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Sensorial Comfort of Textile Materials

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1. Introduction

Sensorial evaluation plays an important role for identification of materials in addition to technical specification. Textiles differs from each other with their technical structures in that it must have sufficient strength, performance characteristics and at the same time it has to be flexible, elastic, easy to pleat and shape, comfortable in aesthetic and sensorial aspects.

In order to find a method for the sensational evaluation of textiles, the concept of "fabric hand" is commonly used (Mäkinen et al., 2005). Understanding and measuring consumer preferences have opened up an important field of interest in recent researches in textile industry known as "handle" or in a broader sense "skin sensational wear comfort" or "tactile comfort" (Bensaid et al., 2006; Das & Ishtiaque, 2004) which refers to the total sensations experienced when a fabric is touched or manipulated in the fingers. Since fabric handle is based on people's subjective preferences, obviously it can mean different things to different people and consumers having different backgrounds. The preferences for certain fabric types are diverse and, in extreme cases, even opposite (Pan et al., 1988). Hand influences consumers' preferences and their perception of the usefulness of the product, and consequently retailer's saleability of the apparel. This fabric property is critical to manufacturers, garment designers, and merchandisers in developing and selecting textile materials, especially the textiles intended for use in apparel (Kim & Slaten, 1999; as cited in Pan & Yen, 1992; as cited in Pan et al., 1993).

In the literature, handle is defined in several ways as given in the following:

- The judgement of the buyer which depends on time, place, seasons, fashions and personal preferences (Bakar, 2004; as cited in Peirce, 1930)
- The quality of fabric or yarn assessed by the reaction obtained from the sense of touch (Bishop, 1996; as cited in The Textile Institute, 1995)
- A person's estimation when feeling fabrics between fingers and thumb (Bishop, 1996; as cited in Thorndike & Varley, 1961)
- The total of the sensations expressed when a textile fabric is handled by touching, flexing of the fingers, smoothing and so on (Bishop, 1996; as cited in Dawes & Owen, 1971)
- A perception of clothing comfort which is sensory responses of nerves ending to external stimuli including thermal, pressure, pain, etc producing neuro physiological impulses which are sent to the brain (Dhinakaran et al., 2007).

It is no doubtful that the hand judgement of fabrics is one of the important fabric tests and has been used widely by many people that can be classified as experts in textile factories and general consumers. The experts in factories especially in finishing departments carry out this judgement to control the property of their products every day. On the other hand each of the consumers also examines the property of the fabric by his "hand" to select a good clothing material according to his feeling and experience during purchasing (Kawabata, 1980). In both cases, fabric hand is examined mainly by the sense of touch and the sensory signals sent to the brain are formulated and clustered as subjective perception of sensations as follows:

- Tactile sensations: prickly, tickling, rough, smooth, craggy, scratchy, itchy, picky, sticky.
- Moisture sensations: clammy, damp, wet, sticky, sultry, non-absorbent, clingy.
- Pressure (body fit) sensations: snug, loose, lightweight, heavy, soft, stiff.
- Thermal sensations: cold, chill, cool, warm, hot (Bishop, 1996; Dhinakaran et al., 2007).

Fabric handle is a complex parameter and is related to the several fabric properties such as flexibility, compressibility, elasticity, resilience, density, roughness, smoothness, surface friction and thermal characteristics (Ozcelik et al., 2007, 2008). Fabric properties mostly influencing fabric handle are generally listed as fabric smoothness (28%), softness (22%), stiffness (8%), roughness (7%), thickness (5%) and weight (5%). Such fabric properties like warmth, hardness, elasticity, creasing propensity, drape and other properties less influencing the textile hand enter the residual part of 25% (Bishop, 1996; Grinevičiūtė et al., 2005).

This chapter presents one of the most challenging properties of the textile materials, "the sensorial comfort" in detail. The first part deals with the factors influencing the fabric handle, such as fiber, yarn and fabric properties and finishing treatments. The second part of the chapter summarizes the mechanical properties related with the sensorial properties such as bending, shear, tensile, thickness and compression, drape, friction and roughness as well as other fabric sensory properties related to the assessment of fabric handle and quality such as fabric thermal properties, surface appearance, prickle, noise and odour. In the third part, subjective evaluation methods, systems and devices for the objective measurement of fabric handle are examined. Finally, the relationship between the subjective evaluation and objective measurement of fabric handle is given.

2. Factors influencing the fabric sensorial comfort

In textile products the basic elements that can fundamentally affect fabric handle are given below. All these characteristics have an interacted relation in terms of the mechanism of influencing sensorial comfort of the end product. Namely, yarn handle characteristics are the results of the fiber properties and similar relationship can be observed between yarn and fabric features.

- Fiber characteristics: Material type, morphological structure, fineness, length, friction property, resilience, compressibility etc.
- Yarn characteristics: Yarn type (staple fiber, continuous filament, textured), linear density, twist etc.
- Fabric characteristics: Production method (woven, knitted, non-woven), fabric construction, weight, thickness, surface roughness, structure, yarn density etc.

- Method and type of dyeing and finishing processes (heat treatment, brushing, calendaring, softening, etc.) (Dillon et al., 2001; Behery, 2005; Shanmugasundaram, 2008).

2.1 Effect of fibers

The fiber type (natural/man made, staple/filament) is the first criterion for obtaining various fabrics having diffferent sensorial comfort characteristics.

Linen is a fiber that gives fabrics comparatively higher toughness. 100% linen fabrics offer the highest tensile resilience, bending rigidity and bending hysteresis, whereas the lowest values are obtained in terms of the shear rigidity and shear hysteresis values. Cotton, viscose and cotton/linen, viscose/linen blended fabrics give comparatively lower surface friction, surface roughness and bending rigidity compared to 100% linen fabrics. (Behera, 2007). The surface properties of the yarns and fabrics are affected by the morphological properties of the animal fibers (Supuren, 2010). As the fiber diameter increase, the prickliness of the fabrics increases for this type of fabrics (Behera, 2007). Linen is a fiber that gives the fabrics comparatively higher toughness; the toughness is reduced by blending the fiber with viscose. 100% linen fabrics offer the highest tensile resilience, bending rigidity and bending hysteresis, whereas the lowest values are obtained in terms of the shear rigidity and shear hysteresis values. Cotton, viscose and cotton/linen, viscose/linen blended fabrics give comparatively lower surface friction, surface roughness and bending rigidity compared to 100% linen fabrics (Behera, 2007). The surface properties of the yarns and fabrics are affected by the morphological properties of the animal fibers (Supuren, 2010). As the fiber diameter increase, the prickliness of the fabrics increases for this type of fabrics (Behera, 2007).

The finer the fibers are, the smoother and more flexible the yarn is and the fabric drape gets better. Longer fibers and smaller variation in the fiber length distribution result in smoother yarn and fabric surfaces. Micro denier filament fabrics give a better drape and handle properties compared to the normal denier filament fabrics (Behera et al., 1998).

The cross-sectional shape of the fiber affects the smoothness and bending of the yarn (Shanmugasundaram, 2008; Behery, 2005). It also determines how light interacts with the fiber. For example, a round fiber will appear more lustrous than a trilobal fiber made of the same polymer (Behery, 2005).

Another property that is important for fabric handle is the fiber friction. The fiber–fiber friction influences the way that the fibers interact with each other. The friction properties affect the flexibility of the yarns. As the fiber–fiber friction increases, the ability of the fibers to slide from each other during yarn and fabric deformation decreases (Behery, 2005).

Besides the typical mechanical methods to alter the handle of fabrics/fibers, handle can be improved by by chemical treatments. 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. Another method of changing fiber hand is to alter the chemical nature of the fibers themselves. A very common method is the mercerization of cellulose. As cellulose is mercerized, the overall shape of the fiber becomes more circular and more uniform than its irregular form thus becoming stronger and smoother to touch. With its round shape, mercerized cellulose becomes more lustrous (Behery, 2005).

Crystallinity also affects the handle of the fabrics by influencing the way that the fibers move and respond to bending. If the molecules in a fiber are aligned along the fiber axis, the fiber will be strong in uniaxial tension along the fiber axis. A more crystalline fiber is more resistant to bending (Behery, 2005).

2.2 Effect of yarns

The twist of the yarns which the fabrics are made of, is one of the main parameter affecting the fabric behaviour including bending, stiffness and shearing property (Shanmugasundaram, 2008). The amount of twist, together with the characteristics of the fibers (luster, hand, cross-sectional shape, etc.), determines the appearance and feel of the yarn. 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 than similar fabrics composed of yarns with less twist. Increased yarn twist leads to greater internal (fiber-to-fiber) friction within the yarn structure and reduce softness and bulkiness, in general, and hairiness in the case of spun yarns (Behery, 2005).

Another factor affecting handle is the number of the yarns folded. In plied yarns, i.e. two or more single yarns twisted together, the stiffness is increased compared to single yarns (Shanmugasundaram, 2008).

Filament yarns are sometimes put through an additional process known as texturizing. The process modifies the handle of the filament yarns by adding bulkiness and/or stretchiness to the filaments and therefore changes the smooth surface feel of fabrics (Behery, 2005). The feel of textured-yarn fabrics against the skin is considerably different than that of flat-yarn fabric. Textured yarns give a fabric more pleasant hand, fabric becomes warmer and softer and it has less synthetic feeling (Shanmugasundaram, 2008; as cited in Mahar & Pestle, 1983).

Fiber linearity and fiber-packing density in yarn structures are also important for the tactile qualities of a fabric, when not masked by twist (Behery, 2005). Comparing multifilament yarns of the same size and fiber composition, yarns containing more filaments (finer) are much less stiff than multifilament yarns containing less filaments (coarser). Fabrics produced from coarser filament textured yarns have higher thickness, compression characteristics than that of the fabrics made of finer filament textured yarns but there is no significant difference in fabric recovery and resiliency (Mukhopadyhay et al., 2002).

Yarn type has a significant effect on the handle properties of the fabrics. The static friction coefficient of cotton fabrics made of combed ring spun yarn is much lower than that for fabrics made of rotor yarn due to the more regular, denser and smoother structure of the ring spun yarn compared to the rotor yarn, on the surface of which there are visible wrapped fibers. The plain weft knitted fabric produced from the sirospun yarn is thicker, softer, of poorer recovery from compression, less rough and less stiff. For finer sirospun yarn, the shape retention is worse as the hysteresis of bending and shear is greater. (Sun & Cheng, 2000). Air-jet spun yarns produce thicker, less compressible, more extensible and stiffer fabrics than fabrics made from ring spun yarns (Behery, 2005; as cited in Vohs et al., 1985).

The fancy yarn structure also influences the subjective handle properties of the fabrics. In the production of fancy yarns, as the feeding rate increases; the fabric thickness, fabric weight, bending rigidity and friction coefficient of the fabric increase (Özdil et al., 2008).

2.3 Effect of fabrics

The handle of the fabrics is affected by mainly fabric structure and fabric geometry. Fabric construction and yarn densities play major role in determining fabric handle (Shanmugasundaram, 2008; Na & Kim, 2001). Variations in warp and weft densities and in the number of warp and weft yarns have significant effects on the handle characteristics of the fabrics (Shanmugasundaram, 2008). Sensory analysis shows that fabric hand can be influenced more by fabric weave than by the component yarn. Weaves that use fewer yarn interlacing improve the handle characteristics of the fabrics (Behery, 2005; as cited in Vohs et al., 1985).

Fabrics for which the warp and weft twist are unidirectional (Z & Z twist direction) perform higher shearing rigidity, (smooth rounded curvature) in comparison to those for which the warp and weft twist directions are opposite to each other (Yazdi & Özçelik, 2007).

The tightness factor of the knitted fabrics is another factor affecting the handle, with the increment of this factor, stiffness, which is related to bending rigidity, increase. Fullness, softness and smoothness decrease with the higher tightness factor (Park & Hwang, 2002).

Nonwoven fabrics differ from knitted or woven fabrics, because they are not based on webs of individual fibres, which can be bonded to each other by several means that changes the texture ranges from soft to harsh. Fiber composition influences performance far more for nonwoven fabrics than for fabrics containing yarns. High strength combined with softness is one of the most difficult property combinations to be achieved in nonwoven fabrics because the geometrical factors that permit high strength also lead to increased stiffness (Shanmugasundaram, 2008).

2.4 Effect of finishing

There are many researches in the literature related with the effects of finishing process on sensational properties of the fabrics. The diversity of fabric types with finishes available for any end-use continues to increase, making the selection of the most appropriate fabric an increasingly difficult task (Shanmugasundaram, 2008).

Different kind of end products can be produced from the same unfinished woven or knitted fabric by using various finishing treatments. High-speed scouring and milling create a fibrous surface as well as modifying other properties of the fabric, notably shear rigidity and specific volume. Heat treatments may cause fibres to crimp, increasing the bulkiness of the fabric. Soft handle and in some cases the ‘peach skin' effect can be obtained by enzymatic treatment. By using cellulose enzyme, which acts on the fibril ends and causes their shortening, a slight pick-out surface can be obtained. Light brushing is another mechanical treatment that gives peach-skin effect to the fabrics. Raising and teaseling are the mechanical processes which draw fibres to the surface of a fabric to create a pile. Calendaring and also many chemical treatments (softening compounds, resins) give flatter surface that affect the fabric hand. Pressing and decatising are designed to flatten the fabric and create a smooth surface. Cropping and singeing are the processes which are designed to remove fibrous protrusions from the body of the fabric and thereby create a smooth surface. After the process of flame-retardant finishing, the stiffness parameters, especially bending and shear properties, increase significantly (Le et al., n.d., as cited in Stewart & Postle, 1974; as cited in Boos, 1988; Shanmugasundaram, 2008; Mamalis et al., 2001; Frydrych et al., 2002).

Pigment printing is the most effective finishing process on the stiffness of the fabrics and mercerization before dyeing and printing results in improvements in various fabric properties; however cause negative effect in the fabric softness values (Özgüney et al., 2009).

The effects of the stiffness and softening agents on the friction and stiffness properties of the fabrics are apparent. When compared to the untreated fabric, all the softening and stiffening treatments result in decrease in the both static and dynamic friction coefficient values. Especially for softeners, this decrease is obvious. Shirley stiffness values of the fabrics treated with stiffeners are quite higher compared to untreated one whereas all the fabrics treated with softeners have lower values. The most stiffening effect is obtained with starch (Namligöz et al, 2008).

3. Fabric basic properties affecting sensorial comfort

Fabric handle is related to the basic mechanical properties of fabrics, especially initial low-stress region of those properties (Mitsuo, 2006). Since the stresses involved in fabric handling are low compared with those applied in other types of textile performance testing (e.g. for ultimate tensile strength, tear strength, seam strength, etc), the methodology is sometimes referred to as measurement of “low-stress fabric mechanical and surface properties” (Bishop, 1996).

The stimulation of the feeling sensors greatly depend on the mechanical properties of the textile products, for instance a lower value of bending rigidity supports the positive impression of sensorial comfort (Ozcelik et al., 2005). The main mechanical and surface properties of fabrics that influence the sensorial properties of fabrics are tensile, bending, shearing and thickness (Figure 1).

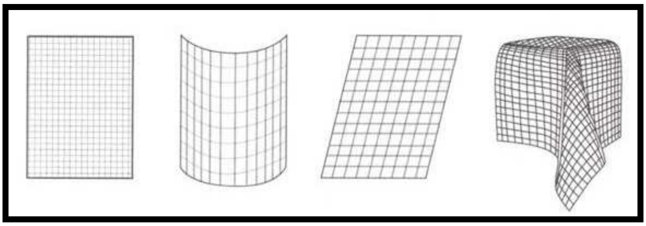


Fig. 1. The types of fabric deformation (Hu, 2004)

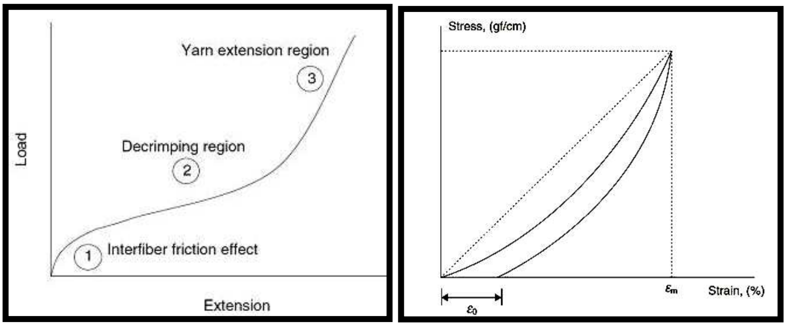
3.1 Tensile properties of woven fabrics

Tensile properties are one of the most important properties governing the fabric performance during usage. Each pieces of fabric consist of large quantity of fibers and yarns, and hence any slight deformation of the fabric will lead to a chain of complex movements among these constituent fibers and yarns (Hu, 2004).

There are three stages for the extension mechanism. The first part is dominated by inter fiber friction that is the frictional resistance due to the yarn bending. Second part, a region of lower modulus, is the decrimping region resulting from the straightening of the yarn set in the direction of application of load, with the associated increase in crimp in the direction perpendicular to the yarn direction. This is commonly referred to as “crimp interchange”.

The last part of the load extension curve, is due to the yarn extension. As the crimp is decreased, the magnitude of the loading force rises very steeply, and as a result, the fibers themselves begin to be extended. This is clearly a region of higher modulus (Figure 2a).

If the fabric undergoes in a cycling loading process, the fabric is first stretched from zero stress to a maximum and the stress is fully released, then an unloading process follows the loading process. As a result, a residual strain ε_0 is observed, since textile materials are viscoelastic in nature. Due to the existence of residual strain, the recovery curve never return to the origin, as shown in Figure 2b. This is the hysteresis effect which denotes the energy lost during the loading and unloading cycle. Due to the existence of hysteresis, a deformed fabric cannot resume its original geometrical state (Hu, 2004; Schwartz, 2008).



(a) (b)

Fig. 2. (a) Schematic of a typical load- extension curve for a woven fabric (Schwartz, 2008), (b) Loading and unloading cycle in the tensile stress-strain curve (Hu, 2004)

3.2 Bending properties of woven fabrics

Bending properties of fabrics govern much of their performance, such as hang and drape, and are an essential parts of complex fabric deformation analysis. The bending properties of a fabrics are determined by yarn bending behavior, the weave of the fabric and the finishing treatment of the fabric, the relationship among them are highly complex (Schwartz, 2008). Two parameters that characterize the fabric bending behavior are its bending rigidity and bending hysteresis. Bending rigidity can be defined as the resistance of textile against flexion by its specific weight and external force. Bending hysteresis can be considered as a measure of fabric's ability to recover (Pavlinić & Geršak, 2003).

Figure 3 illustrates the typical bending curve for a woven fabric. For this curve, there are two stages with a hysteresis loop under low stress deformation. Firstly, there is an initial, higher stiffness non linear region (OA); within this region the curve shows that effective stiffness of the fabric decreases with increasing curvature from the zero motion position, as more and more of the constituent fibers are set in motion at the contact points. Secondly, a close to linear region (AB), since all the contact points are set in motion, the stiffness of the fabric seems to be close–to-constant (Schwartz, 2008).

In applications, where the fabrics are subjected to low curvature bending, such as in drapes, the hysteresis is attributed to the energy loss in overcoming the frictional forces. Under high curvature bending, the viscoelastic properties of the fibers must be considered (Schwartz, 2008).

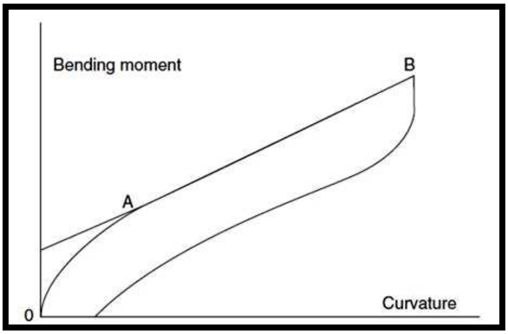


Fig. 3. Typical bending curve of woven fabrics (Schwartz, 2008)

3.3 Shear properties of woven fabrics

The shearing behaviour of a fabric determines its performance properties when subjected to a wide variety of complex deformations in use (Hu, 2004). The shear mechanism is one of the important properties influencing drapeness, pliability and handling of woven fabrics (Schwartz, 2008).

Shear deformation is very common during the wearing process since the fabric needs to be stretched or sheared to a greater or less degree as the body moves (Hu, 2004). This property enables fabric to undergo complex deformations and to conform to the shape of the body. The ability of a woven fabric to accept shear deformation is a necessary condition for a conformable fitting to a general three dimensional surface and is the bases for the success of woven textiles as clothing materials. This property is affected by the yarn characteristic and fabric structure (Yazdi & Ozcelik, 2007).

Shear hysteresis is defined as the force of friction occurring among interlacing points of the warp and weft yarns, when they are moving over each other, having their origin in the forces of stretching/shrinking, since the system of warp and weft yarns stretches/shrinks under strain (Pavlinić & Gerśak, 2003). Shear angle is one of the main criteria for characterizing the formability of fabrics. As the fabric is fitted onto a spatial surface, shearing occurs increasingly until the critical shearing angle is reached. When this angle exceeds a strict value, the specimen starts to buckle, i.e. wrinkling is observed (Domskienė & Strazdienė, 2005).

If a fabric is deformed at low levels of strain, the shear resistance is initial large and decreases with increasing strain (Figure 4). In this region the shear behaviour is dominated by frictional mechanism and the decreasing incremental stiffness is generally attributed to the sequential movement of frictional elements. As soon as the stress is large enough, to overcome the smallest of the frictional restraints acting at the intersection regions, the system starts to slip and the incremental stiffness falls (AB). At point B, the incremental stiffness reaches to the minimum level and remains almost linear over a range of amplitudes with slope that are called elastic elements in the fabric. At amplitudes greater than a certain amount C, the incremental stiffness again begins to rise and closed curves increase in width with increasing amplitudes of shear angle (Schwartz, 2008).

In the case of closely woven fabrics, there is not much slippage between warp and weft yarns under shearing strain, the result being just a higher friction between individual yarns. More loosely woven fabrics, with lower cover factor, exhibit lower friction between warp and weft yarns (Pavlinić & Gerśak, 2003). Shear deformation of woven fabrics also affects the bending and tensile properties of woven fabrics in various directions rather than in the warp and weft directions only (Hu 2004; as cited in Chapman, 1980; as cited in Skelton, 1976).

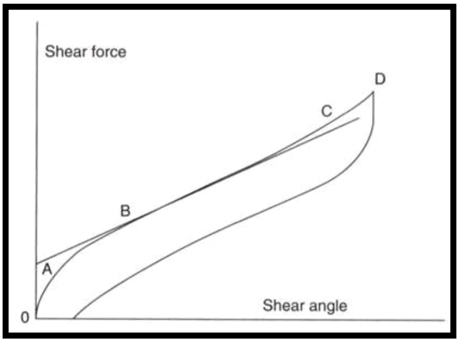


Fig. 4. Stress-strain curve of woven fabric during shear deformation (Schwartz, 2008)

3.4 Thickness and compression properties of woven fabrics

Thickness and compressional properties of the fabric are very important characteristics in terms of fabric handle, especially for the fabrics used in garment manufacture. Fabric compressional characteristics depend on several factors like the compressional properties of the constituent warp and weft threads and the structure of the fabric (Mukhopadyhay et al., 2002).

The thickness of a fabric is one of its basic properties giving information on its warmth, heaviness or stiffness in use. In practice thickness measurements are rarely used as they are very sensitive to the pressure used in the measurement (Saville, 1999).

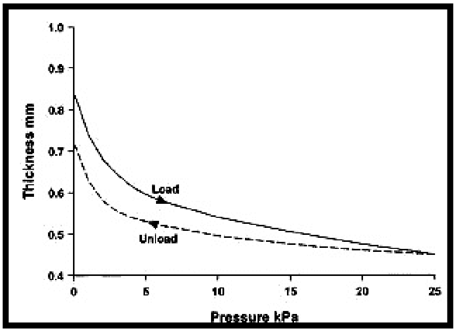


Fig. 5. The change in thickness with pressure (Saville, 1999)

Fabric thickness is generally evaluated by measuring the distance between two parallel plates separated by a fabric sample, with a known arbitrary pressure applied and maintained between the plates (Majumdar & Saha, 2008; as cited in BS Handbook, 1974).

Figure 5 shows the change in thickness with pressure for a soft fabric together with the recovery in thickness as the pressure is removed. The steep initial slope of the curve makes it very difficult to measure thickness with any accuracy as a small change in pressure in this region causes a large change in measured thickness. Thickness at zero pressure always has to be obtained by extrapolation of the curve, as a positive pressure is needed to bring any measuring instrument into contact with the fabric surface (Saville, 1999).

3.5 Other fabric properties related to sensorial comfort

It is evident from studies on the subjective evaluation of fabric handle that warm-cool feeling of a fabric very often makes an important contribution to the perception of its over-all handle and quality in the context of a given end use (Bishop, 1996). Alambeta instrument developed by Hes can be used for measuring the warm-cool feeling (Bishop, 1996; Özçelik et al., 2008; Mazzuchetti et al., 2008; Hes, 2004). This feeling, which is generated when fabric initially contacts the skin, is related to the heat flow between the skin and the contacted object. Rough fabric surface reduces the area of contact appreciably, and a smoother surface increases the area of contact and the heat flow, thereby creates a cooler feeling. The correlation between transient heat flux and the warm/cool feeling was investigated by several researchers (Barker, 2002; as cited in Rees, 1941; as cited in Hollies et al., 1953; as cited in Kawabata et al. ,1985). It has been reported that transient heat flux significantly affects clothing comfort in next-to-skin fabrics (Barker, 2002; as cited in Kawabata et al., 1985).

Prickle is a rather negative attribute associated particularly with fabrics containing a proportion of coarse animal fibres, having diameters of about 30 μm or more. When evaluating the handle and quality of wool containing fabrics, there has been obtained good correlation and therefore prickle characteristics of the fabrics should also be taken into consideration in objective handle measurements (Bishop, 1996). Although the luster and fuzzes of the fabric surface are not generally included in objective handle measurements, since the appearance of fabrics make an important contribution to consumers` garment preferences, the measurement of these properties should also be of interest in handle evaluation. The fabric noise and odour are not redundant in the subjective evaluation of textiles but these properties can be useful to evaluate fabric handle (Mitsuo, 2006).

Fabric handle according to fabric sound has been investigated in recent days. Fabric sound in the forms of sound spectra through Fast Fourier Transform analysis was analyzed (Mitsuo, 2006; as cited in Yi & Cho, 2000). Level pressure of total sound, level range and frequency differences of fabric sound were compared to mechanical parameters measured by KES system (Mitsuo, 2006; as cited Cho et al., 2001, 2005). The physiological responses evoked by friction sounds of warp knitted fabrics to that of electroencephalog, the ratio of high to low frequency were also studied (Mitsuo, 2006).

4. Sensorial comfort of fabrics

4.1 Subjective evaluation of fabric handle

Subjective assessment treats fabric hand as a psychological reaction obtained from the sense of touch (Bakar, 2004). Traditionally, in the textile and clothing industries, the assessment of the fabric handle is carried out subjectively by individual judges. The judgements strongly rely on personnel criteria (Yick et al., 1995).

When a person runs their finger across the surface of a fabric, a complex multi-sensory, emotional and cognitive experience takes place. A memory is stirred, an emotion, feeling and association is evoked and a decision is made, an impression becomes embossed in the mind. Decisions and motivations are based on anticipated reality of preference, personality, emotion and moods, for audience or non-audience participation (Moody et al., 2001).

The subjective hand is the result of touch sensation and therefore is dependent on the mechanisms of human tactile sensations. The somatic senses are those nervous system mechanisms by which sensory information is collected from within body. The somatic senses are classified to the three groups:

1. Mechanoreceptors – stimulated by mechanical displacement of various tissues at the body
2. Thermo receptors – stimulated by temperature changes
3. Nocio receptors – representing the human pain sense

It is then clear that subjective hand sensing is the combination of various receptors responsible for feeling of texture, pressure, stretching, thermal feedback, dynamic deformation and vibration and from the sum of their complex responses humans can perceive and discriminate between the textiles (Militky& Bajzík, 1997).

In the subjective assessment process of textiles, fabric hand is understood as a result of psychological reaction through the sense of touch. There are variations in how individuals actually feel textiles because people do not have the same sensory perception of identical occurrences. Affecting aspects can be grouped in sociological factors and the physiological factors.

The other main factors affecting the subjective handle evaluation can be defined as; the judges, the criteria of judgement, assessment conditions, assessment technique, the method of ranking and scaling the assessment, analysis of the results (Mahar et al., 1990; as cited in Brand, 1964; Bishop, 1996). Gender, age, education and cultural backgrounds are potential influencing factors. Female individuals in general respond more delicately and sensitively than male individuals and therefore have a finer assessment of a specific parameter (Mäkinen et al., 2005; as cited in Kweon et al., 2004; as cited in Dillon et al., 2000).

Since the services of expert judges are not widely available for research activities, generally students, laboratory assistants and other consumer groups work as panelists. Such panels should be capable of making consistent judgements of textile attributes and due to the high variability of these panelists compared to the expert judges, larger panel sizes should be preferred, at around 25-30 persons (Bishop, 1996).

In order to ensure the reliability of subjective assessments, it is critical to choose the right expressions for the description of a fabric handle parameter (Mäkinen et al., 2005). There are different sensory attributes identified by numerous authors. These are grouped as given in Table 1 (Hu, 2008). The words "thickness," "thinness," "softness," "stiffness," "slippery," "roughness," "tightness," "fullness" and "pliable" are mostly used expressions to describe the feel of a fabric (Sülar & Okur, 2007).

Generally, in order to evaluate the handle of the fabric, fingers are slid on the surface of the fabric, compressed between the thumb and sign finger. The fingers containing more than

250 sensors per cm^2 are the crucial important organs determining the fabric quality (Bensaid et al., 2006). Tightening of the fabric between fingers gives idea about thickness, bulkiness, compressibility, thermal absorptivity and surface properties of the fabrics, whereas slipping of the fingers on the surface of the fabrics with a pressure renders about structure and elongation of the fabrics (Aliouche & Viallier, 2000).

Stiffness/crispness/pliability/flexibility/limpness	Anti-drape/spread/fullness
Softness/harshness/hardness	Tensile deformation/ bending/surface friction/sheer
Thickness/bulkiness/sheerness/thinness	Compressibility
Weight/heaviness/lightness	Snugness/loosenes
Warmth/coolness/coldness (thermal characteristics)	Clinginess/flowing
Dampness/dryness/wetness/clamminess	Quietness/noisiness
Prickliness/scratchiness/roughness/coarseness/itchiness/tickliness/stickiness/	Smoothness/fineness/silkiness
Looseness/tightness	

Table 1. Sensory attributes of fabrics

There are generally four handle methods for the evaluation of fabric handle, as shown in Figure 6. The multiple finger pinch and the touch-stroke are the most relevant ones.

However, using just the index finger has also proved acceptable. Evaluated properties of the fabrics by these handle techniques are given in Table 2 (Moody et al., 2001; as cited in Dillon & Moody, 2000).

Fig. 6. Handle techniques (1. Touch stroke, 2.Rotating cupped, 3.Multiple finger, 4.Two handed rotation) (Moody et al., 2001)

	Handle Technique	Properties Evaluated
1	Touch-stroke	Surface quality (texture), temperature
2	Rotating cupped action	Stiffness, weight, temperature, comfort, overall texture, creasing
3	Multiple finger pinch: Rotating between the fingers action with one hand (thumb and 1 or 2 fingers)	Texture, stiffness, temperature, fabric structure, both sides of a fabric, friction, stretch (force-feedback)
4	Two handed rotation action	Stretch, sheerness

Table 2. Properties evaluated by different handle techniques (Moody et al., 2001)

The assessment conditions of subjective handle evaluation are critically important. Different skin hydrations of individuals affect notably the feel of a textile. A higher moisture level on the skin makes it more sensitive to the sense of touch (Mäkinen et al., 2005).

The evaluation is carried out in three different conditions: sight only, touch only and sight and touch together. During the assessment, in order to prevent the effect of colour and appearance on the assessments, wooden boxes with holes on the facing sides, through which the hands can easily go, can be used. Fabric samples are placed in these boxes prior to assessments. This helps the jury to assess the fabric without seeing it (Sülar &Okur, 2008b).

The first attempts of ranking and scaling the assessment methods in hand evaluation of textiles in an organized and quantitative manner were published as early as 1926 and have continued up to the present time and two basic procedures of subjective hand evaluation is proposed as follows: (Bakar, 2004; as cited in Howorth,1964):

a. Direct method - is based on principle of sorting of individual textiles to defined subjective grade in ordinal scale (e.g., 0 - very poor, 1 - sufficient, 5 - very good, 6 - excellent).
b. Comparative method - is based on sorting of textiles according to subjective criterion of evaluation (e.g., ordering from textiles with the most pleasant hand to textiles with the worst hand) (Bakar, 2004). If the number of samples is high, the second approach can be considered rather time consuming (Sülar & Okur, 2007).

It is preferable to use a paired comparison technique during assessment, the so-called bipolar pairs of sensory attributes, such as “thin/thick” or “soft/harsh” (Mahar et al., 1990; as cited in Brand, 1964). For the same reason, fabric hand attributes are measured on specific scales thus avoiding the intrinsic weakness of descriptive terminology. In case of using bipolar descriptors in the assessment of the handle, control fabrics are better to be used for the training of the panel members. Control fabrics are chosen according to the related objective properties. The test results for objective properties that are related to sensory attributes were sorted in ascending order for each parameter. The fabrics with minimum, maximum and medium values are determined and used for the initial tests for the selection of the control fabrics (Sülar & Okur, 2007).

It is crucially important to convert the subjective assessment results to the numerical values for finding a relationship between objective measurements to analyze statistical evaluation. Therefore, using these types of ranking scale is preferable (Table 3).

1	…	5	…	10
thinnest	…	medium	…	thickest
1	…	5	…	10
softest	…	medium	…	stiffest
1	…	5	…	10
smoothest	…	medium	…	rougest
1	…	5	…	10
proper	…	medium	…	most proper

Table 3. Handle components and the rating scale (Sülar & Okur, 2008a)

This subjective hand evaluation system requires years of experience and can obviously be influenced by the personal preferences of the assessor as mentioned before. A fabric may be felt light, soft, mellow, smooth, crisp, heavy, harsh, rough, furry, fuzzy or downy soft. So there is a need to replace the subjective assessment of fabrics by experts with an objective machine-based system which will give consistent and reproducible results (Hu, 2008).

4.2 Objective evaluation of fabric handle

For a long time, handle has been estimated by the organoleptic method. The producers and users of textile products try to formulate in words the impression of touching the flat textile product. In general, fabric hand is primarily assessed subjectively in a few minutes. Although this is a fast and convenient sort of quality control, the subjective nature of fabric handle leads to serious variations in quality assessment (Sülar & Okur, 2008a) and does not analyze the core of the problem connected with the influence of factors creating the particular sensations. This was why in the 1930s investigations were commenced into an objective measurement of the features which are decisive for handle. The common goal in objective measurement systems was to eliminate the human element in hand assessment and develop quantitative factors that could be measured in a laboratory (Kocik et al., 2005).

Peirce was a forerunner of such investigations with his works connected with determining the bending rigidity and compressibility of flat textile products (Kocik et al., 2005; as cited in Pierce, 1930). At the turn of the 1960s, researchers from the Swedish Textile Institute (TEFO) (Kocik et al., 2005; as cited in Eeg-Olofsson, 1957; as cited in Eeg-Olofsson, 1959; as cited in Olofsson, 1965; as cited in Olofsson & Ogucki; 1966; as cited in Lindberg et al., 1961; as cited in Lindberg et al., 1960) carried out intensive investigations into this matter. These research works led to determining the dependencies between the features of flat textile products subjected to bending, buckling, shearing, and compressing, and the susceptibility of these products to manufacturing clothing. Lindberg (Kocik et al., 2005; as cited in Lindberg et al., 1960) was the first researcher who applied the theory of buckling for estimating the behaviour of fabrics in the clothing manufacturing process. Kawabata and Niwa were followers of Peirce and the Swedish researchers, who since 1968 have conducted research into handle. These investigations have been crowned by the design and construction of a measuring system which serves for objective estimation of handle (Kocik et al., 2005; as cited in Kawabata et al., 1973; as cited in Kawabata et al., 1996).

Objective assessment attempts to find the relationships between fabric hand and some physical or mechanical properties of a fabric objectively. It quantitatively describes fabric hand by using translation result from some measured values of relevant attributes of a fabric. Techniques used for objective hand evaluations are based on special instruments for measuring handle related properties (Bakar, 2004).

Several attempts have been made to measure fabric handle properties objectively described simply as “Fabric Objective Measurement (FOM)”, and also a number of items of equipment have been introduced for this purpose (Hasani & Planck, 2009; Bishop, 1996).

4.2.1 Objective measurement systems

The KES-F system (Kawabata’s Hand Evaluation System for Fabrics) was developed in Japan by the Hand Evaluation and Standardization Committee (HESC, established in 1972) organized by Professor Kawabata. In this fabric objective measurement method, scientific principles are applied to the instrumental measurement and fabric low stress mechanical and surface properties such as fabric extension, shear, bending, compression, surface friction and roughness are measured. The fabric handle is calculated from measurements of these properties. Empirical equations for calculating primary hand values and total hand values were put forward by Kawabata and Niwa (Mäkinen et al., 2005; as cited in Kawabata, 1980; as cited in Shishoo, 2000).

The process of the subjective evaluation according to Kawabata can be given as follows (Bona, 1994):

Touch of fabric by hand	Detection of fabric basic mechanical properties such as bending, stiffness, etc.	Summarized expressions → about fabric characters by "primary hand"	Overall →judgement of fabric quality
Physiological sensing data processing in man's brain			

The first part of Kawabata`s work was to find the important aspects of handle and the contribution of each to the overall rating of the fabric. For each category such as stiffness, smoothness, etc. were identified and the title of primary hand values were give. The original Japanese terms of these primary hand definitions together with English meanings are given in Table 4. The primary hand values are combined to give an overall rating for the fabric categories such as man's summer suiting, man's winter suiting, lady's thin dress, and man's dress short and knitted fabrics for undershirts. The conversion of the primary hand values is done by using a translation equation for a particular fabric category determined empirically. This total hand value is rated on a five point scale, where five is the best rating (Kawabata, 1980).

The second stage of Kawabata`s work was to produce a set of instruments with which to measure the appropriate fabric properties and then to correlate these measurements with the subjective assessment of handle. The aim was that the system would then enable any operator to measure reproducibility the total hand value of a fabric (Saville, 1999).

The Kawabata Evaluation System for Fabric (KES-F) which has been widely used since the 1970's consists of four specialized instruments: FB1 for tensile and shearing, FB2 for bending, FB3 for compression and FB4 for surface friction and variation. A total of 16 parameters are measured at low levels of force (Table 5). The measurements are intended to simulate the fabric deformations found in use (Hu, 2008; Chen et al., 2001).

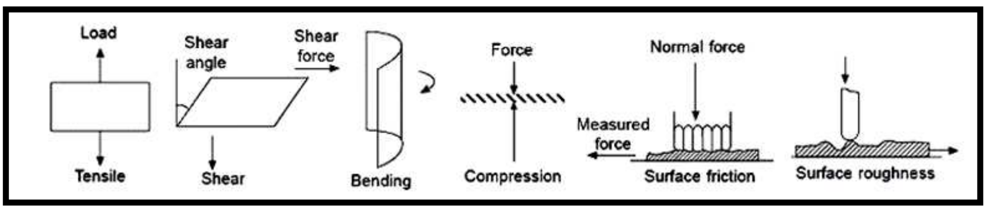


Fig. 7. Measuring principles of the KES system

Hand		Definition
Japanese	**English**	
Koshi	**Stiffness**	A stiff feeling from bending property. Springy property promotes this feeling. High-density fabrics made by springy and elastic yarn usually possess this feeling strongly.
Numeri	**Smoothness**	A mixed feeling come from smooth and soft feeling. The fabric woven from cashmere fiber gives this feeling strongly.
Fukurami	**Fullness and softness**	A bulky, rich and well-formed feeling. Springy property in compression and the thickness accompanied with warm feeling are closely related with this feeling (*fukurami* means 'swelling').
Shari	**Crispness**	A feeling of a crisp and rough surface of fabric. This feeling is brought by hard and strongly twisted yarn. This gives a cool feeling. This word means crisp, dry and sharp sound made by rubbing the fabric surface with itself).
Hari	**Anti-drape stiffness**	Anti-drape stiffness, no matter whether the fabric is springy or not. (This word means 'spread').
Kishimi	**Scrooping feeling**	Scrooping feeling. A kind of silk fabric possesses this feeling strongly.
Shinayakasa	**Flexibility with soft feeling**	Soft, flexible and smooth feeling.
Sofutosa	**Soft touch**	Soft feeling. A mixed feeling of bulky, flexible and smooth feeling.

Table 4. The definitions of primary hand (Kawabata, 1980)

The characteristic values are calculated from recorded curves obtained from each tester both in warp and weft direction. Tensile properties (force-strain curve) and shear properties (force-angle curve) are measured by the same apparatus. Bending properties (torque-angle curve) are measured by bending first reverse sides against each other and after that the face sides against each other. Pressure-thickness curves are obtained by compression tester. The measurements of surface friction (friction coefficient variation curve) and surface roughness (thickness variation curve) are made with the same apparatus using different detectors.

The tensile properties are measured by plotting the force extension curve between zero and a maximum force of 500 gf/cm, the recovery curve as the sample is allowed to return to its original length is also plotted to give the pair of curves shown in Figure 8a. From these curves the following values are calculated (Saville, 1999):

Tensile energy *WT* = the area under the load strain curve (load increasing)

Linearity *LT*=*WT*/area triangle *OAB*

Resilience RT=area under load decreasing curve /*WT* x 100

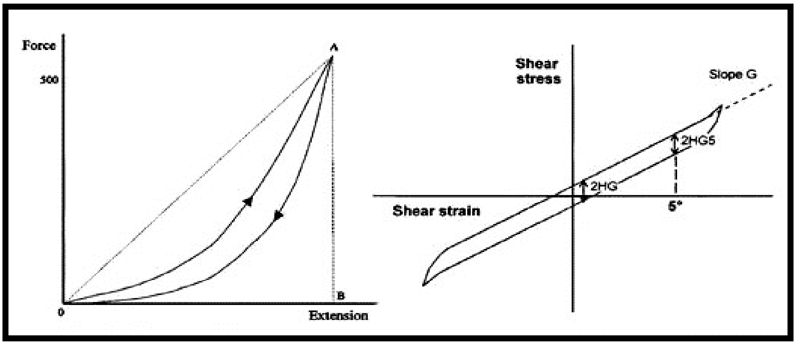


Fig. 8. (a) Load extension recovery curve (b) Hysteresis curve for shear (Saville, 1999)

Characteristic values measured in KES-F system			
KES- FB1	**Tensile**	LT	Linearity of load-extension curve
		WT	Tensile energy
		RT	Tensile resilience
	Shearing	G	Shear rigidity
		2HG	Hysteresis of shear force at 0.5° shear angle
		2HG5	Hysteresis of shear force at 5° shear angle
KES- FB2	**Bending**	B	Bending rigidity
		2HB	Hysteresis of bending moment
KES- FB3	**Compression**	LC	Linearity of pressure-thickness curve
		WC	Compressional energy
		RC	Compressional resilience
KES- FB4	**Surface**	MIU	Coefficient of friction
		MMD	Mean deviation of MIU, frictional roughness
		SMD	Geometrical roughness
Fabric construction	**Weight**	W	Weight per unit area
	Thickness	T	Thickness at 0.5 gf/cm^2

Table 5. Characteristic values in KES-F system (Mäkinen et al., 2005; as cited in Kawabata, 1980)

In order to measure the shear properties, a sample in dimensions of 5cm x 20cm is sheared parallel to its long axis keeping a constant tension of 10 gf/cm on the clamp. The following quantities are then measured from the curve as shown in Figure 8b.

Shear stiffness G = slope of shear force-shear strain curve

Force hysteresis at shear angle of 0.5° 2HG = hysteresis width of curve at 0.5°

Force hysteresis at shear angle of 5° 2HG5 = hysteresis width of curve at 5°

In order to measure the bending properties of the fabric, the sample is bent between the curvatures -2.5 and 2.5 cm^{-1}, the radius of the bend is the reciprocal of the curvature as shown in Figure 9a. The bending moment required to give this curvature is continuously monitored to give the curve as shown in Figure 9b (Saville, 1999).

Compressibility is one of the most important properties in terms of fabric handle for the fabrics used in garment manufacture (Mukhopadyhay et al., 2002). The compression test for fabric is used to determine the fabric thickness at selected loads, and reflects the 'fullness' of a fabric (Hu, 2008).

The compression energy, compressibility, resilience and thickness of a specimen can be obtained by placing the sample between two plates and increasing the pressure while

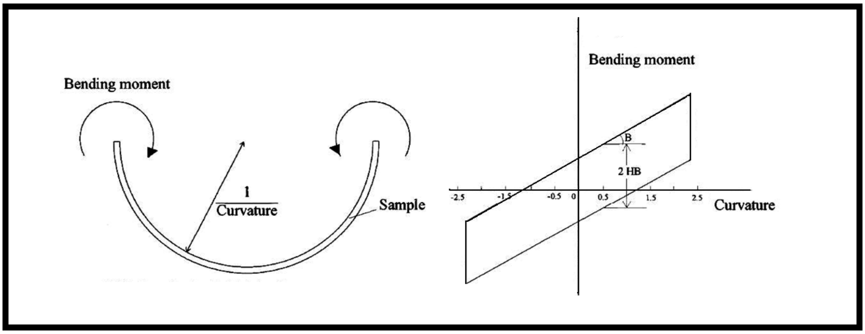


Fig. 9. a) Forces involving in fabric bending; b) Plot of bending moment against curvature (Saville, 1999)

continuously monitoring the sample thickness up to a maximum pressure of 50 gf/cm^2. A circular compressing board of 2 cm^2 attached with a sensor is used to apply the force on the fabric specimen (Figure 10) (Saville, 1999).

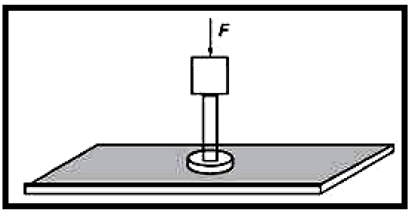


Fig. 10. Compression test on the KES-F system (Hu, 2008)

The surface friction is measured in a similar way by using a contactor which consists of ten pieces of the same wire as used in the surface roughness. A contact force of 50 gf is used in this case and the force required to pull the fabric past the contactor is measured. For the surface roughness, the contact force that the wire makes with the surface is 10gf (Chen et al., 2001).

Kawabata developed through extensive human subjective evaluations of a range of fabric types and the ranking of characteristics. The weighing factors are believed to be appropriate for the population within which the data were taken but there is some question as to the application of the same weighing factors in a different culture (Adanur, 2001). Critics still exist due to the high cost of the instrument. The system also requires experts for the interpretation of the resulting data. These deficiencies led to the development of another testing device called the FAST (Hu, 2004).

The Australian CSIRO designed and developed the FAST (Fabric Assurance by Simple Testing) set of instruments, as a simpler alternative to a KES system, which in terms of practicality and testing speed, go a long way towards meeting the requirements of garment makers, finishers and is designed to be relatively inexpensive, reliable, accurate, robust and simple to operate. Unlike the KES-F system, FAST only measures the resistance of fabric to deformation and not the recovery of fabric from deformation (Shishoo, 1995; Behery, 2005; Mazzuchetti et al., 2008; Potluri et al., 1995).

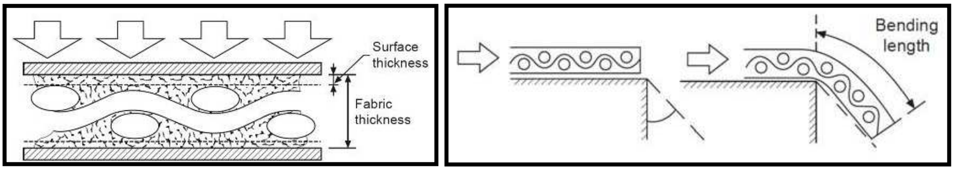
FAST gives similar information on the aesthetic characteristics of fabric as KES-F does, but in a simple manner, and is more suited to a mill environment. The FAST system includes FAST-1 for thickness, FAST-2 for bending, FAST-3 for extensibility and FAST-4 for dimensional stability. Through the objective measurements of fabric and a data set on a chart or 'fingerprint', manufacturers can identify fabric faults, predict the consequences of those faults and identify re-finishing routes or changes in production (Hu, 2008).

Characteristics measured in FAST system		Symbol	Unit	Device
Fabric weight		W	g/m^2	
Compression	Total thickness Surface thickness	ST	mm mm	FAST-1
Bending	Bending length	B		FAST-2
Tensile	Warp elongation Weft elongation Crosswise elongation	E	% % %	FAST-3
Dimensional stability	Relaxation shrinkage Hygral expansion	RS HE	% %	FAST-4

Table 6. List of fabric properties measured using FAST (Saville, 1999)

FAST-1 is a compression meter enabling the measurement of fabric thickness and surface thickness at two predetermined loads (Hu, 2004). The fabric thickness is measured on a 10 cm^2 area at two different pressures, firstly at 2 gf/cm^2 and then at 100 gf/cm^2. This gives a measure of the thickness of the surface layer which is defined as the difference between these two values (Figure 11a). The fabric is considered to consist of an incompressible core and a compressible surface (Saville, 1999).

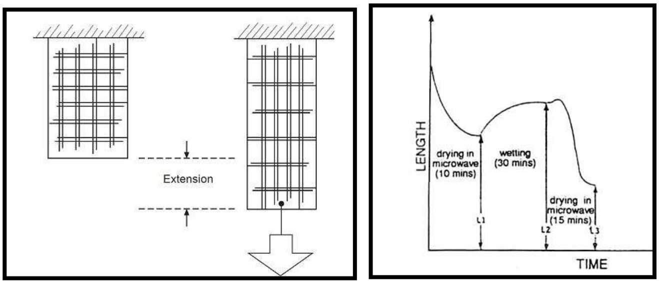
FAST-2 is a bending meter, which measures the bending length of the fabric. From this measurement, the bending rigidity of the fabric can be calculated. The instrument uses the cantilever bending principle described in BS: 3356. However, in FAST-2 the edge of the fabric is detected using a photocell. The bending rigidity, which is related to the perceived stiffness, is calculated from the bending length and mass/unit area. (Saville, 1999; Hu, 2004).



(a) (b)

Fig. 11. (a) Measuring principle of the FAST-1 compression meter; (b) Measuring principle of the FAST-2 bending meter (Hu, 2004)

FAST-3 is an extension meter which operates on a simpler principle as shown in Figure 12a (Hu, 2004). The extension of the fabric is measured in the warp and weft directions at three fixed forces of 5, 20 and 100 gf/cm (sample size tested 100mm x 50mm). The extension is also measured on the bias in both directions but only at a force of 5gf/cm, this enables the shear rigidity to be calculated (Saville, 1999).



(a) (b)

Fig. 12. (a) Measuring principle of the FAST-3 extension meter (Hu, 2004); (b) Dimensional stability curve (Bona, 1994)

The final component of FAST is a test method which measures the changes in the dimensions of fabrics that occur when the fabric is exposed to changing environmental conditions (Hu, 2004). A small amount of shrinkage (usually below 1%) is required for fabrics intended to be pleated. In order to measure dimensional stability the fabric is dried in an oven at 105ºC and measured in both warp and weft directions to give the length L_1. It is then soaked in water and measured wet to give the wet relaxed length L_2. It is then re-dried in the oven and measured again to give the length L_3. The following values for dimensional stability are then calculated from these measurements for both warp and weft.

$$\text{Relaxation shrinkage} = \frac{L_1 - L_3}{L_1} x100(\%) \quad \text{Hygral expansion} = \frac{L_2 - L_3}{L_3} x100(\%)$$

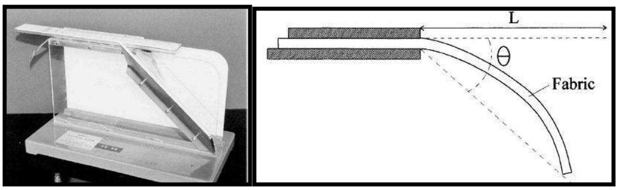
Since the sensation is related to physical properties of the material, physical measurements constitute significant data in terms of objective evaluation. Disadvantages of the complex measuring systems such as high costs, difficulties in maintenance and reparation have resulted in conducting studies on improving simpler and individual instruments for each handle related objective fabric properties (Ozcelik et al., 2008).

4.2.2 Individual objective measurement testers

Shirley stiffness tester and circular bending rigidity tester for bending properties, cusick drape meter and sharp corner drape meter for drape properties, universal tensile testers for tensile and shear properties, thickness gauges for thickness and compression properties, universal surface tester and Frictorq for friction properties can be listed as commonly used simpler devices for measuring handle related properties of textile materials. Fabric extraction method and devices such as Griff-Tester (Kim & Slaten, 1999; Strazdienė & Gutauskas, 2005), robotic handling systems (Potluri et al., 1995) and various individual devices are some of the other objective measurement systems (Özçelik et al., 2008).

Cantilever stiffness tester supplies an easy way for measuring the fabric stiffness (Figure 13a). In the test, a horizontal strip of fabric is slid at a specified rate in a direction parallel to its long dimension, until its leading edge projects from the edge of a horizontal surface. The length of the overhang is measured when the tip of the specimen is depressed under its own mass to the point where the line joining the top to the edge of the platform makes a 41.5° angle with the horizontal. It is known as bending length (Figure 13b) and from this measured length, the flexural rigidity is calculated by using the formula given below (ASTM D 1388).

$G = 1.421 \times 10^{-5} \times W \times c^3$; where: G = flexural rigidity (μjoule/m), W = fabric mass per unit area (g/cm²) and c = bending length (mm).



(a) (b)

Fig. 13. (a) Cantilever stiffness tester, (b) Bending length (Saville, 1999)

Ring Loop: $l_0 = 0.3183\ L$ $\theta = 157^{o}\ (d/l_0)$
Bending length $C = L\ 0.133\ f_2(\theta)$

Pear loop: $l_0 = 0.4243\ L$ $\theta = 504.5^{o}\ (d/l_0)$
Bending length $C = L\ 0.133\ f_2(\theta) / \cos 0.87\ (\theta)$

Heart loop: $l_0 = 0.1337L$ $\theta = 32.85^{o}\ (d/l_0)$
Bending length $C = l_0\ f_2(\theta)$ $f_2(\theta) = (\cos\theta / \tan\theta)^{1/3}$

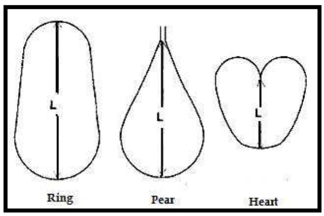
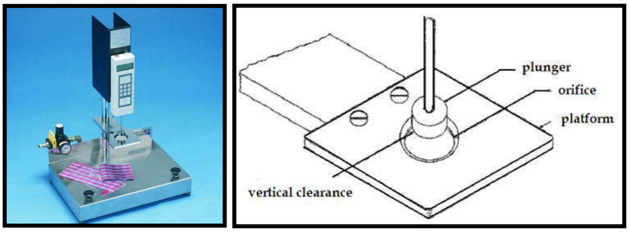


Fig. 14. Different shapes of hanging loops (Saville, 1999)

The cantilever method is not suitable for the fabrics that are too limp or show a marked tendency to curl or twist at a cut edge. The heart loop test can be used for these fabric types. A strip of fabric is formed into a heart-shaped loop. The length of the loop is measured when it is hanging vertically under its own mass (ASTM D 1388–08). The undistorted length of the loop l_o, from the grip to the lowest point is calculated (Saville, 1999; as cited in Peirce, 1930) for three different loop shapes: the ring, pear and heart shapes. If the actual length l of the loop hanging under its own weight is measured, the stiffness can be calculated from the difference between the calculated and measured lengths $d = l - l_0$.

Another instrument which has the same working principle with Kawabata KES-F system is TH 7 bending rigidity tester. The instrument has clamp, which firstly rotates 90° to the front and after that comes to the starting point and moves 60° to the backwards. The required forces to bend the sample in different angles are recorded (Ozcelik & Mertova, 2005).

In circular bending rigidity test, that gives fabric stiffness in all direction, a plunger forces a flat, folded swatch of fabric through an orifice in a platform (Figure 15). The maximum force required to push the fabric through the orifice is an indication of the fabric stiffness (resistance to bending). The circular bend procedure gives a force value related to fabric stiffness (ASTM D 4032 – 08).



(a) (b)

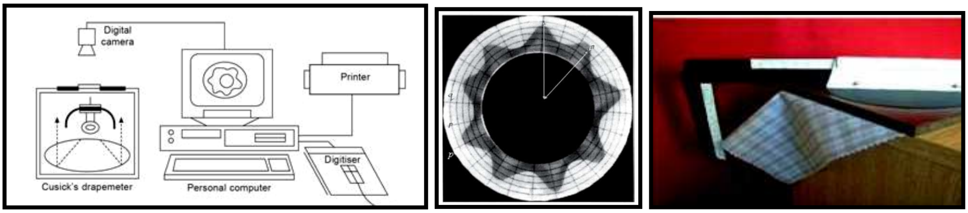
Fig. 15. (a) Circular bending rigidity tester (www.sdlatlas.com), (b) Platform and plunger of the tester (ASTM D 4032 – 08)

Drape is the term used to describe the way a fabric hangs under its own weight (Saville, 1999). Basically, fabric drape is not an independent fabric property. It relates to fabric bending, shear, tensile, fabric thickness and fabric weight (Hu, 2004; as cited in Niwa & Seto, 1986; as cited in Collier, 1991; as cited in Hu & Chan, 1998).

In cusick drape meter, the specimen deforms with multi-directional curvature and consequently the results are dependent to a certain amount upon the shear and bending stiffness properties of the fabric. In the test, a circular specimen is held concentrically between two smaller horizontal discs and is allowed to drape into folds under own weight (Saville, 1999). A light is shone from underneath the specimen as shown in Figure 16a and a fabric drape profile can be captured in a two dimensional image by using a digital camera (Figure 16b). The drape profile can be observed from the computer screen and drape coefficient can be calculated by using image analysis software. The stiffer fabric means that the area of its shadow is larger compared to the unsupported area of the fabric so the higher the drape coefficient is. It is considered that the drape coefficient by itself is not sufficient for the drape characteristic of a fabric (Stylios & Powell, 2003; as cited in Stylios & Zhu, 1997) and therefore a feature vector, consisting of the average minima and average maxima fold lengths and the evenness of the folds is defined (Stylios & Powell, 2003; as cited in Ballard & Brown, 1982).

Measurement of drape angle by means of a special tool (table) is carried out by moving this sample towards the sharp corner of the table, in such way that the axis of the 90°

angle coincides with the warp or weft direction. The fabric motion stops, when the peak of the corner reaches to the center of the sample. Then the fabric folds and forms a direct edge, whose inclination φ against the horizontal plane measured. The sin φ value measured by means of simple ruler (Figure 16c), then characterizes the level of drape (Hes, 2009). The fabric becomes harder as the drape angle gets smaller (Ozcelik et al., 2008; Hes, 2004).

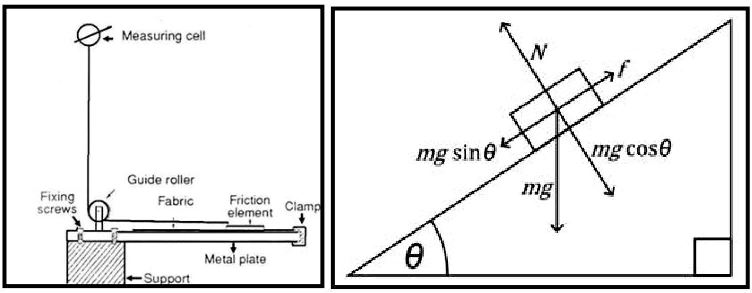


(a) (b) (c)

Fig. 16. The set up for the measurement of fabric drape profile: (a) Image analysis system, (b) Captured image on the drapemeter (Hu, 2004), (c) Sharp corner tester (Hes, 2004)

Friction coefficient is not an inherent characteristic of a material or surface, but results from the contact between two surfaces (Lima et al., 2005; as cited in Bueno et al., 1998). Two main ways are generally used to measure fabric friction. In one of these methods, as shown in Figure 17a, a block of mass (*m*) is pulled over a flat rigid surface, which is covered with the fabric being tested. The line connected to the block is led around a frictionless pulley and connected to an appropriate load cell in a tensile testing machine. This can measure the force (*F*) required both to start the block moving and also to keep it moving, thus providing static and dynamic coefficients of friction from the relation: Coefficient of friction $\mu = F / (m.g)$ (Figure 17a).

The second method used for measuring fabric friction is the inclined plane as shown in Figure 17b. The apparatus is arranged so that the angle of the plane can be continuously adjusted until the block begins to slide. At this point, the frictional force (*F*) is equal to component of the mass of the block parallel to the inclined plane (Saville, 1999).



(a) (b)

Fig. 17. Basic fabric friction measurement methods (Bona, 1994)

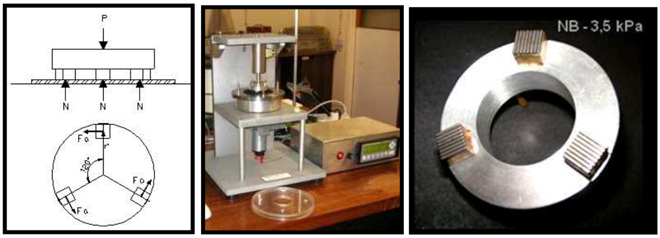
Frictorq is based on a new method to measure the coefficient of friction of the fabrics, using a rotary principle and, therefore, measuring torque. The upper body is a specially designed contact element, restricted to 3 small pads with an approximately square shape (covered by a number of calibrated steel needles), and placed over the fabric sample. This upper body is forced to rotate around a vertical axis at a constant angular velocity. Friction coefficient is again proportional to the torque measured with a precision torque sensor (Silva et al., 2010).

$$T = 3.F_a.r\ ,$$

$$F_a = \mu.N\ ,$$

$$N = P/3 \text{ and } \mu = T/\ (P.r)$$

where, r is the radius of the upper body, P is the vertical load and μ is the coefficient of friction (Silva et al., 2010).



(a) (b) (c)

Fig. 18. (a) Loads in the measurement unit, (b) Frictorq instrument,
(c) The upper body with 3 small pads (Silva et al., 2010)

Haptics, which derive from the Greek word haptesthai, means to touch and refers to simulate the feel of touch in the computer interface area (Govindaraj et al., 2003a). The other touch feedback systems do not have the sensitivity required for accurate simulation of fabric hand. PhilaU Haptic Device was developed to meet these requirements. During the development stage, the device called PHANToM® that uses a pen like probe to scan a virtual surface and generate the feel of surface, was used. By holding a pen with a stylus and moving the pen over a constructed surface in the virtual space, a feed back response was felt on the hand. The limitation of the device was that the contact with the virtual surface was over a line. However, it was possible to gain considerable information about a surface by moving a pencil-point across the surface, therefore it did not provide a tactile feeling (Govindaraj et al., 2003b, as cited in Katz, 1925). In order to overcome this limitation, the PhilaU Haptic Device (Figure 19) was designed as a combination force feed back and a tactile display. The device consists of a feeler pad at the end of an articulated arm joints, which is equipped with magnetic brakes, apply a force feed back to the hand holding the feeler pad assembly. The magnetic brakes get their input voltage proportional to surface friction of the fabric, while the tactile pins follow the contour. Together, the device provides a virtual fabric touch and feels (Govindaraj et al., 2003b).

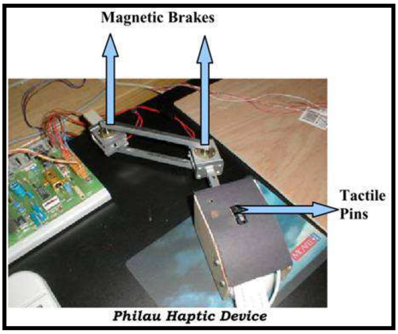
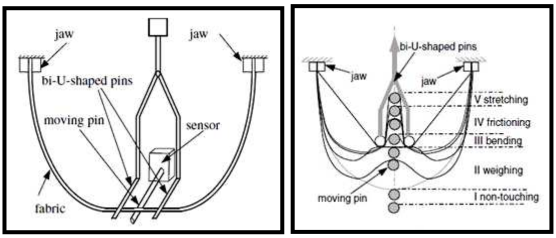


Fig. 19. PhilaU Haptic Device (Govindaraj et al, 2003a)

A robotic system developed by Potluri et al., designed for conducting all the fabric tests on a single sample, without operator intervention can be computed fabric properties such as tensile energy, shear stiffness, bending stiffness and compression energy. Uniform pressure is applied on the fabric sample by a manipulating device, attached magnetically to the robot arm, to avoid possible shear distortion or shear buckling (Potluri et al., 1995).

Several researches have been conducted for measuring the handle related mechanical properties of the fabrics by using universal tensile testers. The comprehensive handle evaluation system for fabrics and yarns (CHES-FY) is a kind of apparatus that is capable of measuring mass, bending, friction and tensile behavior just through one pulling-out test, and is able to characterize the handle of fabrics (Figure 20). The shape of a hung fabric was captured by a digital camera, and its weight was calculated. Then, a three-point bending in principle was utilized to model and analyze the bending properties of the fabric, and the corresponding formula was obtained for calculating the bending rigidity of the fabric (Du & Yu, 2007).



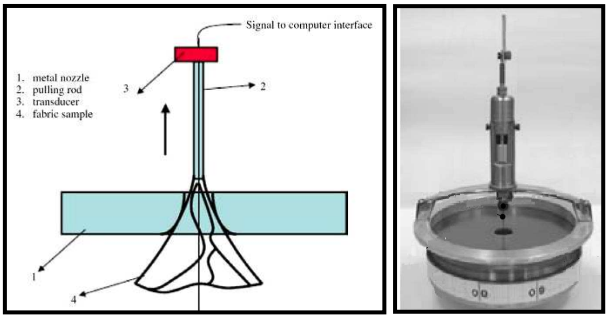
(a) (b)

Fig. 20. (a) A schematic structure and (b) separated extraction steps of the CHES-FY (Du & Yu, 2007)

An alternative simple approach has been investigated by many researchers in order to predict fabric handle from the properties of fabric extraction through a ring or orifice (Wang et al., 2011; as cited in Alley & McHatton, 1978; Kim & Slaten, 1999). Extraction method is based on holding the sample at its centre and then pulling it through a ring of appropriate diameter by using a tensile tester (Yazdi & Shahbazi, 2006; as cited in Grover, 1993). For a properly designed nozzle, if the fabric extraction process is carefully examined, it will be found that during the process the sample is deformed under a very complex low stress state including tensile, shearing and bending as well as frictional actions, similar to the stress state, when handling the fabric (Figure 21a) (Pan, 2006). The behaviour of the fabric during testing is recorded on the load-elongation chart of the tensile testing machine (Yazdi & Shahbazi, 2006). Consequently, all the information related to fabric hand is reflected by the resulting load–displacement extraction curve.

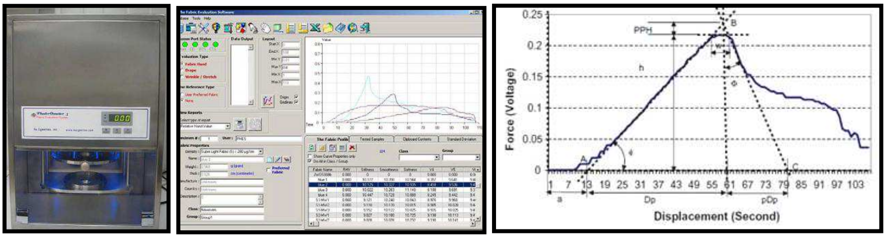
A universal test unit (KTU-Griff-Tester) (Figure 21b) is recently developed as textile hand evaluation method based on pulling a disc-shaped specimen through a rounded hole operating together with either the standard tensile testing machine or an individual drive (Strazdienė & Gutauskas, 2005; as cited in Grover et al., 1993). It allows registration of the specimen pulling force-deflection curve and capturing of the shape variation images of the specimen (Strazdienė & Gutauskas, 2005).

Previously conducted researchers have used only one feature of the curve, e.g. the peak or the slope at a point (Pan, 2007; as cited in Alley, 1976), and discarded the rest of the information (Pan, 2006; as cited in Pan &Yen, 1984, 1992). The PhabrOmeter™ Fabric Evaluation System based on the research by Pan and his co-workers (Pan, 2006; Pan et al., 1993) was introduced. When compared to the KESF and FAST systems, the PhabrOmeter system uses a single instrument capable of testing the low-stress mechanical and physical properties of the fabrics related to the fabric handle. The objective data, obtained from extraction curves are sagging of unloaded fabric across orifice, slope of incline, height of curve peak, position deflection at peak height, post-peak height, width of peak, slope of decline, deflection post-peak height, work area underneath the curve within the triangle obtained from the PhabrOmeter tester (Figure 22). By using these objective parameters, a series of multiple linear regression models are developed and successfully validated to predict eight handle characteristics considered important for the handle of next-to-skin fabrics such as overall handle and primary handle characteristics, such as rough–smooth, hard–soft, loose–tight, hairy–clean, warm–cool and greasy-dry (Wang et al., 2011).



(a) (b)

Fig. 21. (a) The fabric extraction technique (Pan, 2006) (b) KTU-Griff-Tester clamping device (Strazdienė & Gutauskas, 2005; as cited in Strazdiene et al., 2002)



(a) (b) (c)

Fig. 22. (a) Hardware of PhabrOmeter model 3, (b) The user interface, (c) Extraction curve (Wang et al., 2011)

5. The relationship between the subjective evaluation and objective measurement of fabric handle

The subjective evaluation of fabrics leads to a set of linguistic terms strongly related to consumer preference but difficult to be quantized. It depends on many elements from raw materials to finishing processes. However, this evaluation restricts the scientific understanding of fabric performance for those who wish to design high-quality fabrics by engineering means. In the industry, the subjective evaluation is one of the main causes of conflict between producers and consumers on quality of products. Therefore, it is necessary to develop a normalized criterion representing the subjective evaluation or to replace it by an objective evaluation method. From any existing method of objective fabric evaluation, a set of precise quantitative data describing the fabric hand can be obtained but their relationship with the subjective evaluation is not completely discovered. Research has been done for modeling this relationship (Zeng & Koehl, 2003; as cited in Kawabata, 1996; as cited in Hu, 1993). However, progress in this field is rather slow because of the existence of uncertainties and imprecision in subjective linguistic expressions and the lack of mathematical models that constitute a nonlinear complex system for explaining the relationship between subjective and objective data, that, where no mathematical models are available (Zeng & Koehl, 2003).

Numerous methods such as Steven`s law, rank correlation, linear regression model, multiple-factor analysis, weighted euclidean distance, component analysis, decision and information theory, canonical correlation methods and as intelligent techniques fuzzy logic–based methods, neural network statistical models and mathematical models have been introduced for the generation of a quantitative criterion characterizing the quality of textile products and modeling relationships between the subjective fabric hand evaluation and objective numerical data. Since all these methods require tedious computations and are thus inappropriate for providing quick responses to consumers, in recent works fuzzy comprehension evaluation, neural network aggregation of data, classification methods are widely used. Advantages of these techniques can be stated as computing with numerical data and words, computing with uncertainty and imprecision, taking into account nonlinear correlation, computing with few numbers of data (Bishop, 1996; Hui et al., 2004; Bakar, 2004).

The modeling and the simulation of textile fabrics represent an important field of scientific research. Several disciplines involve in this field, such as mathematics, mechanics, physics, and informatics. This activity of research aims to produce simulations of textile fabrics behavior with more realism while remaining faithful to the physical and mechanical properties of this type of materials (Hedfi et al., 2011).

6. Conclusion

In this chapter, fabric sensorial comfort which has been studied by many researchers since the early 1900s, was dealt with in detail. As the studies are analyzed, it can be stated that, the previous studies generally focus on subjective evaluation whereas, in the last decades new objective evaluation methods and techniques simulating human tactile feeling and prediction methods are developed. It seems, as being an interesting research area, sensorial comfort will continue to attract the attention of researchers in the future.

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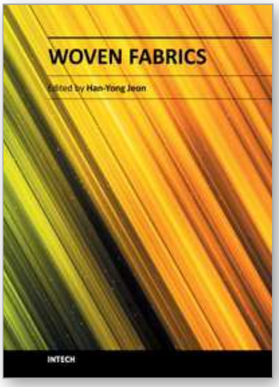

Woven Fabrics

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"Woven Fabrics" is a unique book which covers topics from traditional to advanced fabrics widely used in IT, NT, BT, ET, ST industry fields. In general, woven fabrics are known as the traditional textile fabrics for apparel manufacturing and are used widely in various fabric compositions as intermediate goods that affect human activities. The relative importance of woven fabrics as traditional textile materials is extremely large and currently application fields of woven fabrics as technical textiles are rapidly expanded by utilizing its geometric features and advantages. For example, the book covers analytical approaches to fabric design, micro and nano technology needed to make woven fabrics, as well as the concept for industrial application.

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