Part II

Effect of fibre yarn and fabric factors on fabric hand

6
Effect of fiber factors on fabric hand

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6.1 Introduction

The understanding and measurement of fabric hand has been described in the previous chapters of this book. Testing of the fabrics is performed to determine the hand value of these products; however, to enable design of new products, we must gain an understanding of how the component properties lead to the hand of the fabric. All of the fabrics discussed in this book are made of fibers. It is therefore logical to gain an appreciation for the way that fiber properties and behavior influence fabric hand. In this chapter, the fiber properties that can affect fabric hand will be discussed. These include fiber type, fineness, cross-sectional shape, length, friction, crimp, moisture properties and molecular orientation. The response of the fibers to deformation will impact the fabric hand properties significantly. Some of the standard testing procedures will be described and the relationship between the measured values and the fabric hand will be presented. Finally, the future trends in fiber development and testing will be proposed along with the identification of sources of information for further study.

6.2 Describing fibers

The Complete Textile Glossary (Celanese Acetate LCC 2001) defines fiber as ‘a unit of matter, either natural or man-made, which forms the basic element of fabrics and other textile structures. A fiber is characterized by having a length at least 100 times its diameter or width.’ Fibers are the building block for fabrics and their behavior influences the way that the fabrics respond to various modes of deformation.

As stated in the definition of fiber given above, the fiber can be natural or man-made and this is usually the first classification used to identify fibers. Table 6.1 lists the most commonly used fibers using this type of classification. The commonly used name of the fiber along with the polymer name is given. Other properties that help describe a fiber are its shape, color, luster, specific

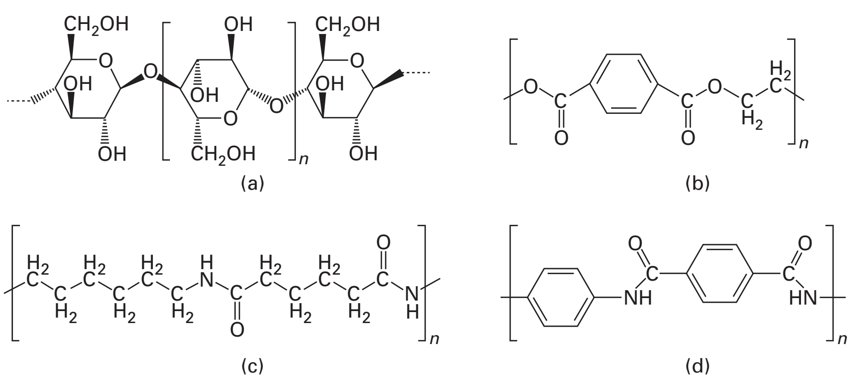
Table 6.1 Commonly used fibers and the polymers associated with them

Source	Fiber name	Polymer
Natural	Cotton	Cellulose
	Linen	Cellulose
	Silk	Polypeptide
	Wool	Polypeptide
Man-made	Acetate	Modified cellulose
	Acrylic	Polyacrylonitrile
	Kevlar	Poly-paraphenylene terephthalamide
	Modacrylic	Polyacrylonitrile
	Nomex	Polyamide
	Nylon	Polyamide
	Olefin	Polyethylene, polypropylene or other
	PBI	Polybenzimidazole
	Polyester	Polyester
	Rayon	Modified cellulose
	Spandex	Polyurethane

gravity, linear density, crimp and length. Before we discuss these properties, it is necessary to understand the building blocks of the fibers, polymers.

6.2.1 Polymers

A polymer is a long-chain macromolecule that is made up of many 'mers' or units. For example, cotton fiber is composed of cellulose (Fig. 6.1(a)), while polyester (a man-made fiber) is made of units that contain the ester linkage (Fig. 6.1(b)). Nylon (Fig. 6.1(c)) and aramids such as Kevlar (Fig. 6.1(d)) contain the amide linkage. Other polymers such as polypropylene have relatively simple chemical structures. The *n* in Fig. 6.1 indicates the number

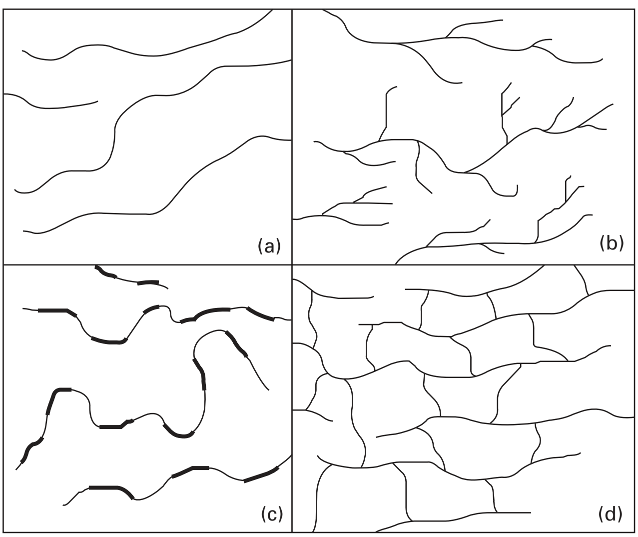


6.1 Polymer repeat units for (a) cellulose, (b) PET, (c) nylon 6-6, and (d) Kevlar.

of polymer units in the polymer chain and is also called the degree of polymerization.

The types of elements and the way they are bonded together greatly influence the behavior of the polymer and its processability. For example, polypropylene was discovered in the 1950s but was not processed into fibers until the 1980s because of a small change in the way that the polymer units were put together.

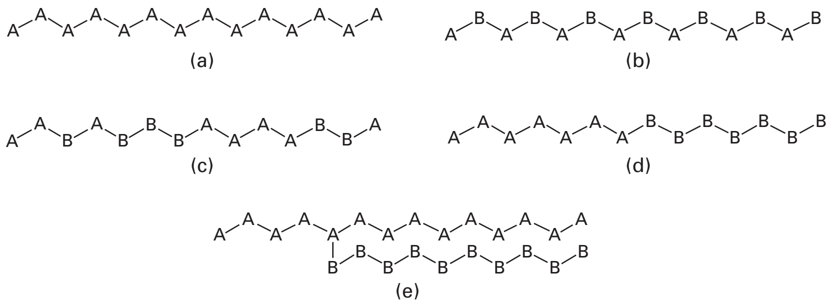
Some of the terms used to describe the different polymer structures are linear, branched, or cross-linked. They can also be classified as homopolymers (made of only one type of mer) or copolymers, which are made of more than one type of unit. This is usually done to gain the characteristics of both types of polymer units. Figure 6.2 shows all of these structures in schematic representation. The structure can also be described as flexible, such as Nylon 6-6, or stiff, such as Kevlar. This type of flexibility refers to how easily the molecular chain can change its configuration. The bonds in the Nylon 6-6 are very flexible, but the aromatic rings of the Kevlar polymer are quite rigid. This stiffness will be related to the stiffness of the fibers made from the polymer. Hence, the Kevlar fibers are more resistant to bending as compared to the nylon fibers. Polyurethanes are made up of units that contain highly extensible sections held together by stiffer sections. This structure leads to the highly extensible fibers such as Spandex.



6.2 Schematic representation of (a) linear, (b) branched, (c) copolymer and (d) cross-linked polymers.

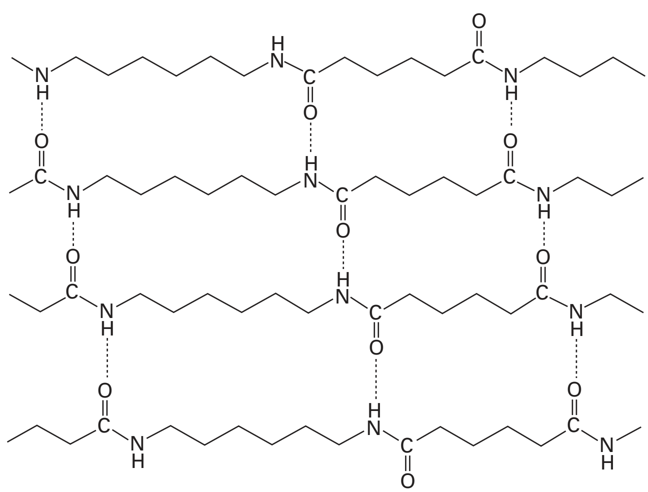
Other than changing the overall polymer structures such as linear, branched, or cross-linked, copolymers can be used to alter factors such as flexibility.

Figure 6.3 shows the variations that are possible in copolymer systems in which A is one monomer unit and B is a different monomer unit. In this way, a combination of the behavior of the two units is achieved. By adjusting where and how many times the monomer units in the copolymer repeat, it is possible to create a polymer that meets a precise specification. In Fig. 6.3, only two monomers are used, through copolymers can be made with more monomers.



6.3 Copolymer variations: (a) homopolymer, (b) alternating, (c) random, (d) alternating, and (e) graft.

The chemical structure of the polymer chain also determines the way that they can interact with each other. For example, the amide linkage in the nylon 6-6 polymer can form a hydrogen bond with the amide linkage on other chains. In this way, the bulk polymer, which contains many polymer molecules, will have a crystalline structure (Fig. 6.4). The crystalline structure

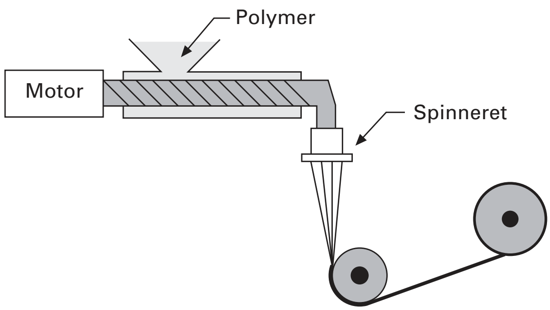


6.4 Hydrogen bonding in nylon 6-6.

will change during processing and it is important to note that all Nylon 6-6 fibers will not have the same crystallinity and, therefore, will not have the same response to deformation. There are many books and journal articles reporting the ways to measure crystallinity of polymeric fibers and explaining how the crystallinity affects the fiber properties. A list of some of these references for further reading is given at the end of this chapter.

6.2.2 Fiber spinning

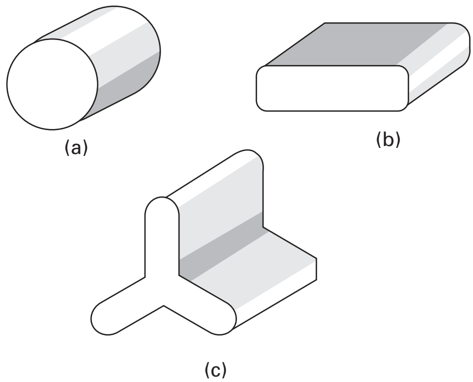
There are many ways to process the polymers into fibers. Melt spinning is done by melting the polymer and extruding it through a die called a spinneret (Fig. 6.5). In cases where the polymer cannot be melted or when melt spinning does not yield the desired molecular orientation, other spinning methods must be used. For example, acetate fibers are formed via dry spinning. In this type of spinning the polymer is put into a volatile solvent and then is pushed out of a spinneret. The solvent is driven off by an air flow and the fiber is wound onto a package. Rayon and acrylic fibers are also formed by making a polymer-solvent solution; however, the solution is pushed out of a spinneret into a bath containing a second solvent. The first solvent remains in the bath and the polymer fiber is removed. This type of fiber spinning is called wet spinning. Gel spinning is a special type of wet spinning with the polymer-solvent being a very dilute solution, i.e. a small concentration of polymer. Gel spinning produces a fiber with the molecular chains of the polymer highly oriented or organized. The fibers that are produced by all of these methods are termed ‘as spun’ fibers. In most cases the fibers will be further processed to obtain the desired fiber properties.



6.5 Schematic of melt spinning.

6.2.3 Fiber properties

It is useful to describe the geometry of the fibers and to note how different geometries lead to fiber mechanical responses. Some measures of fiber geometry are fiber cross-sectional area, diameter or nominal diameter, and fiber length. Additionally, if the fiber is not circular in cross-section, the shape of the cross-section is usually specified and other measures such as the minor and major axis for an oval cross-section or minimum and maximum diameter for a trilobal cross-section are used (Fig. 6.6). The diameter of the fiber is also a measure of fineness.

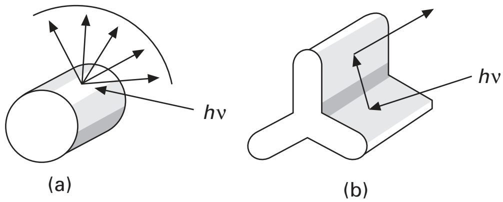


6.6 Fibers with (a) circular, (b) oval and (c) trilobal cross-sections.

Cross-sectional shape

Fibers come in many shapes and sizes. Natural fibers such as cotton vary greatly in cross-sectional size and shape, even for fibers from the same plant. The cross-section also varies along the length of a fiber. Other natural fibers such as wool have a near-circular cross-section. However, wool fibers will also vary in length and cross-sectional area. Man-made fibers will also have variations in the cross-section. The cross-section is determined by the fiber spinning method, the shape of the holes in the spinneret and the way that the fiber is processed after it is spun. For example, dry and wet spun fibers are usually made with spinnerets that have a circular cross-section; however, the fiber produced has a serrated cross-section. This is caused by the removal of the solvent during the spinning process. A melt spun fiber, on the other hand, has a cross-sectional shape very similar to the spinneret hole used to produce it. *Textile World* has produced the 'Textile World 2003 Man-Made Fiber Chart' (*Textile World* 2003), which contains typical photomicrographs of fibers used for textile materials.

The cross-sectional shape of a fiber will determine how light interacts with the fiber. For example, a round fiber will appear more lustrous than a trilobal fiber made of the same polymer. This is explained by looking at the way light bounces off of surfaces. Figure 6.7 shows a schematic representation of this concept. As light or $h\nu$ hits the surface of the fiber it is scattered in multiple directions. Due to the shape of the round fibers, no light being



6.7 Schematic representation of how light (*hv*) bounces off a fiber surface.

reflected is blocked from view as with the trilobal fiber. The trilobal geometry also has other benefits. Because of its larger surface area per length of fiber as compared to a round fiber with the same volume, the fiber may have more desirable moisture properties. For example, Nike Dri-FIT (Nike 2005) garments are made from fibers that have a high surface to volume ratio and/or have striations along their length to channel moisture, similar to that shown in Fig. 6.7(b). The multilobal fibers are also more efficient at 'hiding dirt' because of their light-scattering properties. Because of their ability to scatter light, they are frequently used in carpets and other applications.

As discussed above, the cross-section of a fiber changes along its length and may vary greatly in natural fibers and in man-made fibers that are spun out of a solution of polymer and solvent. Since the fibers are small, the cross-section may be non-circular and varies along the fiber length; the diameter is not an accurate measure of size of the fiber. Therefore, another measure is used. This measure is the linear density and is a measure of the mass of a given length of fiber. For fibers made from the same polymer, the larger the linear density the larger the fiber cross-sectional area. The linear density can be expressed in grams per meter or by two other units, which are commonly used. These two units are *denier* and *tex.* A denier is the mass of 9000 meters of fiber and a tex is the mass of 1000 meters of fiber. It is useful to note that for a fiber with a circular cross-section, the diameter of the fiber can be calculated if linear density, η, and density, ρ, are known (Equation (6.1)).

$$\text{Diameter} = \sqrt{\frac{4\eta}{\pi\rho}} \tag{6.1}$$

This equation can also be used to calculate the nominal diameter for a fiber with a non-circular cross-section.

Moisture properties

The way that the fiber interacts with moisture will impact its processability as well as its comfort. The ability of a fiber to take moisture into the fiber is called absorption. Adsorption is the ability of moisture to travel along the surface of the fiber. Adsorption is also described as wicking or wicking ability. As discussed previously, the surface area of the fiber has been increased by changing the cross-sectional area and/or shape to gain more desirable moisture properties.

Fiber size

We have already discussed how fiber size can affect the moisture properties of the fiber bundle. The fiber bending properties will also be governed by the shape and size of the fiber. For example, the bending resistance is proportional to the diameter to the fourth power as will be shown later in Equation (6.3). To see the effect of this, let us look at a given volume of polymer. For this volume of polymer, one can make any number of fibers. The surface area of these fibers is related to the square root of the number of fibers. This means that if the number of fibers is increased from one to four, the surface area doubles; and if the number of fibers is multiplied by 100, the surface area increases by 10 times. As pointed out, the fiber's resistance to bending is proportional to the fiber radius to the fourth power. Therefore, if the radius is decreased by a factor of 2, the bending resistance decreases by a factor of 16. Gone are the days of polyester fabrics that are uncomfortable to wear and have a harsh hand. The development of polyester microfibers has enabled the development of fabrics with desirable flexibility and moisture transport properties. These microfibers are fibers that have linear density less than 1 denier (9 tex). Fabrics made from these microfibers are soft and have good wicking ability because of the low bending resistance and the high surface area.

Fiber length

The length of fiber will also influence the way that the fiber properties translate to fabric hand. Short fibers having a length in the 2 to 3 cm range are called short staple fibers, while longer fibers such as wool have a staple length of 7 to 10 cm and are called long staple fibers. Continuous filament or filament yarns are ones that have very long lengths. Silk fibers are naturally occurring filament fibers, while man-made fibers are produced as filaments as described in section 6.2.2. The man-made filaments that will later be made into staple yarns (those made from staple fibers) will require that the filaments be cut before they are made into yarns. Fibers used to make non-woven fabrics, which do not require yarns to be formed, may be continuous filament or staple fibers.

Crimp

Fibers are characterized by the level of crimp in them. Crimp is a measure of the comparison of the actual length of fiber and the length of the fiber in its resting state. Crimp may be naturally occurring as in cotton or wool, or can be imparted on a man-made fiber through a process called texturing. Texturing adds bulk to the fibers, causing them to take up more volume than in their untextured state. This leads to the ability of the fiber to cover more space, as is desirable in carpets, or to allow air to be trapped in the fiber, which will change the thermal properties of the yarns and fabrics made from the fibers. Texturing will also change the way that light interacts with the fibers. Man-made fibers that are combined (blended) with fibers that have natural crimp are usually textured before blending with the natural fiber.

Fiber friction

Another property that is important to fabric hand is the fiber friction. The fiber–fiber friction influences the way that the fibers interact with each other. The fiber–fiber friction is reported as a friction coefficient. The friction properties will affect the flexibility of the yarns that are made from the fibers as well as how the yarns interact with each other. As the fiber–fiber friction increases, the ability of the fibers to slide past each other during yarn and fabric deformation decreases. This leads to a higher resistance to the deformation as compared with a fabric made from yarns with fibers that have a lower fiber–fiber friction coefficient.

6.2.4 Properties of common fibers

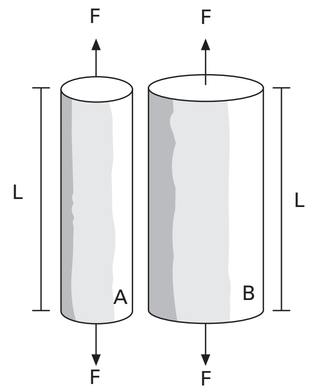
Table 6.2 contains some of the properties for some common fibers. These were taken from the Textile World 2003 Man-made Fiber Chart (*Textile World* 2003) and *Textiles* (Kadolph and Langford 2002). The chart contains properties of many other fibers; however, we have concentrated on the most widely used fibers.

6.3 Mechanical properties

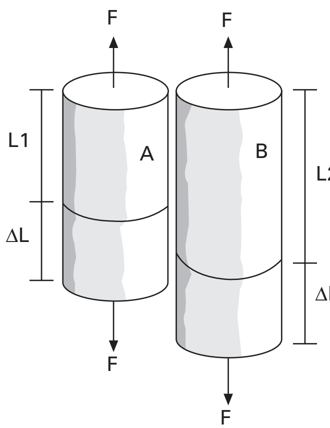
The mechanical properties of the fibers are important to the mechanical behavior of the fibrous structure in which they are incorporated. As discussed in Chapter 2, the tests used to determine the hand of a fabric are relatively low deformation tests. Therefore, the tensile modulus, bending or flexural modulus, and torsional modulus are of interest. These properties correspond to three different types of deformation as shown in Figs 6.8, 6.9, 6.10 and 6.11. The tensile modulus is used to describe the response of a fiber to tensile

Table 6.2 Mechanical properties of some common fibers

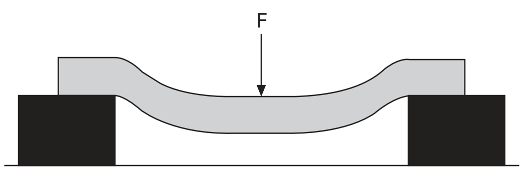
Fiber	Breaking tenacity (gpd)		Tensile strength (psi)	Breaking elongation		Elastic recovery (%)	Average stiffness (gpd)	Specific gravity	Moisture regain 65% rh and 70F
	Standard	Wet		Standard	Wet				
Acetate	1.2–1.4	0.8–1.0	20–24	25–45	35–50	48–65 at 4%	3.5–5.5	1.32	6.3–6.5
Acrylic	2.2–2.3	1.8–2.4	30–40	40–55	40–60	99 at 2%; 89 at 5%	5–7	1.17	1.5
Herculon (olefin)	3.5–4.5	3.5–4.5	41–52	70–100	70–100	96 at 5%; 90 at 10%	20–30	0.9	0.01
Modacrylic	1.7–2.6	1.5–2.4	45–60	45–60	45–65	100 at 1% 95 at 10%	3.5	1.35	2.5
Nylon 6	3.5–7.2	3.7–6.2	62–98	30–90	42–100	100 at 2%	17–20	1.14	2.8–5
Nylon 6,6	2.9–7.2	2.5–6.1	40–106	16–75	20–47	82 at 3%	10–45	1.13–1.14	4.0–4.5
Polyester	2.4–7.0	2.4–7.0	39–106	12–55	12–55	81 at 3%	12–17	1.38	0.4
Polypropylene	2.5–5.5	2.5–5.5	12–60	30–150	30–150	93 at 5%; 85 at 10%		0.91	0.01
Rayon	1.9–2.3	1.0–1.4		20–25	24–29			1.48–1.54	
Spandex	1.0		11–14	400–625		97 at 50%	0.13–0.20	1.21	1.3



6.8 Schematic representations of two fibers with different cross-sectional areas and the same length.

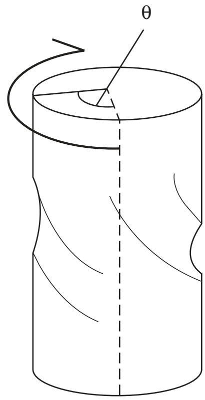


6.9 Schematic representations of two fibers with the same cross-sectional area and different lengths.



6.10 Schematic representation of the bending of a fiber to determine flexural modulus.

loading as indicated by the arrows in Figs 6.8 and 6.9. Bending modulus relates to the response of a fiber to a bending moment that can be imparted by a 'beam bending' type test or a 'loop test' (Fig. 6.10). When a fiber is twisted along its axis, the torsional modulus is used to characterize the response (Fig. 6.11).



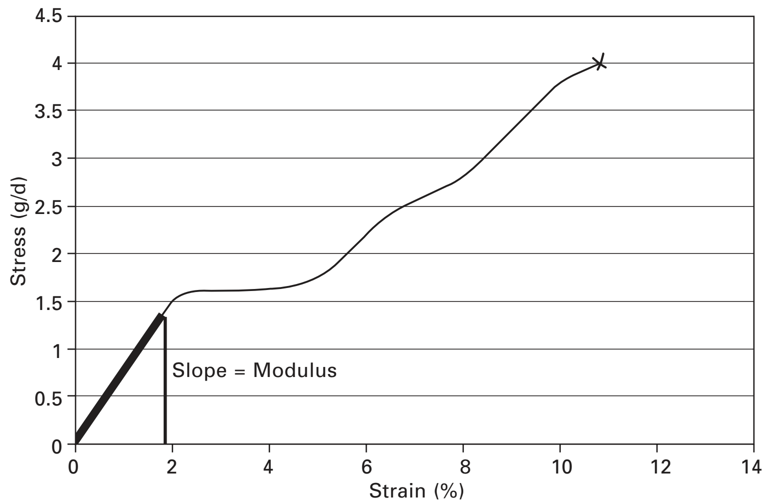
6.11 Schematic of torsional deformation of a fiber.

6.3.1 Tensile modulus

There are standard tests available to measure a fiber's response to tensile loading; ASTM D638–03 (ASTM 2004b) gives a more general testing method for polymers subjected to tensile loading. In ASTM method D2256 (ASTM 2004c), the fiber is held in two places by a set of grips. The grips are then displaced and the resistance to the displacement is monitored using a load cell. The results can then be presented as values of resistance (load) and displacement. Often the load is converted into specific stress (load/linear density) measured in grams per denier or centi-newtons per decitex. The displacement is used along with the original length between the grips (gauge length) to calculate the strain. Specific stress and strain are used to make the comparison of different fibers easier. To illustrate this we show two fibers in Fig. 6.8. These fibers are the same length but fiber A has a smaller cross-sectional area than fiber B. If these fibers are tested as described above and they both fail at the same load, we would say that they have the same strength. However, we would know that the fiber with the smaller cross-sectional area (fiber A) outperformed fiber B. The cross-sectional area is related to the linear density as shown in Equation (4.1), therefore we can divide the load by the linear density to yield the specific stress and then note that fiber A breaks at a higher specific stress than fiber B.

The argument for calculating strain is similar. Figure 6.9 shows two fibers with the same cross sectional area but with different lengths, L1 and L2. These fibers are displaced and are found to fail when they have been stretched the same amount, ΔL. Again, one fiber has outperformed the other. The strain is given by the displacement divided by the original length (gauge length). When the strain is calculated, the strain to fail for fiber A is greater than that of fiber B. Strain has no units and is presented as a decimal value or as a percentage. Strain is also known as elongation.

A typical specific stress versus strain curve is shown in Fig. 6.12. The initial slope of this curve is termed the tensile modulus or initial modulus. This low deformation response is very important to fabric hand. Another response that can be measured in a tensile test is the fiber's ability to recover from a deformation. This is called the elasticity of the fiber and it can be measured by subjecting the fiber to a tensile load, removing the load and measuring the changes in fiber length. It can also be measured by monitoring the specific stress vs. strain response of the fiber as it is repeatedly subjected to tensile loading and unloading. In many cases, the hysteresis is used as a measurement of recovery or elasticity of the fiber.



6.12 Stress versus strain curve for cotton fiber.

6.3.2 Bending or flexural modulus

Flexural modulus is defined by Dow Chemical Company as the ratio of stress to strain within the elastic limit, when measured in the flexural mode (Dow Chemical Company 2005). This property is used to indicate the bending stiffness of a material. Since fibers are similar in geometry to beams, many researchers have used beam bending models and theory to describe the behavior of fibers. Beam bending has been modeled and discussed for many years. Many mechanical engineering textbooks discuss the models in detail. Figure 6.10 illustrates one of these models where the ends of the beam (fiber) are fixed and a force is applied to the center of the beam. Linear beam theory shows that the force, F, required for fiber bending is given by

$$F = \frac{48\,EI}{l}h \tag{6.2}$$

where E = Young's modulus, I = geometrical moment of inertia of a fiber, h = half value of the deflection of a fiber, and l = the length of the sample. For a fiber with a circular cross-sectional area, I is related to the diameter of the fiber to the fourth power. The effect of changing the fiber size (fineness) on the flexural modulus is clear. As the fineness decreases, the flexural modulus decreases. This relationship has been exploited in the development of microfibers, which form fabrics with low flexural modulus as compared to fabrics made from larger fibers. As fibers continue to become finer and finer, fabrics with softer hand and lower resistance to bending will be developed. The flexural moduli for some commonly used fibers are given online at MatWeb (MatWeb 2005). Flexural properties of polymers can be measured using ASTM D790-03 (ASTM) 2004a)

6.3.3 Torsional modulus

A third way that fibers are deformed is by being twisted along their axis. Figure 6.11 is a schematic of this type of deformation. In this figure, one end of the cylinder (fiber) is stationary, while the other end is displaced about its axis as indicated by the arrow. The resulting displacement can be described by the angle, theta (θ). The magnitude of the couple to cause this deformation is given by

$$C = \frac{\pi n r^4 \theta}{2l} \tag{6.3}$$

where n is the torsional modulus, r is the fiber radius, and l is the fiber length. As with the bending deformation described above, the microdenier fibers have a low resistance to torsional deformation.

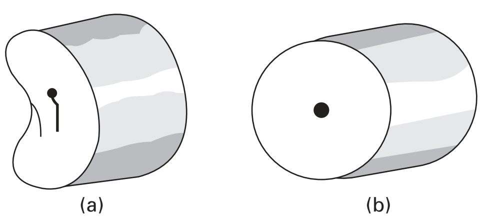
6.3.4 Resiliency

Resiliency is the ability of a fiber to recover or spring back after deformation. This may include bending, twisting, compressing, or a combination of these deformations. All of these properties are subjectively measured when a consumer handles a fabric. For apparel fabrics, resiliency is important in fabrics with a relatively large thickness or where the insulating properties are important. Resiliency of the fabric is directly related to the resiliency of the fibers as well as the fiber–fiber friction properties and the fabric structure. Resiliency is particularly important in applications such as carpets where they are deformed and expected to recover quickly. Recovery from long-term deformation, such as from a heavy object placed on the carpet, is also desired.

6.4 Chemical modification of fibers for improved fabric hand

Other than the typical mechanical methods to alter the hand of fabrics/fibers, hand can be improved by chemically treating the fiber. Two ways to chemically treat a fiber will be discussed: one way is to treat the surface and the other is to change the chemical make-up of the fiber. In treating the fiber surface, chemicals called 'softeners' are usually used. Softeners work by lubricating the surface of the fiber. This reduces the fiber–fiber friction, which makes the fabric move and flow more easily. Softeners are a type of textile auxiliary called surfactants that have the basic shape of a long hydrophobic carbon chain with a hydrophilic cationic end. By having a softener on the surface of the fiber, the fiber will not wear down or pill as fast as it would without the softener, thus maintaining good hand.

Another method of changing fiber hand is to alter the chemical nature of the fibers themselves. A very common method used is the mercerization of cellulose. Mercerization is the chemical treatment of cellulose with a caustic alkali such as sodium hydroxide. In this process the fiber swells, becomes stronger and more susceptible to dye, and has an increased luster. The pretreated cellulose fiber has a cross-section similar to that of a bean, as seen in Fig. 6.13. As cellulose is mercerized the overall shape of the fiber becomes more circular and more uniform than its irregular predecessor, thus becoming smoother to touch. With its round shape, this new cellulose or mercerized cellulose becomes more lustrous as demonstrated by the round fiber in Fig. 6.7. In addition to luster, the fibers are now able to absorb a larger amount of dye into the substrate, leading to richer shades of color. This is due to the solid-state structures being reformed. In this case there is a decrease in fiber crystallinity. For fibers that can form crystallites, the molecular orientation in the fiber can be classified as either crystalline or amorphous. In the crystalline areas, the fiber molecules are orientated to form crystallites. These crystalline areas are nearly impermeable to moisture or chemicals. The amorphous areas, on the other hand, are not orientated and are disordered. The chemicals and moisture can penetrate these areas. After mercerization, there is a decrease in the crystalline regions in the cellulose. Therefore, there are more amorphous

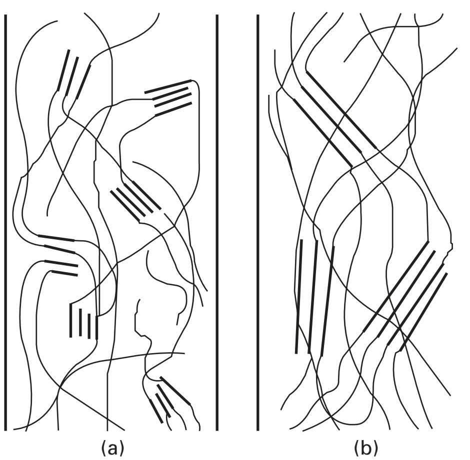


6.13 Fiber cross-section of (a) cellulose and (b) mercerized cellulose.

regions for the dyes to penetrate, which leads to better coloration of the fibers. Finally, the mercerization process also relieves some residual stresses. The result is a stronger fiber. In general, higher order of the molecules in the fiber leads to higher strength; however in the case of mercerization, the increase in strength from stress relaxation outweighs the loss in strength due to fewer crystalline regions.

6.5 Crystallinity in fibers

In general, the strength of a fiber increases with increasing degree of order of the molecules that make up the fiber. In other words, if the molecules in a fiber are aligned along the fiber axis, the fiber will be strong in uniaxial tension along the fiber axis. The orientation of the molecules in the fibers can be classified in two general classes or regions: the amorphous or unordered region and the crystalline or ordered region. Crystalline regions are areas in a fiber or material in which the molecules line up in a single direction, and amorphous regions are areas in which the molecules have no common direction. Crystallinity of a fiber can be expressed as a percentage of the volume that is crystalline. Although crystallinity can be used to get a general idea of the strength of a fiber, it is not all that is necessary to understand how the fiber behaves. We must also understand how the areas or regions are arranged in the fiber, the size of each region and the number of regions in a given volume of fiber. For example, Fig. 6.14 shows two fibers that have the same crystallinity. That shown in Fig. 6.14(a) is made up of smaller crystals, while Fig. 6.14(b) shows a fiber made of large crystals. Although the crystals in Fig. 6.14(b) are much larger, the volume of crystalline regions is the same in both fibers, thus

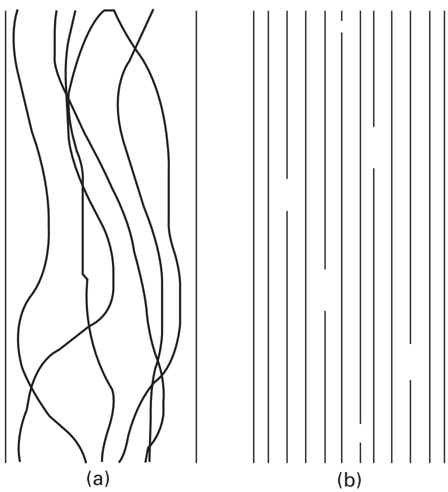


6.14 Fiber with (a) small crystals and (b) large crystals.

they have the same crystallinity. The differences in the size and number of crystalline regions lead to different levels of mobility of the molecules in the fibers. What this means is that with smaller crystals, the fiber shown in Fig. 6.14(a) can move with more freedom and less restriction than that in Fig. 6.14(b) with its large crystals.

The size and number of crystalline regions can be controlled by processing the fibers after they are spun. Typically this is done through drawing (stretching) the fiber in a heated state and setting the new structure. The process of setting the structure with heat is termed 'heat setting'. During heat setting, the fiber is heated to a temperature near its melt temperature. At this temperature small crystals in the fiber become amorphous while larger ones are maintained. The molecules from the newly melted small crystallites can then become part of the larger crystals. This will lead to a more crystalline fiber that is also stronger. Heat setting the fiber in a moist environment also affects the size and number of crystalline regions.

The drawing process involves the elongation of fibers by means of stretching. The stretching is achieved through the use of sets of heated rollers with varying speeds. As the fibers are stretched, so are the molecules in the fibers. With the stretching, the molecules become more ordered in the direction of drawing (see Fig. 6.15). With this higher orientation the fiber becomes stronger.



6.15 Fibers that are (a) unoriented and (b) oriented.

Crystallinity will also affect the hand of the fabrics made with the fibers by influencing the way that the fibers move and respond to bending. A more crystalline fiber like that in Fig. 6.15 is more resistant to bending. If an article of clothing were made from a highly crystalline fiber, it would feel stiffer as compared to a fabric made of fibers with a lower crystallinity. The desire to have a strong (highly crystalline) fiber which is also flexible is achieved by manipulating the size of the fiber. As shown in Equation (6.2), the flexibility of a fiber varies with its moment of inertia and its initial modulus. We have already discussed how the flexibility varies with fiber diameter. The crystallinity and fiber size and cross-section can be manipulated to obtain a fiber with the strength and bending behavior that is desired. Although the modulus increases with crystallinity (in most cases), the fiber size can be decreased to obtain a strong flexible fiber. As with many other materials, the design of a fiber requires tradeoffs.

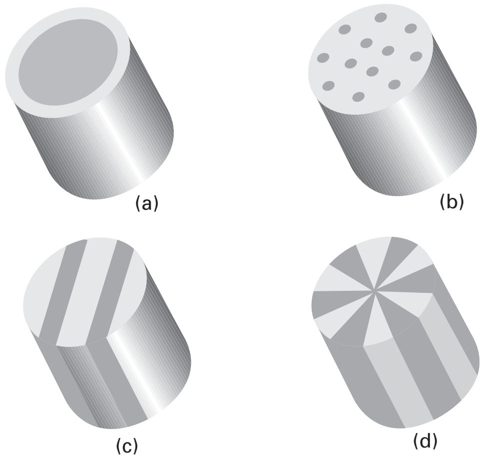
6.6 Future trends

In the field of polymers there is a great deal of research being done. Fibers that can carry electricity and sensors are being developed in clothing for medical, recreational, military and other purposes. The challenge will be in designing these new structures such that they have good fabric hand, while providing a robust system that can withstand normal washing conditions.

We have seen how the fiber size can be manipulated to yield fibers that are strong and flexible and have good moisture properties. The future will see the further miniaturization of fibers. Already, electrospun fibers with very small diameters are being produced in laboratories. A search of the compendex (2005) database using the search term ‘electrospinning’ yields over 150 journal articles published in 2004. In this spinning process, fibers are spun from a syringe that has an electrical current applied to it. The resulting fibers have diameters in the order of 1/10 to 1 microns. Yarns made from these fibers would have very high surface area to volume ratios. Researchers have been able to form electrospun fibers with a porous structure, thus increasing the surface area even more. The use of these fibers will be in applications such as filters, protective garments and biomedical applications, as well as in apparel.

Still other small structures are being developed (Fig. 6.16). For example, the ‘island in the sea’ fiber structure is shown in Fig. 6.16(b). In these fibers, two or more types of polymers are combined to obtain fibers that have the desired properties. In some cases the supporting ‘sea’ is removed after fiber extrusion to yield very small fibers, while in other cases the entire fiber is used. Researchers are currently working to develop these fibers with carbon nano tubes as the ‘islands’ in a ‘sea’ of another polymer (Kumar 2005). Through this type of technology, they will be able to form very small conducting fibers.

Currently, several research laboratories and companies are developing electronic textiles. These structures will become available to consumers in the next few years. In these products, thin conducting wires are incorporated into the garment to enable information to be passed from one part of the



6.16 Bicomponent fibers with (a) sheath-core structure, (b) island in the sea structure, (c) layer-by-layer structure, and (d) segmented pie structure (Kumar 2005).

garment to the other. The combination of the ‘island in the sea’ nano fibers and the idea of a garment that can act to enable input and output will lead to structures that can support many different electronic devices, all in a person’s clothing.

Carbon nano tubes have also been used to try to obtain fibers with much higher strengths. The nano tubes are incorporated into the fiber to reinforce the polymer. The further development of this technology will lead to fibers that are flexible yet have incredible strength.

Fibers are being developed that are made from polymers that change color with a stimulus such as light or an electrical charge. Still other fabrics are being developed from liquid crystal polymers to be used for flexible displays. In this application, the flexibility of the fabric is important as well as its ability to act as a display device. One of the challenges is to obtain fabrics with good hand that also display the desired optical properties.

The progress that has been made and that will be made in the future in materials development will lead to yet other fibers and fiber structures. Most of the applications, whether it be apparel, medical, composites or others, will require specific material properties, and therefore the hand of the fabrics formed from the fibers made from these new materials will be of great interest.

Here we have discussed only a few of the fiber developments being made at this time. For more current information, we suggest that you refer to the many polymer journals available online or through your local college or company library.

6.7 Sources of further information and advice

In this chapter the basic properties of fibers that are important to understanding fabric hand are discussed. Various dictionaries and glossaries are available online and in print. Three of these are Beech *et al*. (1988), Celanese Acetate LLC (2001), and Dow Chemical Company (2005). There is active research in the area of development of polymers for fiber forming, development of fiber processing methods and results from various testing of fibers. Additionally, there is an entire body of work investigating the mechanical response of fibers and modeling their behavior. Most of the work has been presented in the form of technical papers, journal articles and conference proceedings. The *Textile Research Journal* is a good technical source of research results concerning the modeling of fibers, yarns and fabrics. Listed here are examples of the types of research being reported in the literature concerning the mechanical properties of fibers, yarns and fabrics: Cheng *et al.* (2004), Gong and Mukhopadhyay (1993), Hoffman and Beste (1951), Honald and Grant (1961), Hunter *et al*. (1982), Kawabata *et al.* (2002), Ko and Jovicic (2004), Matsudaira *et al.* (1984, 1993), Sen *et al.* (2003), Sujica *et al*. (2003), Taylor (1972), Vasanthan (2004), Yamaura *et al.* (2004), Yu *et al*. (2003), Yusheng and Matsudaira (1993) and Zhang and Qiu (2003). A paper by Huang *et al*. (2005) contains many useful references concerning fiber properties and fabric hand.

There are also various books that can be used as reference materials. *Understanding Extrusion* (Rauwendaal 1998) includes an interactive training disk and teaches about the extrusion of polymers. For more details about fiber properties, the *Textile World* 2003 Man-Made Fiber Chart has already been mentioned. This chart is poster sized and contains fiber identification properties such as chemical reactivity and burning characteristics as well as mechanical properties for over 50 fibers. It includes sample stress versus strain curves for these fibers as well as numerical values for the mechanical properties. *Textiles*, 9th edition (Kadolph and Langford 2002) contains a table in the third chapter that summarizes the translation of certain fiber properties to fabric properties and is a good reference to use in understanding how fabric hand is influenced by fiber properties. Additionally, *Understanding Textiles* (Collier and Tortora 2001) contains information about fibers and their properties as well as a discussion of the basics of polymers. For a more in-depth discussion of fiber sciences, readers can go to *Fiber Science* (Warner 1995) and *Advances in Fibre Science* (Mukhopadhyay 1992).

The ASTM standards should be consulted for more information on the standard methods used to test fibers. These are readily available online or from your local college or company library. Other papers concerning the measurement of fiber properties include Collier and Epps (1998), Peykamian and Rust (1999), and Shao and Filteau (2004).

For more reading on electrospinning and if you have an interest in nano fibers and/or nano tubes as part of a composite fiber, a quick search of an engineering database such as Compendex or Web of Science (Web of Science 2005) will yield a list of the most recent research results available. Compendex is a very comprehensive engineering database that has almost 7.5 million records referencing engineering journals as well as conference materials. Compendex is available through universities that offer engineering degrees as well as by online access.

6.8 References

ASTM D790-03 (2004a), 'Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials'.

ASTM D638-03 (2004b), 'Standard Test Method for Tensile Properties of Plastics'.

ASTM D2256 (2004c), 'Standard Text Methods for Tensile Properties of Yarns by Single-Strand Method'.

Beech, S.R., Farnfiels, C.A., Whorton, P. and Wilkins, J.A. (1988), *Textile Terms and Definitions*, 8th revised edition, Warrington, UK, The Textile Institute.

Celanese Acetate LLC (2001), Complete Textile Glossary, Charlotte, NC, Celanese Acetate LLC, http://www.celaneseacetate.com/textile_glossary_filament_acetate.pdf.

Cheng, M., Chen, W. and Weerasooriya, T. (2004), 'Experimental investigation of the transverse mechanical properties of a single Kevlar® KM2 fiber', *Int. J. Sol. Struct*, 41, 22–23, 6215–6232.

Collier, B.J. and Epps, H.H. (1998), *Textile Testing and Analysis*, Englewood Cliffs, NJ, Prentice Hall.

Collier, B.J. and Tortora, P.G. (2001), *Understanding Textiles*, 6th edition, Englewood Cliffs, NJ, Prentice Hall.

Compendex (2005), Engineeing village 2, Elsevier Engineering Information Inc., Hoboken, New Jersey, USA.

Dow Chemical Company (2005) http://www.dow.com/styron/design/guide/flexural.htm

Gong, R.H. and Mukhopadhyay, S.K. (1993), 'Fabric objective measurements: a comparative study of fabric characteristics', *J. Text. Inst*., 84, 2, 192–198.

Hoffman, R.M and Beste, L.F. (1951), 'Some relations of fiber properties to fabric hand', *Text. Res. J*., 21, 66–77.

Honald, E. and Grant, J.N. (1961), 'Softness of cotton yarns as affected by fiber and yarn properties', *Text. Res. J*., 643–650.

Huang, H., Parachuru, R., Gupta, B.S. and El-Mogahzy, Y. (2005), 'Fabric friction behavior and tactile comfort', submitted to *Text. Res. J.*

Hunter, L., Kawabata, S., Gee, E. and Niwa, M. (1982), 'The effect of wool fiber diameter and crimp on the objectively measured handle of woven fabrics', in Kawabata, S., Postle, R. and Niwa, M. (eds), *Objective Specification of Fabric Quality, Mechanical Properties and Performance* (pp. 167–182), Osaka, Textile Machinery Society of Japan.

Kadolph, S.J. and Langford, A.L. (2002), *Textiles*, 9th edition, Englewood Cliffs, NJ, Prentice Hall.

Kawabata, S., Niwa, M. and Yamashita, Y. (2002), 'Recent developments in the evaluation technology of fiber and textiles: Toward the engineered design of textile performance', *J. Appl. Polym. Sci.*, 83, 3, 687–702.

Ko, F.K. and Jovicic, J. (2004), 'Modeling of mechanical properties and structural design of spider web', *Biomacromolecules*, 5, 3, 780–785.

Kumar, S. (2005), Personal communication, Georgia Institute of Technology, Atlanta, GA.

Matsudaira, M., Kawabata, S. and Niwa, M. (1984), 'The effects of fiber crimp on fabric quality', *J. Text. Inst.*, 75, 273–277.

Matsudaira, M., Tan, Y. and Kondo, Y. (1993), 'The effect of fiber cross-sectional shape on fabric mechanical properties and handle', *J. Text. Inst.*, 84, 3, 376–386.

MatWeb (2005) http://www.matweb.com/reference/flexuralstrength.asp

Mukhopadhyay, S.K. (1992), *Advances in Fibre Science*, Millbrook, Southampton, UK, The Textile Institute.

Nike (2005), www.nike.com.

Peykamian, S. and Rust, J.P. (1999), 'Yarn quality indexing using a mechanical stylus', *Text. Res. J.*, 69, 6, 394–400.

Rauwendaal, C. (1998), *Understanding Extrusion*, Cincinnati, OH, Hanser/Gardner Publications.

Sen, K., Bajaj, P. and Sreekumar, T.V. (2003), 'Thermal behavior of drawn acrylic fibers', *J. Polym. Sci., Part B: Polym. Phys.*, 41, 22, 2949–2958.

Shao, Y. and Filteau, M. (2004), 'A systematic analysis of fiber contents in textiles', *AATCC Review*, 4, 6, 18–21.

Sujica, M.Z. and Smole, M.S. (2003), 'Structure–mechanical properties relationship of poly(ethylene terephthalate) fibers', *J. Appl. Polym. Sci.*, 89, 12, 3383–3389.

Taylor, M.A. (1972), *Technology of Textile Properties*, 3rd edition, London, Forbes Publications.

Textile World (2003), 'Textile World 2003 Man-Made Fiber Chart', http://www.textileworld.com/Products.htm?CD=21&ID=38

Vasanthan, N. (2004), 'Effect of heat setting temperatures on tensile mechanical properties of polyamide fibers', *Text. Res. J.*, 74, 6, 545–550.

Warner, S.B. (1995), *Fiber Science*, Englewood Cliffs, NJ, Prentice Hall.

Web of Science (2005) http://www.isinet.com/products/citation/wos/

Yamaura, K., Katoh, T., Koezuka, K., Iwaseya, M. and Dai, L. (2004), 'Spinning of the solutions of poly(vinyl alcohol)/NaCl/H_2O systems and their fiber properties', *J. Mat. Sci.*, 39, 5, 1609–1614.

Yu, W., Yan, H. and Postle, R. (2003), 'Evaluating single fiber and fiber bundle tensile curves', *Text. Res. J.*, 73, 10, 875–882.

Yusheng, T. and Matsudaira, M. (1993), 'Hand analysis of polyester fabric with high-shrinkage fibers by the KES objective evaluation method', *Sen-I Gakkaishi*, 49, 8994.

Zhang, C. and Qiu, Y. (2003), 'Modified shear lag model for fibers and fillers with irregular cross-sectional shapes', *J. Adhesion Sci. Tech.*, 17, 3, 397–408.

7
Effect of yarn factors on fabric hand

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7.1 Introduction

According to the ASTM (American Society for Testing and Materials), yarns have been defined as 'a generic term for continuous strand of textile fibers, filament, or material in a form suitable for knitting, weaving, or otherwise inter-twining to form a textile fabric'.

Yarns constitute the major elements upon which the characteristics of the end products (fabrics or otherwise) are determined. In the course of this chapter the emphasis will be directed towards the effect of yarn properties – physical, mechanical, or both – on fabric hand.

Commercially, there is a huge variety of yarns. It would appear that there could be no limit to the number of distinctly different yarns.

7.2 Yarn types

Yarns have been classified into different types according to the methods of characterization and specification. In order to have full comprehension of these methods, and of the variety of possible yarns, it could be shown that any of the yarns available in the market will fall within one or more of the following categories.

7.2.1 Major categories of yarn types

The four major categories are:

- Types of fibers
- Yarn structure
- Yarn twist
- Method of manufacturing

If there are 10 possibilities in each of these categories, by simple probability there will be 10^4 different types of yarns. The following is an overview of the above categories.

Classification according to types of fibers and their length

Yarns are produced from two main types of fibers according to their lengths:

1. Staple-fiber yarn. In this type, the fiber length is of a staple type, either short, medium, or long staple, such as cotton and/or wool and worsted fiber, or any kind of man-made fibers or silk.
2. Continuous filament yarn. These are mostly man-made filaments which are of continuous length or of natural type, like silk.

Of the above fibers, yarns are produced in different types according to the different constituents. These could be:

- Entirely of one kind of fiber (natural or man-made)
- A blend of two or more fibers to obtain the desired yarn properties according to the percentages of the different fibers in the blend. In addition, in continuous filament yarns, there are two more special types of yarns:
- Bi-constituent yarns, in which each filament in the yarn is composed of two or more different polymers
- Bi-component yarns have filaments made from one type of polymer that are combined to form the yarn.

Classification according to yarn structure

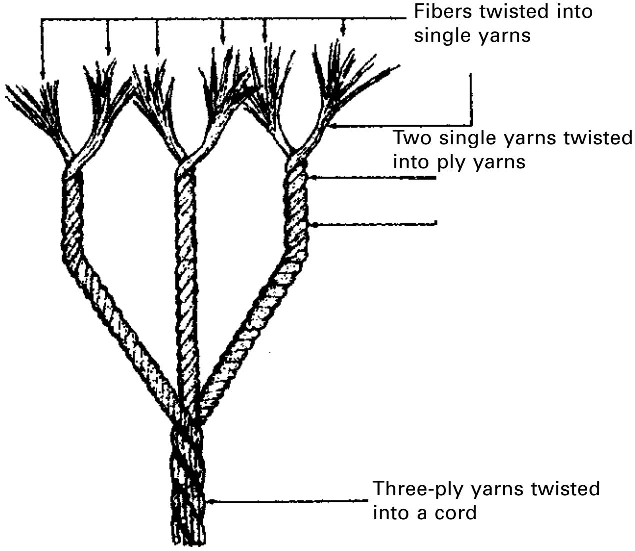
Yarn structure is another highly significant factor, which plays a major role in the physical and mechanical properties of the yarn. This, in turn, may affect the fabric properties which may reflect among other things on the fabric hand, as presented and discussed throughout this book. Six yarn structures are well known in the textile industry and are used according to their physical and mechanical properties, as well as the performance characteristics of the yarn. The different yarn structures are:

- Single yarns
- Plied yarns
- Cabled or cord yarns
- Complex yarns (core-spun)
- Fancy yarns
- Modified continuous-filament yarns.

Single yarns are made from a group of staple fibers or filaments twisted together.

Plied yarns are made by twisting together two or more single yarns. Each single yarn twisted into the plied yarn is called a ply.

Cabled or cord yarns are made by twisting together two or more ply yarns. Cord yarns are used in making ropes, sewing thread and cordage, and are woven as decorative yarns in novelty fabrics. Figure 7.1 shows an illustration of single, ply, and cord yarns.



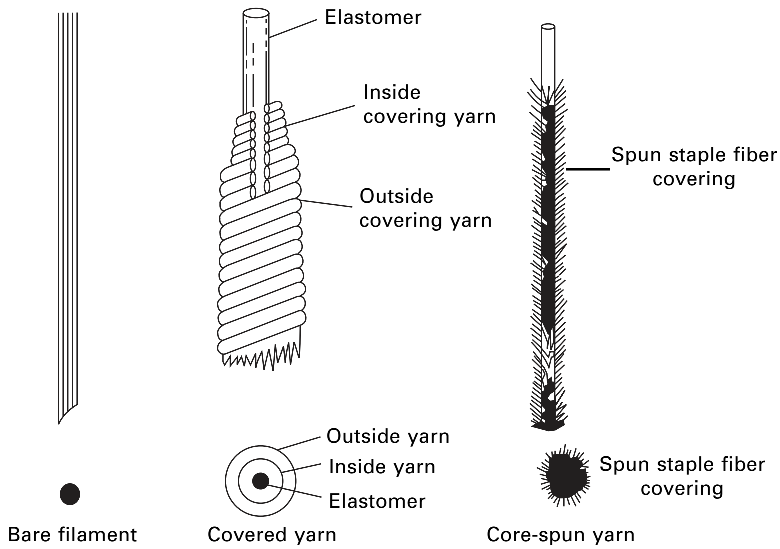
7.1 Single, ply, and cord yarns. *Source: Understanding Textiles*, 5th edn, by P.G. Tortora and B.J. Collier, 1997, Prentice Hall.

Core-spun yarns are yarns made with a central core of one fiber around which is wrapped or twisted an exterior layer of another fiber. Core-spun yarns could be made with an elastomeric core, such as Spandex, covered by another fiber to produce a stretch yarn. Figure 7.2 shows an illustration of types of elastomeric yarns (lengthwise and cross-section).

Fancy yarns are usually made by the irregular plying of staple or continuous-filament yarns and are characterized by abrupt and/or periodic effects. The periodicity of such ‘effect’ yarns is preferred to be random. Figure 7.3 illustrates different types of fancy yarn (sometimes referred to as novelty yarns or specialty yarns).

Continuous-filament yarns are mostly produced as man-made materials, such as nylon, polyester, or acetate and rayons. The filaments produced are joined to form multi-filament yarns by twisting them together either loosely or more tightly. The amount of twist, together with the characteristics of the fibers (luster, hand, cross-sectional shape, etc.), will determine the appearance and feel of the yarn.

In order to change the smooth surface feel of fabrics made from continuous-filament yarns and to be able to simulate the feel of fabrics made from staple



7.2 Covered and core-spun yarns. *Source: Understanding Textiles*, 5th edn, by P.G. Tortora and B.J. Collier, 1997, Prentice Hall.

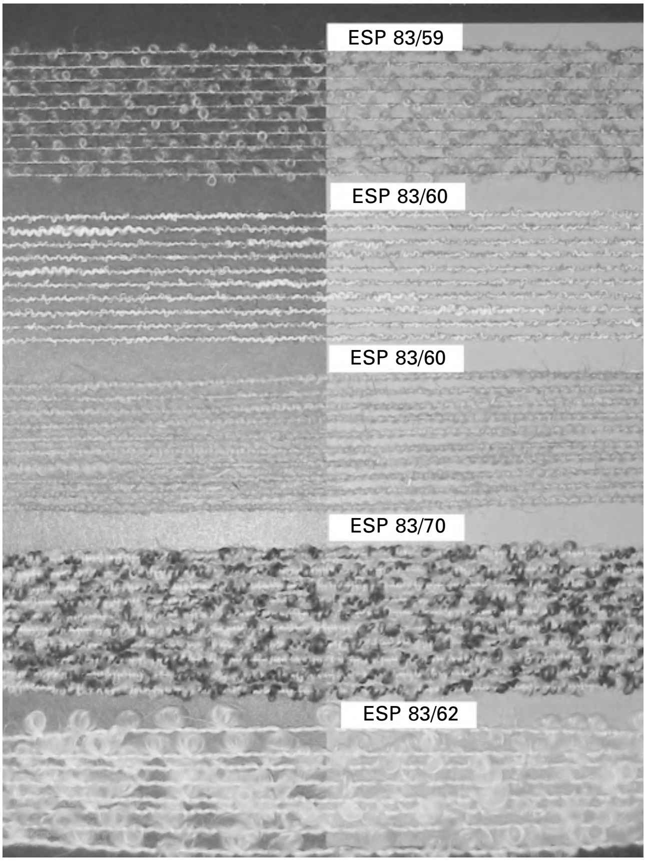
fiber yarns with the hairy surface condition, filament yarns are sometimes put through an additional process known as texturizing. The process modifies the feel of the filament yarns by adding bulk and/or stretch to the filaments: the yarns produced are known as **modified continuous-filament yarns**. The different processes used will be presented later in the chapter.

Classification according to yarn twist

Yarn twist is one of the most important parameters in determining the major properties of the yarn. Mostly, yarns are twisted at some level or another. The degree of twist given to a yarn affects a number of aspects of its appearance, behavior, and durability. As a general rule, increasing twist decreases apparent yarn size.

Yarn tensile strength increases in staple fiber yarns as twist increases up a certain twist level known as 'optimum twist'. Beyond this point, the strength of the yarn begins to decrease. On the other hand, filament yarns are stronger untwisted, and the strength decreases as twist increases.

The appearance and hand of fabric are affected to a large extent by the twist of the yarn. For example, if filament yarns of higher luster are given only very low twists, they will reflect greater quantities of light in mirror-like fashion and, therefore, appear brighter and of smoother hand than the same yarns when they are more highly twisted. Loosely twisted worsted yarns produce a smooth, more even surface.



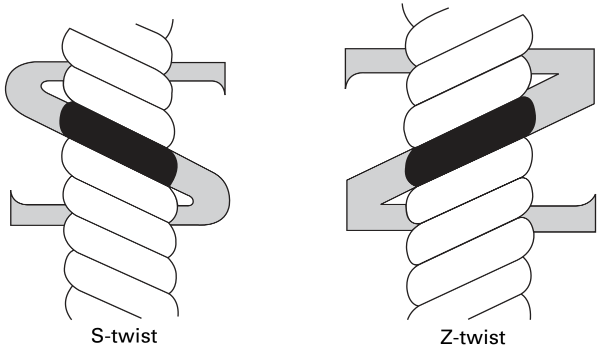
7.3 Different types of fancy yarn.

Direction of twist

In the textile industry, the terminology describing the direction of twist in yarns is called S or Z twist (Fig. 7.4). Z-twisted yarns are twisted so that the direction of the fibers or the filaments follows the center bar of the letter Z. In S-twisted yarns, the yarn twist direction follows the center bar of the letter S. The adoption of these terminologies is simply to facilitate the description of the direction of twist in the yarns, instead of right or left twist. Most single yarns are produced with Z-twist and are twisted in the S-direction when plying two single yarns together.

Methods of yarn manufacture

Yarns are also classified according to the method of manufacture since these methods adopt different technologies and, hence, produce different types of



7.4 Direction of twist. *Source: Understanding Textiles*, 5th edn, by P.G. Tortora and B.J. Collier, 1997, Prentice Hall.

yarns. The different methods of manufacturing yarns are summarized as follows:

- Short staple spinning
- Modified short staple spinning
- Worsted yarn spinning system
- Woolen yarn spinning system
- Tow-to-top conversion system (by either cutting or stretch breaking)
- Texturizing.

The most popular systems to process staple fiber yarns of short, medium or sometimes long staple fibers are:

- Ring spun yarns, either carded or combed
- Open-end spinning
- Air-jet spinning
- Friction spinning.

As the technological details of yarn manufacture are outside the scope of this book, the reader is advised to refer to the suggested reading list at the end of this chapter.

7.3 Effect of yarn structure on fabric hand

An overview of the relationship of yarn structure and fabric hand has been outlined by Scardino [1]. He has pointed out that in the case of visual aesthetics, the contribution of yarn structure to the tactile qualities of fabrics is transmitted through the surface geometry of the constituent yarns. Exceptions to this tendency, once again, can be found in the case of heavily napped, brushed, or felt-finished fabrics and in the case of apparel fabrics that have been given heavy coatings or chemical treatments.

However, the tactile qualities of a fabric are also dependent on the compressive behavior of the fabric. The dimensional stability of the cross-section of the constituent yarns plays a major role in fabric compression. Thus, the behavior of yarn cross-section during fabric compression is quite fundamental to the hand of fabrics.

The role of yarn structure in tactile aesthetics of fabrics is somewhat dominated by yarn twist. For example, fabrics composed of yarns with higher levels of twist are known to have higher bending stiffness, less compressibility, less fiber mobility, lower surface friction, less bulkiness, and less potential contact with a contiguous surface than similar fabrics composed of yarns with less twist. Increased yarn twist leads to greater internal (fiber-to-fiber) friction within the yarn structure. The constituent fibers or filaments tend to bend as a group rather than individually, thereby increasing the bending stiffness of the yarn. The increased fiber entanglement and internal friction caused by yarn twist also provide for a more dimensionally stable yarn structure that does not deform as much under compressive loads. On the yarn surface, the segment of fiber length between points of entanglement is reduced with increased yarn twist. This effect severely restricts fiber mobility and the chance of snagging of fibers or filaments. Yarn twist creates lower surface friction and potential surface contact because of less yarn flattening under low levels of compressive loading. Increased twist tends to reduce softness, covering power, and bulkiness, in general, and hairiness in the case of spun yarns.

Fiber linearity and fiber-packing density in yarn structures are also important to the tactile qualities of a fabric, when not masked by twist. In untextured filament yarns, the fiber linearity and packing density are quite high. Consequently, the yarn leads to a smooth, uncompressible feel in fabric. With similar yarns that have been textured, the low packing density of filaments and the non-linear protruding filament loops produce a soft, compressible but resilient (spring-back) feel in fabric.

7.4 Fundamental structural features of yarn

Scardino [1] has also explained that yarn structural features depend mainly on the properties of the constituent fibers or filaments and the inherent characteristics of the processing systems. Excluding generic-related parameters (such as fiber friction, modulus, resilience, extensibility, and elasticity), the fiber properties of greatest importance are length, fineness, crimp, and cross-sectional shape. The inherent characteristics of the processing system are fiber orientation and entanglement. Fiber orientation refers to the position of the fiber or filament segments in relation to the yarn axis and, in general, the degree of linearity of the fibers or filaments in a yarn. Fiber entanglement, as used here, relates to both the nature of the entanglement and the frequency or the degree of entanglement.

7.5 Comparison of hand of fabrics produced with air jet and ring spun yarns

A study was conducted on objective evaluation of fabrics woven with air jet yarns in comparison with ring spun yarn. The study was published in two parts: Part I, for mechanical and surface properties (Vohs *et al.* [2]) and Part II, for hand properties (Vohs *et al.* [3]). The objective of the study was to use KES-F instruments to examine differences in properties of fabrics woven with the two types of yarns. The main intention of the study was to determine how mechanical and surface properties of fabrics woven with air jet spun (AJS) yarns are influenced by fabric weave and thread density. Also, subjective evaluations of the hand of the two fabrics were compared.

7.5.1 Experimental procedures

Test fabrics

A set of fabrics was woven that permitted a direct comparison of air jet and ring spun yarns in samples of similar construction. Twill and plain weaves were produced at three different pick densities. All the samples have 92 warp ends per inch and were unfinished, except for desizing.

The air jet yarn was produced on a Murata spinning frame and had a 28's cotton count. The ring yarn had a 27's count. Both types of yarn used a 65/35 blend of polyester and cotton fibers. Table 7.1 describes fabrics used in this research.

Table 7.1 Test fabrics

Yarn types	Fabric design	Pick density	Weight (mg/cm^2)
Air jet spun	Plain weave	50	15.32
Air jet spun	Plain weave	55	16.09
Air jet spun	Plain weave	60	16.89
Air jet spun	3/3 Twill weave	50	14.50
Air jet spun	3/3 Twill weave	55	15.21
Air jet spun	3/3 Twill weave	60	15.89
Ring spun	Plain weave	50	15.10
Ring spun	Plain weave	55	16.04
Ring spun	Plain weave	60	16.83
Ring spun	3/3 Twill weave	50	14.62
Ring spun	3/3 Twill weave	55	15.05
Ring spun	3/3 Twill weave	60	16.01

Source: Objective Measurement: Applications to Product Design and Process Control, by S. Kawabata, R. Postle and M. Niwa, 1986, The Textile Machinery Society of Japan.

Fabric testing

Two 20 cm × 20 cm samples containing different warp and filling yarns were cut from each fabric sample and tested on the KES-F instruments for tensile and shearing, bending, compression, surface smoothness and friction properties. Four separate measurements were taken on each sample. For the directional properties, two measurements were taken in the filling direction and two in the warp direction. For some surface testing, four measurements were taken in each direction. Table 7.2 lists the properties measured by the KES-F system.

Table 7.2 Mechanical property parameters

Property block	Symbol	Characteristic value	Unit
Tensile	LT	Linearity	–
	WT	Tensile energy	gf · cm/cm^2
	RT	Resilience	%
Bending	B	Bending rigidity	gf · cm^2/cm
	2HB	Hysteresis	gf · cm/cm
Shearing	G	Shear stiffness	gf/cm · degree
	2HG	Hysteresis at $\theta = 0.5°$	gf/cm
	2HG5	Hysteresis at $\theta = 5.0°$	gf/cm
Compression	LC	Linearity	–
	WC	Compressional energy	gf · cm/cm^2
	RC	Resilience	%
Surface	MIU	Coefficient of friction	–
	MMD	Mean deviation of MIU	–
	SMD	Geometrical roughness	micron
Weight	W	Weight per unit area	mg/cm^2
Thickness	T	Thickness at 0.5 gf/cm^2	mm

Source: *Objective Measurement: Applications to Product Design and Process Control*, by S. Kawabata, R. Postle and M. Niwa, 1986, The Textile Machinery Society of Japan.

Yarn testing

In order to examine the contribution of yarn properties to fabric properties, yarn samples from the filling supply package were tested for compression, bending and tensile properties on the KES-F instruments. To test yarn tensile and bending properties, a special procedure was developed for mounting parallel arrays of yarns in the instrument jaws. Three groups of 25 yarns were tested from each yarn type. High-sensitivity test settings were used.

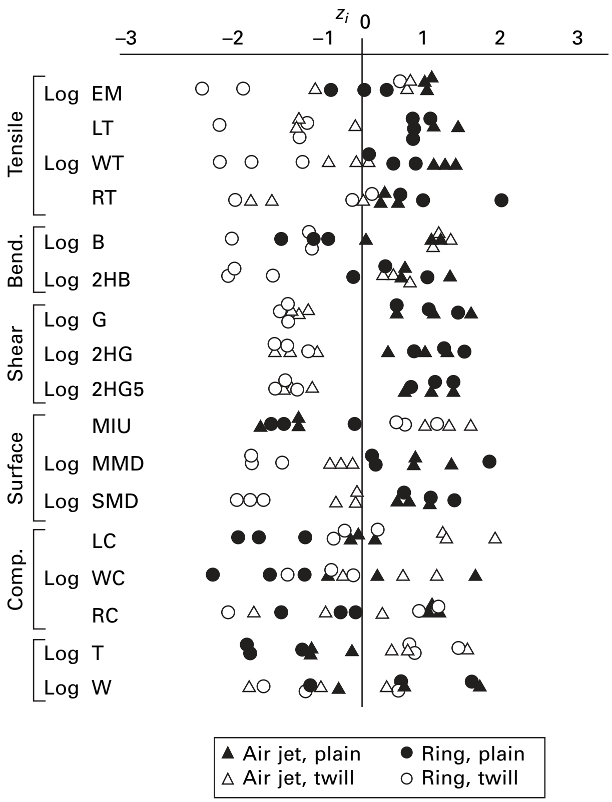
7.5.2 Results and summary

The following properties were tested for the yarns and fabrics:

- Yarn properties: compression, bending stiffness, and tensile properties
- Fabric properties: thickness, compression, bending, shear, tensile properties, and surface properties.

Figure 7.5 summarizes comparisons between mechanical and surface properties of fabrics woven with AJS yarn and fabrics made with ring spun yarns. Findings can be summarized as follows:

1. AJS yarns produce fabrics that are thicker and less compressible than fabrics made with ring spun yarns. The differences in fabric compressional properties related to yarn type increase with the thread count of the fabric and are more obvious in comparisons made between tightly woven plain weave constructions. The greater bending stiffness of AJS yarns apparently



7.5 Summary of comparison of standardized KES properties of fabrics. A standardized value of zero means that the fabric property is equal to the mean for all fabrics. *Source:* 'Objective evaluation of fabrics woven with air-jet yarns', by K.M. Vohs, R.L. Barker and M.H. Mohamed, from *Objective Measurement*: *Applications to Product design and process control*, 1986, The Textile Machinery Society of Japan.

plays a greater role in determining the compressional response of fabric in constructions that produce higher yarn interlacing and higher yarn crimp levels.

2. Fabrics made with AJS yarns are significantly more extensible than similar fabrics made with the ring spun yarns when the tensile load is applied in the direction of the filling yarns. Fabric weave is the overriding factor determining extension, with plain weaves being more stretchable than twill weaves regardless of the yarn type used in fabric construction.
3. For all fabric constructions, AJS yarns produce fabrics that are stiffer in bending than fabrics made with ring spun yarn. However, differences in bending stiffness caused by AJS yarns are greater when comparisons are made between twill weaves and when the bending deformation is in the direction of the warp yarns. In general, fabrics made with AJS yarns recover less energy in bending than fabrics woven with ring spun yarns. The bending stiffness of AJS fabrics (in the filling direction) is lower in twill constructions.
4. Fabric construction (i.e., weave, thread density, not differences in yarn properties) plays the major role in determining fabric shear stiffness. Since shearing properties are controlled by fabric weave and thread density, there is little disadvantage in using AJS yarns from the standpoint of fabric shearing rigidity.
5. KES surface measurements show that fabrics produced with ring spun yarns are smoother and, generally, have lower contact friction than similar constructions that use AJS yarns. However, the roughness of fabrics made with AJS yarns is significantly reduced by choosing twill weaves or weaves with longer surface floats.

This study demonstrated that observed differences in fabric mechanical and surface properties were consistent with expected differences in the properties of yarns formed using air jet or ring spinning systems. It suggested that comparisons made between fabrics woven from these types of yarns can be drastically affected by the choice of weave design and construction. The study provided an explanation for the characteristic hand of air jet spun yarn fabrics and suggested that many negative properties, especially surface harshness, compressional response and bending stiffness, might be improved by choosing a weave that permits the greatest yarn mobility (e.g., twill or satin weaves).

7.6 Subjective hand evaluation of fabrics

Sensory evaluation methods used were based on the protocols adapted by Winakor *et al*. [4] and Kim and Piromthamsiri [5]. This test began by defining the primary components of hand in terms of polar word pairs, or words that have opposite meaning such as stiff and flexible, or gentle and harsh. These words were selected to match the modes of deformation that occur when a fabric is tested using KES-F instruments. Table 7.3 lists these polar word pairs.

Table 7.3 Hand components used in subjective test

Word pair	Associated property
Gentle – Harsh	Surface
Smooth – Rough	Surface
Soft – Hard	Compression
Thin – Thick	Thickness
Light – Heavy	Weight
Flexible – Stiff	Bending
Limp – Crisp	Bending
Sleazy – Firm	Shear
Loose – Compact	Shear/Tensile
Stretchy – Not stretchy	Tensile
Desirable – Undesirable	Fabric Hand

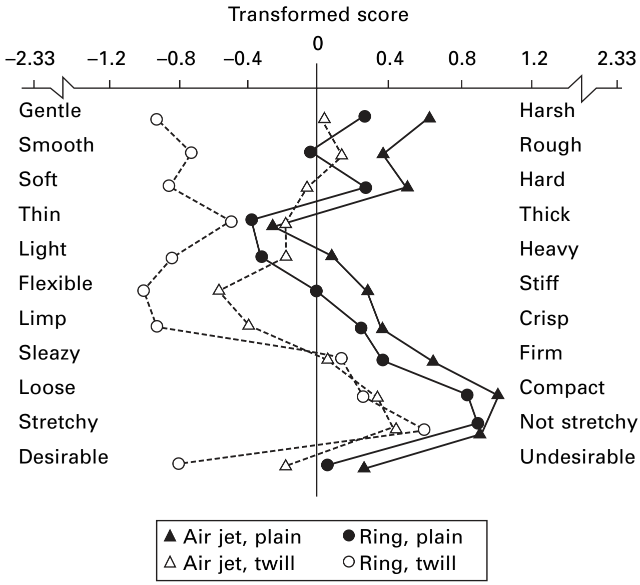
Source: *Objective Measurement: Applications to Product Design and Process Control*, by S. Kawabata, R. Postle and M. Niwa, 1986, The Textile Machinery Society of Japan.

7.6.1 Procedure for subjective evaluation of fabric hand

Twenty-eight college students participated in the survey. While the majority of the evaluators had some background in textiles, the overall makeup of the panel was more like consumers than experts. There were 15 male judges and 13 female judges ranging in age from 19 to 29 years old. This was a blind test: a simple screen was set up so the judges could feel but not see the fabrics. The judges gave two types of responses using a 99-point certainty scale. The first response indicated which adjective of the word pair best described the fabric, and the second response indicated how certain they were of their response. A score of 1 meant the judge felt very strongly that the left adjective best described the pair. A score of 99 meant that the judge felt very strongly that the right adjective best described the pair. A score of 50 meant that the judge was uncertain about which adjective best described the fabric. Evaluators rated each fabric for the complete set of quality word pairs. They used the same material rating scale to evaluate each fabric on the basis of total or overall desirability of hand. A detailed description of the protocol used in the subjective test is found in Reference 6.

7.6.2 Results

Sensory data were transformed to normal deviates (or linear responses) using the PROBIT function of SAS [7]. The transformation weights scores at the ends of the scale higher, reflecting more certainty of judgment. The scores near the middle of the scale receive lower weightings, reflecting less certainty. A score of 50 was transformed to 0, a score of 1 to –2.33, and a score of 99 to +2.33. These scores were averaged and plotted on sensory response diagrams (Fig. 7.6). The horizontal axis of the sensory response profile shows the scale of the transformed data and the vertical axis lists the word pairs. These diagrams, along with the analysis of variances, provide a wealth of information on factors influencing fabric hand.



7.6 Sensory response profiles for fabrics woven with AJS yarns and ring spun yarns. *Source:* 'Objective evaluation of fabrics woven with air-jet yarns', by K.M. Vohs, R.L. Barker and M.H. Mohamed, from *Objective Measurement: Applications to Product design and process control*, 1986, The Textile Machinery Society of Japan.

7.6.3 Effect of yarn type and fabric weave

The subjective evaluation showed that hand was primarily determined by weave and by whether AJS yarns or ring spun yarns were used in the construction. Fabric thread density had no significant effect on the hand ratings. Comparisons (shown in Fig. 7.6) can be summarized as follows:

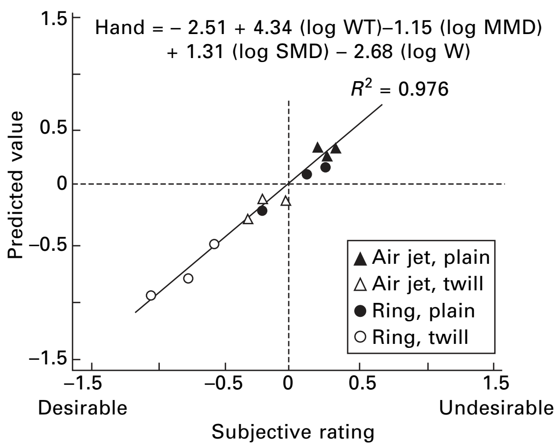
1. Fabrics woven with ring spun yarns were judged to have characteristics of gentleness, smoothness, and softness, and were thought to feel light and limp. Similar fabrics made with AJS yarns were rated as harsh, rough and hard. Fabrics made with AJS yarns were judged to be less desirable, apparently in the perception of negative surface textures. There was little

difference between AJS yarn fabrics and ring spun yarn in perceived thickness, firmness, compactness or stretchiness. As predicted by the analysis of mechanical properties, these characteristics were controlled more by the fabric construction than by the type of yarn component.
2. Twill weave constructions, regardless of the component yarn, were judged to be gentle, smooth, soft, flexible, and limp, and to have a desirable hand. Plain weave fabrics, as a group, were rated as harsh, rough, stiff, crisp, firm, and less desirable than twill weaves.

The most significant finding from subjective testing was that fabric weave had a greater influence on hand and primary hand components than the yarn component used in the construction of these fabrics. In spite of the inherent disadvantages of AJS yarns from the standpoint of hand, comparisons could be made to find fabrics woven with AJS yarns more highly rated than fabrics made with ring spun yarns. This was true in the case of a comparison between AJS twill constructions and plain woven fabrics using ring spun yarns (see Fig. 7.6).

7.6.4 Predicting hand from KES measurements

A formula was derived for predicting subjective hand ratings from fabric properties measured on the KES-F instruments. This was done using multivariate linear regression techniques to qualify the relationships between sensory assessments and fabric mechanical and surface properties. This yielded useful information regarding the relative contribution of specific properties to hand evaluation. Figure 7.7 shows how fabric properties combine to predict



7.7 Hand rating in subjective evaluation compared with rating computed from measured fabric properties. *Source*: 'Objective evaluation of fabrics woven with air-jet yarns', by K.M. Vohs, R.L. Barker and M.H. Mohamed, from *Objective Measurement: Applications to Product design and process control*, 1986, The Textile Machinery Society of Japan.

hand for this group of fabrics woven with AJS and ring spun yarns. These results show that the hand of this small group of fabrics can be reliably predicted using only a few of the data generated by KES instruments. Tensile energy, bending hysteresis, and surface roughness emerge as the most important predictors of hand.

7.6.5 Conclusions

Sensory analysis shows that fabric hand can be influenced more by fabric weave than by the component yarn. Weaves that use fewer yarn interlacings improve the otherwise poorer hand characteristics of fabrics made with air jet spun yarns.

The study showed that it could reliably predict the hand of a small collection of similar weight fabrics using only three or four of the constants generated by KES instruments. Analysis of contributing properties shows that the hand of fabrics woven with AJS yarns can be improved by reducing bending stiffness, especially the inelastic component of bending deformation. AJS yarn fabrics could also be improved by changes in the weave or finish that reduce the energy needed to deform the fabric and by improving surface properties to achieve a ‘smoother feel’.

7.7 Assessment of hand property of fabrics woven from various types of staple-fiber yarn

A study was conducted by Lord *et al.* [8] to establish a correlation between measured parameters and the perceived properties of a series of woven fabrics in which each warp was intersected with a variety of wefts of the same nominal count. Three types of weft yarns were used: ring spun, rotor spun, and friction-spun yarns.

7.7.1 Fabric constructions

Fourteen fabrics with five constructions were studied. In each construction, except the first, three kinds of weft were intersected with a common warp at the same pick density. Both plain and 3/1 twill weaves were used. In plain weave, two ends and four ends per dent were used. Details of the fabrics are given in Tables 7.4, 7.5 and 7.6.

7.7.2 Assessment of fabric hand

A panel of 24 women from a homemakers’ club was asked to judge the series of fabrics, and the choice was made because these persons were thought to represent the ultimate consumer in the particular geographical area reasonably

Table 7.4 Normalized and visual assessments of plain-weave fabrics

	Fabric (ends/in × picks/in)							
Warp	72 × 70 30/1 (19.7-tex) Cotton		90 × 50 30/1 (19.7-tex) Continuous-filament			62 × 52 17/1 (34.7-tex) Polyester-fiber/wool		
Weft	Ring	Friction	Ring	Rotor	Friction	Ring	Rotor	Friction
Attributes								
Smooth/Rough	0.87	1.56	0.96	0.91	1.22	0.96	0.66	0.85
Silky/Scratchy	1.44	1.19	0.96	1.01	1.19	0.76	0.69	0.78
Crisp/Limp	1.08	1.01	1.10	1.03	1.08	0.91	0.88	0.88
Shiny/Dull	1.19	1.01	1.28	1.16	1.30	0.59	0.73	0.72
Thick/Thin	0.94	0.85	0.94	1.08	0.99	1.01	1.05	1.16
Loose/Compact	0.89	0.75	0.96	1.04	1.07	1.09	1.12	1.07
Averages	1.07	1.06	1.03	1.05	1.14	0.89	0.86	0.91

Values > 1.00 indicate that the fabrics were smoother, silkier, crisper, shinier, thicker, or looser than average as the case may be.
Values < 1.00 indicates that the fabrics were rougher, scratchier, limper, duller, thinner, or more compact than the average as the case may be.
Source: 'Assessment of the tactile properties of woven fabrics made from various types of staple-fiber yarn', by P.R. Lord, P. Radhakrishnaiah and G. Grove, from *Journal of the Textile Institute*, vol. 79, no. 1, p. 32, 1988. Reproduced with permission from *Journal of The Textile Institute*.

Table 7.5 Normalized manual and visual assessments of 3/1 twill fabrics

	Fabric (ends/in × picks/in)						
Warp	56 × 56 17/1 (34.7-tex) Cotton			56 × 34 30/1 (19.7-tex) Cotton			
Weft	Ring	Rotor	Friction	Ring	Rotor	Friction	Average
Attributes							
Smooth/Rough	1.29	1.13	1.30	0.76	0.79	0.75	1.00
Silky/Scratchy	1.16	1.10	1.13	0.84	0.78	0.99	1.00
Crisp/Limp	1.17	1.16	1.11	0.87	0.93	1.19	1.00
Shiny/Dull	1.13	1.19	1.15	0.67	0.81	1.04	1.00
Thick/Thin	0.93	1.12	0.95	1.06	0.93	1.02	1.00
Loose/Compact	0.88	0.96	0.95	1.07	1.07	1.08	1.00
Averages	1.09	1.11	1.10	0.88	0.89	1.01	1.00

Values > 1.00 indicate that the fabrics were smoother, silkier, crisper, shinier, thicker, or looser than average as the case may be.
Values < 1.00 indicates that the fabrics were rougher, scratchier, limper, duller, thinner, or more compact than the average as the case may be.
Source: 'Assessment of the tactile properties of woven fabrics made from various types of staple-fiber yarn', by P.R. Lord, P. Radhakrishnaiah and G. Grove, from *Journal of the Textile Institute*, vol. 79, no. 1, p. 32, 1988. Reproduced with permission from *Journal of The Textile Institute*.

Table 7.6 Relative values of surface roughness determined by manual assessment

Weft	Manual		Kawabata	
	Rotor	Friction	Rotor	Friction
Weave (ends/in × picks/in) Warp				
Plain 72 × 70 30/1 Cotton	–	1.82	–	1.01
Plain 90 × 50 30/1 Continuous-filament	0.94	1.26	0.96	1.10
Plain 62 × 52 17/1 Polyester-fiber/wool	0.68	0.88	1.19	1.08
3/1 Twill 56 × 56 17/1 Cotton	0.88	1.01	1.05	1.12
3/1 Twill 56 × 34 17/1 Cotton	1.05	1.01	0.90	1.12
Averages	0.89	1.20	1.03	1.09

Values > 1.00 indicate that the fabric is smoother than ring fabric.
Values < 1.00 indicate that the fabric is rougher than ring fabric.
Source: 'Assessment of the tactile properties of woven fabrics made from various types of staple-fiber yarn', by P.R. Lord, P. Radhakrishnaiah and G. Grove, from *Journal of the Textile Institute*, vol. 79, no. 1, p. 32, 1988. Reproduced with permission from *Journal of The Textile Institute*.

well. At first, the fabrics were mounted on boards, so that only the face of the fabric could be felt or seen, and the assessments for smoothness/roughness were carried out. The fabrics were then removed from the boards so that they could be handled between the thumb and fingers in the normal fashion. No attempt was made to make the hand assessments with the fabrics hidden from view, since this is not a circumstance that occurs in normal purchasing by an ordinary buyer.

The participants used a 0–5 scale, the higher value being associated with the last-named of each pair of attributes in the tables. In this paper, the rating scale used is 0–5, the higher number representing the first-named attribute mentioned in the tables. Assessors are normally reluctant to give low ratings, and bias is usually evident. Thus, when the results were translated by subtracting the assessor ratings from 5, the results came out low, but the bias was removed, even if the width of the scale was, in reality, narrowed. Ratings on this basis, and normalized against the average value for each pair of attributes, are given in Tables 7.4 and 7.5.

It was desired to test whether the assessors were capable of detecting differences between the various fabrics. For this purpose, the data relating to all attributes for a given fabric were lumped together, and a global average was calculated. The global average *per se* is not very valuable, but the comparison of the global averages at least shows whether the assessors could discriminate between the fabrics. The global average rating for all plain-weave fabrics with a 30/1 (19.7-tex) warp was 1.94, the average of the plain-weave fabrics with a 17/1 (34.7-tex) warp was 1.58, and the average for all the twill fabrics with a 17/1 (34.7-tex) warp was 1.64. It is clear that the assessors were able to discriminate between fabric construction and warp linear density. They were also able to discriminate between very loose and normal twills.

The overall averages for ring, rotor, and friction plain-weave fabrics were 1.80, 1.70, and 1.88 respectively. There was no sample with rotor-spun weft for the 70 × 72 fabric, and this is likely to have reduced the 1.70 value below what it should have been; nevertheless, the comparable values in the two other plain-weave fabrics were low with respect to the others. The corresponding averages for the twill fabrics were 1.62, 1.65, and 1.67, respectively. In general, the friction fabrics showed up well in the aesthetic properties assessed, whereas the rotor fabrics appeared to be slightly inferior to the others. It was reasonably clear that the assessors could discriminate between ring, rotor, and friction fabrics.

Since it is a matter of taste whether a fabric should be silky, scratchy, shiny, dull, thick, thin, loose, or compact, and since the perception associated with these words varies, normalized values will be limited to the smoothness/roughness assessments. The relative ratings are given in Table 7.6, in which the assessments of the fabrics with rotor- and friction-spun wefts are expressed as ratios of the assessments of similar fabrics with ring-spun wefts. The perception that friction plain-weave fabrics were smoother than the others was clear, but, with heavy warps, the differences were worse than the others in plain weaves, but the differences narrowed in the twill weaves. Plain weaves were more sensitive to changes in the structure of the weft yarns.

7.8 Conclusions

Correlation between human evaluation and the surface-roughness measurements was quite reasonable over the frequency range from 20 to 100 repeats/in. Correlations were also noticed between surface roughness and many of the perceptions of the panel of assessors. It seemed likely that there were interactions and many of the perceptions were based on several attributes of the fabrics rather than single ones.

7.9 References

1. Scardino, F. (1985), ‘The effect of yarn structure on fabric aesthetics’, in proceedings of the third Japanese–Australian Symposium on ‘Objective measurement: Applications to product design and process control’, edited by Kawabata, S., Postle, R. and Niwa, M., Textile Machinery Society of Japan, p. 175.
2. Vohs, K.M., Barker, R.L. and Mohamed, M.H. (1985), ‘Objective evaluation of fabrics woven with air jet yarns. Part I: Mechanical and surface properties’, in proceedings of the third Japanese–Australian Symposium on ‘Objective measurement: Applications to product design and process control’, edited by Kawabata, S., Postle, R. and Niwa, M., Textile Machinery Society of Japan, p. 121.
3. Vohs, K.M., Barker, R.L. and Mohamed, M.H. (1985), ‘Objective evaluation of fabrics

woven with air jet yarns. Part II: Hand properties', in proceedings of the third Japanese–Australian Symposium on 'Objective measurement: Applications to product design and process control', edited by Kawabata, S., Postle, R. and Niwa, M., Textile Machinery Society of Japan, p. 130.
4. Winakor, K., Kim, C.J. and Wolins, L. (1985), 'Texturing of polyester–viscose blended yarn by batch and continuous process', *Text. Res. J.* 50(10), 610.
5. Kim, C.J. and Piromthamsiri, K. (1984), 'Sensory and physical hand properties inherently flame retardant sleepwear fabrics', *Text. Res. J.*, 54(1), 61.
6. Vohs, K.M. (1985), Master's thesis, North Carolina State University.
7. SAS users guide; Basics (1982), Edition, Cary, NC; SAS Institute, Inc.
8. Lord, P.R., Radhakrishnaiah, P. and Grove, G. (1988), 'Assessment of the tactile properties of woven fabrics made from various types of staple-fiber yarn', *J. Text. Inst*. 79, 32.

Suggested reading

Tortora, P.G. and Collier, B.J. (1997), *Understanding Textiles*, 5th edition, Prentice Hall.
McCreight, D.J., Feil, R.W., Booterbaugh, J.H. and Backe, E.E. (1997), *Short Staple Yarn Manufacturing*, Carolina Academic Press, Durham, NC.

8

Effect of woven fabrics on the fabric hand of cotton and CO/PES fabrics assessed on the Instron tensile tester

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8.1 Introduction

In this chapter it is shown that objective hand tests made on a very complicated and expensive system can be replaced by less complicated tests done on the Instron tensile tester; a derivation of general hand factor (GHF) for such measurements is presented. The second problem outlined concerns the main factors that influence fabric hand. Third, the chapter presents the results of tests on mechanical properties under small stresses for cotton and CO/PES fabrics.

The trends predicted in the near future concerning hand assessment can be described as follows. People would like to be conscious that hand is a measurable value; 75 years ago this was not so obvious for everybody. This tendency has become more common and hopefully will be natural in a few years.

Textiles produced for apparel first of all have to comply with modern fashion trends. Second, clothing fabrics should assure an appropriate degree of comfort for the apparel user [1, 4]. Comfort impression is a very sophisticated feeling. It is defined as a nice state of psychological, physiological and physical harmony between the human being and the environment. It is determined mainly by means of physiological and mechanical fabric properties as well as by fitting of these properties to the appropriate clothing.

One of the comfort components is sensorial comfort, which can be expressed by the fabric hand [1, 5, 10–15, 24, 30, 31, 33], including such properties as softness, elasticity, smoothness, and so on. It is very important to know the behavior of woven fabrics in use. Woven fabrics for clothing manufacture, which are exposed to the action of mechanical forces, require tests concerning the influence of these forces on their hand. Knowledge of this latter feature is needed for the selection of suitable fabric assessment criteria for utility clothing.

Fabric hand is a property assessed very often in daily life, providing information mostly for the finishing and clothing industry. In the past, it was a feature evaluated organoleptically. The first approach to objective hand measurement was given by Peirce in 1930 [30].

Nowadays, it is possible to measure fabric hand on two systems: FAST (Fabric Assessment System for Textiles) [2, 3], invented in CSIRO (Australia) by Postle, or KES-FB (Kawabata Evaluation System for Fabrics) [16]. The fabric's formability coefficient, which is defined as the ratio of bending rigidity to the initial modulus, can be calculated on the basis of results obtained by the FAST system.

The KES-FB was invented in 1986 by Kawabata in Japan [16–23]. An automatic version of the system called KES-FB-AUTO is presently produced [6]. KES-FB-AUTO consists of four devices measuring 16 fabric parameters, which can be grouped into six blocks: tensile, shear, bending, compression, surface properties and physical parameters. On the basis of these 16 parameters describing the mechanical behavior of fabrics under small stresses, Kawabata and Niwa [21–23] proposed the calculation of Total Hand Value (THV) using a block-stepwise regression method.

Kawabata proposed that a given fabric can be estimated using two factors calculated on the basis of mechanical parameters determined by the KES-FB system: the aforementioned Total Hand Value (THV), which expresses the general hand value, and the Total Appearance Value (TAV), which determines the fabric appearance. Kawabata in his further work tried to find out the ideal fabric for winter and summer suiting [20]. For winter he used wool and for summer polyester as a raw material.

Because the KES-FB system is very expensive, similar measurements of mechanical fabric parameters can be done using the Instron tensile tester following the procedure proposed by Pan [29, 35]. Using this procedure the mechanical parameters of fabrics under small stresses can be measured. Only a graphic multi-axial system for presenting the data, which characterizes a flat textile product, has been elaborated by Pan; in such a system, each quantity measured by the Instron tensile tester was presented on individual axis [29]. A summarized factor, the so-called General Hand Factor (GHF), which would be a measure of the fabric's hand based on the objective instrumental assessment with the use of an Instron tensile tester, has been developed by Frydrych and Matusiak [10].

From the analysis of performed tests (section 8.4), raw woven fabrics are characterized by the lowest value of GHF, whereas woven fabrics with elastomeric finishing have the highest GHF value; this is in accordance with the assumption accepted in the planning phase of the experiments. When considering the type of weave, fabrics with twill and canvas weaves were characterized by the best hand; whereas those with a plain weave were characterised by the worst one. The highest values of GHF were obtained for fabrics with the lowest weft density.

KES-FB as well as FAST was invented initially to measure the mechanical properties of worsted, woolen or blended (wool/PES) fabrics. Then, Matsudaira and colleagues [23, 25–28] tried to measure the mechanical properties of silk fabrics. In research presented in this chapter we tried to determine the hand of cotton and cotton/PES fabrics [7–10].

In section 8.5 we consider the mechanical parameters assessed on the Instron tensile tester, and investigate whether the type of raw material, weave and finishing, the spinning system, and weft density in the case of plain weave, influence the analyzed parameters [7]. Other factors influencing hand have already been analyzed elsewhere [9, 34], even the influence of pigment printing on mechanical fabric properties [32].

8.2 Description of measurement procedure on the Instron tensile tester

The majority of the parameters measured by KES-FB can also be measured on the Instron tensile tester as was proposed by Pan *et al.* [29]. A short description of the measurement procedure is given below. It is very important to maintain the appropriate stress level (much lower than the breaking one). Nevertheless, the stress level should enable the detection of nonlinear fabric behavior. All the measurements can be done at the determined jaw displacement or strain.

The sample sizes and Instron tester adjustments are given in Table 8.1. The following fabric parameters were determined:

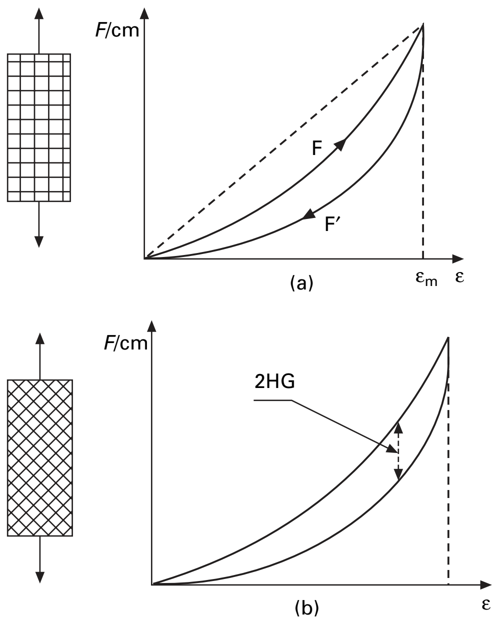
- Tensile linearity (LT)
- Tensile loading energy (WT)
- Tensile resilience (RT)
- Width of the hysteresis loop at shearing (HG)
- Width of the hysteresis loop at bending (HB)
- Compression loading energy (WC)
- Compression linearity (LC)
- Compression resilience (RC)
- Coefficient of static friction (μ_s)
- Coefficient of kinetic friction (μ_k)

Table 8.1 Sample sizes and Instron tester adjustment

Measurement conditions	Tensile/ shear	Bending	Compression	Friction
Sample length (cm)	7.6	3.8	3.8	20
Sample width (cm)	1.3	1.9	3.8	10
Speed of crosshead (mm/min)	1	10	0.5	10
Displacement (mm)	2	2	to 2.5 g/cm^2	40

8.2.1 Tensile and shear test

Because the Instron tester is designed for tensile testing, there is no problem in realizing this test. Table 8.1 gives the sample size parameters and appropriate Instron adjustments during the tensile and shear tests. Figure 8.1 presents graphs obtained in tensile and shear tests.



8.1 (a) Tensile hysteresis of fabric; (b) shear test [23].

On the basis of the tensile test done on samples cut along the warp and weft directions, the following parameters were determined (Fig. 8.1(a)):

- Tensile linearity: $$LT = \frac{WT}{WOT} \tag{8.1}$$
- Tensile loading energy: $$WT = \int_0^{\varepsilon_m} f\,d\varepsilon \tag{8.2}$$
- Tensile resilience: $$RT = \frac{WT'}{WT} \times 100\% \tag{8.3}$$

where WT = tensile loading energy (area under the curve F),
WOT = tensile energy of the sample in the case of a linear relationship (area surrounded by the dotted line):

$$WOT = F_m \varepsilon_m / 2 \tag{8.4}$$

where F = tensile force per fabric unit width,
F' = stress relieving force,
WT′ = tensile energy corresponding to the relieving force (area under the curve F′),
F_m and ε_m = maximum values of F and ε respectively,
ε = tensile strain (not a % unit, but dimensionless).

Shearing the fabric is done mainly to measure a thread displacement inside the fabric. Because carrying out the pure shear test on the Instron tensile tester was impossible, the skew tensile test was adopted (similar to that used in the FAST system).

Although Grosberg indicated that there are some differences between the shear test and the skew tensile test, at small stresses both provide the same information on the thread displacement. Therefore, the shear test can be replaced by the skew tensile test. The shear test was done by stretching the samples cut at an angle of 45° in relation to the warp and weft directions. For these samples the width of the hysteresis loop HG in the widest place was measured (Fig. 8.1(b)).

8.2.2 Bending and compression test

In order to carry out the bending test on the Instron tester, a compression head is used. By sewing the rectangular sample its cylindrical shape can be obtained. The bending test is performed by compressing the cylindrical sample to the determined jaw displacement (Table 8.1) as shown in the Fig. 8.2(a).

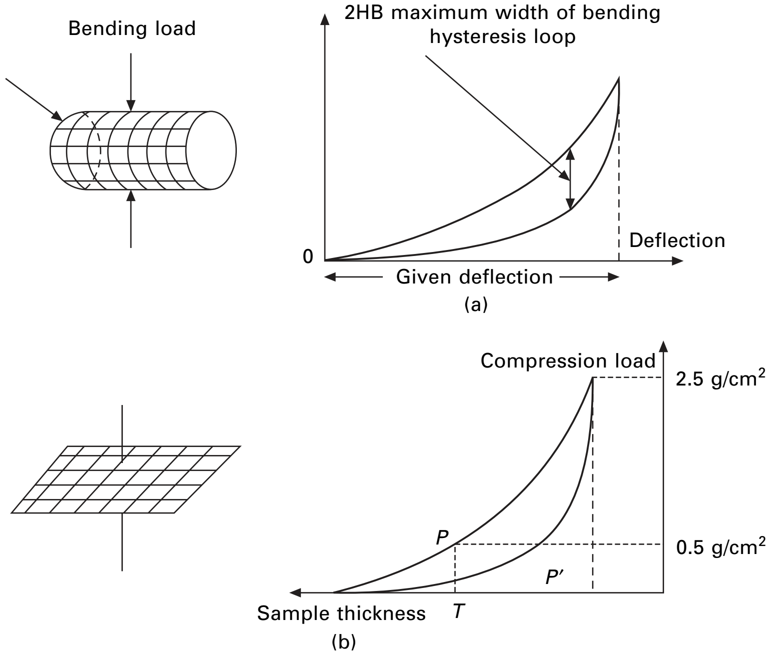
It is also easy to carry out the fabric compression test on the Instron tester (Fig. 8.2(b)). The operator should pay attention to maintaining the appropriate optimum compression load for all the samples (Table 8.1). Parameters from the compression test are calculated as follows:

- Compression linearity: $$LC = \frac{WC}{WOC} \quad (8.5)$$
- Compression energy: $$WC = \int_{T_0}^{T_m} P dT \quad (8.6)$$
- Compression resilience: $$RC = \frac{WC'}{WC} \times 100\% \quad (8.7)$$

where WC = compression energy (area under the curve P),
WOC = compression energy of the sample in the case of a linear relationship (area surrounded by the dotted line):

$$WOC = P_m(T_0 - T_m)/2 \quad (8.8)$$

where P = compression force per fabric unit width,



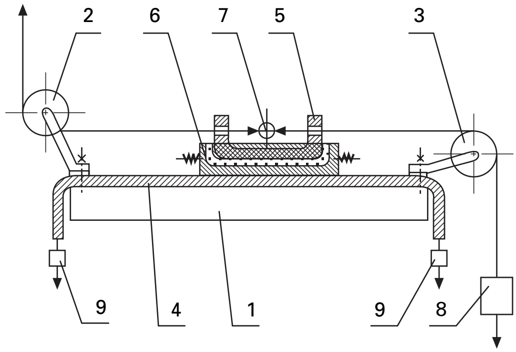
8.2 (a) Bending hysteresis loop; (b) compression hysteresis of fabric [23].

P' = stress relieving force,
WC′ = compression energy corresponding to the relieving force (area under the curve P′),
T = sample thickness,
T_m = sample thickness at the maximum pressure,
T_0 = sample thickness at the minimum pressure,
P_m = compression force at the maximum pressure.

8.2.3 Friction test

In order to determine the coefficient of fabric friction in wear it is essential to reproduce the friction conditions on a laboratory scale. In the case of fabrics a reciprocating, rather than unidirectional, rubbing motion is most often encountered.

An original method of measuring the coefficient of fabric friction has been developed in the Institute of Textile Metrology, Nonwovens and Clothing Technology of the Technical University of Łódź (Polish Patent No. 119497). The device developed for measuring the real friction force between the fabrics being tested and the rubbing medium (Fig. 8.3) consists of the plate 1 fastened in the lower clamp of the tensile tester and rotary blocks 2 and 3



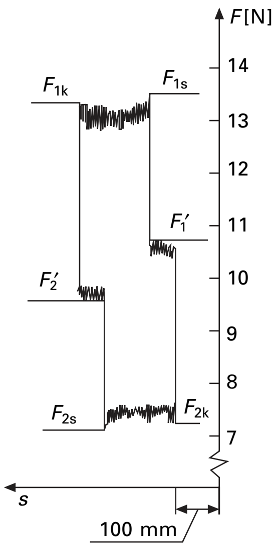
8.3 Device for measuring the friction coefficient: 1 – plate; 2, 3 – rotary blocks; 4 – rubbing medium; 5 – carriage; 6 – test fabric specimen; 7 – rod; 8, 9 – weights.

mounted at opposite edges of the plate 1. The rubbing medium 4 loaded with weight 9 and the hollow rectangular prism 5 (carriage) with the test fabric specimen 6 are all installed on the plate 1. The rod 7 positioned inside the hollow rectangular prism 5 is connected with a pull cord, one end of which passes round the block 2 and is attached to a load cell, while the other pull cord end passes round the block 3 and is loaded by weight 8. The magnitude of the weight 8 is selected in such a way that the force exerted by it on the pull cord exceeds the friction forces between the specimen 6 and the rubbing medium 4 as well as those acting on blocks 2 and 3. During measurements the rectangular prism block 5 moves initially with respect to plate 1 and towards the load cell, and the force acting on the load cell is recorded. The direction of motion of plate 1 is then reversed, so that the cubicoid block 5 is pulled backwards by weight 8, and the force acting on the load cell is simultaneously recorded.

The mass of the weight is 1000 g, the carriage dimensions are 50 mm × 73 mm, the carriage weight is 316.3 g, the tensile tester cross-head speed is 50 mm/min, the recorder chart speed is 100 mm/min, and the carriage travel is 500 mm.

A typical recorder trace obtained for a measuring cycle is shown in Fig. 8.4. In the initial stage of plate 1 downwards motion, the tension of the pulling cord is F_1. When the rod 7 touches the front wall of the rectangular prism (carriage) the pulling cord is taut. Once the pulling cord tension has attained a value equal to the static friction force between the test fabric specimen and the rubbing medium (F_{1s}), the carriage starts to move forward. At the same time, the pulling cord tension keeps decreasing until a tension value corresponding to the kinetic friction force is reached (F_{1k}).

In the case of upwards travel of plate 1 analogous forces F_2', F_{2s} and F_{2k} are obtained. The friction force between the bodies being investigated is given by the following formula:



8.4 Relationship between magnitude of friction force and carriage reciprocating motion (according to the new testing method): *s* – distance, *F* – force.

$$T = \frac{1}{2}(F_1 - F_2) - F_w \tag{8.9}$$

where T = net friction force between bodies being investigated,
F_1 = force indicated by the load cell, when the test specimen moves towards the load cell,
F_2 = force indicated by the load cell during test specimen return motion,
F_w = friction force acting on the blocks.

The static friction force is calculated based on the recorded data by substituting the values of F_{1s} and F_{2s} into equation (8.9). The kinetic friction force is determined by substituting the recorded values of F_{1k} and F_{2k} into the same equation. The friction force F_w is obtained from the load cell readings F_1' and F_2' using the equation:

$$F_w = \frac{1}{2}(F_1' - F_2') \tag{8.10}$$

Recorded traces obtained for three successive testing cycles for a given pair of test specimens were found to be almost ideally superimposed one on another in the successive testing cycles, which indicates that the testing procedure applied gives the real value of the friction force of fabrics. No reduction of friction force values with an increasing number of testing cycles was observed. Since friction force changes in successive testing cycles were negligibly small, the time required to perform the tests is considerably reduced in comparison with that of testing procedures with the use of the tensile tester applied so far. In this testing method it is sufficient to execute a single complete loop, i.e., a single testing cycle, instead of the many cycles required by some other test methods with the use of the tensile tester applied before. It is worth mentioning that the standard deviation of measurements is very small.

8.3 General hand factor (GHF) of fabrics based on the mechanical parameters from the Instron tester

The fabric General Hand Factor (GHF) on the basis of the mechanical parameters measured under small stresses by the Instron tensile tester was proposed by Frydrych and Matusiak [10]. GHF was elaborated experimentally in the frame of research granted by the Polish Scientific Council (7 T09E 04616).

8.3.1 Description of material used for experiment

In order to elaborate the GHF and to assess the influence of fabric structure factors on the GHF value, raw fabrics characterized by different weaves and different cover factor values resulting from the different weft density values were produced; next, they were finished using two types of finishing. In order to produce the woven fabric samples the following yarns of nominal linear density 20 tex were applied:

- Cotton 100% rotor and combed ring-spun
- Ring-spun blended cotton/PES of successive 33%, 50%, and 67% shares of PES fibers.

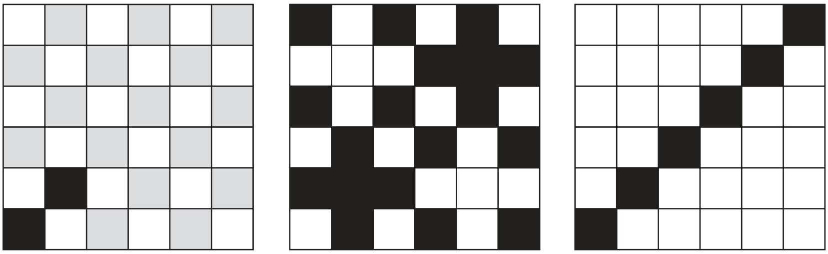
The physical and mechanical properties of the yarns used are presented in Table 8.2. From the mentioned yarns, plain raw fabrics of the same nominal warp density (33/cm), but of different weft densities (22/cm, 27/cm and 32/cm) were produced. Moreover, fabrics of the same nominal warp (33/cm) and weft (32/cm) densities, but of different weaves (plain, canvas and twill (1/5)) were manufactured (Fig. 8.5). The set of sample variants is given in Table 8.3.

The samples of raw fabrics were finished using two types of finishing: classic (starch) and ennoblement (elastomeric). The fabric finishing process was carried out according to the following scheme:

- Desizing
- Washing in warm (50°C) and cold water

Table 8.2 Specification of yarn parameters used for woven fabric manufacture

Parameter	Unit	CO100%OE	CO100%	CO67%/PES33%	CO50%/PES50%	CO33%/PES67%
Linear density	tex	19.9	20.1	20.2	20.7	20.3
Variation coefficient of linear density	%	0.94	1.31	1.03	1.04	1.16
Breaking force	cN	248.4	349.3	342.0	377.4	394.3
Variation coefficient of breaking force	%	6.40	5.70	6.93	8.52	10.30
Tenacity	cN/tex	12.5	17.4	16.9	18.2	19.4
Strain	%	6.90	6.90	7.43	8.99	9.89
Variation coefficient of strain	%	7.20	6.30	7.38	7.35	7.80
Twist	m^{-1}	803	916	933	948	892
Twist variation coefficient	%	5.30	5.03	4.01	5.13	4.60
Metric twist coefficient		113.3	129.9	132.4	136.4	127.1
CV%	%	15.10	14.70	14.42	14.12	15.36
Thin places /1000 m		13.6	3.2	6.4	0	26.4
Thick places/1000 m		20	46	66	36	128
Neps /1000 m		24	64	50	47	49



8.5 Weaves of fabrics: (a) plain, (b) canvas, (c) twill.

Table 8.3 The set of fabric variants

Raw material content	Weave	Weft density per cm	Number of fabric specimen		
			Raw	Starch	Elastomeric
CO 100% OE	Plain (P)	22	1	26	51
		27	2	27	52
		32	3	28	53
	Combined (canvas C)	32	4	29	54
	Twill (1/5 Z) (T)	32	5	30	55
CO 100%	Plain (P)	22	6	31	56
		27	7	32	57
		32	8	33	58
	Combined (canvas C)	32	9	34	59
	Twill (1/5 Z) (T)	32	10	35	60
CO 67% PES 33%	Plain (P)	22	11	36	61
		27	12	37	62
		32	13	38	63
	Combined (canvas C)	32	14	39	64
	twill (1/5 Z)(T)	32	15	40	65
CO 50% PES 50%	Plain (P)	22	16	41	66
		27	17	42	67
		32	18	43	68
	Combined (canvas C)	32	19	44	69
	Twill (1/5 Z) (T)	32	20	45	70
CO 33% PES 67%	Plain (P)	22	21	46	71
		27	22	47	72
		32	23	48	73
	Combined (canvas C))	32	24	49	74
	Twill (1/5 Z) (T)	32	25	50	75

- Treating with 100% NaOH
- Washing in water at 50°C
- Bleaching
- Washing in water at 50°C again
- Neutralization
- Drying at 100–130°C, over 5%
- Appreting and optical lightening
- Drying.

The appret bath content is given in Table 8.4, and properties of the raw and finished fabrics are presented in Table 8.5.

Table 8.4 Appret bath content

	Type of finishing	
	Starch	Elastomeric
Components	White dexin – 40 g/l Perustol VNO 500 – 10g/l Volturin M – 5 g/l Heliofor PBD – 4 g/l	Stabilex GFA–50g/l $MgCl_2$ – 5 g/l Rucofin GWS – 20 g/l Heliofor PBD – 4 g/l
Drying temperature	140°C	150–160°C

Starch finishing (designated further as A) is applied in general to bed linen, whereas elastomeric finishing (designated as B) is generally used for fabric improvement. The finishings mentioned above were selected at the experiment planning phase; the intention was to select those types of finishing that could facilitate the differentiation of the fabric's hand after processing, and also to ensure significant differences in the hand after finishing in comparison with that of raw fabrics.

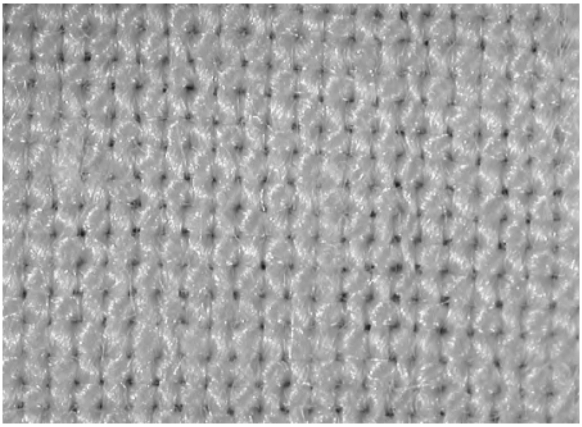
Figure 8.6 presents microscopic images of fabrics made of blended yarn CO33%/PES67%. These fabrics are characterized by weft density 32/cm, elastomeric finishing and three weaves: plain, canvas and twill. These images clearly show the differences in the fabric structure. The fabrics of canvas weave have the most porous structure. The microscopic observations confirmed also the lower porosity of fabrics with elastomeric finishing in comparison to fabrics with the starch finishing. At the same time they have lower porosity than raw fabrics (Fig. 8.7).

8.3.2 Derivation of general hand factor of fabrics

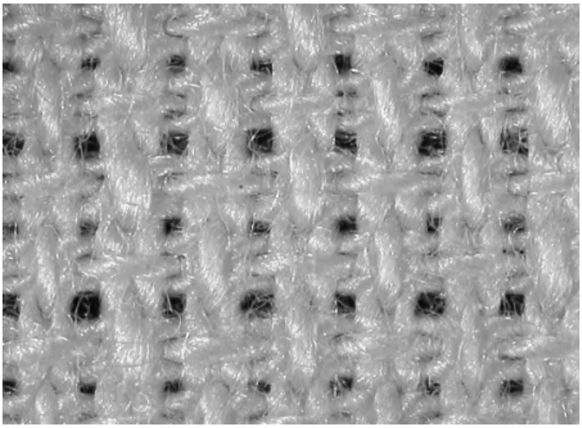
When elaborating the general hand factor, the assumption was made that the finished woven fabrics should have a better hand than the raw fabrics, and that the elastomerically finished fabrics should also be characterized by a

Table 8.5 The mechanical properties of fabrics

		Unit		CO 100% OE					CO 100%					CO 67%/PES 33%					CO 50%/PES 50%					CO 33%/PES 67%				
				P-22	P-27	P-32	C-32	T-32	P-22	P-27	P-32	C-32	T-32	P-22	P-27	P-32	C-32	T-32	P-22	P-27	P-32	C-32	T-32	P-22	P-27	P-32	C-32	T-32
Raw	Width	cm		154.0	153.2	152.8	152.2	151.7	153.8	152.8	152.2	152.2	151.7	149.4	146.8	147.8	148.7	150.2	150.5	147.1	147.5	148.0	149.1	153.2	152.2	150.3	151.1	150.8
	Number of threads per 1 dm		warp	316.0	317.0	318.0	321.0	321.0	319.0	321.0	322.0	323.0	322.0	325.0	328.0	330.0	326.0	324.0	323.0	329.0	329.0	328.0	324.0	318.0	319.0	321.0	327.0	329.0
			weft	229.0	284.0	333.0	332	327.0	230.0	283.0	335.0	331.0	329.0	253.0	316.0	335.0	326.0	322.0	262.0	336.0	341.0	337.0	335.0	238.0	294.0	357.0	321.0	311.0
	Crimp of threads	%	warp	6.5	7.3	10.1	5.1	2.8	6.5	6.1	8.3	4.4	2.7	8.2	9.2	11.3	5.8	2.7	10.7	12.5	12.5	6.5	3.7	6.7	6.4	9.3	4.1	2.3
			weft	5.3	6.0	7.7	8.0	7.1	5.5	6.3	6.9	7.0	6.7	6.0	7.8	7.7	7.9	7.3	5.7	8.2	8.2	7.8	7.7	5.2	6.2	8.0	7.9	7.3
	Mass per square meter	g/m^2		123.5	135.8	147.3.	145.0	140.7	123.4	135.4	147.8	145.4	143.5	124.5	138.2	151.6	141.2	139.1	137.9	158.8	159.7	154.5	151.2	134.4	150.4	153.0	147.9	144.1
	Thickness	mm		0.33	0.32	0.32	0.38	0.4	0.32	0.32	0.33	0.39	0.41	0.34	0.32	0.34	0.43	0.43	0.31	0.31	0.33	0.42	0.4	0.32	0.32	0.33	0.39	0.38
Starch finishing	Width	cm		142.0	141.5	141.0	141.5	140.7	140.0	140.1	140.1	140.8	140.5	140.5	138.2	138.5	146.1	141.9	140.6	139.4	138.9	140.5	140.5	141.4	139.8	139.3	140.6	141.8
	Number of threads per 1 dm		warp	343	345	344	342	345	344.0	345.0	345.0	343.0	345.0	345.0	349.0	349.0	344.0	344.0	342.0	344.0	346.0	344.0	345.0	341.0	343.0	347.0	344.0	341.0
			weft	226	275	326	331	332	223.0	272.0	312.0	316.0	320.0	232.0	299.0	326.0	322.0	331.0	225.0	285.0	333.0	333.0	335.0	229.0	281.0	316.0	304.0	308.0
	Crimp of threads	%	warp	3.3	4.2	4.6	2.7	1.7	2.7	3.5	3.8	2.4	1.5	3.8	4.8	5.6	2.6	1.7	3.9	4.9	5.0	3.0	1.5	4.2	4.9	5.0	2.9	1.8
			weft	9.1	9.3	10.3	8.5	8.6	7.6	8.4	9.4	8.2	8.6	9.5	10.2	10.5	8.7	9.4	8.2	9.3	9.6	8.9	9.2	7.4	8.1	9.6	9.3	8.8
	Mass per square meter	g/m^2		114.3	126.0	137.57	135.4	136.1	116.1	128.5	137.09	135.8	136.4	124.75	142.4	151	145.2	145.2	127.28	142.1	153	148.2	150.2	123.9	139.4	144.9	142.7	139.9
	Thickness	mm		0.26	0.28	0.32	0.34	0.33	0.28	0.28	0.31	0.35	0.36	0.33	0.34	0.36	0.4	0.4	0.29	0.32	0.33	0.37	0.41	0.28	0.32	0.30	0.39	0.4
Elastomeric finishing	Width	cm		141.7	141.0	140.4	140.0	139.5	141.1	140.1	139.8	139.9	139.0	140.7	140.0	138.6	139.6	140.1	139.6	139.6	139.5	140.5	140.5	140.8	140.2	139.5	139.9	141.3
	Number of threads per 1 dm		warp	342	344	343	347	345	342.0	347.0	346.0	352.0	348.0	344.0	343.0	346.0	345.0	345.0	345.0	344.0	346.0	344.0	343.0	344.0	344.0	346.0	346.0	342.0
			weft	225	274	305	307	311	227.0	278.0	308.0	318.0	318.0	240.0	287.0	333.0	326.0	328.0	242.0	286.0	333.0	337.0	328.0	229.0	281.0	316.0	320.0	329.0
	Crimp of threads	%	warp	4.8	5.6	5.7	3.5	2.3	4.2	4.5	5.1	3.3	2.1	4.4	4.9	5.2	3.1	2.0	4.7	5.1	6.3	3.5	1.7	3.8	4.5	5.7	3.2	1.8
			weft	8.2	9.1	10.0	9.7	10.0	9.5	10.2	11.3	10.7	11.5	8.3	9.2	10.7	9.7	10.0	9.7	9.2	9.6	9.8	10.0	8.4	8.8	9.5	9.4	8.9
	Mass per square meter	g/m^2		115.86	127.3	136.43	134.8	136.8	116.32	130.1	137.81	139.5	139.3	125.4	134.1	145.9	142.9	141.0	129.88	145.03	154.66	151.6	147.7	120.92	134.64	148.5	145.7	144.5
	Thickness	mm		0.33	0.32	0.32	0.38	0.4	0.32	0.32	0.33	0.39	0.41	0.34	0.32	0.34	0.43	0.43	0.31	0.31	0.33	0.42	0.4	0.32	0.32	0.33	0.39	0.38



(a)



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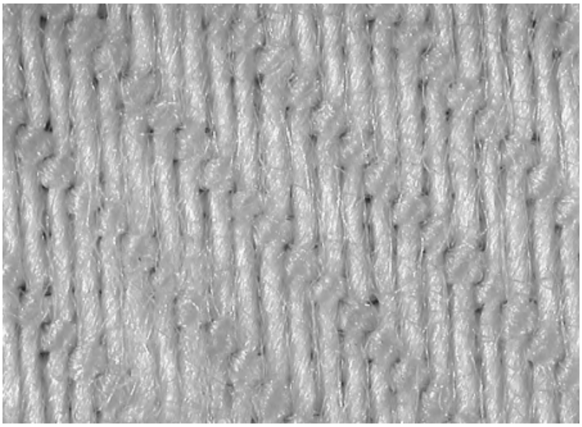
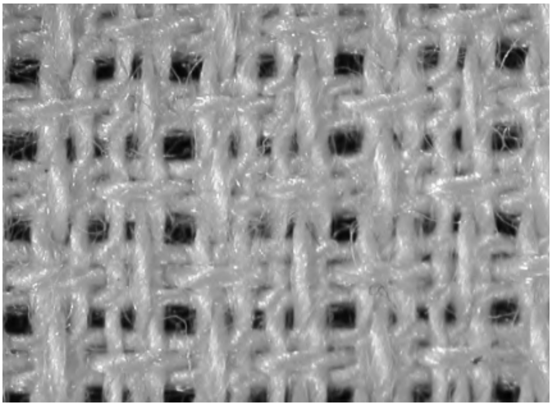
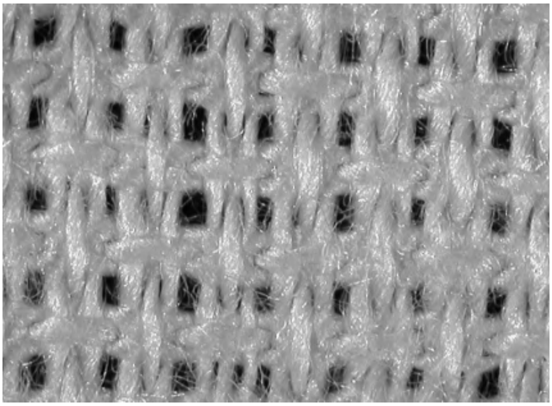


(c)

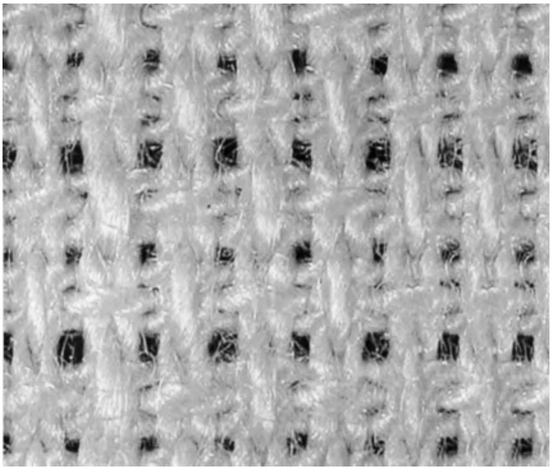
8.6 Comparison of microphotographs of fabric structure (elastomeric finished fabrics, weft density 32/cm): (a) plain, (b) canvas, (c) twill.



(a)



(b)

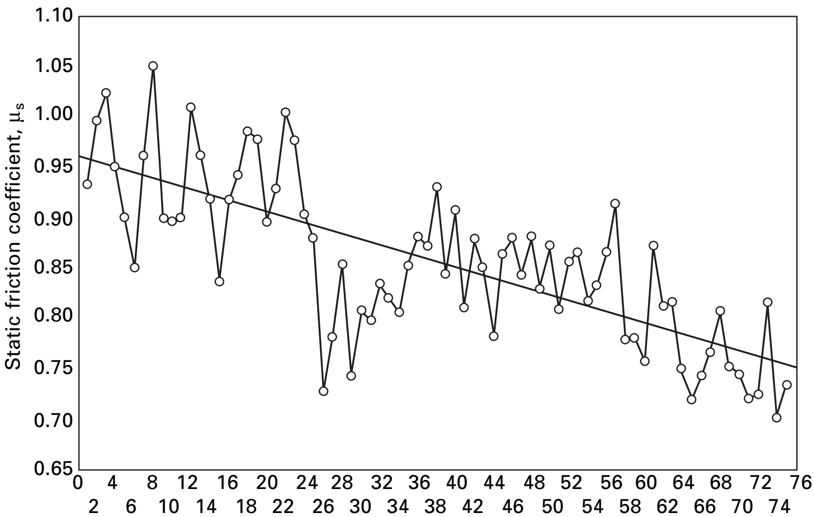


(c)

8.7 Comparison of microphotographs of fabrics of canvas weave (a) raw, (b) with starch finishing, (c) with elastomeric finishing.

better hand (due to the better mean applied for finishing) than those finished in a classic way by starch.

In the first investigation phase, estimation was made of which trends in changes of the particular parameters (determined by the Instron tensile tester) exist depending on the type of finishing. Next, plots of values of the particular mechanical parameters for all raw and finished fabrics were drawn. The particular test variants were arranged on the abscissa of every plot (for every parameter). The order was arranged in such a manner that the first group consisted of raw fabrics, the next group of fabrics with starch finishing, and the last with elastomeric finishing (Fig. 8.8). Straight lines, which characterized the trends of changes for each parameter determined, were drawn on the plots (beginning from the raw fabrics in the direction of the starch (A) and the elastomerically (B) finished fabrics).



8.8 Trend of the static friction coefficient for arranged fabrics, starting with raw fabrics, through fabrics finished with starch to fabrics elastometrically finished.

The analysis of these plots allowed estimation of how the values of the particular parameters are changed depending on type of finishing, which (in accordance with the assumption accepted at the beginning of our consideration) should improve the hand of fabrics. The analysis performed revealed that in the case of tensile linearity (LT) and tensile resilience (RT) no visible trend occurs that depends on the finishing. Therefore, these two parameters were omitted in further considerations as having no distinct influence on the fabric's hand.

It was observed that the values of the remaining mechanical parameters decreased, starting with the highest parameter values for raw fabrics, through those of fabrics with starch finishing (A), and ending with the parameters of fabrics that were elastomerically (B) finished. Only in the case of compression linearity (LC) was a contrary tendency noted, i.e., an increase of the parameter value in the direction of fabrics with better finishing. These observations allowed us to assume that the following parameters (determined with the use of the Instron tensile tester) influence the fabric's hand:

- Tensile loading energy (WT)
- Width of the hysteresis loop at shearing (HG)
- Width of the hysteresis loop at bending (HB)
- Compression linearity (LC)
- Energy of compression (WC)
- Compression resilience (RC)
- Coefficient of static friction (μ_s)
- Coefficient of kinetic friction (μ_k).

A procedure similar to that used during elaboration of the general quality factor, GQF, [10], was applied in further considerations, approaching the derivation of one summarized fabric hand factor (the general hand factor, GHF). All the parameters listed above were accepted as the individual mechanical parameters for elaborating the general factor.

Degrees of importance u (from $u = 1$ to $u = 5$) were assigned to all parameters determined by the Instron tensile tester, proportionally to the pitch of the line, which indicates the trend of the particular parameters (in the direction from the raw fabrics to the fabrics finished elastomerically). The greater the trend of deflection from the horizontal line, the higher the degree of importance. Next, the weight coefficient was calculated for each parameter from the following formula:

$$p_i = \frac{u_i}{\sum_{i=1}^{8} u_i} \times 100 \qquad (8.11)$$

where u_i = degree of importance of the ith parameter,
p_i = weight coefficient of the ith parameter.

The assigned degrees of importance (u_i) and weight coefficients (p_i) calculated are specified in Table 8.6.

Next, the relative values of the particular factors were calculated. These values are equal to the ratio of the particular parameter's value of the given variant of fabric to the maximum value of all values, which were obtained in this parameter:

$$b_{ik} = \frac{a_{ik}}{a_{i\max}} \qquad (8.12)$$

where b_{ik} = relative value of the ith parameter for the kth fabric variant,
a_{ik} = absolute value of the ith parameter for the kth fabric variant,
$a_{i\max}$ = maximum value of the ith parameter from all values of this parameter determined by the Instron tensile tester.

It should be emphasized that usually, when elaborating the general quality factor (GQF), the quotient of the value of the determined parameter is calculated using the optimal value as a divider. However, in the case analyzed, there has hitherto been a lack of data, which could allow the acceptance of the optimal value as a divider, and the maximum value obtained by measurement was taken instead of this.

The value of the general quality factor (GQF) was calculated for each fabric variant from the formula:

$$\mathrm{GQF}_k = \sum_{i=1}^{8} p_i b_{ik} \tag{8.13}$$

where GQF_k is the value of the general quality factor GQF for the kth fabric variant.

Considering that the trend of compression linearity (LC) changes depending on fabric finishing is contrary to the trends of all remaining parameters, the sign of the component concerning compression linearity in the GQF_k sum was accepted as negative. Finally, the equation describing the general quality factor as determined on the basis of the parameters measured with the use of the Instron tensile tester ($\mathrm{GQF}_{\mathrm{IN}}$) can be described as follows:

$$\mathrm{GQF}_{\mathrm{IN}} = 6.3\frac{\mathrm{WT}}{\mathrm{WT}_{\max}} + 6.3\frac{\mathrm{HG}}{\mathrm{HG}_{\max}} + 15.6\frac{\mathrm{HB}}{\mathrm{HB}_{\max}} - 9.4\frac{\mathrm{LC}}{\mathrm{LC}_{\max}} + 15.6\frac{\mathrm{RC}}{\mathrm{RC}_{\max}} + 15.6\frac{\mu_{\mathrm{s}}}{\mu_{\mathrm{s}\max}} + 15.6\frac{\mu_{\mathrm{k}}}{\mu_{\mathrm{k}\max}} \tag{8.14}$$

Table 8.6 Specification of importance degrees *u* and weight coefficients *p*

No.	Parameter	Designation	*u*	*p*
1.	WT	a_1	2	6.3
2.	HG	a_2	2	6.3
3.	HB	a_3	5	15.6
4.	WC	a_4	5	15.6
5.	LC	a_5	3	9.4
6.	RC	a_6	5	15.6
7.	μ_s	a_7	5	15.6
8.	μ_k	a_8	5	15.6
Total			32	100

The procedure that was accepted for calculating the general quality factor assumed that the value of the output parameters increases with the increase of the fabric's quality. In the case of the mechanical parameters determined with the use of an Instron tensile tester, a contrary situation was observed; that is, with the increase in the value of particular output parameters (excluding the compression linearity, LC), a worsening in hand is observed.

Considering such a behaviour of the finished fabrics, the reciprocal of the general quality factor calculated from formula (8.14) was proposed as a measure of the fabric's hand. This measure was designated as the general hand factor (GHF) of fabrics and its value can be calculated from the following formula:

$$GHF_{IN} = \frac{1}{GQF_{IN}} \tag{8.15}$$

The final form of the equation, which allows calculation of the general hand factor on the basis of measurements of the mechanical fabric parameters with the use of the Instron tensile tester, was obtained by the substitution of GQF_{IN} in formula (8.15) by equation (8.14):

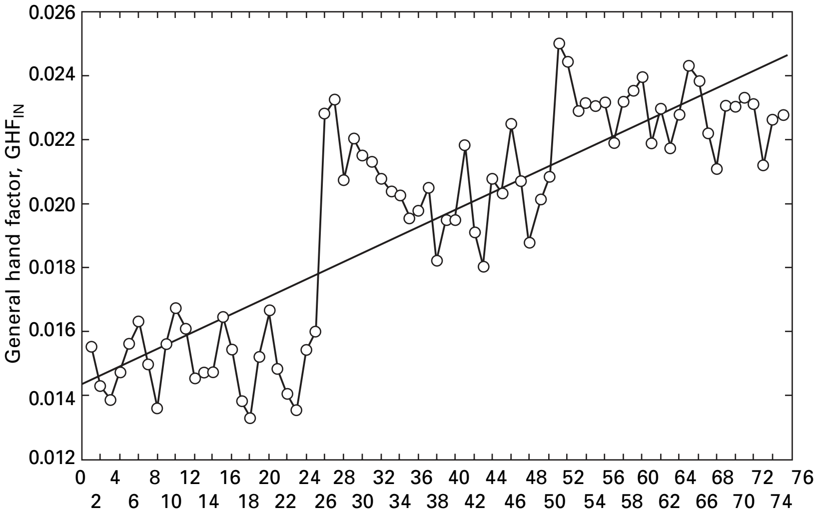
$$GHF_{IN} = \frac{1}{6.3\frac{WT}{WT_{max}} + 6.3\frac{HG}{HG_{max}} + 15.6\frac{HB}{HB_{max}} - 9.4\frac{LC}{LC_{max}} + 15.6\frac{RC}{RC_{max}} + 15.6\frac{\mu_s}{\mu_{s\,max}} + 15.6\frac{\mu_k}{\mu_{k\,max}}} \tag{8.16}$$

With the use of equation (8.16), the values of the general hand factor for all variants of raw and finished fabrics manufactured for conducting the experimental part of this investigation were calculated. The values obtained are presented in Fig. 8.9. According to our expectations, it could be stated that the values of the factor increase, starting with those of raw fabrics, through those of fabrics with starch finishing (A), and ending with values for elastomeric finishing (B). This confirms the appropriateness of the proposed procedure (Fig. 8.9), as by experimental planning such types of finishing were accepted that could enable differentiation of the fabrics' hand, and of its improvement compared to the hand of raw fabrics.

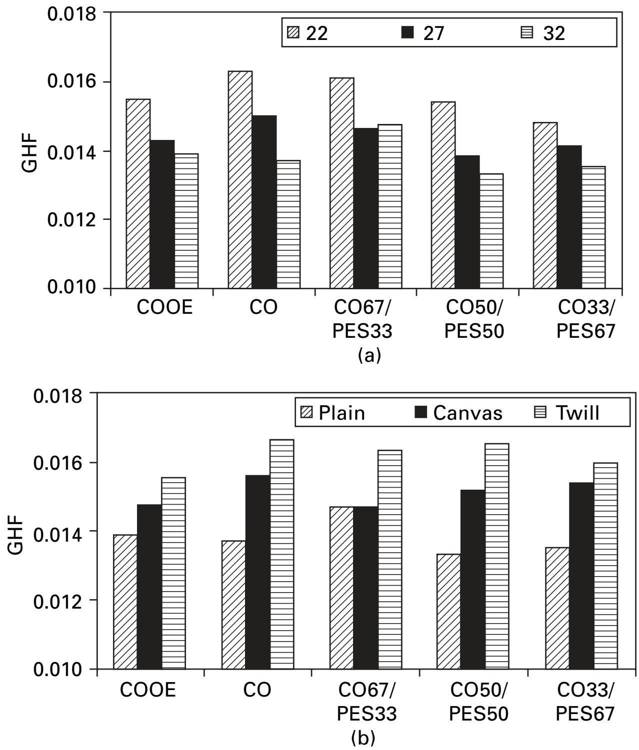
However, on the basis of calculated values it can be stated that the remaining factors, i.e., the type of raw material used, weave, and weft density, also influence the GHF independently of the influence of finishing type.

8.4 Analysis of influence of the weft density, weave, and finishing type on the general hand factor

The influence of weft density and weave used on the general hand factor (GHF) of raw fabrics is shown in Fig. 8.10.



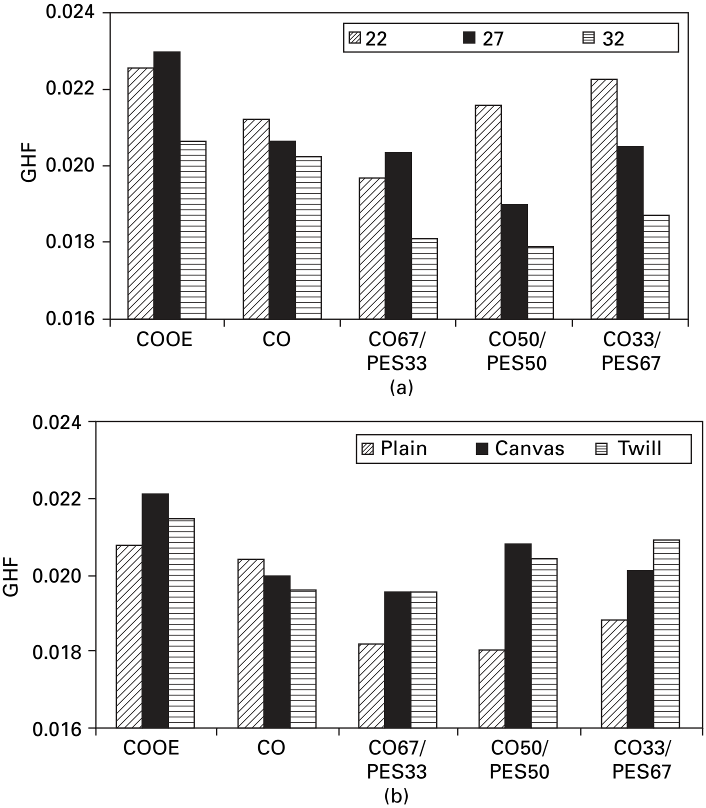
8.9 Trend of the general hand factor (GHF$_{IN}$) for all fabric variants.



8.10 General hand factor (GHF) for raw fabrics depending on (a) weft density, (b) fabric weave.

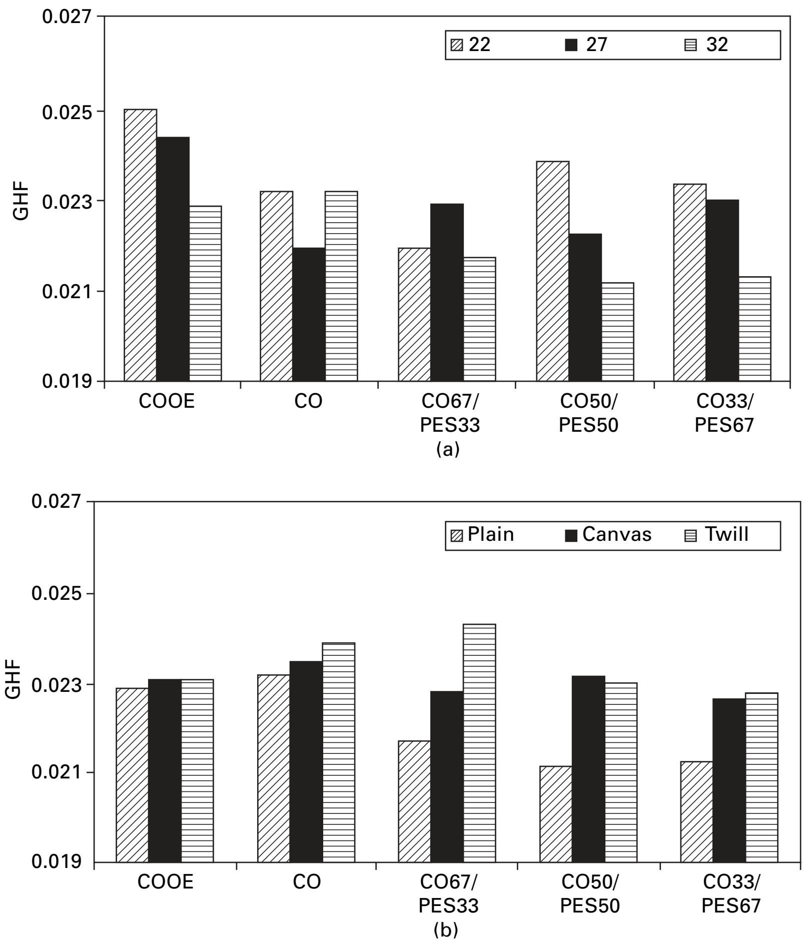
Plain woven fabrics with the smallest weft density (22/cm) are characterized by the best hand, those of 27/cm weft density by a worse hand, and those of 32/cm by the worst one. Among fabrics of 32/cm weft density, the highest value of the general hand factor was noted for fabrics with twill weave, a lower value for fabrics with canvas weave, and the lowest for those with plain weave.

Similar trends could also be observed for the majority of finished fabrics, although not for all (see Figs 8.11 and 8.12).



8.11 General hand factor (GHF) for fabrics finished with starch depending on (a) weft density (b) fabric weave.

For fabrics with starch finishing manufactured from cotton rotor yarn and cotton/polyester ring spun yarn with a content of CO67%/PES33%, the maximum value of the general hand factor was achieved for fabrics of intermediate weft density – 27/cm (Fig. 8.11(a)). Moreover, the fabrics manufactured from the cotton rotor yarn and blended ring spun yarn with a content of CO50%/PES50% and canvas weave are characterized, in the case



8.12 General hand factor (GHF) for elastomerically finished fabrics depending on (a) weft density, (b) fabric weave.

of starch finishing, by better hand than fabrics of twill and plain weave (Fig. 8.11(b)).

Using elastomeric finishing it was noted that in two cases (for fabrics of plain weave manufactured from cotton rotor yarn and of blended cotton/polyester ring spun yarn with a content of CO67%/PES33%) a distinct difference in the trends observed for raw fabrics was observed, together with opposite trends for both of the fabric groups mentioned above (Fig. 8.12).

No explicit influence of the type of raw material used on the hand of raw and finished fabrics was observed, though fabrics manufactured from different raw materials differ among themselves by the value of the general hand factor. However, as a rule it can be stated that the factors of fabrics with a content of PES fibers have lower GHF values.

The influence of the type of fabric finishing on the value of the general hand factor (GHF) is presented in Fig. 8.13. The results are arranged separately for each group of fabrics manufactured from the same raw material:

- Fabrics from cotton rotor yarn
- Fabrics from cotton ring spun yarn
- Fabrics from blended ring spun yarn of content CO67%/PES33%
- Fabrics from blended ring spun yarn of content CO50%/PES50%
- Fabrics from blended ring spun yarn of content CO33%/PES67%.

The highest general hand factor of all analyzed groups of fabrics was noted for fabrics with elastomeric (B) finishing, whereas raw fabrics were characterized by the lowest value of the general hand factor, which means the worst hand.

In the end it can be stated that there is a possibility of anticipating the fabric's hand on the basis of mechanical fabric parameters with the use of the Instron tensile tester.

8.5 Effect of weave, weft density, raw material content, and finishing type on the mechanical fabric hand parameters

General hand factor is an objective measure of fabric hand calculated based on the values of mechanical parameters determined using the Instron tensile tester.

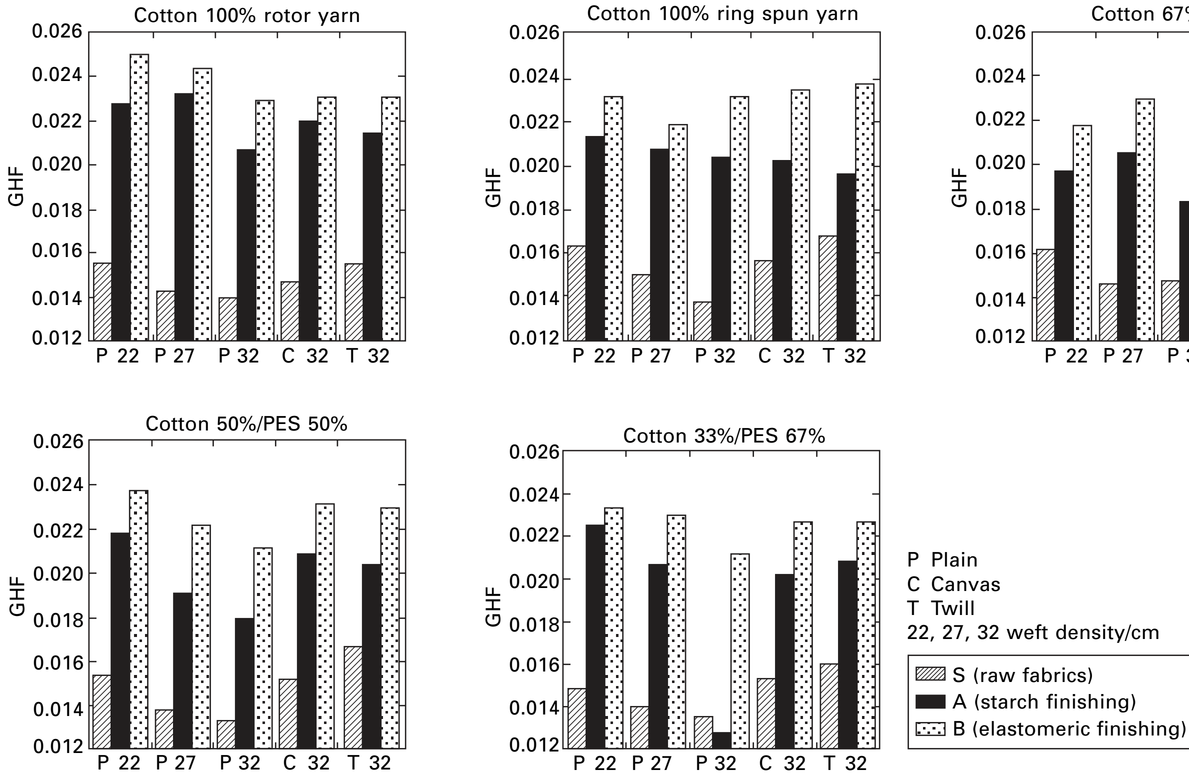
As was mentioned earlier (section 8.3.2) among 10 parameters determined in particular tests on the Instron tensile tester only eight contribute to the GHF value. These parameters depend on type of raw material, fabric structure and finishing. Knowing these relationships the values of mechanical parameters determined on the Instron tensile tester can be shaped in an appropriate way, and at the same time influence the fabric hand.

Since tensile linearity (LT) and tensile resilience (RT) do not contribute to the GHF value, the description of influence of particular structural parameters and type of finishing on these two parameters was omitted in further considerations.

In order to assess the influence of:

- type of weave, when the weft density is the same,
- weft density for plain fabrics,
- different finishings (raw fabrics, fabrics with starch and elastomeric finishing),
- different yarn compositions (100%CO, 67%CO/33%PES, 50%CO/50%PES, 33%CO/67%PES),

on the mechanical parameters measured at small stress action on the Instron



8.13 Influence of type of finishing on the general hand factor (GHF).

tensile tester in the Department of Textile Metrology of the Technical University of Łódź, a multivariate analysis of variance was applied. First, the distribution of the mechanical parameters mentioned was tested. In all cases a normal distribution was found. In a majority of cases the stated influence of particular factors was significant, both independently and in interactions with the other factors. For checking the statistical significance of differences, Tukey's test was applied.

8.5.1 Tensile test

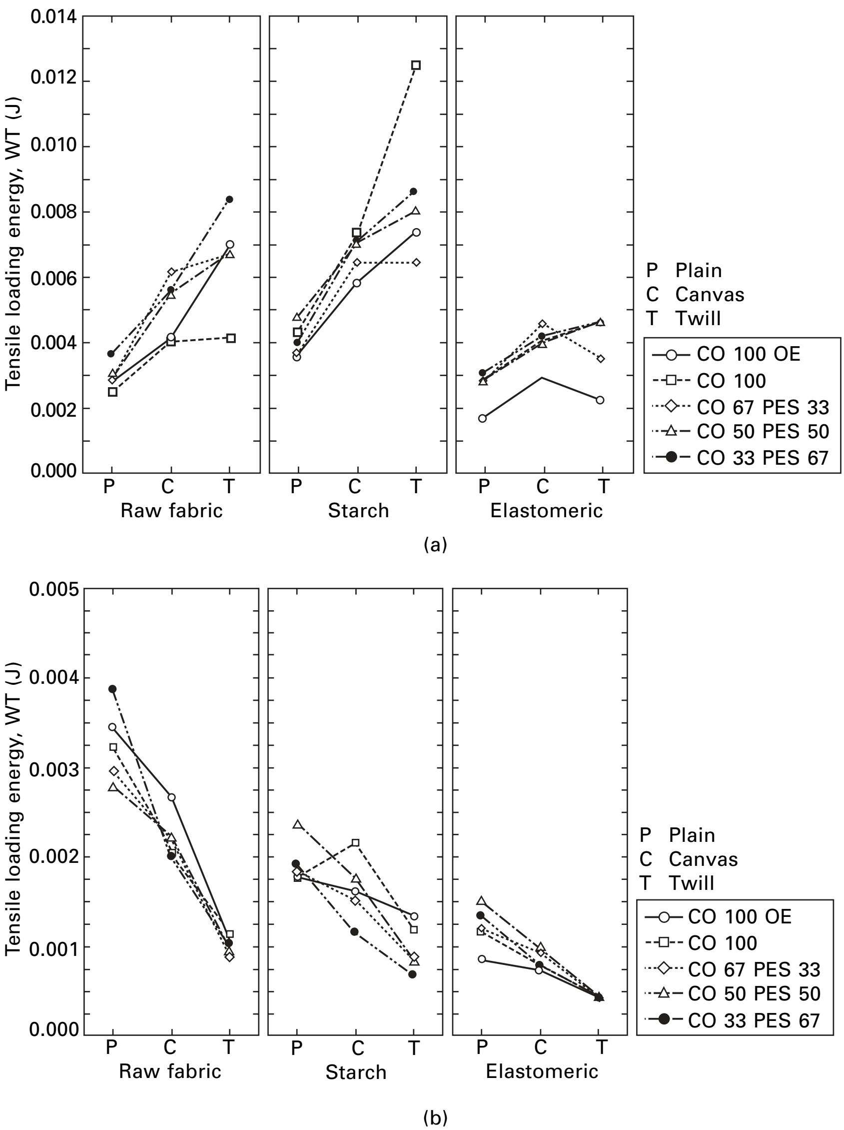
Influence of raw material content, weave and type of finishing

Tensile loading energy, WT

The factors introduced were type of raw material (1), weave (2), and finishing (3). The results concerning the influence of the analyzed factors on tensile loading energy (WT) are given in Fig. 8.14 for (a) the warp direction, and (b) the weft direction. When analyzing the results for the warp direction presented in Fig. 8.14(a) one can see that the lowest tensile loading energy (WT) is needed to stretch the plain fabrics, and the highest to stretch the twill. This may result from the longest length of warp per fabric length unit due to the highest number of interlacements in the plain fabric, and from the opposite situation in the twill.

The situation is quite different in the case of the weft direction – Fig. 8.14(b). Due to the calendering operation during the finishing process, fabrics were extended in the warp direction. This resulted in the increase of the warp density and decrease of the weft density (see Table 8.5 and the table in Reference 8). For this reason the tensile loading energy (WT) in the weft direction takes much lower values than in the warp direction. The effect of such a phenomenon is stronger for fabrics with the longer float length, i.e., canvas and twill. Loading energy in the weft direction is also lower because of the lower weft density and higher weft crimp. For the plain weave the tensile loading energy (WT) takes almost the same value in the weft and warp directions, while for twill and canvas it is much lower for the weft. This may result from the highest number of interlacements in a plain fabric, making the fabric structure more resistant to deformation.

After finishing, the tensile loading energy (WT) in the warp direction increases for the starch add-on and decreases for the elastomeric one. For the weft direction the loading energy decreases for both types of finishing. The following conclusion can be drawn: the elastomeric finishing causes a decrease of loading energy and the starch finishing effects an energy increase. These effects are disturbed by an initial fabric extension in the warp direction during the calendaring process. Thus, for the warp direction, where the fabric has been initially extended during the finishing process, further stretching



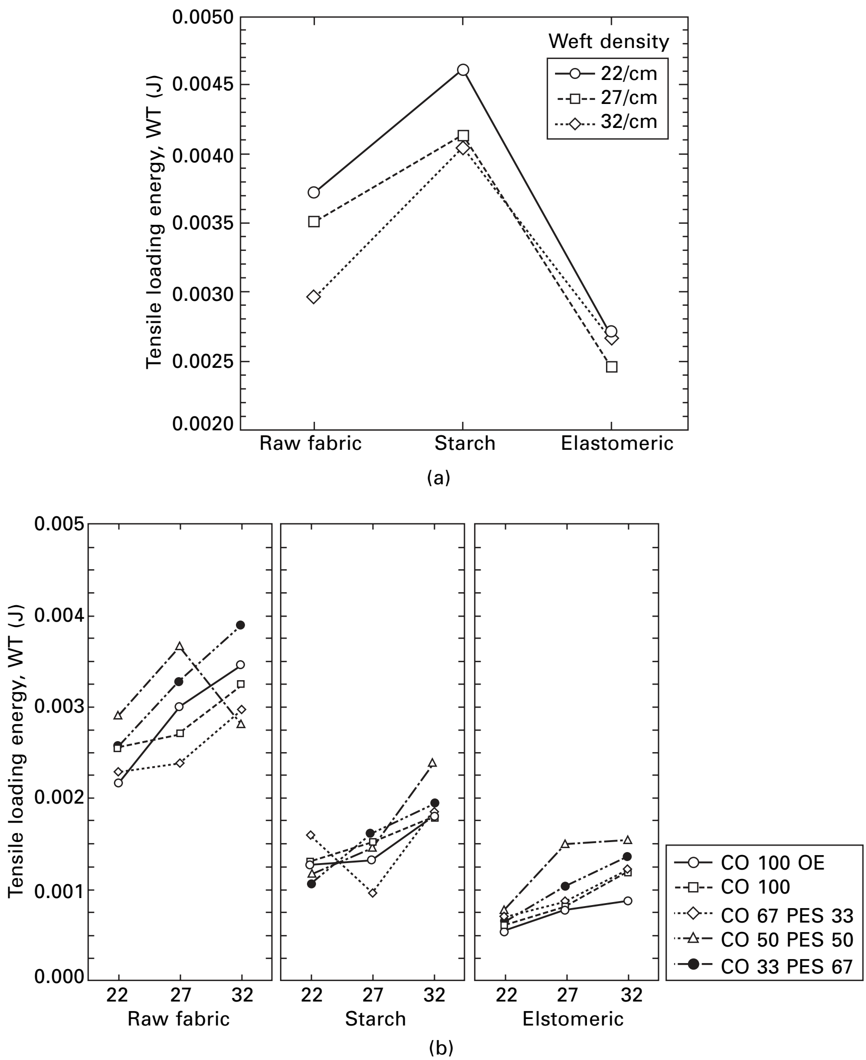
8.14 Influence of raw material content, weave and finishing on tensile loading energy (WT) in (a) the warp direction; (b) the weft direction.

needs more work to be done, while in the weft direction further stretching means a reversion to the raw fabric structure, despite the starch add-on.

Influence of raw material content, weft density and type of finishing

Tensile loading energy, WT

Results of multivariate analysis of variance concerning the tensile loading energy (WT) for plain fabrics of different weft densities are presented in Fig. 8.15.



8.15 (a) Influence of weft density and kind of finishing on tensile loading energy (WT) in the warp direction; (b) influence of raw material content, weft density and kind of finishing on WT in the weft direction.

In the warp direction (Fig. 8.15(a)) the highest value of tensile loading energy (WT) was noted for fabrics of weft density 22/cm. The higher the weft density, the lower the tensile loading energy (WT). In comparison to raw fabrics, starch finishing causes an increase of WT, whereas elastomeric finishing causes a decrease.

Tensile loading energy (WT) in the weft direction (Fig. 8.15 (b)) increases with the weft density. This is to be expected, because a higher weft density means more interlacements for both arrangements, and therefore, higher friction resistance. Moreover, with the increase of the weft density, more threads are stretched, which requires higher energy. This relationship occurs in raw fabrics as well as those finished by starch and elastomers. The fabric finishing causes a decrease of tensile loading energy (WT), elastomeric finishing decreasing WT more than starch finishing.

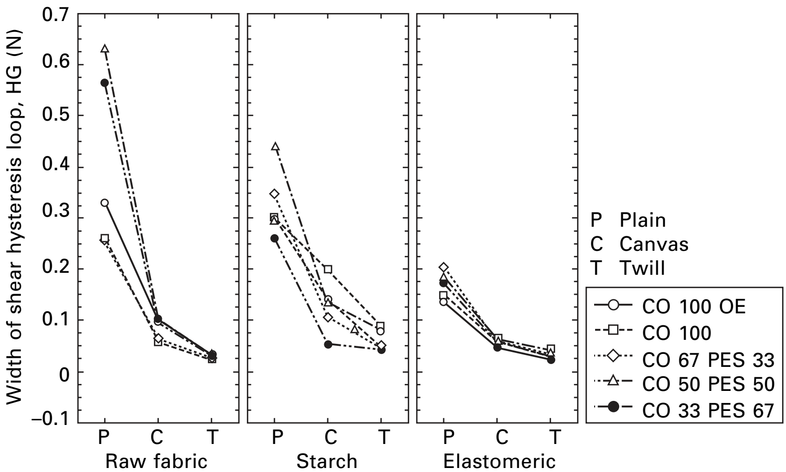
8.5.2 Shear test

Influence of raw material content, weave and type of finishing

Shear hysteresis loop width, HG

Fabric behavior under stretching in the 45° direction characterized by the width of the shear hysteresis loop (HG) shows an analogy with that under the tensile test. The highest values of HG were observed for plain weave, lower for canvas and the lowest for twill, regardless of the type of raw material and finishing.

The widest hysteresis loop was observed for raw plain fabric due to the highest number of interlacements (Fig. 8.16). This reflects the high fabric



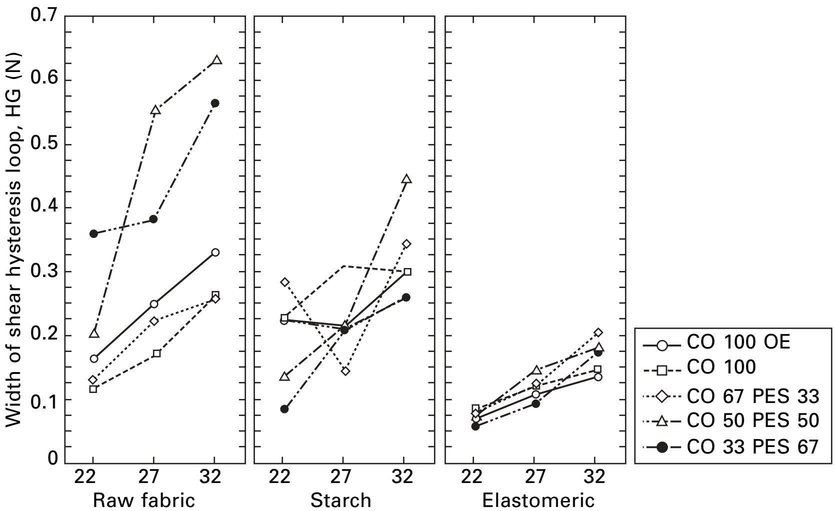
8.16 Influence of kind of raw material, weave and finishing on the width of the shear hysteresis loop (HG).

rigidity and a loss of elasticity of component yarns. The plain weave fabric is the only one for which the finishing changes the shear behavior significantly. In the case of the other weaves (especially twill) the finishing does not influence the shear parameter. This can be explained by the relatively low stress to which the fabric is subjected during stretching of the skewed sample to the same value of extension. That is why the fabrics with fewer interlacements and thus lower rigidity even after finishing still show good shear resilience, HG.

Influence of raw material content, weft density and type of finishing

Shear hysteresis loop width, HG

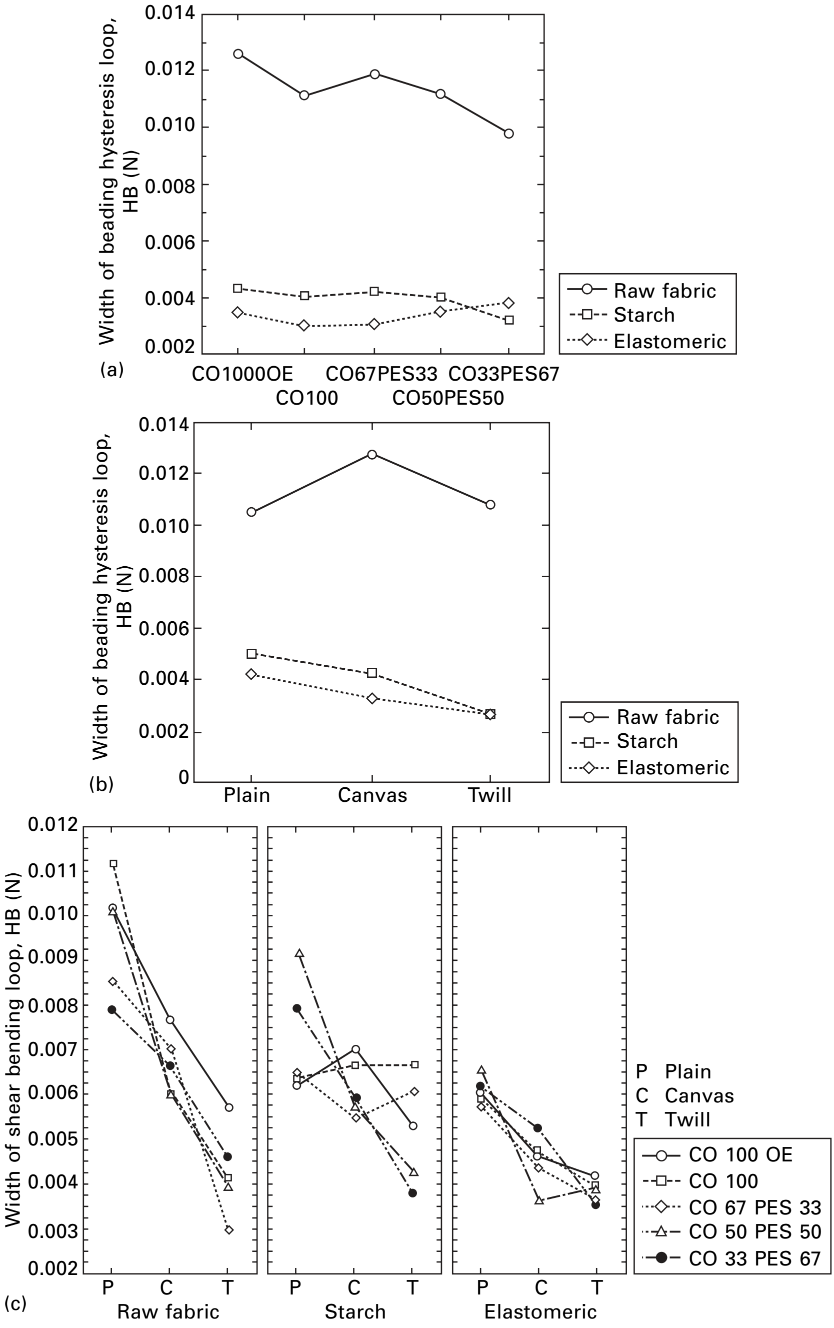
The shear hysteresis loop width (HG) increases with the increase of the weft density of plain fabrics, as seen in Fig. 8.17. The more dense the fabric and the more interlacements it has, the more difficult is its return to the primary shape after shear deformations. The fabric finishing reduces the shear hysteresis loop width (HG) and at the same time improves the shear resilience of fabrics. Starch finishing improves it less, but elastomeric finishing much more.



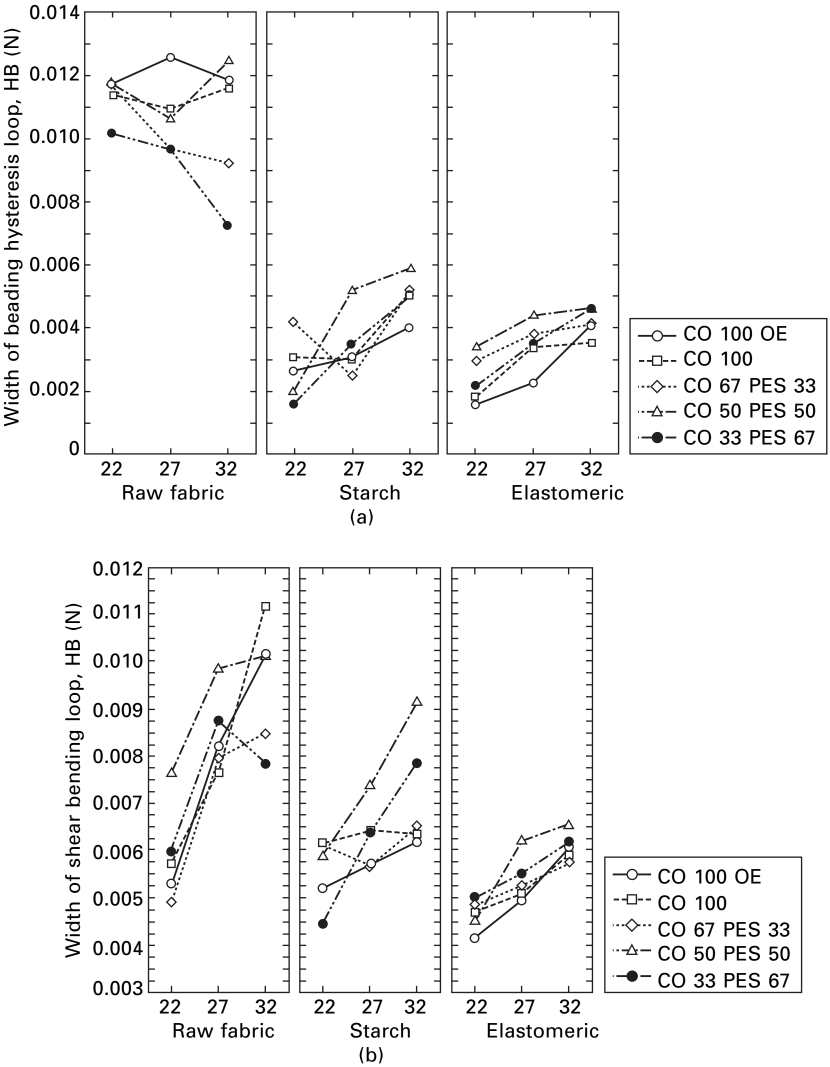
8.17 Influence of raw material content, weft density and finishing on the width of the shear hysteresis loop (HG).

8.5.3 Bending test

In the bending test under small stresses imposed by the Instron tester the width of the bending hysteresis loop (HB) was determined. The results of the bending test in the warp and weft directions are presented in Fig. 8.18 and 8.19.



8.18 (a) Influence of raw material content and finishing on the width of the bending hysteresis loop (HB) in the warp direction; (b) influence of weave and finishing on HB in the warp direction; (c) influence of raw material content, weave and finishing on HB in the weft direction.



8.19 (a) Influence of weft density, raw material content and finishing on the width of the bending hysteresis loop (HB) in the warp direction; (b) influence of raw material content, weft density and finishing on HB in the weft direction.

Influence of raw material content, weave and type of finishing

On the basis of the results obtained, the effect of raw material content, weave and type of finishing on the bending hysteresis loop width (HB) was analyzed. The stated relations are discussed for the warp and weft directions.

Bending hysteresis loop width, HB

The results of multivariate analysis of variance for the bending test in the warp direction are presented in Figs. 8.18(a) and 8.18(b).

On the basis of Fig. 8.18(a), for raw fabrics the lowest value of the bending hysteresis loop width (HB) was noted for fabrics with the biggest (67%) share of PES fibers and for fabrics made of cotton combed yarn.

For raw fabrics and fabrics with starch finishing the lowest value of HB of fabrics made from blended yarn (CO33%PES67%) results from a very good elasticity of PES fibers. Fabrics made of CO/PES blends are characterized by a diversified value of the bending hysteresis loop width (HB) depending on the proportion of PES fibers. The lower the PES fiber content, the higher the value of HB.

Considering only cotton fabrics, the classic yarn gives a lower value for HB than the rotor yarn. During fabric bending the displacement of fibers in the yarn can take place. The scale of this phenomenon depends on the cohesion forces between fibers and the tightness (compactness) of the yarn structure. The combed yarn is characterized by a tense structure and a more oriented fiber arrangement in comparison to the rotor yarn. This supports the stated differences between the HB values for cotton fabrics made of rotor and ring spun yarns.

The width of the bending hysteresis loop (HB) in the warp direction depends on the fabric weave (Fig. 8.18(b)). For raw fabrics the highest value is for canvas, whereas for finished ones it is for plain. The lowest value for all the fabrics is for twill, which has the fewest interlacements. The narrow bending hysteresis loop of twill fabrics results probably from the loose structure of this weave and a low fabric cover factor. The loose fabric structure facilitates return to a state close to the initial one after the release of bending stresses.

We also studied the influence of finishing on the results for the bending test parameter (HB) in the warp direction. Fabric finishing causes a big reduction of the value of HB in comparison to raw fabrics, meaning that the finishing improves the resilience after bending.

Type of finishing is also important. Fabrics with elastomeric finishing are characterized by a lower mean value of the bending hysteresis loop width (HB), and in the same way by better bending elasticity in the warp direction than fabrics with a starch finishing. The reason is that the elastomeric finishing causes the creation of a rubber-like substance on the fiber, which has excellent adhesion to its surface. Elastomers show an ability to return immediately to their primary shape after big changes in room temperature.

On the basis of this analysis of the results in the weft direction, as far as raw material content is concerned, statistically significant differences between the mean values of HB are noted for fabrics made of blended CO/PES yarns as well as between cotton fabrics made of different yarns (classic and rotor). Statistically insignificant were differences between the mean values of HB for cotton fabrics made of ring spun yarn and fabrics made of blended yarns with 33% and 50% PES fiber.

On the basis of these results it was stated that the width of the bending hysteresis loop (HB) in the weft direction for cotton fabrics made of rotor yarn is much higher than for cotton fabrics made of combed yarn. There was no universal tendency for HB to depend on the proportion of PES fiber. But it was noted that HB in the weft direction for fabrics with some PES fiber is lower than for cotton fabrics. This was confirmed by Tukey's test results.

The value of the bending hysteresis loop width (HB) in the weft direction, as in the warp direction, depends on the applied weave (Fig. 8.18(c)). The highest values are for plain fabrics, medium for canvas and the lowest for twill. There was a consistent relationship between the HB value and the number of interlacements in the weave pattern. The more interlacements, the wider was the bending hysteresis loop in the weft direction, and the more difficult the return to the primary shape after bending.

We also concluded that there was a significant effect of finishing on the bending hysteresis loop width (HB). Similarly as in the warp direction, also in the weft direction finishing causes a big reduction of HB. Moreover, fabrics with elastomeric finishing are characterized by a narrower bending hysteresis loop than fabrics with starch finishing. This can be explained by the high elasticity of elastomers used for finishing.

The influence of raw material content, weft density and type of finishing

Bending hysteresis loop width, HB

The results of multivariate analysis of variance for the bending test in the warp direction for plain fabrics are presented in Figs. 8.19(a) and 8.19(b).

In the warp direction the highest values of the bending hysteresis loop width HB are for raw fabrics. Much lower values of HB are noted for finished fabrics, but fabrics with starch finishing are characterized by a slightly wider bending hysteresis loop than fabrics with elastomeric finishing 8.19(a)). These relationships are in agreement with expectations, because the raw fabrics contain the sizing mean in the warp, which causes high rigidity of these fabrics in the warp direction. Elastomeric finishing of cotton and CO/PES fabrics limits their wrinkle formation. The presence of elastomers in the fabric structure facilitates an almost immediate return to the primary (or very close to the initial) state after release of the bending load. Therefore, they have the narrowest bending hysteresis loop compared to raw fabrics and fabrics with starch finishing.

In the case of finished fabrics, the weft density also had a clear influence on the width of the bending hysteresis loop (HB). In the majority of cases, HB increases with increase of the weft density. The denser a fabric, the more difficult is its return to the primary shape after bending. This relationship was not observed for raw fabrics.

There was no universal relationship between the results of the bending test in the warp direction and the type of raw material used for fabric production. It was noted only that among the finished fabrics a wider bending hysteresis loop occurred for fabric made from 50% CO/50% PES.

On the basis of Fig. 8.19(b) there was also no universal relationship between the bending hysteresis loop width (HB) in the weft direction and the type of raw material from which the fabric was produced. As in the warp direction, it was noted only that the highest value of HB occurred for fabrics made from blended yarn (CO50%/PES50%). This is true for the group of fabrics of different weft densities and also of different finishings.

Very clear tendencies were observed in the case of the other two factors (weft density and type of finishing). The width of the bending hysteresis loop (HB) in the weft direction increases with increase of weft density (Fig. 8.19(b)). The bigger the weft density, the more tense is the fabric structure. A high cover factor of fabrics causes the creation of initial stress in fibers, which can lead to plastic deformation or fiber breakage. Moreover, tenser fabric structure hinders the return to the primary state after fiber displacement caused by fabric bending.

Fabric finishing causes a significant decrease of the value of HB. Moreover, it was noted that elastomeric finishing gave a lower value of HB in the weft direction than did the starch finishing. This results from the 'specifics' of the applied means of finishing. Elastomeric finishing is an ennoblement and antishrinkage treatment. Elastomers at room temperature are able to return almost immediately to the primary state or very close to this after large deformation.

The stated differences between the mean value of HB in the weft direction for raw fabrics and all finished fabrics are statistically significant.

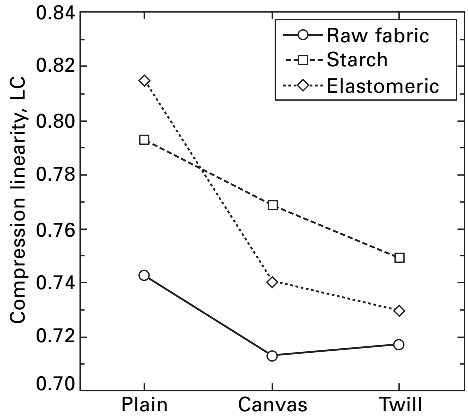
8.5.4 Compression test

Influence of raw material content, weave and type of finishing

Compression linearity, LC

Results of multivariate analysis of variance concerning the compression linearity (LC) are presented in Fig. 8.20. The highest value of LC was noted for fabrics made of cotton rotor yarn. The values of LC for fabrics made of cotton classic yarn as well as for blended yarns are more or less on the same level. This was confirmed by the Tukey's test results (Table 8.7).

The compression linearity (LC) increases with more interlacements in the fabric weave pattern (Fig. 8.20). Plain fabrics are characterized by higher LC than fabrics of canvas or twill weaves. It was also stated that LC is much



8.20 Influence of weave and finishing on the compression linearity (LC).

Table 8.7 Results of Tukey's test for compression linearity, LT

(a) Main effect: raw material

LC		{1}	{2}	{3}	{4}	{5}
		0.761147	0.752774	0.744843	0.755134	0.745801
CO 100 OE	{1}		0.515253	0.018233	0.787875	0.032312
CO 100	{2}	0.515253		0.563985	0.991765	0.683054
CO67PES33	{3}	0.018233	0.563985		0.288894	0.999761
CO50PES50	{4}	0.787875	0.991765	0.288894		0.392948
CO33PES67	{5}	0.032312	0.683054	0.999761	0.392948	

(b) Main effect: weave

LC		{1}	{2}	{3}
		0.783491	0.740708	0.731621
Plain	{1}		2.18E-05	2.18E-05
Canvas	{2}	2.18E-05		0.068589
Twill	{3}	2.18E-05	0.068589	

(c) Main effect: finishing

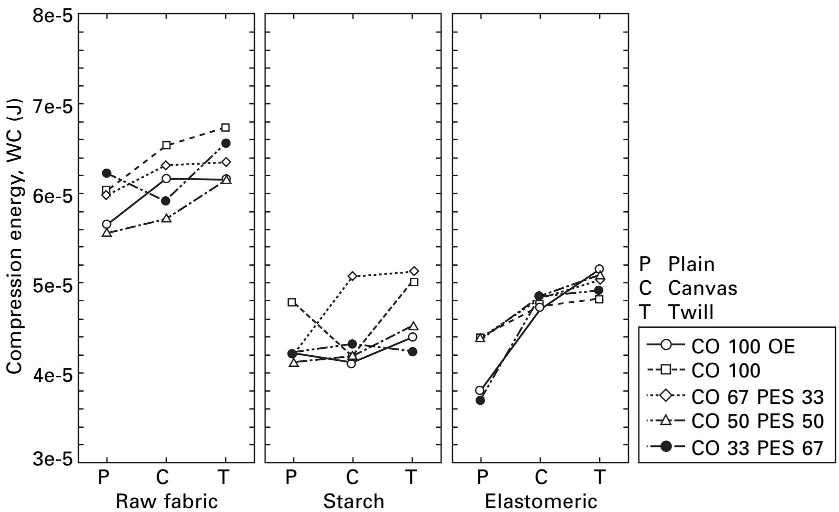
LC		{1}	{2}	{3}
		0.724104	0.770100	0.761615
Raw	{1}		2.18E-05	2.18E-05
Starch	{2}	2.18E-05		0.095295
Elastomeric	{3}	2.18E-05	0.095295	

lower for raw fabrics than for finished ones. The influence of finishing on the compression linearity is modified by the weave.

In the case of twill or canvas weaves fabrics with starch finishing are characterized by the highest compression linearity (LC), fabrics with elastomeric finishing by lower LC and raw fabrics by the lowest. Plain fabrics with elastomeric finishing are characterized by higher LC than fabrics with starch finishing and by much higher LC than raw fabrics.

Compression energy, WC

In Fig. 8.21 the results of multivariate analysis of variance concerning the compression energy (WC) are presented. The highest value of compression energy was observed for the group of fabrics made of classic combed cotton yarn (Table 8.7). The lowest was noted for fabrics made of OE cotton yarn and blended yarn, CO50%/PES50%.



8.21 Influence of weave, raw material content and finishing on the compression energy (WC).

Weave affected the compression energy. The lowest value of WC was observed in a majority of cases for plain fabrics, and the highest for twill. Fabric finishing reduced WC considerably. Fabrics finished with elastomeric finishing had higher WC than those with starch finishing (Table 8.8). The influence of weave on the compression energy is modified by the raw material content and type of finishing.

In the case of fabrics with elastomeric finishing, there is a clear relationship between compression energy (WC) and weave: the lowest value is for the

Table 8.8 Results of Tukey's test for compression energy, WC

(a)Main effect: raw material

WC		{1}	{2}	{3}	{4}	{5}
		0.000049	0.000052	0.000051	0.000049	0.000049
CO 100 OE	{1}		1.72E-05	1.72E-05	0.943304	0.507799
CO 100	{2}	1.72E-05		0.466131	1.72E-05	1.72E-05
CO 67 PES 33	{3}	1.72E-05	0.466131		1.73E-05	4.23E-05
CO 50 PES 50	{4}	0.943304	1.72E-05	1.73E-05		0.918213
CO 33 PES 67	{5}	0.507799	1.72E-05	4.23E-05	0.918213	

(b) Main effect: weave

WC		{1}	{2}	{3}
		0.000047	0.000050	0.000053
Plain	{1}		2.18E-05	2.18E-05
Canvas	{2}	2.18E-05		2.18E-05
Twill	{3}	2.18E-05	2.18E-05	

(c) Main effect: finishing

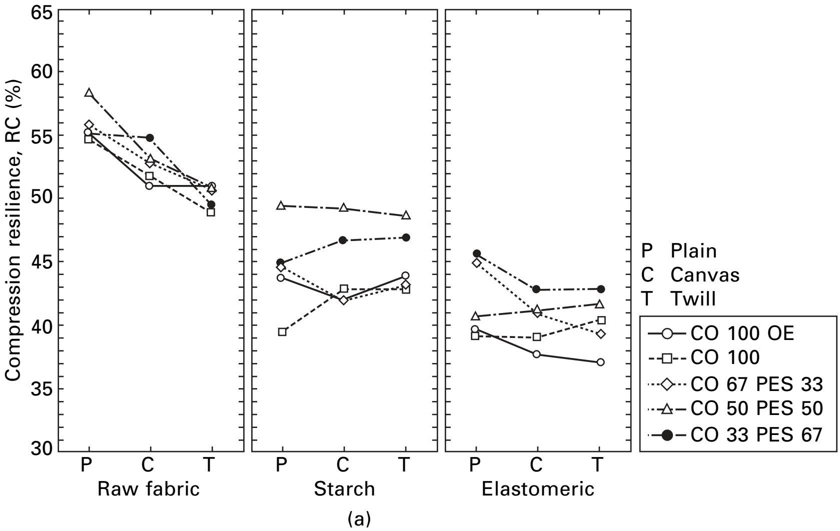
WC		{1}	{2}	{3}
		0.000061	0.000044	0.000045
Raw	{1}		2.18E-05	2.18E-05
Starch	{2}	2.18E-05		3.71E-05
Elastomeric	{3}	2.18E-05	3.71E-05	

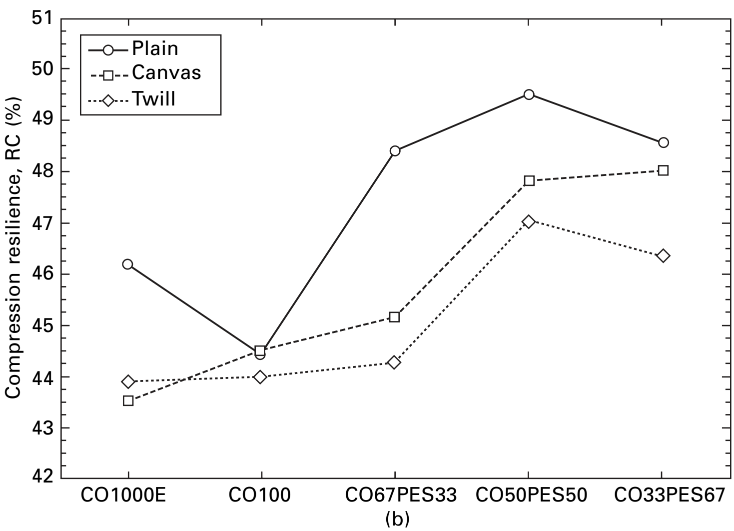
plain, higher for canvas, and the highest for twill (Fig. 8.21). In the case of raw fabrics this tendency is seen only for fabrics made of cotton yarn and for those made from blended yarns (with 33% and 50% PES fibers). For fabrics finished by starch there is no universal relationship between WC and weave.

On the basis of Tukey's test results, differences between WC values of different weaves and types of finishing are statistically significant at the test probability 0.95 (Table 8.8). There were also statistically significant differences between WC values of fabrics made of cotton rotor yarn and of ring spun yarns: 100% CO and CO 67%/PES 33%. Statistically significant differences were also found between the values of WC for fabrics made of the blended yarns with different properties of PES fiber. In the other cases the observed differences are not statistically significant.

Compression resilience, RC

Compression resilience (RC) takes the highest values for fabrics of plain weave and the lowest for twill (Fig. 8.22(a)). This means that twill fabrics





8.22 (a) Influence of raw material content, weave and finishing on the compression resilience (RC); (b) influence of raw material content and weave on RC.

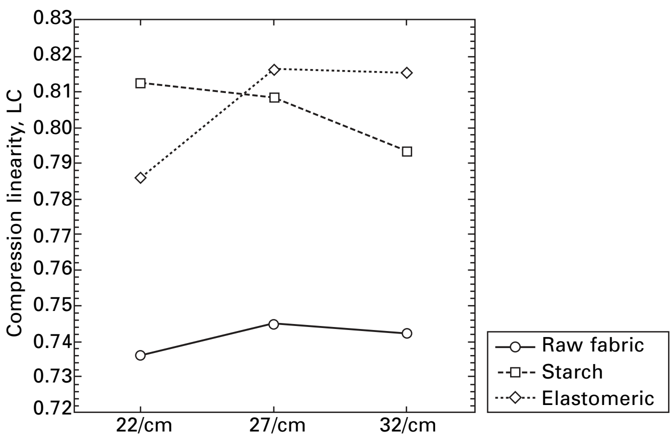
have the lowest ability to recover their primary shape after compression because of their least number of interlacements. We also studied the influence of fabric finishing on RC. The highest value of RC was observed for raw fabrics and the lowest for fabrics with elastomeric finishing (Fig. 8.22(a)), so finishing worsened the ability to recover the primary shape after compression. We also observed the influence of the raw material content on RC independently of the fabric weave (Fig. 8.22(b)). The highest values of RC were for fabrics with the highest percentage of PES fibers (50% and 67%), because of their high elasticity.

In the case of plain fabrics, the compression resilience (RC) for those made of cotton rotor yarn is higher than for those made of classic combed yarn. But in the case of fabrics of twill and canvas weaves, the value of RC is higher for fabrics made of cotton classic yarn than for fabrics made of rotor yarn.

The influence of raw material content, weft density and type of finishing

Compression linearity, LC

The highest value of compression linearity (LC) was observed for plain fabrics of the medium weft density, 27/cm. The influence of weft density on the value of LC is modified by the kind of finishing (Fig. 8.23). Among fabrics with elastomeric finishing, those of lowest weft density (22/cm) have the lowest value of LC, whereas among the fabrics with the starch finishing those of lowest weft density are characterized by the highest value of LC.

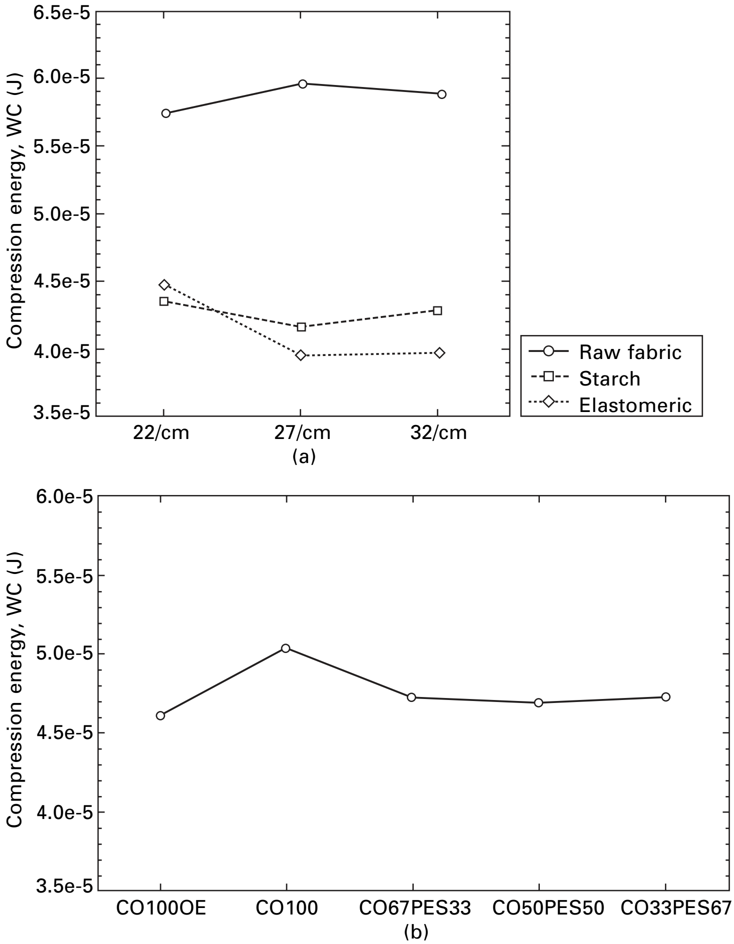


8.23 Influence of raw material content, weft density and finishing on compression linearity (LC).

Compression energy, WC

Results of multivariate analysis of variance concerning the compression energy (WC) of plain fabrics of different weft densities are presented in Figs. 8.24(a) and 8.24(b).

As in the case of fabrics of the same weft density but different weaves also in the case of plain fabrics the highest compression energy (WC) was noted for raw fabrics (Fig. 8.24(a)).



8.24 (a) Influence of weft density and finishing on compression energy (WC); (b) influence of raw material content as a main effect on WC.

In the case of finished fabrics, those with elastomeric finishing have lower values of WC than those with starch finishing. This is the opposite tendency to that fabrics of different weaves.

On the other hand, as for fabrics of different weaves, for plain fabrics those made of 100% cotton produced by the ring spinning system have the highest value of WC (Fig.8.24(b)). This is so for all the weft density variants (22, 27 and 32 wefts per cm). The compression energy of all the fabrics made of blended yarns is more or less on the same level independently of the PES fiber percentage.

Compression resilience, RC

Compression resilience (RC) of cotton and CO/PES fabrics made of the classic yarn increases with the proportion of PES fibers (Fig. 8.25(a)). In the case of 100% cotton fabrics, those made of the rotor yarn have higher RC, probably because of the rotor yarn morphology, which is characterized by a looser structure, worse fiber orientation and greater diameter than for the classic yarn of the same linear density. The compression resilience of plain fabrics is highest at the medium weft density, 27/cm (Fig. 8.25(b)).

There was a clear relationship between RC and type of finishing (Fig. 8.25(c)). The highest compression resilience was observed for raw fabrics. Fabric finishing (which includes a calendering operation) caused a decrease of mean RC. Among the finished fabrics, those with starch finishing are characterized by higher RC (better resilience) than fabrics with elastomeric finishing. The relationship between RC and type of finishing occurred independently of the raw material content.

8.5.5 Friction test

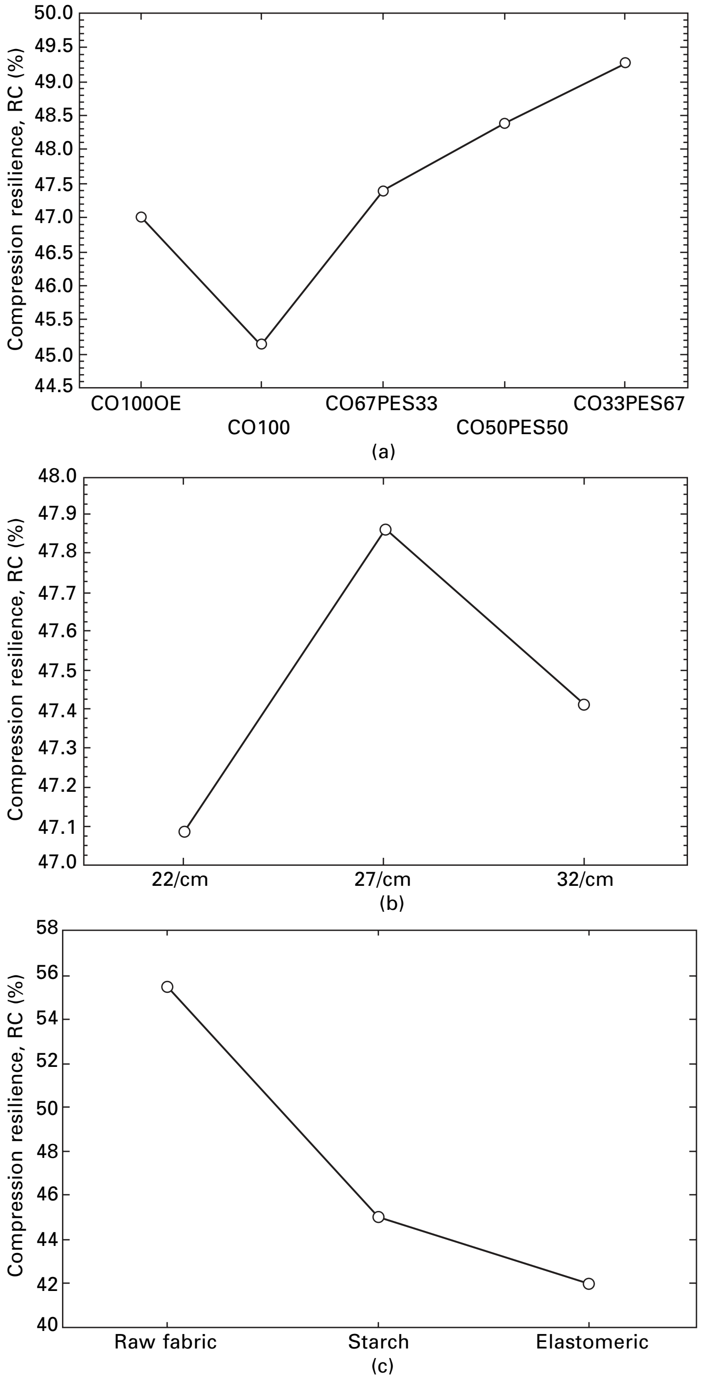
For each fabric variant a friction test was carried out in three arrangements: warp–warp, weft–weft, warp–weft. In each case five replications were done. Friction was tested on the face sides of the specimens. Two values of friction coefficient were determined: static μ_s and kinetic μ_k. Then, on the basis of the results obtained, the general friction coefficients (static and kinetic) were calculated as arithmetic means of the appropriate values for the three fabric arrangements.

Influence of raw material content, weave and type of finishing

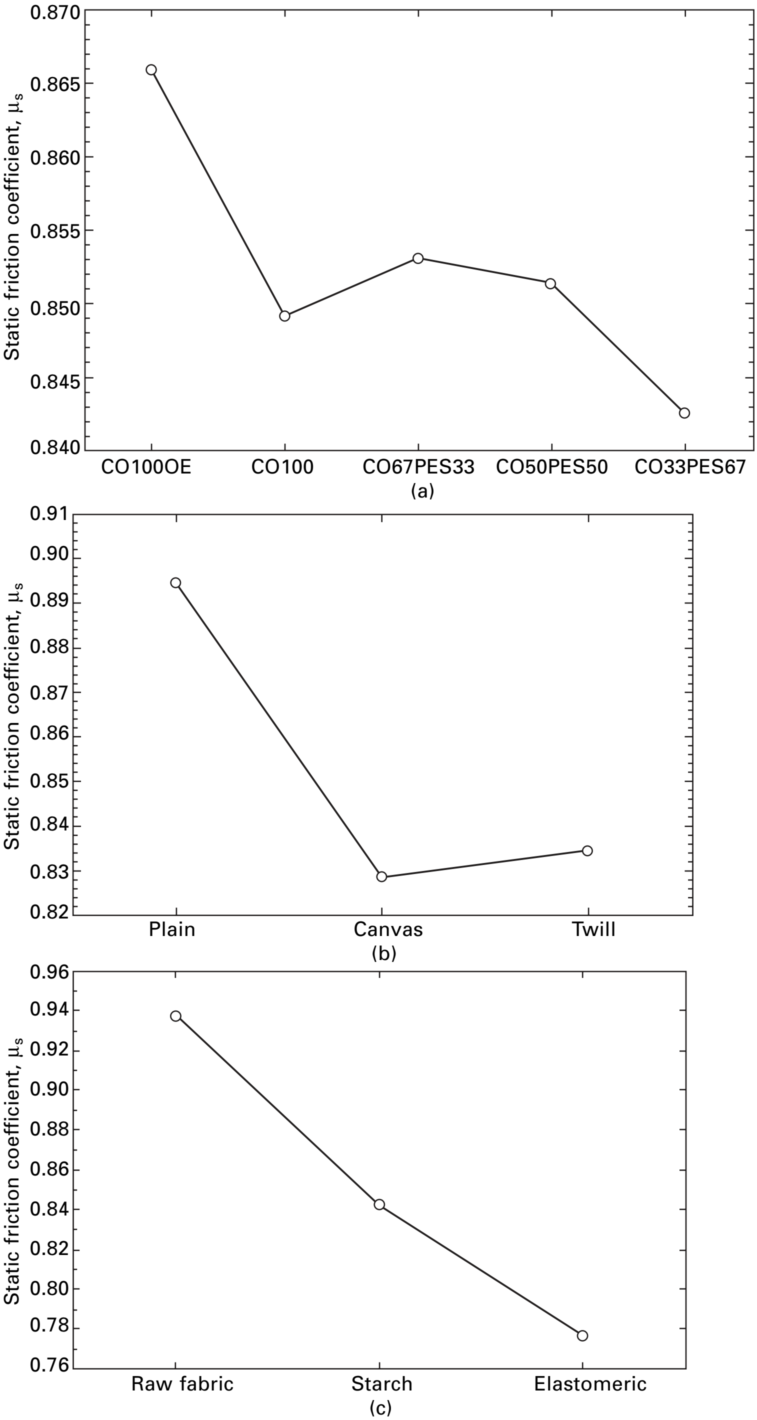
Static friction coefficient, μ_s

The static friction coefficient of cotton fabrics made of combed ring spun yarn is much lower than that for fabrics made of rotor yarn. This results from the characteristics of ring spun yarn, which has a more regular, denser and smoother structure than the rotor yarn, on the surface of which there are visible wrapped fibers (Fig. 8.26(a)). Moreover, ring spun yarns are characterized by smaller diameter than rotor yarns having the same linear density. This is why the surface of fabrics made of ring spun yarn is smoother than that of fabrics made of rotor yarn.

In the case of fabrics made of blended CO/PES yarns, the value of the static friction coefficient slightly decreases with the increase of PES fiber share. Nevertheless, the differences between the values of the static friction coefficient of particular blended fabric variants are not statistically significant. A statistically significant difference was noted only between the static



8.25 (a) Influence of raw material content as a main effect on compression resilience (RC); (b) influence of weft density as a main effect on RC of plain fabrics; (c) influence of type of finishing as a main effect on RC of plain fabrics.



8.26 (a) Influence of (a) raw material content, (b) weave, and (c) finishing, as a main effect on the general static friction coefficient μ_s.

friction coefficients for fabrics made of rotor yarn and the other fabric variants.

The weave also influences the value of the static friction coefficient (Fig. 8.26(b)). The value of μ_s for plain fabrics is significantly higher than for fabrics of canvas and twill; the value of μ_s for both canvas and twill is similar.

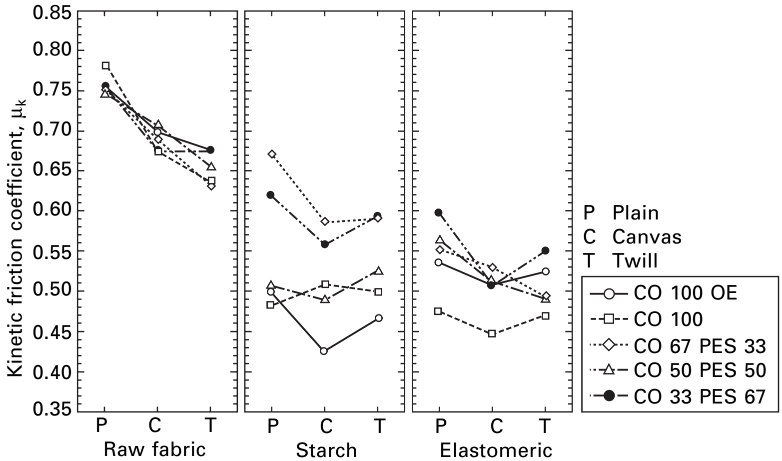
Fabric finishing causes a significant drop in the value of μ_s from its value for raw fabrics (Fig. 8.26(c)). This results from the nature of the finishing process, the aim of which is an improvement of fabric properties (including surface properties) and greater fabric smoothness.

Starch finishing causes fabric fulfillment and rigidity from gluing the pores between warp and weft threads. The final mechanical operations such as calendering and ironing cause the fabric to be smooth and decrease the friction coefficient. Elastomeric finishing assures better smoothness of the fabric surface than starch finishing, because of the specifics of this type of finishing already described in previous sections of this chapter.

Kinetic friction coefficient, μ_k

No universal tendency was noted for the kinetic friction coefficient μ_k to change depending on the raw material used. In comparison with the static friction coefficient, the values of the kinetic friction coefficient are more differentiated.

The relationships between μ_k, weave and type of finishing are analogous to those observed for μ_s. In both cases the influence of raw material is modified by type of finishing (Fig. 8.27).



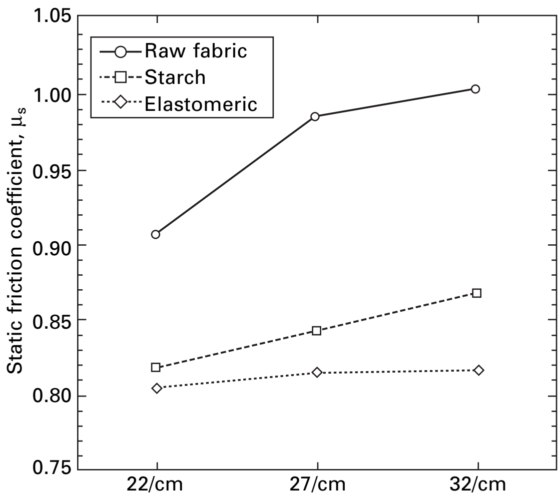
8.27 Influence of raw material content, weave and finishing on the general value of the kinetic friction coefficient μ_k.

Only for raw fabrics were noted very clear differences between the values of μ_k for plain fabrics and for other weaves (i.e., canvas and twill). In the case of fabrics finished both by starch and by elastomer, the values of the static and kinetic friction coefficients are similar, since fulfillment of pores by finishing smoothes the fabric surface and levels the differences in surface resulting from applying the different weaves.

Influence of raw material content, weft density and type of finishing

Static friction coefficient, μ_s

The value of the static friction coefficient μ_s increases with the increase of the weft density of plain fabrics (Fig. 8.28). The biggest variation with weft density is noted for raw fabrics. In the case of finished fabrics there is an analogous tendency, i.e., static friction coefficient increases with weft density, but the observed differences are less than for raw fabrics.

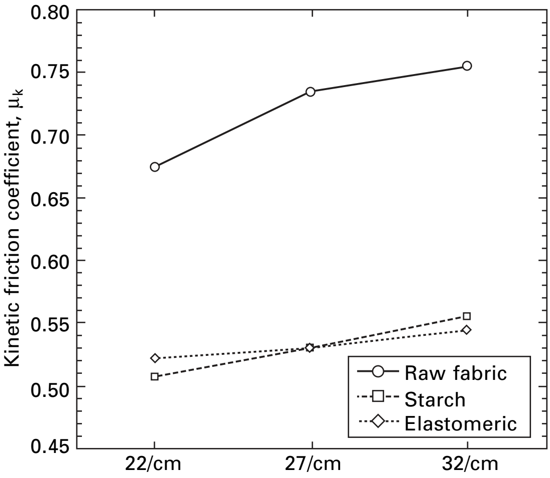


8.28 Influence of weft density and finishing on general static friction coefficient μ_s.

Kinetic friction coefficient, μ_k

Analogously to fabrics of different weaves, fabrics with a share of PES fibers are characterized by much higher values of the kinetic friction coefficient μ_k than for cotton fabrics. As in the case of μ_s, the value of μ_k increases with increase of weft density (Fig. 8.29).

Raw fabrics are characterized by much higher values of μ_k than finished ones. There was no statistically significant difference between the general values of μ_k for fabrics with starch and elastomeric finishing.



8.29 Influence of weft density and finishing on general kinetic friction coefficient μ_k.

8.6 References

1. Ajayi, J.O. (1992), *Fabric Smoothness, Friction and Hand*, Text. Res. J. **62**(1), 52–59.
2. Bona, M. (1990), *Modern Cotton Techniques in the Textile Finishing and Making-Up*, Comett, Eurotex.
3. De Boos, A.G. and Tester, D.H. (1991), *The FAST Approach to Improved Fabric Performance*, Textile Objective Measurement and Automation in Garment Manufacture, ed. George Stylios, Ellis Horwood.
4. El Mogahzy, Y.E. (1998), *The Theory and the Practice of Understanding Fabric Comfort*, TEXSCI'98, Liberec.
5. Frydrych, I. (1997), *Objective Hand Assessment (Obiektywna ocena chwytu),* Parts.1 and 2, Przegląd Włókienniczy, nos 3 and 4.
6. Frydrych, I. and Dziworska, G. (2000), *The Newest Prof. Sueo Kawabata's Devices: KES-FB AUTO i THERMO LABO II (Najnowsze przyrządy Prof. Sueo Kawabaty: KES-FB AUTO i THERMO LABO II)*, Przegląd Włókienniczy, no. 6, 9–11.
7. Frydrych, I., Dziworska, G., Jakubczyk, J. and Cybulska, M. (2002), *Influence of Raw Material, Kind of Weave and Finishing on the Mechanical Parameters of Fabrics under Small Stresses*, 1st International Textile, Clothing and Design Conference – Magic World of Textiles, Dubrovnik.
8. Frydrych, I., Dziworska, G. and Matusiak, M. (2003), *Influence of the Kind of Fabric Finishing on Selected Aesthetic and Utility Properties,* Fibres and Textiles in Eastern Europe, no. 3, 31–37.
9. Frydrych, I. and Matusiak, M. (2000), *Influence of Weft Density and Kind of Yarn on the Mechanical Parameters of Raw Fabrics Influences their Hand,* STRUTEX 2000, Liberec, December.
10. Frydrych, I. and Matusiak, M. (2003), *Changes in Fabric Hand Resulting from Different Fabric Finishing*, Fibres and Textiles in Eastern Europe, no. 2, 42–47.
11. Ganssauge, D., Lehman, K.H. and Augenadel, A. (1998), *How do Fabric Attributes*

Influence the Hand Characteristics of a Fabric?, Melliand International, no 2, 103–106.

12. Gong, R.H. and Mukhopadhyay, S.K. (1993), *Fabric Objective Measurement: A Comparative Study of Fabric Characteristics*, J. Text. Inst. **84**(2), 192–198.
13. Howorth, W.S. (1965), *Fabric Hand,* J. Text. Inst. **56,** T94–T95.
14. Huffington, J.D. (1965), *The Hand of Textile Fabrics*, J. Text. Inst. **56**, T513–T516.
15. Inoue, T. and Niwa, M. (2002), *Objective Evaluation of the Quality of Ladies' Garment Fabrics*, Journal of the Textile Machinery Society of Japan **55**(5), 48–58.
16. Kawabata, S. (1973), *Characterization Method of the Physical Properties of Fabrics and the Measuring System for Hand Feeling Evaluation*, Journal of the Textile Machinery Society of Japan **26**, 721–728.
17. Kawabata, S. (1979), *Examination of Affect of Basic Mechanical Properties of Fabrics on Hand. Mechanics of Flexible Fiber Assemblies*, NATO Advanced Study Institute Paper, 405–417.
18. Kawabata, S. (1980), *The Standardization and Analysis of Hand Evaluation,* The Textile Machinery Society of Japan, Osaka.
19. Kawabata, S. (1982), *The Development of the Objective Measurement of Fabric Hand: Objective Specification of Fabric Quality*, Mechanical Properties and Performance, The Textile Machinery Society of Japan, Osaka.
20. Kawabata, S. (2000), *A Guide-Line for Manufacturing Ideal Fabrics*, International Journal of Clothing Science and Technology, vol. 12, no. 2, 134–140.
21. Kawabata, S. and Niwa, M. (1976), *Fatigue Phenomena in the Mechanical Properties of Clothing Fabrics during Repeated Shear Deformation under Constant Extention Load,* Journal of the Textile Machinery Society of Japan **29**, T171–T182.
22. Kawabata, S. and Niwa, M. (1980), *Formulas KN-101 and KN-201 for the Translation of Fabric Mechanical Properties of Fabric into Hand Value and KN-301 from the Hand Values into the Total Value*, Journal of the Textile Machinery Society of Japan **33**, P164–P169.
23. Kawabata, S., Niwa, M. and Matsudaira, M. (1985), *Analysis of Fabric Hand of Silk Weaves,* Proceedings of the International Symposium of Fiber Science and Technology, p. 238.
24. Kim, J.O. and Slaten, B.J. (1999), *Objective Evaluation of Fabric Hand. Part I: Relationships of Fabric Hand by the Extraction Method and Related Physical and Surface Properties*, Text. Res. J. **69**(1), 59–67.
25. Matsudaira, M. and Kawabata, S. (1988), *A Study of the Mechanical Properties of Woven Silk Fabrics. Part I: Fabric Mechanical Properties and Hand Characterizing Woven Silk Fabrics,* J. Text. Inst. **79**, 458–475.
26. Matsudaira, M. and Kawabata, S. (1988), *A Study of the Mechanical Properties of Woven Silk Fabrics. Part II: Analysis of the Shearing Properties of Woven Silk Fabrics*, J. Text. Inst. **79**, 476–487.
27. Matsudaira, M. and Kawabata, S. (1988), *A Study of the Mechanical Properties of Woven Silk Fabrics. Part III: A Study of the Extensibility of Continuous-Filament Woven Silk Fabrics in the Small-Load Region,* J. Text. Inst. **79**, 490–503.
28. Matsudaira, M. and Matsumi, M. (1992), *Features of Mechanical Properties of Fabric Hand of Silk Weaves*, J. Text. Inst. **83**, 133–143.
29. Pan, N., Zeronian, S.H. and Ryu, H.S. (1993), *An Alternative Approach to Objective Measurement of Fabrics*, Test. Res. J. **63** (10), 33.
30. Peirce, F.T. (1930), *The Hand of Cloth as a Measurable Quantity*, J. Text. Inst. **21**, T377–T416.

31. Ramkumar, S.S. (1997), *Study of the Hand Characteristics of Knitted Fabrics*, 78th World Conference of Textile Institute, Thessaloniki.
32. Robinson, K.J., Chambers, E. and Gatwood, B. (1986), *Influence of Pattern Design and Fabric Type on the Hand Haracteristics of Pigment Prints,* Text. Res. J. **67**(11), 837–845.
33. Tsunoda, Y. (1973), *Complex Mechanical Properties Relating to Fabric Hand*, Journal of the Japan Research Association of Textile End Uses, **14**(1), 4–7.
34. Xuegian, W. (1986), *Relation between Fabric Hand and Density*, Text. Res. J. (6), 592–595.
35. Yan, H., Zhao, S., Yang, S. and Pan, N. (1985), *A New Approach to the Prediction of Fabric Hand from the Mechanical Properties of Woven Fabrics*, Third Japan–Australia Joint Symposium on Objective Measurement Applications to Product Design and Process Control, The Textile Machinery Society of Japan, Osaka, pp. 28–30.