# REVIEW ON COMPRESSION PROPERTIES OF TEXTILE MATERIALS

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***Abstract:*** One of the property measured for objective evaluation is compression property. Kawabata system characterizes compressional energy (WC), the linearity of the compression/decompression curve (LC) the resilience (RC) and the percentage compression (%C). FAST-I compression meter has been developed to measure fabric thickness at two loads of 2gf/cm$^2$ and 100gf/cm$^2$. Many authors defined the compression property. Various authors work done were presented in this paper. Types of fabrics tested were also given here. The importance, suggestions of future research and an understanding of work done by various authors were presented. It may be noted that holes which occur after repeated compressional deformations should be studied. All the discussions and conclusion reveal the very important aspect of compressional property.

***Index Terms***; compressional property, fabrics, fibres, helical filament, yarns, equipment.

## 1. Introduction

A Chapter on compressional resilience is included in Kaswell's classic book on. "Textile Fibers yarns and fabrics" obviously due to its importance in contributing to the hand of the fabric. It is stated by him that a considerable work must be done on this area to have a better understanding of the role of fibre and the fabric structural properties on the hand and compression. A number of papers have been published on the yarn and fabric compression, but in none of these the effect of fabric structural parameters on the compression have been considered. The use of KES compression tester has been found to be very important, and this chapter highlights these aspects. Compressional properties play a very significant role in the handle and comfort characteristics of fabrics. Consumers prefer a fabric with a soft feel rather than a fabrics with a hard feel. Recent research findings have proved that the compressibility is a principal component in quantifying the handle of fabrics. Kawabata system characterizes the compressional characteristics using four different parameters such as the compressional energy (WC), the linearity of the compression/ decompression curve (LC) the resilience (RC) and the percentage compression (%C). The higher the WC values, the more the fullness and the compressibility of the fabrics.

The higher the RC values, the more springy the fabric and the better hand. Thinner fabrics have higher RC values. This obviously results in soft feel and better comfort properties. Handle could also be defined with the help of percentage compression values; the higher the percentage compression values, the higher the softness of the fabrics and the handle characteristics.

The relevant outputs from the KES compression tester for the two fabrics are given in Fig.1 to illustrate the differences that are existing in them.

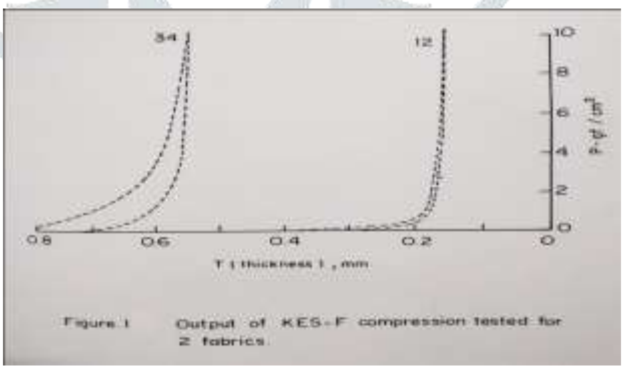


Figure 1 Output of KES-F compression tested for 2 fabrics

## 2. Definition

### Compression of Fabrics

Compressional deformation is the result of the opposing forces applied from two sides of the fabric in a direction normal to the plane of the fabric. The surfaces of the fabric are typically highly compressible (Mahar 1988). Hearle (1967) has defined compression as the decrease in intrinsic thickness with an appropriate increase in pressure and compressibility as the ratio of compression to intrinsic thickness expressed as percentage. A list of methods used for measuring compression of fibres is provided by Oxenham (1974).

Hebert et al. (1963) defined compressional resilience as the ratio of energy expended by the fabric in recovering from the deformation to the energy absorbed in deforming a fabric.

Several research workers developed different methods for determining the compressibility of fabrics. Schiefer (1933) used the compresso meter for evaluating the thickness compressibility and compressional resistance of textiles.

Knapton and Lo (1975) suggested a method to measure the compressional property of fabrics by using thickness gauge at several pressures. The measurement of the lateral or thickness compression properties of fabrics forms an integral part of objective measurements (de Jong et al. 1986).

FAST – 1 compression meter has been developed to accurately measure fabric thickness at two loads of 2gf/cm$^2$ and 100gf/cm$^2$ (Allen et al., 1989, Tester and DeBoos, 1989).

Although the FAST system does not make a quantitative estimate of fabric handle, measurement of fabric thickness, surface layer thickness, and relaxed surface layer thickness gives an indication of the appearance and handle of the fabric.

Kawabata Evaluation System (KES-F) gives the complete hysteresis of compression curves and LC, WC,RC, To, Tm Values were obtained from the output datas.

Hebert et al. (1963) related the results of wrinkle recovery test and the compressional resilience of fabrics since they are manifestations of phenomenon elasticity, viewed from, different aspects. A high correlation exists between wrinkle recovery and compressional resilience.

Samson 1972 in a work on compression of plain woven woolen fabrics by the flow of water, found that dry fabrics offered slightly more resistance to compression than the equivalent wet layers.

De jong et al. (1986) presented a mechanical model that describes the compression curves measured on a large number of woven fabrics over the pressure range of 2 to 5000gf/cm$^2$. The model reduces the fabric to three layers – a relatively incompressible core layer in contact with a more compressible surface layer on either sides.

Kothari and Das (1993) studied the compressional behavior of spun bonded non-woven fabrics. The compressional behavior of fabrics has been characterised by evaluating two parameters α and β representing the compression and curves respectively.

Matsudaira and Qin (1995) analysed the compression curves by approximating to linear and experimental equations. Theoretically calculation was made and it agreed well with the experimental value. Principal component analysis was carried out and the nature of slope on every region was considered to study the behavior of fabrics due to compression.

Kothari and Das (1993) developed a new compression tester with load cell and LVDT and continuous compression curve plotting was made. Conventional method of calculating the compression curves was compared with the computerized compressional curves.

**3. Various work done on compressional property**

Various work done available for measuring compression properties are objective evaluation of fabric handle with Kavabata's evaluation (25), study of mechanical properties for silk fabrics (41), CSIR Inter-laboratory trial with poor reproducibility of KES-F (37), Fabric quality evaluation in KES-F system (7), Comparison of KES-F and FAST instruments (59), Thousand samples handle evaluation in KES-F with translation formula (28), Multivariate analysis method (9), Theoretical and experimental determination of design of textile structures (20), Slope of curves for compressional property (42), Compression energy function (33), Load compression relation (34), Compression of helical filament under distributed forces (35), Compression modulus (12), Resistance to abrasion (21), Lateral compression (38), Lateral compression modulus of fibres (45), Elastic modulus in lateral compression (6), Transverse compression (8), Compression modulus and strain analysis(50), Compression of mono filament (3), Initial modulus in compression (43), Transverse compression and strain behavior of monofilaments (16), Filament compression modulus (18), High compression of textile fibres (30), compressibility and resilience of fibrous materials (51), Bulk compression resilience of man made fibres (58), Bulkometer instrument for fibres mass (44), Bulkness and compressibility of wool (13), Relation between fibre and yarn compression (10), Acoustic impedance on compression of fibre masses (14), Measuring of yarn softness (54), Diameter and compressibility of wool yarns (2), Thickness and compression of yarns (47), Factors affecting thickness and compressibility of worsted spun yarns (46), Compression and recovery properties of continuous filaments and staple fibre yarns (49), Percent compression and permanent set compared in Instron tensile tester (27), Van wyk's model study on compression of yarns (40), Textile compressional resilience new tester (41), Initial compressional behavior of fibre assembly (42), Note on compressibility of wool (43), Theory of compression resistance (49), Studies on compressional behavior of non-woven fabrics Part I (31), Part II (32), Modelling of two component yarns Part I (23), The influence of natural variation of fibre properties of bulk compression of wool (11), A new method of fabric objective measurement (56), The effect of regain variation on fabric finishing and fabric mechanical properties (55), Effect of RH% for compressional properties (52), Surface modification of polyster fibres (24), Lateral compression of ring and rotor spun yarns (26), A poisson model of non-woven fibre assemblies in compression at high stress (53), Handle of double jersey fabrics (22), Knitted fabric compression properties (1), Compression properties of polyster fibre shingosen fabrics (39), Simulation theory of two component yarns (19), Compression tester (4) (48) (5), Compression of grey state fabrics as a function of yarn structures (15).

**4. Types of fabrics tested for compression property**

Viscose, Acetate, Nylon, Silk, Polyster, Wool, Wool blend, Cotton, P/C, Linen, P/W blend, Commercial fabrics, Suitings, Polypropylene, Polyurethane, PET Nylon, Aramid, Worsted, Acrylic, Nylon spectra, Kevlar, Fibre glass, Shingosen fabrics, Rubber filaments were tested for compression property by various authors.

**5. Importance of compression property**

The compression property is measured in axial direction of fabrics. Ironing is done to have good appearance while wearing the garments. The mechanism of ironing should be fully understood. First the surface fibre gets compressed. Then the air pockets in the fabric are filled with fibres. After that the yarns tend to form oval shapes. At this point it may be noted that the thickness is reduced. Further application of pressure deforms fibres, twist in yarn, breakage of fibre, slippage of fibre from yarn and structural damage and holes results. So compression while wearing garment and ironing requires much care. Compression breaks fibres which after washing becomes pills over the fabric. After the fibre break, the air permeability reduces and hence comfort is less. Structural damage make the garment awkward. Hoes production ends the life of the garment. Compression squeezes out the dyes present in the fibre and it makes the places ugly. So with this discussion how important is the compression property could be understood.

The fabric is classified as light, medium and heavy gsm types. Different thickness shows different compression curves. According to the application of garment compressibility of fabric must be analysed and used in market. The different combinations of fibres should be tried to suit the need of the customers. Compression is analyzed for fibres, yarns, fabrics, helical filaments, low load compression, high load compression, different treated fabric compression, heat effect on compression light effect on compression, Atmospheric effect on compression and other affecting criterias. These make the garment more durable and high usage is effected.

**6. Suggestions for future research**

The compression property of application types such as sportswear, shirtings, suitings, ladies wear, kidswear can be determined and it can be used for quality purposes. Multiple compression and its effect on tensile properties could be carried out. Different fabrics with many types of fibres can be analysed for compression property. A study of lateral compression of fabrics under extension is warranted in order to study the complex deformations. Various chemical treatment, light effect, colour fading, atmospheric deformations on compression property can be determined.

**7. Understanding of work done by authors**

**Compression of a helical filament**

When two yarns intersect as in wearing or knitting, the inter yarn forces produced tend to compress the yarns: yarn compression takes place as the result of the application of compressive forces distributed along a line parallel to the yarn axis. These forces can be theoretically analysed.

**Compression of fabrics**

It is the result of the opposing forces applied from two sides of the fabric in a direction normal to the plane of the fabric. Compressibility is the ratio of the rate of decrease in thickness to a pressure of one pound per square inch to the standard thickness. It can also be defined as the change in volume under a change in pressure. Kawabata designed an instrument for measuring the compression of fabrics under a pressure of 0.5 to 50gf/cm$^2$. The complete hysteresis of compression and decompression curve is obtained from the instrument. FAST-I compression metre has been developed to accurately measure fabric thickness at two loads of 2gf/cm$^2$ and 100gf/cm$^2$.

**Compression of fibres and fibre assemblies**

The fibres are compressed at higher twist factors in a yarn. Textile fibres range in diameter between 10 to 50μm and are elastic under all strains of the order of 1 to 2% Lateral compression modulus of a single fibre is determined with special apparatus. Instead of determining single fibres compression property, fibre masses compression properties have been determined. Fibre mass is compressed between a cylinder and a piston.

**Compression of yarns**

Number of workers has studied the compression of yarns by different techniques. In many of the methods, the yarn is subjected to a compressive load through the load layer. An apparatus for measuring yarn softness in terms of the percent increase in yarn width has been reported, where the yarn is subjected to lateral pressure between two parallel plane surfaces. By means of an optical arrangement, the vertical distortion of the yarn is magnified and readings are taken. Yarn compression behavior has also been determined on the Instron tester employing the parallel plates. KES-FB3compression tester, which is commercially available, is now used for measuring the lateral compression property of yarn.

The parameters to represent compressional properties is given in table I.

**Table I**

**Compressional Parameters**

| S.No. | Parameter | Author |
|---|---|---|
| 1 | Compression modulus | Denby (1961) |
| 2 | Percent compression | Mason (1966) |
| 3 | Transverse compressive modulus axial tensile modulus longitudinal and transverse modul ratio | Phoenix and Skelton (1974) |
| 4 | Transverse compressive modulus | Bendit and Kelly (1978) |
| 5 | Elastic modul in lateral compression | Batra and Syed (1975) |
| 6 | Compressional energy function | De Jong (1977), Postle (1971) |
| 7 | Thickness index, compression index | Onions et al., (1967) |
| 8 | Yarn diameter at various pressures | Oxenham (1974) |
| 9 | Specific volume of fibre mass | Chauduri and Whiteley (1968) |

**Compressional properties of yarns & fabrics**

Several workers have defined the term resilience in different ways as:-

- The ratio of work of compression to work recovered
- The ability to absorb work
- The energy returned after compression and
- The area of hysteresis loop

Compressibility has been also defined in many ways as the change in volume under a change in pressure, the volume or density at a specific pressure. Other terms such as, specific volume, pliability and softness have also been used.

Compressional properties of yarn and fabrics are measured in terms of compression work (WC), work recovery (WC), resilience (RC) and linearity (LC) in KES-FB 3 compression tester of compression tester (Kawabata, (1980). Other parameters, which have been used are thickness, resilience, crush factor, hardness and compression modulus, hardness index for fabrics (Knapton and Lo,(1975)), percent compression and permanent set (Kaswell et al.,(1961).

A mechanical model of fabric in compression has been suggested using Van Wyk's model and the incompressible layer and its magnitude has been identified (de Jong, (1977). The compressional resilience is a measure of recovery (Fox and Schwarz, (1941).

Thickness index can be taken as a measure of bulk, since it is measured at a smaller strain. The parameter, percent compression, is a dimensionless parameter, which is capable of giving an account of the incompressible layer at very high loads. The parameters WC, LC and RC, which are obtained from the pressure-thickness curve, have also been found to represent the compressibility of yarns. It may also be noted that what is measured in the case of yarns is the minor yarn diameter in lateral compression studies.

**Mechanism of Lateral Compression**

Theoretical studies have postulated that the compressive strain of the fibre assembly is translated directly into the bending strains in the individual fibres and that the resistance of the assembly to an externally imposed strain arises solely from the resulting increase in bending energy in the fibres. Other workers have recognized, however that the compression of fibrous masses causes large and significant fibre to fibre slippage, much of which is irreversible. Carnaby (1980) has predicted the compression hysteresis by classifying all the fibre contact points in the fibre assembly as either slipping or nonslipping.

Based on these fundamental principles, an attempt has also been made to explain the compressive resilience of yarns. When the yarn is compressed, there is a reduction in minor diameter 'b' in direction of compression and an increase in the major diameter 'a' in the direction perpendicular to compression in Figure 2. While the reduction in 'b' that would cause fibre concentration is termed "consolidation"' the increase in 'a' is termed "spreading". The fibre consolidation during compression mainly translates the compressive strain into bending strain. On the other hand, the fibre spreading is mainly frictional phenomenon causing fibre to fibre slippage. While the stored energy during consolidation would help in improving compressive resilience, the loss in energy during spreading would cause a reduction in compressive resilience.

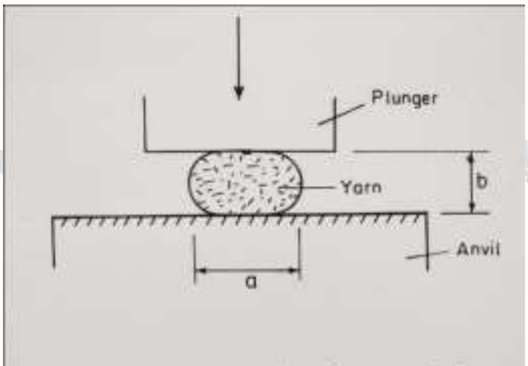


**Figure 2** Cross-section of a yarn during compression.

The consolidation mainly depends on yarn packing, and the spreading on fibre locking. If the fibres are closely packed in a yarn, further consolidation is hardly possible. Any improvement in fibre locking, which has got direct relationship with fibre migration, will restrict spreading. When restriction to one of these phenomena (i.e., either to consolidation or to spreading) increases, the other phenomenon will dominate during compression.

Jayachandran (1992) had done work on lateral compression of ring and rotor yarns. Lateral compressional energy of rotor yarns is higher compared to ring spun yarn. Leaf and oxenharn (1981) derived expressions for compression-energy function. Ly (1984) had done work on bending of a helical wool fibre. Leaf and Tandon (1996) had done work on compression of a helical filament under distributed forces. Sandhya (1994) has shown that compressional energy WC shows an increase with increase of humidity and pick density while compressional resilience shows a drop. Bishop et al., (1998) have described a new yarn bundle compression test to quantify changes in the fibre buckling properties.

**Equipments used**

In practical terms, the extension or stress applied to woven fabrics during manufacturing finishing, garment construction and wear are generally within the low-stress region of their characteristics stress strain behavior. The major stress involved in fabric deformation under low stress conditions are tensile, bending, shear and compression. Thus the analyses in the present work are based on the charts and mechanical properties tested on the Kawabata Evaluation System (KES).

The KES is a new testing methodology that has been used for fabric objective measurement. The KES system consists of four precision instruments originally designed to measure key mechanical properties related to the hand, drape and formability of fabrics. All samples were tested in both warp (wale) and weft (course) directions for:

1. Tensile and shear properties
2. Pure bending properties
3. Compression properties and
4. Surface and friction properties

Compression tester

Max. Stress : $50gf/cm^2$

Area of compression : $2cm^2$

Rate of compression : 1mm/50sec

In the compression test, a standard area of the fabric is subjected to a known compressive load and then the load is gradually relieved. The load is applied through a movable plunger that moves up and down and compresses the fabric on a stationary platform. The following mechanical parameters characterize the comparison and recovery behavior of the fabric:

$T_0$ - Fabric thickness (mm) at a very low compressive stress of $0.5gf/cm^2$

$T_m$ - Fabric thickness at a maximum compressive load of $50gf/cm^2$

WC - Work done in compression represented by the area under the compressive curve

RC - Compressive resilience is the work recovered to the work done, expressed as percentage

LC - Compressive linearity is a measure of the deviation of the deformation curve from a straight deformation curve from a straight line. Higher values of LC imply a higher initial resistance to compression. In general, all fabrics have low values of linearity compared with tensile testing. Values ranges from 0.25 – 0.36

**Table II**

**Mechanical properties measured on the KES System**

| Blocked Properties | Symbols | Characteristics value | Unit |
|---|---|---|---|
| Compression | LC<br>WC<br>RC | Linearity<br>Compressional energy<br>Resilience | -<br>Gf.cm/cm$^2$<br>% |
| Thickness | $T_o$ | Thickness at 0.5gf/cm$^2$ | mm |
| | $T_m$ | Thickness at 50gf/cm$^2$ | mm |

**Factor analysis to compressional property**

KES-F was used for the determination of compressional properties. KES-F system gives LC, WC, RC, $T_o$ and $T_m$ values for the compressional property. Also compression curves could be obtained from KES-F system. The compression process of the fabric is considered to consist of three parts. The first step of the compressional curve is the linear region and is assumed to follow the regression line equation (1) as shown below. The second step is the non-linear region and is assumed to follow the exponential curve [3,4] equation (2) as shown below. The third step is the linear region and is assumed to follow the regression line equation (3) as shown below. The first step of the recovering curve corresponds to the region of elastic recovery and is assumed to follow the regression line equation (4) as shown below. The second step corresponds to the region of recovery from inter-fiber and/or inter-yarn friction and is assumed to follow the exponential curve in equation (5) as shown below. The third step is the region at which instantaneous recovery is impossible. These regression curves are shown as follows:

$$Y = a_1+b_1x \quad \ldots(1)$$
$$Y = a_2\exp(b_2x) \quad \ldots(2)$$
$$Y = a_3+b_3x \quad \ldots(3)$$
$$Y^{/} = a_4+b_4x \quad \ldots(4)$$
$$Y^{/} = a_5\exp(b_5x) \quad \ldots(5)$$

Where Y = compressional force (gf/cm$^2$)
$Y^{/}$ = recovering force (gf/cm$^2$)
X = deformation (mm)
$a_i,b_i$ = regression constants

**Alternative method of studying compression of fabrics**

In this method, the thickness values of fabrics obtained at different pressures are taken and the ratio of $t/t_0$ is computed where $t_0$ is the initial thickness and t the thickness at any pressure. Similarly, $\sigma/\sigma_0$ is computed, where σ is any pressure, and $\sigma_0$ is the initial pressure. λ, which is equal to $t/t_0$, is plotted against $\sigma/\sigma_0$ and it is evident that at '0' pressure, λ should be equal to 1. In other words, the value of λ can reflect on the compressibility and the lower the value of λ, the greater the compressibility. Figure 3 shows the relationship between pressure and thickness.

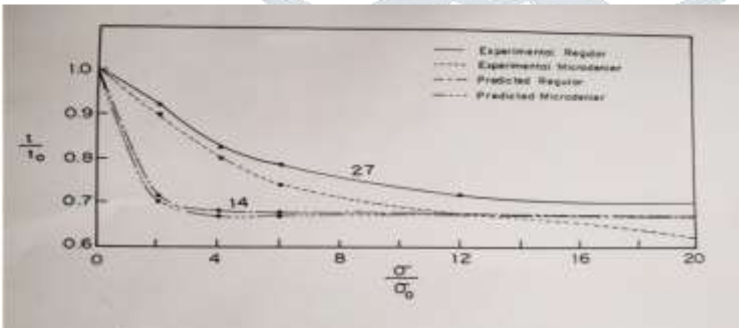


Figure 3 Relation between force and thickness

**Low load compression behavior of fabrics**

A typical pressure thickness curve in low load region for a woven fabric is shown in figure 3. the initial compression region has a very low modulus and is then followed by a rapid increase in the slope. The very low-modulus part of this curve indicates that fabrics are easy to compress in very low load conditions. The resistance to compression of the fabrics increases rapidly with the increase in the compression load. In addition, it can been seen that the latter part of such a curve under a pressure greater than a certain value, usually 6gf/cm$^2$ (0.62 Kpa) is close to a straight line is extremely high, which indicates that fabrics are extremely incompressible under a pressure greater than 6gm/cm$^2$. This shows that compared to the pressure used by Hu and Newton (1977), polyster fabrics can be compressed still at a lower pressure.

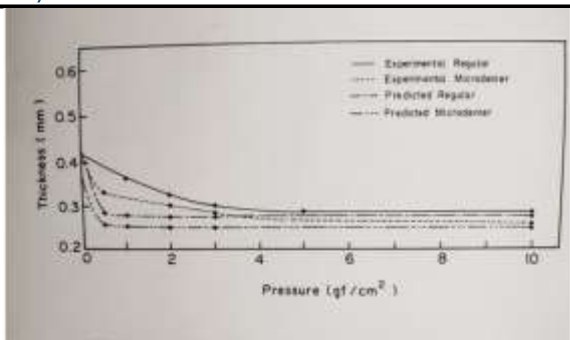


Figure 4 Pressure thickness curve for predicted and experimental regular and microdenier fibres

**VanWyk's law**

De Jong et al., (1986) assumed that the comparison behavior of woven fabrics is related to that of general fibre assemblies. According to VanWyk's law (VanWyk 1946; Carnaby 1980) the pressure-thickness relationship of fibre assemblies is as follows.

$P = a\,(1/(v-v^{/})^3) - (1/(v_0-v^{/})^3)$

Where v is the volume of the fibre mass, and $v_0$ is the value when the pressure P=0, i.e. $v_0$ is the volume of the fibre mass at zero pressure and $v^{/}$ represents its limiting volume at large pressures. In the above equation, if the value of P represents the pressure on unit area of fabric, v equals the fabric thickness at t. The thickness t or volume per unit area of a fabric is large and undefined at zero pressure.

**Comparison of a helical filament under distributed forces**

Tandon (1988) has presented a theoretical study of the large scale compression of helical filaments (the component of the helix model of the yarn) under the action of radial forces distributed along the length of the helix.

A general and complete set of equations of equilibrium of a helical filament compressed by distributed forces are deduced which are used to solve the various cases of helix compression that originate by selecting different combinations of the constraints that are imposed on the helix at its ends (eg., heix is/is not prevented from rotating at its ends and is/is not prevented from extending axially). Both uniform and non-uniform distributed loadings are considered, computer programs are developed and a large number of numerical results are obtained, which describe, for example, how the compression varies with the fraction of the helix length over which the load is distributed, and with the magnitude of the distributed load. These results are then used to deduce empirical formulae which relate the compression energy and the 'principal' strains with the magnitude of the applied forces and the helix angle.

**Study of compressional parameters by principal component analysis**

An analysis of the compression curves obtained from the Kawabata compression tester by factor analysis has shown that $B_3$, $B_4$ WC, $T_0$, and $T_0$-$T_m$ have positive loadings. This repertoire has shown that it is enough if these parameters are measured in order to have a complete characterization of fabric compressional properties.

**Compressional resilience of fabrics**

Prediction of load-thickness curves of fabrics has been done by using Van Wyk's model. The low load lateral compression of fabrics made of polyester blended fabrics has been studied which demonstrates clearly that a considerable amount of compression occurs at very low pressures of 6gf/cm$^2$. Although the surface structures of wool and polyster fabrics are quit different, it is suggested that the power function proposed originally by Van Wyk be applicable to polyester blended fabrics as well as wool analysed by de Jong. The fit of the equation is found to be approximate. An interesting observation is that the incompressible core layer possesses 68% of the whole fabric thickness. This implies that fabrics are highly incompressible.

**8. Discussion**

Compression takes place while sitting, lying down, sleeping and in many other ways in practical situations. All work done by many authors gives better understanding of compressibility of garments. The compressibility is analysed for fibres and fibre assemblies, yarns, fabrics, helical filaments and many theories were proposed. The mechanism of lateral compression were explained. Equipments were used to analyse compression property. Factoral analysis method, alternative method, low load compression of fabrics, Van Vyk's theory, compression of helical filaments under distributed forces, study of compressional parameters by principal component analysis and compressional resilience of fabrics, works were done and they are given here. The occurrence of hole in the fabric is very serious defect while wearing the garment Without abrasion holes occur. The weakest places on fabric, yarn and fibre tends to break and forms hole due to compression. So by analyzing the compressional property using any of the instruments good amount of quality can be obtained in garments.

**9. Conclusions**

Using various work done by the different authors, the compressional values can be used as standard for avoiding holes in fabrics. The work required is the procuring data for all types of fabrics and producing new standard so that no holes occurs in knitted or woven fabrics while wearing the garment. Many countries produce standards on their own and this important property can be used for quality purposes.

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