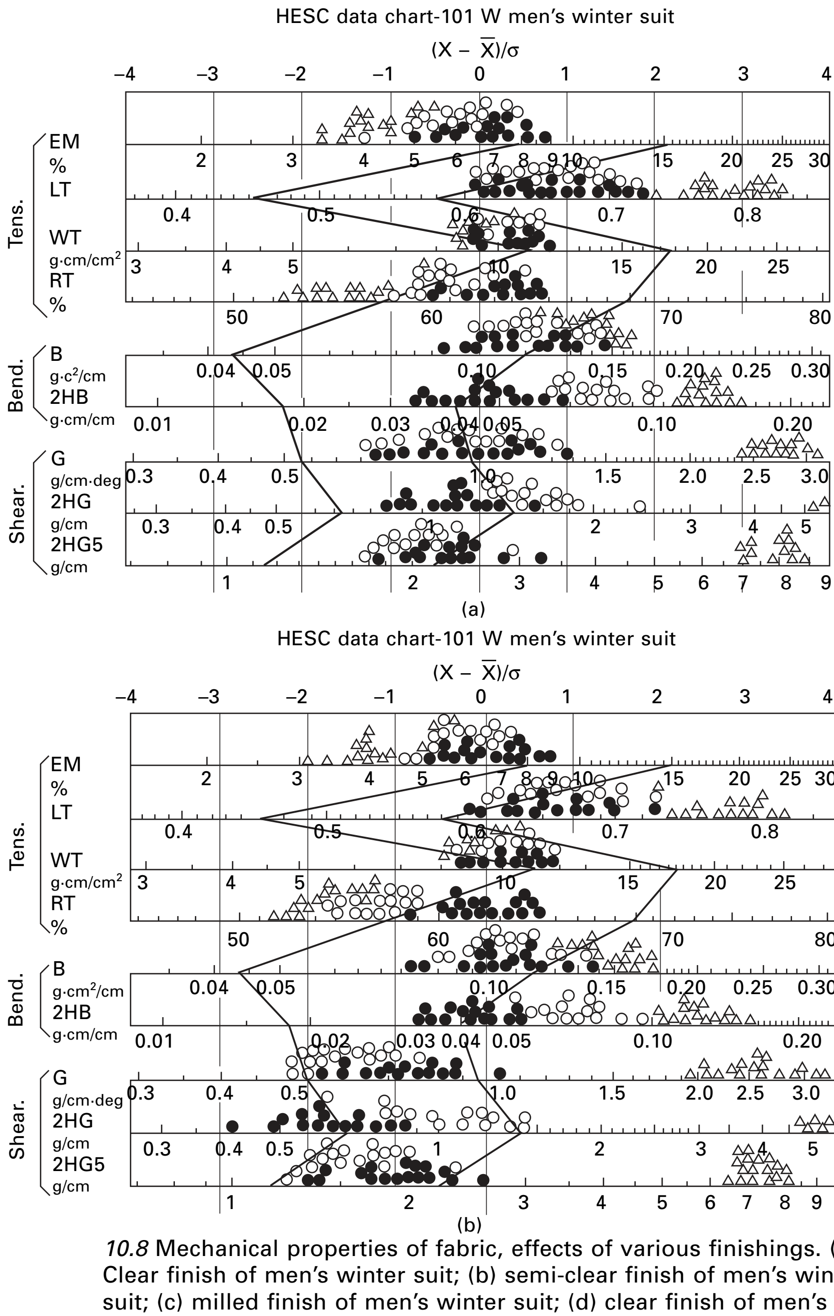
The following general conclusions were made for fall/winter men's suit fabrics regardless of finishing methods:

- Tensile property:
  - LT, WT: no difference through the finishing process.
  - RT, EMT (weft): increase in order of grey, middle and finished states. That is, fabrics become stretchable and springy with the progress of the finishing process.

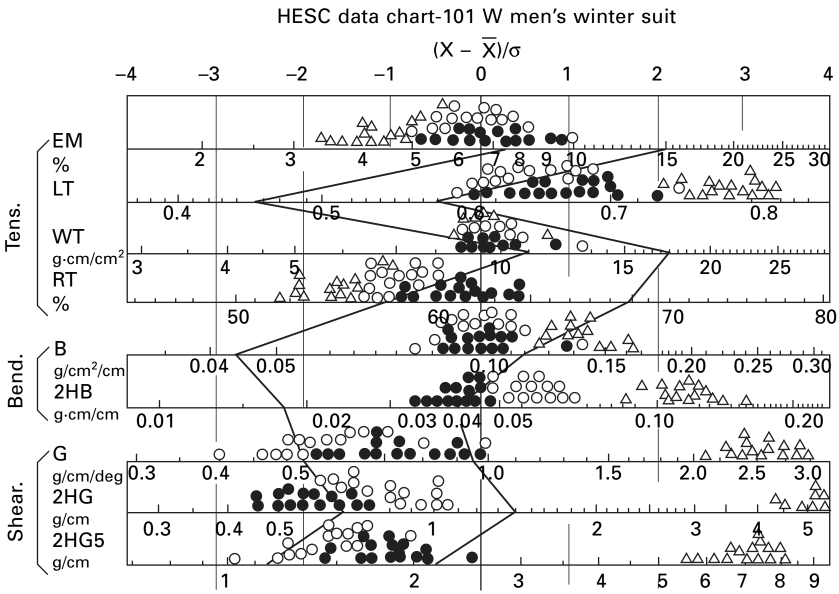
Table 10.2 Mechanical properties of fabrics obtained from various finishing methods and finishing states

		Fall/winter men's suit fabric									Summer		
		Clear finish			Semi-clear finish			Milled finish			Clear finish		
		Grey	Middle	Finished	Grey	Middle	Finished	Grey	Middle	Finished	Grey	Middle	Finished
LT	Mean	0.783	0.669	0.668	0.783	0.656	0.676	0.779	0.670	0.665	0.764	0.717	0.668
	S.D.	0.028	0.029	0.034	0.021	0.036	0.027	0.025	0.032	0.035	0.035	0.033	0.030
WT	Mean	9.36	10.41	10.47	9.45	9.86	9.52	9.49	10.04	9.95	8.53	8.05	8.03
	S.D.	0.57	0.78	0.78	0.77	1.05	0.84	0.79	1.06	0.98	0.86	1.03	1.29
RT	Mean	55.7	60.8	63.4	55.2	58.3	61.6	54.8	56.9	61.8	58.1	64.1	65.9
	S.D.	1.8	1.8	1.6	1.5	1.2	1.9	1.7	1.4	1.9	3.4	3.1	3.2
EMT[a]	Mean	4.21	6.32	6.85	4.37	6.48	6.59	4.23	5.95	6.58	3.15	4.77	5.06
	S.D.	0.59	1.01	0.84	0.65	1.20	0.91	0.69	0.73	0.82	0.73	1.08	1.11
B	Mean	0.143	0.123	0.116	0.140	0.103	0.101	0.149	0.115	0.108	0.134	0.074	0.065
	S.D.	0.012	0.016	0.018	0.012	0.021	0.011	0.014	0.020	0.017	0.019	0.009	0.008
2HB	Mean	0.136	0.081	0.049	0.122	0.063	0.041	0.128	0.073	0.044	0.143	0.049	0.023
	S.D.	0.011	0.012	0.009	0.017	0.015	0.004	0.016	0.014	0.010	0.039	0.009	0.006
G	Mean	2.83	1.00	0.98	2.56	0.61	0.75	2.55	0.62	0.75	2.28	1.02	0.82
	S.D.	0.38	0.21	0.21	0.25	0.14	0.13	0.32	0.08	0.13	0.35	0.17	0.12
2HG	Mean	6.21	1.57	1.09	5.49	0.83	0.55	5.59	1.07	0.62	5.40	1.51	0.76
	S.D.	0.89	0.30	0.19	0.56	0.15	0.09	0.43	0.25	0.12	1.14	0.38	0.16
2HG5	Mean	8.06	2.17	2.34	7.05	1.45	1.85	7.21	1.57	1.89	6.64	2.71	2.29
	S.D.	0.92	0.28	0.36	0.76	0.22	0.27	0.44	0.28	0.35	1.03	0.56	0.43

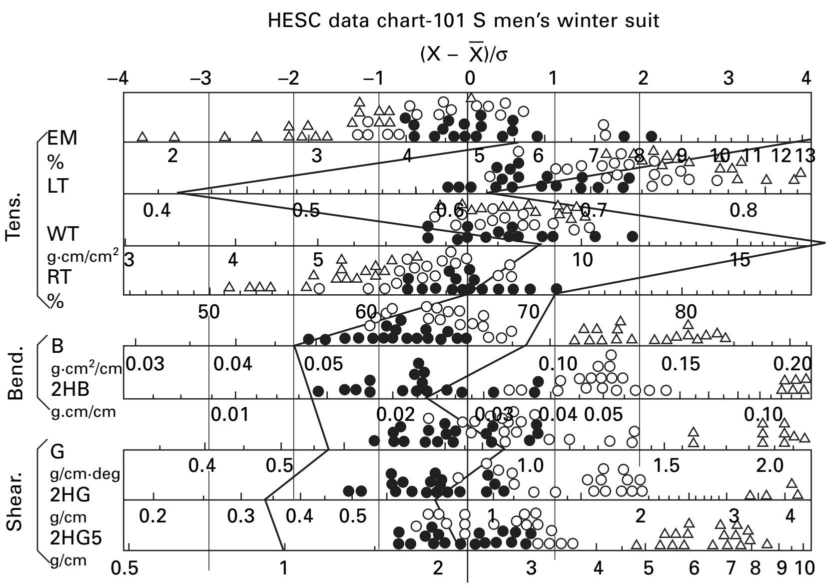
[a]All the data are means of 20 samples and averaged value of warp and weft direction deformation mode except for EMT which is only weft direction.



10.8 Mechanical properties of fabric, effects of various finishings. (a) Clear finish of men's winter suit; (b) semi-clear finish of men's winter suit; (c) milled finish of men's winter suit; (d) clear finish of men's summer suit. In all diagrams, △ grey state, ○ middle, ● finished. *Source*: 'Fabric finishing on the basis of objective measurement of fabric mechanical properties by cooperation with apparel company engineers', by Y. Matsui, from *Objective Evaluation of Apparel Fabrics*, (ed. R. Postle, S. Kawabata and M. Niwa). Reproduced with permission of the Textile Machinery Society of Japan.



(c)



(d)

10.8 Continued

- Bending property:
  - B: no difference between middle and finished states.
  - 2HB: smaller in the finished than in the middle state of fabrics.
- Shearing property:
  - G, 2HG5: larger in the finished than in the middle state.
  - 2HG: smaller in the finished than in the middle state.
  - Mechanical characteristics of shearing obtained by the clear finish are larger than those obtained by the semi-clear or milled finish.

Results for summer men's suit fabrics are as follows:

- Tensile property:
  - LT: approaches the good zone (becomes smaller) in order of grey, middle and finished state of fabrics.
  - WT: no large difference through the finishing process.
  - RT: becomes springy in order of grey, middle and finished.
- Bending property:
  - B: very bad (large) in grey state of fabrics, but becomes smaller (approaches the good zone) as middle and finished.
  - 2HB: very bad (large) in grey, but very good (small) in middle and finished, a little better in finished state of fabrics than middle.

10.10.1 Changes of mechanical properties of fall/winter men's suit fabrics with various decatizing processes

Mechanical properties of fall/winter men's suit fabrics were measured for three decatizing processes after the same wet process. The results are shown in Table 10.3 and Fig. 10.9. It is clear that fabrics processed through the full decatizer after paper pressing show the best properties.

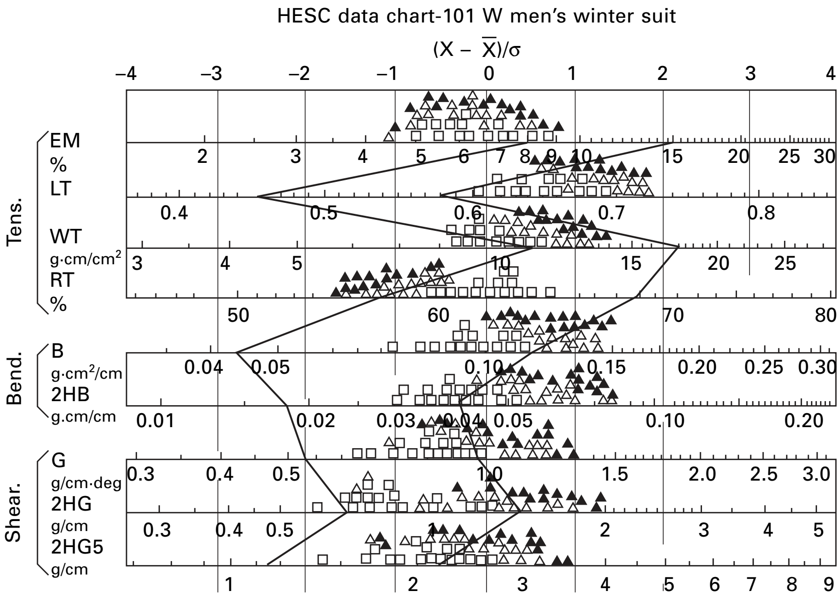
10.11 Future trends

The basic principles of mechanical finishing are quite old and have been known for a long time. Modern machines utilize the same principles; however, they incorporate the latest technology for monitoring and controlling the operating parameters. These controls improve the overall quality of the finish by accurately measuring the speed, pressure and temperature of the various components working on the fabric. This trend will continue in the future as newer, more reliable instrumentation is developed. As the trend of producing textiles in low wage countries continues, the need to generate novel fabrics should take into account the qualities that can be generated by mechanical finishing, either as a single process or in combination. It will be up to the imagination of the designers as to how to incorporate these qualities into their designs.

Table 10.3 Mechanical properties of fall/winter men's suit fabrics obtained from various decatizing proceses

Process[a]		LT	WT	RT	EMT[b]	B	2HB	G	2HG	2HG5
D	Mean	0.684	11.95	57.7	6.66	0.124	0.063	1.07	1.51	2.55
	S.D.	0.018	1.03	1.8	1.03	0.010	0.009	0.06	0.30	0.60
S	Mean	0.700	11.26	59.9	6.29	0.126	0.059	1.00	1.24	2.43
	S.D.	0.022	0.85	1.7	0.94	0.009	0.007	0.19	0.32	0.67
K	Mean	0.658	9.66	63.0	6.37	0.094	0.040	0.80	0.78	2.00
	S.D.	0.023	0.60	1.8	0.85	0.010	0.006	0.08	0.16	0.40

[a]D: Weak decatizing after paper press; S: strong decatizing after paper press; K: full decatizing after paper press.
[b]All the data are means of 18 samples and averaged values of warp and weft direction deformation mode except for EMT which is only weft direction.



10.9 Mechanical properties of fall/winter men's suit fabrics, effects of various decatizing processes: △ weak decatizing, ▲ strong decatizing, □ full decatizing. *Source*: 'Fabric finishing on the basis of objective measurement of fabric mechanical properties by cooperation with apparel company engineers', by Y. Matsui, from *Objective Evaluation of Apparel Fabrics*, (ed. R. Postle, S. Kawabata and M. Niwa). Reproduced with permission of the Textile Machinery Society of Japan.

10.12 Sources of further information

Hall [3] and Midgley [4] are excellent resources dealing with the subject of mechanical finishing, Even though these are old publications, they provide an in-depth discussion of the old machines for each topic. Tomasino [5] devotes a section to a discussion of mechanical finishing. Machinery manufacturers also are a good source of information, not only for describing their equipment but also for providing facts on the quality of fabrics produced on their equipment.

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11
Effect of refurbishment on fabric hand

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11.1 Introduction

Refurbishment processes for apparel is a term generally used to include all operations used in the maintenance and care of apparel and some interior textiles. The term includes dry cleaning, domestic and commercial laundering (aqueous cleaning) and, most importantly, the pressing or ironing operations that are used to restore the smooth, pressed appearance of garments.

The stability of garments to such refurbishment operations has always been considered a key aspect of quality. Quality assurance procedures to measure the stability of a whole range of fabric properties to washing, dry cleaning and pressing are enshrined in standards and tests published by bodies such as the AATCC and ISO. The fabric physical properties considered most important include tensile strength, abrasion resistance, smooth appearance and pilling propensity as well as the fastness of dyestuffs. As key aesthetic features, the stability of the appearance and hand of garments and their component fabrics is an importance determinant of the perceived durability/quality of apparel.

Considerable effort has been made in recent years into looking at the effect of refurbishment processes on hand. This has been the result of several related lines of study and the availability of objective methods of measuring both hand, or, perhaps more accurately, change in hand and the fabric mechanical properties that determine hand. The objectives of the studies have included:

- Stability of new fabrics (e.g. Shingosen) or the hand imparted by new finishes (e.g. crisp hand) to repeated laundering
- The impact of wash additives on hand (e.g. after-rinse softeners) and their durability
- The stability of functional finishes (and the hand imposed by them) to repeated laundering.

It is anticipated that the more recent development of newer nano-finishes designed to impart new hands to traditional fabrics will also require studies of this type.

11.2 Refurbishment of traditional fabrics

Comparison of the many papers that have reported the effects of dry and wet cleaning on the hand of fabrics indicates that the outcomes are extremely complex. It has been demonstrated that the effects of the refurbishment processes vary with the fabric and fibre type, the refurbishment processes and the conditions used, as well as the history of the fabric and/or garment.

The processes of refurbishment have elements in common with processes used to clean or prepare fabrics in finishing during manufacture. Dry-cleaning has a mirror in solvent scouring, whereas aqueous laundering can be compared with the aqueous scouring and milling processes using to finish fabrics. Finally, a number of processes are used to press fabric in finishing to establish a smooth appearance and hand. In garment manufacture, garment parts can also be pressed a number of times before the garment is finished. These pressing processes are mirrored in the pressing or ironing processes used in refurbishment.

Just as the effect of the above finishing operations on fabric physical properties and hand depends on the prior history of the fabric, so do the effects of refurbishment. The conflicting results obtained by workers often reflect the different properties of the fabrics on which they conducted the study rather than a genuine difference of outcomes or conclusions.

11.2.1 Dry cleaning of worsted suiting

Dry cleaning or solvent washing is widely used to clean delicate fabrics/garments for which the action of water would cause unacceptable changes in appearance (including dye bleeding), hand or physical properties. Dry cleaning normally involves four steps:

- Mechanical action while immersed in a solvent (white spirit or perchlorethylene), which may contain a small amount of water that has been emulsified using detergents
- Spin extraction of the excess solvent
- Tumble dry
- Steam press.

A number of studies have used objective measurement of those low stress mechanical and physical properties of the fabric associated with hand to assess the effect of dry-cleaning on a range of fabric types.[1] These properties have been commonly measured using the KES-F or FAST systems, described in earlier chapters. The hand of wool fabrics can be improved by dry cleaning;

the fabrics become more supple and smoother.[2–4] The extensibility of the fabric is increased, the bending and shear rigidity of the fabrics (controlling stiffness) are reduced, the thickness of the fabrics increases, the bending and shear hysteresis are reduced and the resiliency is improved. Subjectively the fabric becomes more supple, smoother and fuller. Only in the specific instance of Japanese summer-weight suiting are such changes associated with a deterioration in hand.

The magnitude of the changes varied with the fabric and the effect was marginally greater when the temperature of the scouring stage was increased. Observations[3,5] of the independent effect of the pressing operation (without pre-laundering) suggest that the effect was to increase fabric stiffness while reducing thickness. In contrast, Shiomi and Niwa[6] and Dhingra *et al.*[4] observed a reduction in bending and shear rigidity and hysteresis in a full dry cleaning cycle as well as in the pressing cycle (independently applied – Table 11.1).

Table 11.1 Effect of dry cleaning and pressing on fabric mechanical properties

Property	Units	Control	Dry clean and press	Press only
Extensibility	%	6.4	7.2	7.6
Tensile resiliency	%	72	71	71
Bending rigidity (B)	μNm	4.7	4.4	5.0
Bending hysteresis (2HB)	μN	120	90	100
Residual curvature (0.5 × 2HB/B)	m^{-1}	13	10	10
Shear rigidity (G)	N/m	26.7	23.6	20.2
Shear hysteresis (2HG)	N/m	0.39	0.33	0.29
Residual strain (0.5 × 2HG/G)	mrad	7.4	7.4	7.3
Thickness	mm	0.47	0.69	0.60
Work to compress	J/m^2	0.12	0.23	0.18
Compressional resiliency	%	53	48	67

Source: Dhingra *et al.*[4]

It is suggested that the answer to this apparent conflict may lie in the different pressing conditions that can be used and the specific behaviour of wool fibres in steam. The effect of pressing depends not only on the conditions used but also on the moisture content of the wool prior to and during pressing.[7,8] When pressed and steamed for a short time, wool is temporarily set (sometimes called cohesive setting). Provided the fabric is cooled while it is still constrained, a high level of temporary set is imparted but there is no relaxation of the strains built up in the pressing action. The increased fibre–fibre contact resulting from pressing can, without relaxation, restrict the relative movement of adjacent fibres and yarns and thereby increase fabric stiffness. If the fabric is released while still hot and cooled while unconstrained (also a common pressing procedure), the temporary set imparted is less and the increase in stiffness related properties lower. The rate at which these setting and relaxation processes occur depends on the moisture content of the fibres, and therefore the steaming conditions, the amount of ‘baking’ (as opposed to ‘steaming’ in the press), and the time between the drying operation and subsequent pressing.

To further complicate the issue, dry cleaning usually has a water load that is suspended using a solvent-soluble surfactant system. This aqueous load aids the removal of water-soluble soils. The water can aid relaxation processes in all fibres, and in the case of wool, promote felting.[9] The overall effect of dry cleaning on hand can thus depend on:

- The solvent and its water load
- The mechanical action in washing
- The solvent temperature
- The extent of drying
- The conditioning time before pressing
- The conditions of pressing (head pressure, steaming, baking and cooling times)
- Any softeners that may be used.[10]

It is not surprising, therefore, that there is some conflict in the literature.

In recent years, the safety problems associated with white spirit and the environmental problems associated with the common chlorinated hydrocarbon solvents (e.g. perchlorethylene) have led to the search for alternative dry cleaning solvents. More recently, machinery has been developed to use supercritical CO_2 for dry cleaning. The machinery is complex and expensive and the technology has yet to be widely adopted. Nevertheless, it is claimed that the process minimises any detrimental effect on garments by the cleaning process, including any deterioration in fabric hand. To date, no objective measurements of properties related to hand have been published on its effect on fabric hand, although it would be expected to be minimal.

Little has been published on the effects of dry cleaning on non-wool fabrics beyond the claims made by manufacturers of dry-cleaning equipment.

11.2.2 Aqueous laundering

Aqueous laundering is the preferred technique for domestic and some industrial applications. The environmental issues of solvent and the simplicity of aqueous systems must be must be balanced by the water pollution and higher energy demand in heating and drying of water-wet garments. For wool and other animal hair products, the natural felting propensity of fabrics is normally overcome by suitable treatment of the fibres, or fabric making aqueous cleaning a viable option for wool garments.

Denim and other cellulosic fabrics

The adverse effects of laundering on cotton fabrics are well recognised by consumers and have been described in a number of studies.[11] In one such study using 100% cotton single piqué knitted fabrics,[12] the changes noted were an increase in stiffness (increased shear rigidity), a reduction in resilience (also seen as an increase in hysteresis in shear deformation), a reduction in extensibility, and an increase in thickness and surface friction. An earlier study on babies' underwear[13] noted similar effects. All these effects are consistent with deterioration in fabric hand, and most particularly in fabric softness. Similar effects were also observed using[14,15] 1×1 rib knit fabrics. This study also included subjective evaluations using a range of hand descriptors. After just one cycle some subjective characteristics (e.g. 'bounciness' – resiliency) are changed. Certainly after 50 cycles, significant changes in most characteristics were noted (including reductions in softness and smoothness). An approximately linear relationship between the changes in fabric properties during laundering and the square root of the number of laundering cycles has been reported.[13]

The detergent used and the method of drying both have significant effects on subjective evaluations. Tumble-drying produced a fabric that was rated thicker and less soft and, it has been reported that,[13] contrary to the labelling advice on many garments, tumble-drying can impart less shrinkage and a better hand to laundered garments.

The changes in the subjective hand and mechanical properties of cotton fabrics resulting from laundering are dominated by the increases in shear and bending stiffness and the reduction in extensibility. These changes are entirely consistent with the observed changes in fabric softness and extensibility occurring in washing, and with consumer complaints that cotton knitwear becomes dry and harsh after laundering. The increase in fabric harshness and the changes in fabric mechanical properties have been variously attributed to increased contact between the cotton fibres (the surfaces of which, when untreated, have high friction)[16] and fibrillation of the fibre under mechanical action.

Several authors have noted the excellent correlation between shear hysteresis and subjective softness of cotton fabrics varying from knits through plain weaves to terry towelling[17,18] in a range of applications.

Synthetic fabrics

The hand of acrylic knitwear, unlike that of cotton, can initially improve on laundering[16] giving a softer, warmer and bouncier feel. These subjective changes are associated with a reduction in shear rigidity and hysteresis and an increase in resiliency of the fabric. On acrylics the effect of gentle wash cycles and line drying is small while multiple severe cycles and tumble-drying contribute to a deterioration in hand. This deterioration has been attributed to the loss of texture and bulk in the fibres, observed by the consumer as stretching and a harsh hand.

Wool

The aqueous laundering of wool products is made complex by the tendency of wool to felt in water under mechanical action. Laundering of wool products, especially where this involves tumble-drying, is rarely practicable unless the fibres or fabric have been treated to prevent felting. There are a number of processes used to prevent the felting of wool and the impact of laundering will depend on the process used. In general, however, provided there is no felting, laundering tends to soften the hand of wool. This often-dramatic change in softness is observed as a reduction in the shear and bending rigidities of the fabric, as well as changes in other properties. The changes normally occur in the first laundering cycles after which the hand of the fabric will be stable while there is no felting. A gradual increase in thickness accompanies an increase in the fuzzing of the surface of wool fabrics as laundering continues. Extended laundering of wool products will lead to a subjectively observed reduction in softness, which is consistent with the observed increase in stiffness and reduction in extensibility and resiliency.

Garments

Garments can behave differently from sample fabrics (or more commonly fabric swatches) in laundering. The three-dimensional structure ensures that different forces (both distortive and abrasive) are imposed in the washing and tumble-drying operations. Moreover, many garments require restorative ironing which further changes the properties of the fabric. Differences between the changes in the hand of fabric-in-garments and samples of the same fabric have been reported.[13]

Little has been published on the effects of pressing and restorative ironing on aqueous laundered garments.

11.2.3 After-wash-rinse softeners

Laundering is normally not a simple matter of detergent, water and mechanical action. The application of domestic softeners in the rinse cycle is now common practice in both the domestic and commercial laundering of all garments. A wide range of rinse products is available, the active ingredients of which are commonly cationic surfactants. The subjective and objective effects of softeners used in rinse aids has been described by several authors and measured in a variety of ways[19–22] for cellulosic, wool and synthetic fabrics and their blends (see Table 11.2). The most notable and widely reported effect of rinse aids or softeners is the large reduction in hysteresis of the softened fabric, particularly in shear deformation, as shown in Fig. 11.1 and Table 11.2.

Table 11.2 Effect of softeners on the properties of cotton and polyester fabric

Mechanical property[a]	Cotton		Polyester	
	Control	Softener	Control	Softener
Extensibility (%)	24.5	28.0	8.5	8.9
Bending rigidity (μNm)	0.020	0.022	0.007	0.006
Residual curvature (m^{-1})	17.5	11.5	7.4	5.6
Shear rigidity (N/m)	0.25	0.20	0.68	0.62
Shear hysteresis (N/m)	1.09	0.71	1.59	0.59
Thickness (mm)	1.03	1.03	0.57	0.57
Compressional resiliency (%)	33.6	33.5	50.1	61.5
Surface friction	0.21	0.21	0.20	0.17

[a]Measured using the KES-F instrumentation, from Inoue *et al.*[19]

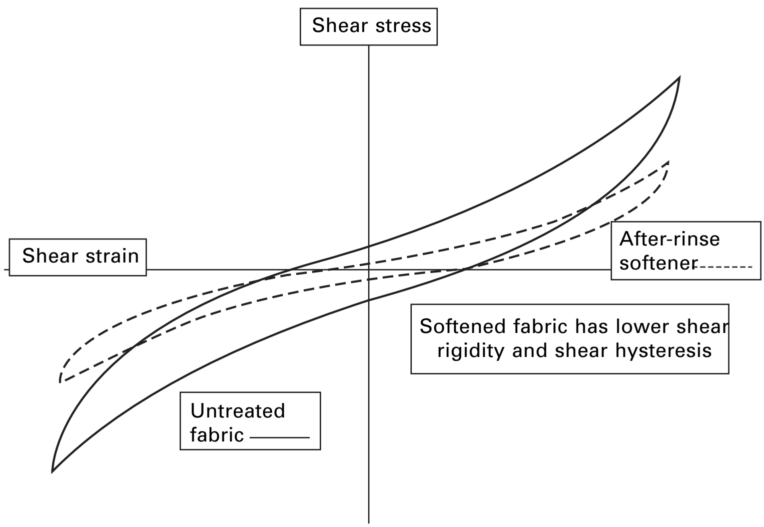

Fig. 11.1 Effect of softeners on fabric deformation in shear.

Inoue *et al.*[19] reported that softeners applied in the final rinse of a laundering process were more effective than those formulated with the detergent, paralleling the situation also reported in the cleaning and conditioning of hair. The absence of less effective detergent–softener complexes and the appropriate orientation of the softener on the fibre surface have been cited as the cause of this widely observed effect (Table 11.3).

The resiliency in compressional deformation has also been shown to be a

Table 11.3 Effect of after-rinse softener and detergent on fabric properties

Property	Units	Untreated	Softener only	Detergent + softener
Shear rigidity (G)	N/m	59.6	46.6	54.0
Shear hysteresis (2HG)	N/m	2.8	1.1	2.0
Residual strain (0.5 × 2HG/G)	mrad	46.6	24.2	37.3
Bending rigidity (B)	μNm	4.0	2.6	3.1
Bending hysteresis (2HB)	mN	367.8	269.7	308.9
Residual curvature (0.5 × 2HB/B)	m^{-1}	45.7	50.9	49.2

From Inone *et al.*[19]

good indicator of softness, especially after laundering. Interestingly, in spite of the subjectively observed improvement in fabric smoothness, changes in surface frictional properties of fabrics have not been consistently observed using the KES-F instrumentation. The reasons for this remain obscure and may reflect differences between the frictional contact of the human hand and the KES-F friction head with the fabric or, alternatively, may reflect the complexity of the relationship between subjective smoothness and fabric properties.

The study on knitwear by Inoue also noted the effect of softener on other aspects of hand. These included 'hydrophobic character', air permeability, thermal conductivity and water vapour transport, all of which are thought to affect hand and ultimately wearer comfort.

11.3 Role of fabric history/finish

Garments rarely arrive at the laundering process without a history. This history includes the finishing of the fabric, the manipulation and pressing of the fabric in garment manufacture and any garment-based processing that may have been undertaken. Garment-based processing of woven products is normally confined to pure cotton garments. It is used in some easycare processes, in the dyeing of some garments and in the achievement of some fashion effects (stone washing).

Apparent inconsistencies in the literature sometimes reflect the history of the fabric used in the study.

11.3.1 Denims

In certain fabrics, notably denims, starches are used to enhanced the stiffness of the fabric to the levels of fashion demands. Laundering softens starched fabrics as does garment finishing operations such as mill or stone washing prior to sale. Similar changes in the stiffness of some denims can also be achieved in laundering processes.

11.3.2 Chemical softeners

Chemical softeners are sometimes used in the finishing of fabrics manufactured from cellulosic fibres (cotton, rayon, etc.) and their blends with polyester.[23] Softeners used in finishing include the wide range of cationic organic compounds used as rinse aids but also include the more expensive aminofunctional silicones that also have wide use as hair conditioners. Softeners applied in finishing modify many of the low stress mechanical properties associated with hand. The large reduction in hysteresis of the softened fabric in shear deformation (2HG, 2HG5) noted previously with laundry softeners and rinse aids has been shown to be a quality control tool for the comparison of softeners[5,19] and for the evaluation of their stability in subsequent laundering.[18]

The effect on laundering of softened fabrics (i.e. treated with softener in the manufacturing process) depends on the stability of the softener. However, as the effects of laundering of cellulosic fabrics are opposite to that of softeners, the response of unsoftened and softened fabrics is more or less ‘in the same direction’. It is anticipated, indeed desirable, that the softener applied in finishing would continue to offset the detrimental effects of laundering for several cycles.

11.3.3 Wrinkle-free fabrics

Durable press resins based on formaldehyde derivatives are widely used in the production of wrinkle-free garments made from cotton, viscose and their blends with polyester. These resins are applied to the fabric and delayed-cured when the garment has been manufactured or applied to the preformed garment. The resins themselves have a significant effect on fabric hand, generally resulting in a stiffening and a loss of fabric extensibility.[24] A wide range of softeners are co-applied with these resins to offset the detrimental effect of the resin on hand. The softeners ameliorate the increase in fabric stiffness (bending and shear rigidity) and increase fabric smoothness, often to a level beyond that of the untreated fabric. The response of wrinkle-free fabrics to laundering can differ from that of the parent fabric in some areas[12] and depends on the resin–softener combinations used. Lau *et al.*[12] reported that the effect of the total wrinkle recovery treatment is to reduce the adverse effects of laundering on many low-stress mechanical properties related to hand. Fabrics with wrinkle-free finishes are more stable to laundering.

11.3.4 Polymer treatments on wool

Woven pure wool fabrics are treated with water-soluble or emulsified polymers to impart shrink resistance. These polymers act by forming interfibre bonds that prevent the relative motion of fibres responsible for felting.

By restricting fibre movement the bonds also stiffen the fabric, an effect associated with a deterioration of the hand of the fabric. Some of these bonds are broken in the first wash, resulting in a partial restoration of hand.[25,26] Indeed, to improve the hand of the fabric prior to sale to garment manufacturers, finishers will wash-off the fabric to duplicate the effects of the first wash. A softener will often be applied in this wash-off. Obviously the changes in the hand of washable wool garments during their first laundering will depend on the procedures adopted in fabric finishing.

11.3.5 The setting of wool

Earlier in this chapter, reference was made to the complexity of the response of wool to refurbishment. The felting propensity of wool and the methods used to prevent the felting of wool garments during laundering are only the first level of this complexity. As wool felts, the fabric becomes subjectively stiffer and thicker, consistent with increases in measured thickness and rigidity (shear and bending). In addition to this, the manner in which the unique setting characteristics of wool fabrics are exploited by finishers and garment makers affect its performance. Like all polymers, wool has a glass transition temperature (T_g) that affects its setting characteristics.[27] Temporary set is imposed by deforming the fibre while it is above the T_g and not releasing it until it is below the T_g. The lower mobility of the protein macromolecules ensures that set is lost slowly while the fibre remains below the T_g but quickly when the fibre is heated or re-wet. Wool is plasticised by water so that the wet fibre is below its T_g while the dry fibre is above T_g.[27,28] This difference is exploited in areas as diverse as the wet–dry waving of hair as well the smooth drying of wool. Other fibres, such as nylon (50–60°C) and polyester (70–80°C) have glass transition temperatures but none is affected by water to the same extent as wool.

Wool has a second apparent transition associated with the permanent setting of the fibre. Unlike other fibres, this setting involves the rearrangement of covalent (disulphide) bonds in the fibre, allowing greater mobility of the macromolecules. The permanent set imparted at high temperatures (around 120°C in the fibre at normal regain), or at lower temperatures using catalysts, is permanent to wetting and heat.

During the finishing of wool fabrics, they are pressed in an operation called decatising. If the decatising is conducted under conditions where the wool is permanently set (high temperature and/or long time) the flattening of the wool will be permanent to laundering. Normally only woven fabrics and a small number of knitted fabrics are pressure decatised to impart permanent set. When temporary setting operations have been used to flatten or press fabrics prior to making up, it is likely that there will be an increase in the thickness and an associated change in hand when the fabric is wet out in the first wash (Table 11.4).

Table 11.4 Stability of the finish/thickness of wool fabric to laundering

Finishing conditions	Thickness (mm)	
	Initial	After wetting and drying
Decatise, 0.5 min, cold release	0.64	0.80
Decatise, 2 min, cold release	0.64	0.77
Decatise, 5 min, cold release	0.66	0.74
Decatise, 10 min, cold release	0.62	0.68
Decatise, 15 min, cold release	0.63	0.68
Decatise, 2 min, hot release	0.73	0.76

11.4 Refurbishment of newer fabric types

As newer fibres are developed (Shingosen, Optim, microfibres[18]), information on their hand and the effects of refurbishment become a key part of the decision to purchase by the consumer and, before that, of the garment maker and retailer.

Matsudaira and Hanyu[29] reported a change in the hand of Shingosen fabrics in the related low-stress mechanical properties after repeated home laundering. Changes in the 'basic mechanical properties are small but their effect of those properties on overall fabric hand is very important'.[29] The extensibility of the fabrics increased as a result of laundering.

11.5 Future trends

The ability to withstand refurbishment without observable deterioration in the aesthetic or functional properties will remain a key aspect of quality in apparel. Although disposable apparel is available, it has specialised uses that have little to do with appearance and perceived quality. Research and development to ensure that fabrics maintain their hand and appearance after refurbishment will continue on a number of fronts:

- Machine makers will continue to produce better, gentler and more environmentally friendly machines for both aqueous laundering and, at least in the short term, dry cleaning.

- Newer techniques for dry cleaning with more environmentally friendly solvents (such as supercritical CO_2) will continue to be developed.
- Detergent makers continue to develop more effective detergents that are less harmful to the fibres and better rinse aids to ensure that garments maintain their soft hand.
- Chemical companies will develop more stable effective auxiliaries to optimise the hand of fabrics and ensure that hand is maintained during any subsequent refurbishment.
- Finally, fabric finishers will seek to ensure that any cloth or garment maintains its excellent appearance in garment manufacture and subsequent use.

It is likely that, in the future and for environmental reasons, the use of dry cleaning will decline and more garments will be required to be stable to aqueous laundering. This will be achievable through the adoption of all the options listed above.

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