NOVEL APPROACH TO STUDY COMPRESSION PROPERTIES IN TEXTILES

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Abstract

Data analysis of a fabric's compression properties can only be done when the limits of compression are known. The best formula is van Wyk's, although the meaning of the physical parameter is still not clear. On the basis of van Wyk's equation, a study of the compressibility of woven fabrics can be initiated in partnership with Pierce, Kemp and Hamilton's approach for circular yarns and the flattened yarns of a fabric under pressure. Neural network models promise to solve the drawbacks of de.Jong's and other models. The fit of the pressure-thickness relationship may be improved by using exponential function and the Iterative method, such as Marquardt's algorithm for evaluating compression properties. Back-propagation promises to give better results, since the KES-FB3 compression measuring instrument works by minimising error levels. The optimisation of low-stress mechanical properties is possible by using trained networks, and this venture forms an absolute method for comparing the functional properties of fabrics.

Key words:

compression, back-propagation, incompressible volume, compressional energy

Introduction

Compression may be defined as a decrease in intrinsic thickness with an appropriate increase in pressure. Intrinsic thickness is the thickness of the space occupied by a fabric subjected to barely perceptible pressure. Compression is one of the important properties of fabric, in addition to friction, bending, tension and shear. In garment automation, for instance, compressibility can be a crucial property for successfully separating plies from a stack. With the growing need for better modelling material for simulation purposes, objective measurements of fabric compression will become increasingly important, since static compression gives an indication of the material's mechanical 'springiness'. A fabric that compresses easily is likely to be judged as soft, possessing a low compression modulus or high compression. Any surface changes in the fabric such as singeing, milling, or pressing, which are generally used to improve the hand, will therefore have an essential impact on the compressibility.

Modelling the compressional behaviour of a woven fabric under pressure would basically involve understanding the relative change in thickness under applied pressure. The compressive force applied allows the yarn to undergo deformation non-linearly, resulting in a change in thickness of the fabric. This change depends on a number of factors which need to be investigated in detail.

The low-load compression behaviour of woven fabrics is very important in terms of handle and comfort. In transforming fabrics into clothing articles, one has to know, as well as the manner of processing, how the fabric will behave during particular manufacturing processes and when exposed to various strains. The answers to these questions may be obtained by investigating fabric mechanics, such as non-linear mechanical fabric properties at lower strains, which is the case in transforming fabrics into garments. The area of structural deformation during processing is quite wide.

Fabrics are exposed to various strains when processed into clothes and behave in different ways. Fabrics are stretched when spread, they are exposed to compression during the cutting operation because of the vacuum present, and in sewing they are transformed from two-dimensional structures into three-dimensional articles of clothing. In surgical compression, the garment's softness of fabric is important for two principal reasons. The fabric should minimise skin irritation during prolonged wear, and has to maximise the chances for the patient to comply with the extended plastic surgery recovery period. This is also the case with non-woven diaper cloths, where compression is very important, apart from the properties of the inner fabrics. The creation of a fabric which is soft, but still meets compression needs, was one of the main objectives behind the design of ComfortWeave. The softness of a fabric can be objectively measured by the Kawabata Evaluation System (KES). This ES is a weighted-regression analysis combining 17 factors measured in five separate tests, including compression, shear, tensile, bending and surface tests. ComfortWeave possess KES values similar to those of knitted silk. PowerWeave, the generic fabric used in most other compression garments, ranks close to emery cloth, a fine grade of sandpaper.

The low mechanical stress properties of fabric also influence the clothing manufacturing process. Seam pucker, pattern matching, long seam sewing, shape retention and pressing are known to be influenced by tensile properties (LT, WT, ET, and RT). Formability and drape is known to be altered by changes in shear and bending properties (G, 2HG, 2HG5, B, 2HB). Garment hand and appearance is influenced by surface (MIU, MMU, SMD) and compressional properties (LC, WC, RC).

Primary hand includes components of total fabric hand (THV) and represents characteristics of stiffness, smoothness, etc. Kawabata et al. have developed an evaluation system for fabric hand, relating subjective standardised hand values obtained by ranking the fabric's experimentally-measured mechanical and surface properties.

Theory on compression of textiles

Compression has been the subject of many studies, but a great number of Investigations have been empirical. The simplest but most realistic theory seems to be that of van Wyk, which is based on the assumption that fibres simply bend as cylindrical rods. The equation relates the applied pressure *'P'* to the inverse cube of the volume *'v'* and the intrinsic volume *'*v_o*'* as follows:

$$P = k_1 Y \left(\frac{m}{\rho}\right)^3 \left[\frac{1}{(v)^3} - \frac{1}{(v_o)^3}\right] \quad (1)$$

The equation is independent of fibre diameter or elasticity, but includes Young's modulus *'Y'*, the mass of the fibres *'m'* and the bulk density *'ρ'* at low pressure. In addition, the equation comprises a dimensionless constant *'*k_1*'* characterising the fibres. This constant, which is generally of the order of 0.01, will vary with the fibre orientation and crimp, and can only be determined if Young's modulus is known independently. This constant 'k_1' and Young's modulus are the dominant parameters in distinguishing the compression of different kinds of fibres in bulk.

From the point of view of engineering mechanics, the non-linear relationship is a clear indication of elasto-plastic deformation, and the cross-section deforms in both the elastic and plastic ranges. Fabric compression involves the movement of fibres and yarns within the diameter axis to which the fabric is oriented. This behaviour is accounted for by studying the fabric's internal non-linear structure, the visco-elastic nature of the fibres themselves, and to some extent the friction between fibres and yarns.

In spite of its usefulness, van Wyk's model has some limitations. The real physical meaning of the 'k_1' constant is undetermined, and the model does not take into account the hysteresis caused by fibre slippage and friction during every compression and decompression cycle. The equation suggested by van Wyk was only suitable for moderate compressive pressures. At larger pressures, the incompressible volume 'v'' was neglected. In order to fit van Wyk's equation to the experimental data, some researchers reduced the order of the formula to 2.5 instead of 3.

Van Wyk himself has made corrections to the equation, and suggested a more elaborate one to include the incompressible volume, this bringing about a new equation, as follows:

$$P = k_1 Y\left(\frac{m}{\rho}\right)^3\left[\frac{1}{(v-v')^3}-\frac{1}{(v_o-v')^3}\right] \quad (2)$$

Van Wyk's equation can be implemented in different forms, First, by using the original Equation 1 which was derived directly from the compression of wool wads, the data would fit close to experimental curves, though deviations may exist. This may be accounted to the omission of the incompressible volume 'v' " which becomes significant when compressing fibre assemblies to a small enough volume(P > 0.5cN/cm^2). Either v_o, which is the volume at zero pressure, is relatively high compared to '*v'* and can therefore be ignored, or *v*, *v'* and v_o have the same order of magnitude and so cannot be neglected.

In addition to van Wyk's equation, there are numerous empirical equations relating the thickness of a fabric to the pressure applied. Hyperbolic functions give the best empirical results, but exponential smoothed curves are also credible.

From these equations, compression energy can be calculated from *'0'* to *'P'*. If *Vo* is higher than *V* and *V'*, then

$$P \approx a\frac{1}{(v-v')^3} \text{ with } a = KY\left(\frac{m}{P}\right)^3 \quad (3)$$

$$W = -\int_0^p p.dv = -\int_{vo}^{v}\frac{a}{\left(v = v')^3\right)}dv \quad (4)$$

$$= \frac{a}{2}\left[\frac{1}{(v-v')^2}-\frac{1}{(vo-v')^2}\right] \quad (5)$$

Still supposing that *Vo* is high in relation to *V*,

$$W = \frac{a}{2}\left(\frac{1}{(v-v')^2}\right) = \frac{p}{2}(v-v') \quad (6)$$

or

$$v' = v - \frac{2w}{P} \text{ and } a = \frac{8w^3}{p^2} \quad (7)$$

As far as we are concerned, we do not believe that *vo* is very high compared with *v* and *v'* , so

$$P = a\left[\frac{1}{(v-v')^3}-\frac{1}{(vo-v')^3}\right]. \quad (8)$$

$$W = -\int_{vo}^{v}\frac{a}{(v-v')^3}dv + \int_{vo}^{v}\frac{1}{(vo-v')^3}dv \quad (9)$$

$$= \frac{a}{2}\left[\frac{1}{(v-v')^2}-\frac{1}{(vo-v')^2}\right] + a\frac{v-vo}{(vo-v')^3} \quad (10)$$

or

$$W = \frac{p}{2}(v-v') + 1.5a\frac{(v-vo)}{(vo-v')^3} \quad (11)$$

As most instruments measure *'W'* more easily than *V*, it is interesting to calculate the values of *a, Vo* and *V'* from the curve *W=f(V).* Smoothing both curves gives very close values.

Interpreting the van Wyk parameters V' and a'

In the analysis, we refer to *v'* as the "incompressible volume", though the physical significance cannot just be interpreted as the volume of the fibres in the fabric excluding the air. *V'* must be defined as the volume of the inner core of the fabric, which is relatively incompressible even for pressures up to 50gf/cm^2 (which is the maximum Kawabata pressure).

Knowing the fibre density *'ρ'* and area density *'m_a'* of the fabric, we can define the packing fraction *'α'* of the fibres for this volume *V'*(or core thickness *T'* per unit area) as follows.

$$\alpha = \frac{m_a}{\rho T'} \tag{12}$$

The second constant in van Wyk's equation, which needs more clarification, is *'a'.* Grouping together Young's modulus *'Y'*, the density *'ρ'* and the mass *'m'*, if the core layer of the fabric is not compressed and surface hairs in the outer layers [*], fibre mass can be calculated using

$$m = \sqrt[3]{\frac{a}{KY}}\rho \tag{13}$$

To arrive at this stage, we use the measured value of the KES-FB3 results. Fibre mass in van Wyk's equation is only a small percentage of the total fabric mass. De Jong et al. measured a mass of surface fibres within the range 3-20g/m^2 for a swatch of woven fabric between 167-323g/m^2. However, there are no calculations involved for geometries of woven materials; the value of 'k_1' is not precisely known, and the influence of the pressure on the constants is still unknown. Here we attempt to improve compressional studies using the geometric thickness of fabric, yarn and fibre structural parameters.

Modelling compression behaviour from fabric construction parameters

Fabric properties

Mukhopadyhay et al. [11] carried out exhaustive work on the thickness and compressional characteristics of air-jet textured yarn woven fabrics, which concludes that compressibility, thickness recovery, compressional energy, recovered energy and resiliency are influenced by fabric constructional parameters. Most of the results are based on the compression-recovery graph obtained from Instron.

Postle et al. [43] concludes that fabric bending, compression and surface characteristics are the three most important characteristics for predicting overall handle and associated quality attributes.

Mechanical and surface properties [44] were determined for different fabrics. Polyester fabric showed higher resistance to tensile deformation than cotton fabric, while the blends showed intermediate resistance. In contrast, the trend was reversed regarding bending and lateral deformation behaviour. Friction behaviour shows relatively little dependence on fibre type, but bending depends on yarn packing density. The tensile stresses studied were ??[[within the range of the magnitude deflections]] found in wear. Lateral compression behaviour indicated that the cotton fabric showed the highest resistance to compression. Compression, friction and contacting surface fibre counts are all related to the increased number of protruding fibres on the cotton and cotton-containing fabrics.

The classical interpretation of fabric friction [45] is viscoelastic, but its correlation with compression curves is poor. Measurements show that at low pressures, friction essentially depends as much on fabric hairiness as on compression. The limit of compressibility is a function of the yarn arrangement, the yarn structure itself being less important. Surface finishes of the fabric are known to influence the cloth's handle.

Yarn properties

Dupuis-D et al. [47] critically analyse the function of yarn structure on compressibility of fabric, and conclude that data analysis of a fabric's compression can only be done using a mathematical model to smooth the results. The best formula is van Wyk's, although the meaning of the physical parameter is very difficult to define for a fabric. On the basis of van Wyk's equation, a study of the compressibility of a fabric whose weft is made of multiple threads (classic ply yarns, open-end, combed or carded) shows that the structure of fabric has greater importance than that of the thread. The mechanical properties of a fabric are supposed to be essentially due to its construction, and to a lesser extent to the threads from which it is made.

Fibre properties

Matsudaira.M et al. [48] uses the crimp of fibres measured from various stages of the spinning process, and studies the effect of this fibre crimp on fabric quality. The following conclusions were drawn:

1. Fibre crimp and crimp recoverability decreases gradually with the progress of the spinning process, and the decrease is most marked during carding.
2. The crimp level of fibres correlates well with the lateral compressional energy of the fibre bundle.
3. There is a clear correlation between fibre crimp and fabric quality evaluated objectively from the mechanical properties of the fabric.
4. A fibre assembly with high crimp is more deformable in both tension and compression, which correlates well with the high quality or high *fukurami* (softness and fullness) of the fabric.

Existing models

Yung Jin-jeong and Tae Jin-kang [9] conclude that a set of equations should be solved which is based of a three-dimensional fabric geometry, and consists of seven differential equations that are severely coupled and have moving boundary conditions . The fabric geometry is also affected by weaving conditions. Using a unit cell model, an attempt has been made to determine the compressive force acting on the cell. Ttwo plates are used; the lower one is fixed, while the upper plate is movable. The upper plate compresses the fabric while it moves downward. Using these assumptions, the analysis of woven fabric deformation under compression forces has been carried out using the finite element package, ABAQUS FEM developed by Hibbit, Karlsson and Sorenson, Inc., (ABAQUS, 1989b). [9] is the latest research reported. Some of the empirical equations to describe the relationship between the thickness and compressive force by Kawabata et.al. 1978b) (Equation 14) was an exponential function, Samson (1972)'s equation (Equation 15) was logarithmic function. Equation 16 was used by inversely proportional function (Holmes and Brown, 1981):

$$P = p_o \exp - \frac{(T - To)}{b} \tag{14}$$

$$\log T = \log a - b \log p \tag{15}$$

$$T = a + \left[\frac{(b)}{(p + p_o)} \right] \tag{16}$$

Where: p_o = initial compressional load
To = initial thickness at p_o and
a, b = constant, determined from the experimental data for each fabric.
However, these empirical approaches have some limitations in explaining the role of the fabric structure and yarn compressional characteristics in the compressional behaviour of fabric.

Poste [2] regards compression as a three-stage process, namely the flattening of the fibres that protrude from the surface of the fabric, the flattening of buckles in the fabric as well as those areas of the fabric that are thicker than average, and the compression of the main body of the fabric. The analysis of the pressure-thickness relationship [3] demonstrates a very prominent effect in terms of fabric construction and yarn structure. The fabric compressibility depends primarily on the fibre material.

De.Jong et al. (1986)[4]'s experiments on wool and cotton fabrics suggests that the exponential function proposed by van- Wyk holds good for cotton fabrics as well as wool fabrics. Since the pressure-thickness curve of fabrics looks similar to what happens under tensile deformation, inspired by the success of tensile stress-strain curve modelling (Hu & Newton, 1993) and the comparison of two groups of curves in low-stress regions, an exponential curve was proposed. The fit of the equation governing the experimental curves may be improved by using a non-linear regression method:

$$P = e^{\alpha t-\beta} - 1 \tag{17}$$

where P is the pressure and t the thickness; the two constants α and β must be estimated.

Vangheluwe & Kiekens [20] modelled the relaxation behaviour of yarn using a non-linear spring placed in parallel with Maxwell elements, called the extended nonlinear Maxwell model. The formula obtained from studying the stress relaxation behaviour of yarns was fitted with experimental relaxation curves using a Marquardt algorithm for non-linear regression. The relaxation curves were classified into ordinary relaxation, mixed relaxation and inverse relaxation curves. Becker used Equation 18 to describe relaxation, and Equation 19 for describing inverse relaxation after unloading the yarn following relaxation testing.

$$P=C(t+a)^n \tag{18}$$

$$P=C_3 .t^{n3} - C_5(t-T_3)^{n5} \tag{19}$$

Where: P - force,
t - time
T_3 - starting time of inverse relaxation
n, n_3,n_5,C,C_3,C_5,a: parameters

For the extended nonlinear Maxwell model represented by a linear spring in parallel with Maxwell elements to model relaxation and inverse relaxation behaviour, the set of equations from 20 to 22 governs the relationship between *F(cN),*strain ε, and time t of the extended nonlinear model.

$$F_{na} = E_b \varepsilon_{n1}^2 \tag{20}$$

$$\frac{\partial \varepsilon_i}{\partial t} = \frac{1}{E_i}\frac{\partial F_1}{\partial t} + \frac{F_i}{\eta_i} \tag{21}$$

$\varepsilon_{n1} = \varepsilon_i = \varepsilon,$ for all i- values, *i = 1 to P.*

$$F = F_{n1} + \sum_{i=1}^{p} F_I \tag{22}$$

where:

F_{n1} and ε_{n1} - force (in CN) and strain of the nonlinear spring,
E_b - spring constant of the nonlinear spring,
Fi and ε_i - force (in cN) and strain of Maxwell element number i,
E_i - spring constant (in cN) of the spring in Maxwell element number i,
η_i - viscosity (cN·s) in Maxwell element number i.

Equation 20 was proposed for the nonlinear spring, whereas the differential equation 21 is valid for the Maxwell elements in the model. A set of equations from 20 to 22 must be solved to establish the relaxation behaviour of yarns.

Modelling from fabric geometry

Assumptions

For the compressional deformation of woven fabric, the following assumptions would be appropriate to facilitate the analytical model:

1. The yarns in the fabric are assumed to be elastic and isotropic, although they have some anisotropy and in-elastic properties.
2. The yarn is assumed to be a solid cylinder.

3. The geometry of the yarn surface is assumed to be smooth and uniform (which is in fact not smooth because of the yarn twist and the protruded fibres present on yarn surface); therefore, the resistance of the fine hairs on the yarn surface is ignored.
4. The difference caused by different fibres and fibre arrangements arising from different spinning technologies is assumed to be captured in the material constant, and is not considered for modelling.
5. The fabric is assumed to be completely relaxed; it means that the fabric does not have any residual force within itself.
6. The response of the fabric to different machine settings (yarn tension, yarns per dent, beat up-force, etc., and post-weaving treatments (de-sizing, bleaching, softening, dyeing, reducing weight, etc.,) will not be taken into consideration.

Initial fabric configuration

By applying geometrical theory, the fabric thickness *'t'* can be calculated as the sum of crimp height and diameter. Let the crimp height be *'h'* and the yarn diameter be *'d'*.
The fabric thickness *'t'* is given by

$$t = h_1 + d_1 \text{ or } h_2 + d_2 \tag{23}$$

Since the yarn diameters are assumed to be circular, we have:

$$t = \max(t_1, t_2) \tag{24}$$

According to Pierce's geometry:

$$h_1 = \frac{4}{3}\, p_2 \sqrt{C_1} \tag{25}$$

$$h_2 = \frac{4}{3}\, p_1 \sqrt{C_2} \tag{26}$$

C_1 and C_2 are in fraction

$$d_1 = \frac{1}{28\sqrt{N_1}} \tag{27}$$

$$d_2 = \frac{1}{28\sqrt{N_2}} \tag{28}$$

Clothing setting and integral cloth stiffness

If the fibres were all quite free to move independently of each other, the cloth stiffness per thread would be equal to the sum of the stiffness of all the 'n' fibres in the thread. Then we refer to it as the integral fibre stiffness. However, if the fibres have no freedom of movement, it can be shown that cloth stiffness per thread will be dependent on n^2 times the fibre stiffness.

The relative freedom of the fibres depends on the closeness of cloth construction as well as the finish. We would also expect the ratio of cloth stiffness per thread to fibre stiffness to tend to be low for the more open cloths, and to be much greater for the close cloths.

The correction of integral fibre stiffness, multiplying by $\frac{100}{(100 + c\%)}$ and by $\cos^2\theta$, where ' θ ' is the twist angle

$$\mathrm{cov}erfactor(Kc) = \frac{n}{\sqrt{N}} \tag{29}$$

then modified cover factor

$$\text{cov}erfactor(Kc') = \frac{n'}{\sqrt{\frac{N}{\rho}}} \tag{30}$$

where N = yarn number in tex, ρ= fibre density, n= threads per inch. At any given cover factor, cloths woven from coarser yarns tend to be stiffer than those woven from finer yarns, which would be expected if cloth stiffness depends on some power of 'n' greater than unity.

Heat setting and post treatment operations may materially reduce the stiffness of a fabric by reducing the mutual pressures between the yarns; other finishing process produce effects by changing inter-fibre friction and adhesion.

Limits of fabric compression

On application of pressure, the crimp of fabric, count of yarn and cloth setting all change as a result of the flattening of the yarns. By introducing a flattening factor 'e', which is a function of crimp of yarn, cloth setting, and count, the thickness using flattening factor is given by

$$\frac{\sqrt{C_1\%}}{n_2} + \frac{\sqrt{C_2\%}}{n_1} = 0.28\, e \left(\frac{1}{\sqrt{N_1}} + \frac{1}{\sqrt{N_2}} \right) \tag{31}$$

(Kemp (1958), J.Text.Inst.49, T44)

but on the application of load 'h_1' and 'h_2', this changes. The values in thousandths of an inch are given by:

$$h_1' = 136 \frac{\sqrt{C_1\%}}{n_2} \tag{32}$$

and

$$h_2' = 136 \frac{\sqrt{C_2\%}}{n_1} \tag{33}$$

$$t_1' = h_1' + \frac{36e}{\sqrt{N_1}} \tag{34}$$

$$t_2' = h_2' + \frac{36e}{\sqrt{N_2}} \tag{35}$$

Hence the cloth thickness 't'' will be the lesser of the two values which follow.

Analysis of fabric elements

Although one would expect the fabric bending rigidity to reflect the yarn bending rigidity, the relationship between the two is highly complex. It is influenced by the weave on the one hand and the finishing treatments on the other. Yarn bending behaviour, in turn, is determined by the mechanical properties of the constituent fibres and the structure of the yarn.

Applying engineering beam theory, the bending moment 'M' under suitable conditions of cross-section symmetry is proportional to the resulting change in curvature 'K'. That is:

$$M = A\,(\Delta K) = A\,(K - Ko) \tag{36}$$

where *'K'* and *'Ko'* are new and original values of curvature, and *'A'* is the bending rigidity of the beam. The bending rigidity *'A'* is defined as the product of the elastic modulus *(Y)* of the material and the cross-sectional moment of inertia *(I),* about the axis perpendicular to the plane of bending.

However, the bending of yarns differs markedly from that of solid beams. It is strongly influenced by the degree of ease or restraint with which the fibres can move relative to each other to accommodate local deformations due to bending. The nature and degree of constraint are governed by the level of twist in the yarn and surface properties of the fibres. In yarns in which the freedom of relative fibre movement is high, the fibres are assumed to bend more or less independently of each other. Consequently, the yarn bending rigidity is effectively equal to the sum of the bending rigidity of individual fibres. Thus the bending rigidity of such a yarn is proportional to the number of fibres in its cross-section. On the basis of the above consideration, the bending or flexural rigidity *'Ay'* of a yarn is usually defined by the relation between the bending moment *'M'* and the curvature 'K' (the reciprocal of the radius of curvature *'ρ'*). If the relation is linear,

$$A_y = \frac{M}{K} \tag{37}$$

If not, it is defined locally by the rate of change of bending moment with respect to the curvature, that is,

$$A_y = \frac{dm}{dk} \tag{38}$$

Analysis of the bending behaviour of yarns therefore consists in relating 'Ay' to the fibre properties and the parameter of the yarn structure. It is almost always based on the idealising assumption that fibres in a yarn follow a right-circular helical path of constant pitch.

Backer carried out a purely geometric analysis of a yarn bent into a torus of constant radius. He calculated the local fibre strains for two extreme cases of deformation: one with complete freedom of movement of fibres relative to each other, and one with a complete lack of movement. He concluded that if the fibres in the yarn were completely free to change their paths, no fibre strain would be developed during bending of the yarn. On the other hand, if complete restriction of fibre movement were imposed, maximum strains would occur in the fibres lying in the outside (tensile) and inside (compressional) of the torus.

Platt.et al. developed this analysis further, and derived moment/curvature relations for the two extreme cases postulated by Baker. They showed that the yarn bending rigidity can be expressed as follows:

$$A_y \text{ (complete freedom)} = N^* A_f f_1(\phi) \tag{39}$$

$$A_y \text{ (no freedom)} = 4N^{*2} A_f f_2(\phi)/Py \tag{40}$$

where 'N' is the number of fibres in the yarn cross-section, 'A_f' is the bending rigidity of a single fibre, Py is the packing fraction of yarn (the values are different from that of value of α in Equation 12), $f_1(\phi)$ and $f_2(\phi)$ are structure-related modifying functions defined by the surface angle 'ф' in the unbent configuration, and 'α' is the yarn packing factor, defined as the ratio of the area occupied by fibres to the total area of the yarn cross-section. The value of the ratio of f_2 (ф) to f_1(ф) is approximately constant, and ranges from 0.2 to 0.25 over the range of twist angle from 0-35 degrees. Yarn bending rigidity in the no-freedom case is therefore 'N/Py' times as high as that in the complete-freedom case. In both cases, it decreases with an increase in twist, and more so in the 'no-freedom' case.

The number of fibres in a yarn 'N' is given by = $\frac{b}{a}$ (41)

where *'b'* is the tex value of yarn and *'a'* is the tex value of fibre.

The bending rigidity of yarn depends upon the number of fibres in the yarn, single fibre bending rigidity, fibre crimp, fibre frictional co-efficient, packing density and yarn twist.

So the yarn bending rigidity is given by

$$A_y = 4N^2 A_f f_2(\phi)/Py \tag{42}$$

The fabric bending rigidity will be

$$G = Z A_y \tag{43}$$

The fibre bending rigidity is given by

$$A_f = Y\,I \tag{44}$$

where $I = \frac{\pi r^4}{4}$, which is the moment of inertia for cylinders.

$$Y = \frac{4A_f}{\pi r^4} \tag{45}$$

Substituting A_f in the above equation, we obtain

$$Y = \frac{A_y P_y}{\pi N^2 f(\Phi) r^4} \tag{46}$$

Substituting A_y from (43) in the above equation, we obtain

$$Y = \frac{G P_y}{Z N^2 f(\Phi) \pi r^4} \tag{47}$$

Specific volume of fabric

Bulk density is defined as the density of bulk materials. Bulk density is a material property and is given by

$$Fabricbulkdensity(g/cm^3) = \frac{fabricweight(g/cm^2)}{Thickness(cm)} \tag{48}$$

Then

$$Fabricspecificvolume(cm^3/gm) = \frac{Thickness(cm)}{Fabricareaweight(gms/cm^2)} \tag{49}$$

Plotting of pressure-thickness curves

The independent variable is normally plotted along the horizontal axis. Most linear equations are functions. When a value is assigned to the independent variable, x, the value of the dependent variable y can be computed. We can then plot the points named by each (x,y) pair on a coordinate grid. Most of the plots relating to pressure-thickness relationships are plotted considering the pressure on the Y axis.

KES-FB3 conditions

The conditions for testing the compression behaviour of fabrics (spun cotton) on the KES-FB3 testing machine are set at a sensitivity level of 2×5, velocity at 50 sec/mm, stroke rate at 5mm/10 V, and the area of the specimen used for testing is 2 $cm^{2.}$

Plotting software

With 10 experimental data points from the sample chosen for modelling, and using LabFit software for plotting the modified exponential curve by the iteration method using a non-linear regression Marquardt algorithm, a close fit for the compressional behaviour of fabrics is obtained. (Figures 1 and 2).

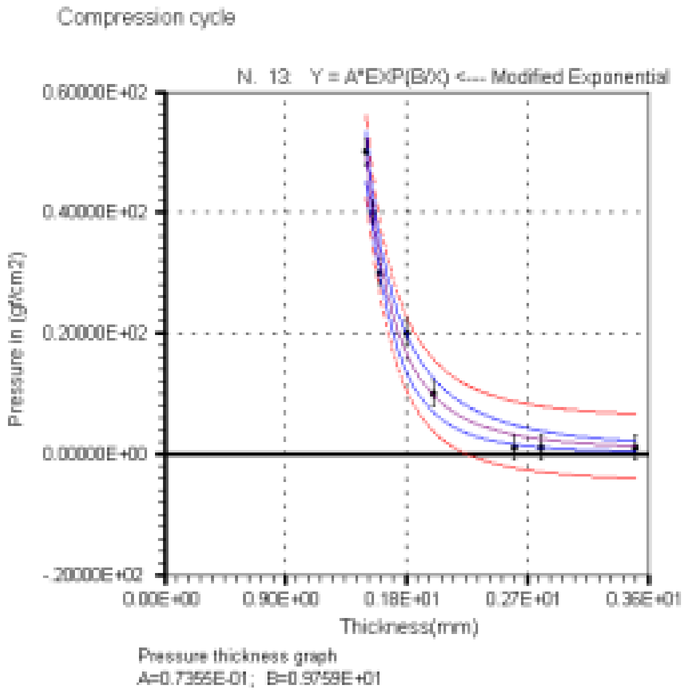

Figure 1. Pressure-thickness curve – compression cycle

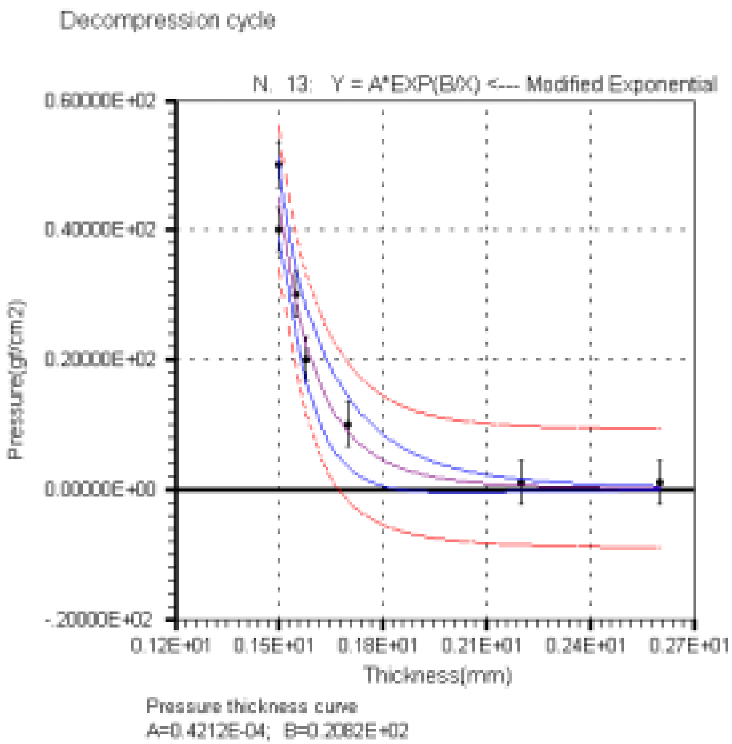

Figure 2. Pressure-thickness curve – decompression cycle

Evaluation of KES-compressional parameters

If the thickness of the fabric sample at zero pressure = T_o, and at pressure P equals T_m, , so the pressure thickness curve would follow as below:

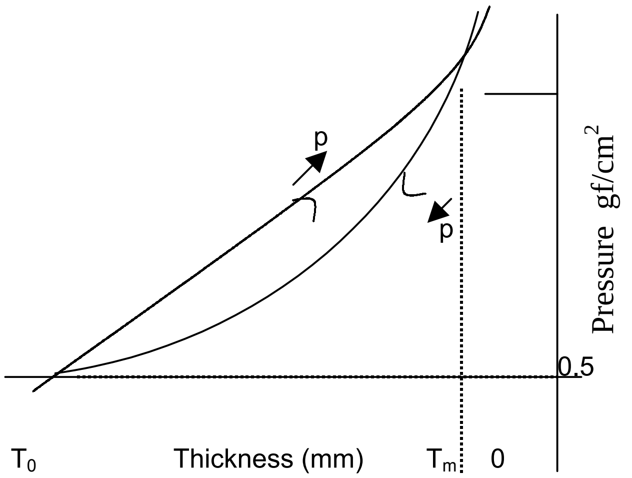

Figure 3. Pressure-thickness evaluation

1. Compressional energy (WC)= $\int_{T_m}^{T_0} \vec{p}\, dT$ (50)

2. Linearity of the compression thickness curve (LC) = $\int_{T_m}^{T_0} \vec{p}\, dT \Big/ \left(0.5 p_m (T_0 - T_m)\right)$ (51)

3. Compressional resistance = RC= $\int_{T_m}^{T_0} \left(\overleftarrow{p}\, dT \big/ WC\right) \times 100$ = $\int_{0}^{T_0} \left(\overleftarrow{p}\, dT \big/ WC\right) \times 100$ (52)

4. EMC = 1 – $\left(\frac{T_m}{T_o}\right)$ (53)

Neural network model

Many neural network models have been used to study prediction characteristics related to the physical and mechanical properties of textiles. Vangheluwe, Sette & Kiekens [34] used back-propagation neural nets to study time functions for extended, non-linear Maxwell models. Back-propagation neural nets are used to model relaxation curves of yarns after dynamic loading. Neural nets were concluded to be a valuable technique for fitting time functions.

Neural networks [39] are used in textiles to estimate Young's moduli of thermo-tropic co-polyesters, to grade cotton colour, and to identify fibre types using the NIR absorbance spectra from a library of large samples. Neural networks provide an alternative approach to understanding and predicting complex relationships among fibre properties, as well as their impact on spinning performance and textile product quality. Most of the results obtained by using neural network models are superior compared to multiple linear regression models.

A neural network is used to predict the concentration of dyes from their spectrophotometric absorbance. It also finds a place to evaluate coloration of textile material for on-line colour monitoring, colour matching and true colour production.

An artificial neural network is used to predict the air permeability of a given fabric. A fuzzy neural network provides an effective tool for predicting the total hand value of outerwear knit fabrics. A neural network is used for the measurement of fabric hand values based on the PCA of drape images. Furthermore, a fuzzy neural network system has been developed to predict and display the drape image of garments made of different fabrics and styles. Modelling of tensile properties of needle-punched nonwoven fabrics by an artificial neural network has been reported.

The application of an artificial neural network has helped many fabric or apparel manufacturing enterprise to predict the performance of apparel fabrics even without a human expert. Fabric processability can be judged by eight items (processability parameters) given a rating from 1 to 5. A rating of 5 indicated the best performance or trouble-free performance, and 1 indicated the worst performance. The parameters were seam pucker, needle damage, unseaming, processing, fusing, laying –up, shape-retention and cutting.

There are opportunities for wide applications of neural networks in areas of marketing, planning and others. A neural network model is proposed for classifying consumer behaviour with regard to clothing according to the attributes and tastes of consumers, in the same way as an experienced fashion expert would, and with equal success.

Predicting performance in clothing manufacture by using artificial neural networks is quite complicated. Although the numbers of input and hidden nodes have some influence on both training speed and prediction error, there are great differences between the results given by different architectures evaluated using neural nets. A significant advantage of ANNs over traditional analytical techniques is that their prediction accuracy will improve while they are being used because they have a built-in learning ability.

Neural network and back propagation application to study compression properties

An important requirement for the use of a neural network is that there should be a possibility (or at least a strong suspicion) that there is a relationship between the proposed known inputs and unknown outputs.

In general, artificial neural networks are used when one is not sure of the exact nature of the relationship between inputs and outputs. The other key feature of neural networks is that they learn the input/output relationship through training. Tables 1-3 (given below) give details of neural network parameters:

Table 1. Input parameter for neural networks

Fabric input variables	**Input code**
Warp yarn count (Tex)	X_1
Weft yarn count (Tex)	X_2
Ends per cm	X_3
Picks per cm	X_4
Warp crimp (%)	X_5
Weft crimp (%)	X_6
Fabric cover	X_7
Fabric weight (gms/sqcm)	X_8
Thickness (mm)	X_9
Fabric bulk density	X_{10}
Yarn input variables	**Input code**
Yarn bending rigidity (gm.cm^2)	X_{11}
Yarn twist (twist per cm)	X_{12}
Fibre input variables	**Input code**
Young's modulus of fibre	X_{13}

Table 2. Network outputs

Compression property	**Output code**
Linearity compression (LC)	Y_1
Compressional energy (WC)(gf.cm/cm2)	Y_2
Recovery compression (RC)(%)	Y_3
To (mm)	Y_4
Tm (mm)	Y_5
EMC (relative compressibility) (%)	Y_6

Table 3. Target outputs (KES – FB3 Instrumental values)

Compression property	Output code
Linearity compression(LC)	D_1
Compressional energy (WC) (gf.cm/cm2)	D_2
Recovery compression (RC) (%)	D_3
To (mm)	D_4
Tm (mm)	D_5
EMC (relative compressibility) (%)	D_6

Back-propagation algorithm

The back-propagation algorithm (Figure 4) consists of two phases: the forward phase, where the activations are propagated from the input to the output layer, and the backward phase, where the error between the observed actual and the requested nominal value in the output layer is propagated backwards in order to modify the weights and bias values.

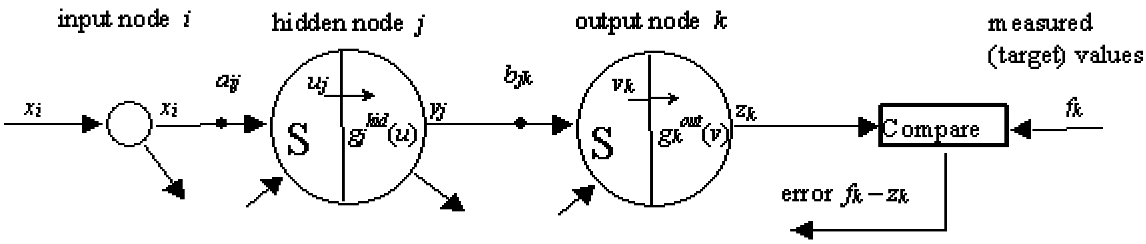

Figure 4. Back propagation algorithm

Back-propagation neural nets, due to their fundamental property of learning by example and working by algorithms in small iterative steps for prediction based upon the current state of its synaptic weights, are found to be more suitable for compression properties of fabrics. The calculated output is then compared with the actual output, and mean square errors are calculated. The error value is propagated backwards through the network, and small changes are made to the weights in each layer. The cycle is repeated until the overall error value drops below the predetermined threshold. One such threshold/modifier function (54) is

$$f(x) = \frac{1}{1+\exp^{-x}} \qquad (54)$$

Stimulation is applied to the inputs of the first layer, and signals propagate through the middle (hidden) layer(s) to the output layer. Each link between neurons has a unique weighting value.

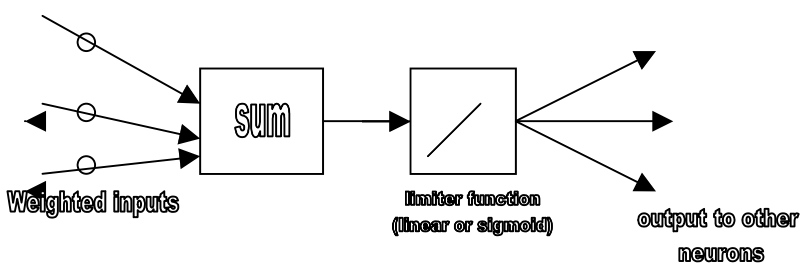

Figure 5. The structure of a neuron

Inputs from one or more previous neurons are individually weighted, then summed. The result is non-linearly scaled between 0 and +1, and the output value is passed on to the neurons in the next layer.
Since the real uniqueness or 'intelligence' of the network exists in the values of the weights between the neurons, it is necessary to apply a method of adjusting the weights to solve a particular problem. For this type of network, the most common learning algorithm is called Back Propagation (BP). A BP

network learns by example, that is, one must provide a learning set that consists of some input examples and the known-correct output for each case. So using input-output examples, network behaviour is learned, and the BP algorithm allows the network to adapt.
The BP learning process works in small iterative steps: one of the example cases is applied to the network, and the network produces some output based on the current state of its synaptic weights (initially, the output will be random). This output is compared to the known-good output, and a mean-squared error signal is calculated. The error value is then propagated backwards through the network, and small changes are made to the weights in each layer.

Derivation of back-propagation

Figure 6 depicts the network components which affect a particular weight change. It must be noted that all the necessary components are locally related to the weight being updated. This is one feature of back-propagation that seems biologically plausible. However, brain connections appear to be unidirectional and not bidirectional, as would be required to implement back-propagation.

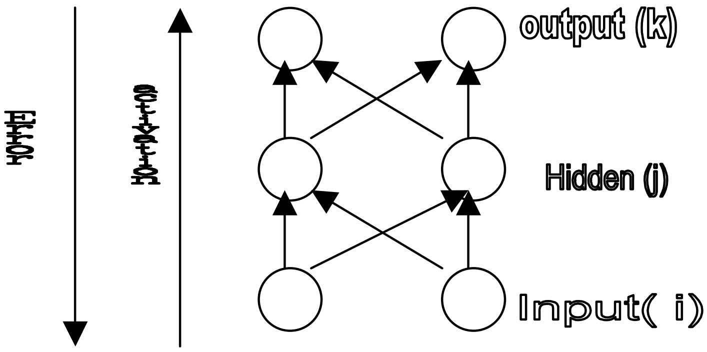

Figure 6. Back-propagation network components

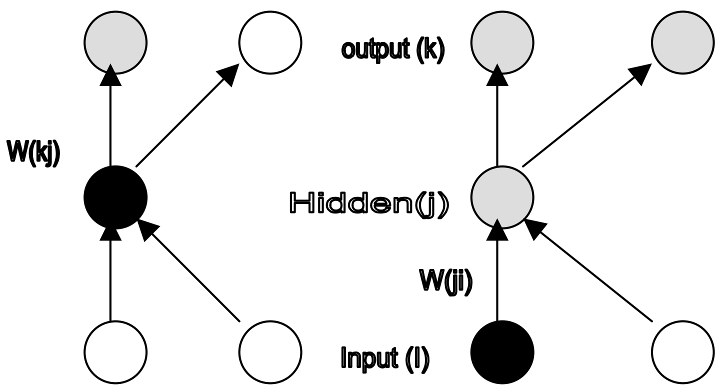

Figure 7. Network components and weight changes

The change to a hidden to output weight depends on error (depicted as a lined pattern) at the output node and activation (depicted as a solid pattern) at the hidden node. While, the change of weight between input and hidden layer depends on an error at the hidden node (which in turn depends on an error at all the output nodes) and activation at the input node.

Optimisation of fabric performance using neural network model

The basic principle underlying this objective is to use an ANN for fabric performance prediction in apparel or clothing manufacturing based on fabric properties.

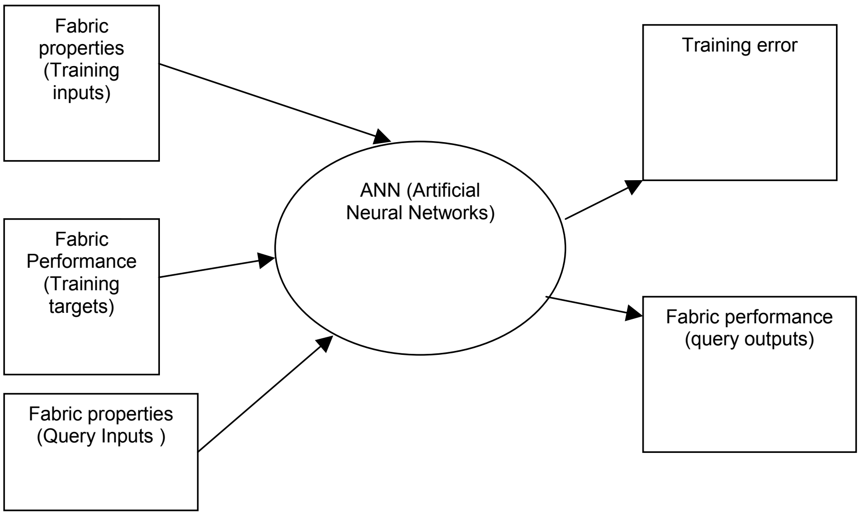

Figure 8. Optimisation process

Table 4. Fabric properties to be used for optimisation

Kawabata parameter	Input code	Output code	Desired code
LT –(linearity tensile)	X_1	Y_1	D_1
WT(Tensile energy) (gf.cm/cm2)	X_2	Y_2	D_2
RT (Tensile resilience) (%)	X_3	Y_3	D_3
G (shear rigidity) (gf/cm.degree)	X_4	Y_4	D_4
2HG (shear hysteresis at 0.5deg)(gf/cm)	X_5	Y_5	D_5
2HG5 (shear hysteresis at 5 deg shear angle) (gf/cm)	X_6	Y_6	D_6
B (Bending rigidity) (gf.cm^2/cm)	X_7	Y_7	D_7
2HB(Bending hysteresis) (gf.cm/cm)	X_8	Y_8	D_8
LC (Linearity compression)	X_9	Y_9	D_9
WC (Compressional energy) (gf.cm/cm^2)	X_{10}	Y_{10}	D_{10}
RC (compression resilience)(%)	X_{11}	Y_{11}	D_{11}
To (mm)	X_{12}	Y_{12}	D_{12}
W (Fabric weight) (mg/cm^2)	X_{13}	Y_{13}	D_{13}
MIU (friction co-efficient)	X_{14}	Y_{14}	D_{14}
MMD (Mean deviation of friction co-efficient)	X_{15}	Y_{15}	D_{15}
SMD (Geometric roughness) (µm)	X_{16}	Y_{16}	D_{16}

Conclusions

These study models provides results of feasibility of the Kawabata data and neural networking technique for computer applications. This characterisation of data for fabric materials will help companies to retain their commercial experience and expertise. This established predicting model can provide guidance to fabric manufacturers, fashion designers, and makers-up in fabric design, fabric selection and proper use. This approach will make online fabric sourcing more realistic. Fabric sourcing experts are now visiting supplier's web sites to track fabrics. Overall, it provides an opportunity to generate a dynamic database for fabric properties, and can hence result in the development of new fabrics or existing fabrics to be updated and so keep pace with fashion.

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