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The Compression Behaviour of Warp Knitted Spacer Fabric

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Abstract
The paper presents the special compressibility of warp knitted spacer fabric based on its construction, and analyses the stress and strain behavior of spacer fabric when compressed. Corresponding influential factors are also discussed here. In order to explore the performance of spacer fabric as a cushioning material for distributing surface pressure and relieving pressure . Further investigation is focused on the bending behaviour of the pile monofilaments within and beyond the direct compressing area. A primary mechanical model is introduced to describe the compressive deformation of the spacer fabric.

Key words: *spacer fabric, compression, spacing monofilament, mechanical model.*

Introduction

We spend a lot of time sitting, not to mention roughly a third of our lives in bed. This is a good reason to place a high value on the construction and components of bed and seat cushioning. which play an important role for a comfortable and healthy life. The cushioning should match the shape of the human body and individual sleeping or seating habits, help to avoid posture problems, promote rest and relaxation during the day or night, and help to create a feeling of well-being throughout the day. This is a job for good, all-round cushion materials, which can meet the complex profile of comfort requirements relating to their mechanical deformation behaviour and climatic physiology. What is more, these characteristics should be maintained for their whole service life. With perfect compression behaviour, moisture-wicking, temperature-controlling characteristics and so on, warp knitted spacer fabric (in short WKSF) is moving into the cushion market, which is dominated by PU-foam and may be a popular cushion material used in furniture in the future.

Therefore, the goal of this research is to provide a model that can predict the compression behavior of warp knitted spacer fabric and create an optimal cushion to withstand the force of human gravity to make sleeping and sitting more comfortable.

Warp knitted spacer fabric and its characteristics

Construction of WKSF

WKSF is a three-dimensional textile made on a double-needle bar Raschel machine. A photo of the cross-section of a WKSF is presented in Figure 1. Its special construction for cushion consists of an upper and lower surface as well as a huge space with erected monofilaments. The thickness of the textile may be up to 6 cm. The bulk space consists of pile monofilaments, and the trapped air between the upper and lower surface plays an important role in the characteristics of WKSF. The monofilaments act as linear springs when the fabric is compressed.

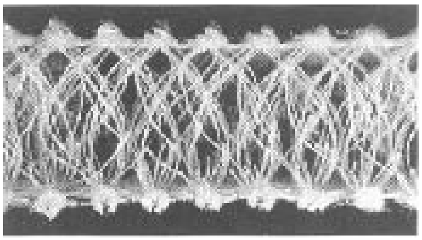

Figure 1. *Cross-section of WKSF.*

Stress-strain behaviour of WKSF in compression

The typical behaviour of compressed spacer fabric can be shown in a stress & strain curve, as indicated in Figure 2. Three important stages can be seen on the curve. These are linear elasticity, collapse plateau and densification. The modulus of elasticity is defined as the initial slope in the linear elastic part of the stress-strain curve. The second stage of the compression is characterised by a relatively large deformation that occurs at a constant stress. During this stage, the individual spacing at the monofilaments bend, and the thickness of the spacer fabric decreases. This constant stress is referred to as the collapse stress or the collapse plateau in Figure 2. It is the most important stage in the study of the compression behavior of the cushion material and determines the user comfort under pressure. The final stage of spacer fabric deformation begins after all of the individual monofilament have collapsed. At this stage the thickness has decreased significantly. After this densification, the stress rises rapidly with a very small increase in strain. The stress-strain curve of spacer fabric is similar to other textiles of a certain thickness and polyuretane (PU) foam.

The construction parameters influence the shape of the curve. The most important construction parameters to determine the compression behaviour of the 3D textile are thickness, the stitch density of the fabric, bend behavior and the lapping of the spacer yarn [1].

Description of the compression behavior of WKSF

Normally, the compression behaviour of cushion can be described using the compression load deflection characteristics (CLDC) and the indentation

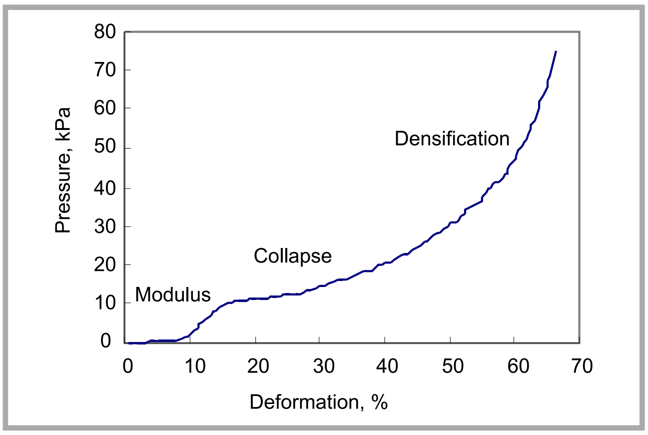

Figure 2. Stress-Strain Curve for WKSF in Compression.

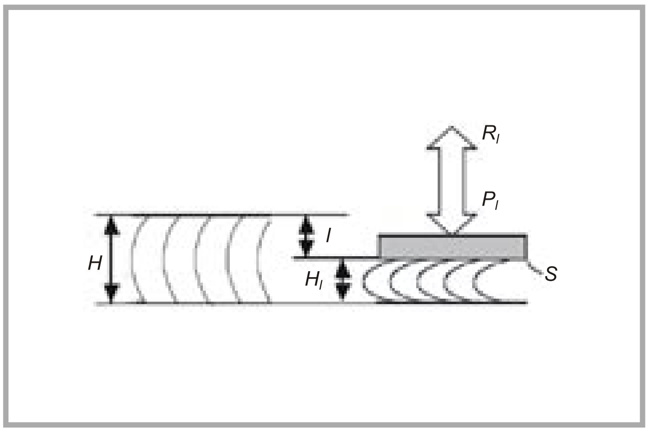

Figure 3. Spacer fabric in natural state (left) and compressed by a plane plate (right).

hardness. The indentation hardness is a measure of the force that is required to achieve a defined deformation. It is a value, which should be tested, of the different standards for cushion in the PU foam industry. CLDC takes the pattern of deformation under a gradual and constantly changing pressure into account. CLDC are an expression of mechanical cushioning characteristics, which can be modified by varying the parameters when producing warp-knitted textiles.

Research into optimising WKSF cushion is ongoing and mainly focused on how to specify the relationships between the compression behaviour and construction parameters. The aim is to reduce the duration of high pressure to a particular sixe by regular repositioning of the sleeper or sitter, or by increasing the distribution through which the pressure is applied for a given time.

Contact pressure of WKSP

To analyse the contact pressure and pressure distribution of compressed WKSP, itis necessary to measure and calculate the force on the individual monofilament. Some special test instruments with pressure sensors can be used to record the pressure of different parts of the body on WKSF cushion. The pressure can be described by different colours in an image. Here we concentrate on how to calculate the contact pressure of the fabric.

Plane plate pressure

Data of the compression resistance obtained by measurement with a plane plate were used for calculation of contact pressure values between a ball-shaped and the samples. A drawing of the cross-sections of a spacer fabric natural state and copressed is presented in Figure 3. The following relationships were used to calculate the pressure force F on the individual monofilament:

$$P_{lv} = \frac{R_l}{S};\ P_{lv} = K_p \mu_l^3;\ \mu = \frac{V_F}{V_l};$$
$$F = \frac{P_{lv}}{S \times N} = K_F \frac{V_F^2}{[(H-l)S]^3 \times N} \qquad (1)$$

where:

P_{lv} is the pressure in Pa under the plate;
V_F is the volume of the spacer yarn;
R_l is sample resistance in N;
V_l is the volume under the plate;
H is the sample height;
l is the depth of indentation (sample deformation);
S is the plate area;
N is the number of spacer yarns (multifilaments) under the plate.

Ball surface pressure

In the case of ball indentation on the sample (Figure 4), the indenting force P_l is dependent on both the indented area and the degree of deformation (depth of indentation) l.

According to Figure 4, we can write e.g.:

$$\Delta a = a_i - a_{i+1};\ a_i^2 = 2rl_i - l_i^2;$$
$$R_i = \pi P_{lv}(a_i^2 - a_{i+1}^2);\ R_l = \sum_0^l R_i \qquad (2)$$

Contact pressure:

$$P_i = \frac{P_{lv}}{\sin a_i};\ \cos a_i = \frac{a_i}{r};$$
$$\sin a_i = \cos(90 - a_i); \qquad (3)$$

where r is the radius of the ball.

Ball indentation is more suitable for testing the pressure distribution of an object with an arc surface, such as the hip of a human which comes into contact with the cushion and withstands more

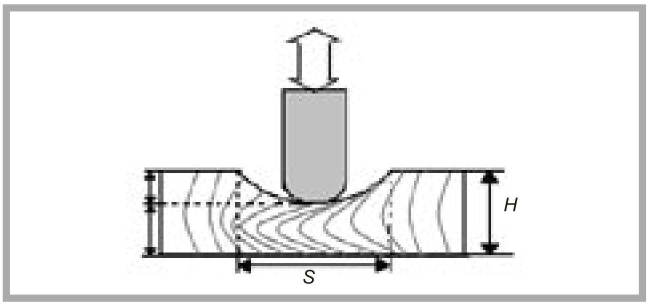

Figure 4. Side elevation of spacer fabric compressed by a ball surface solid.

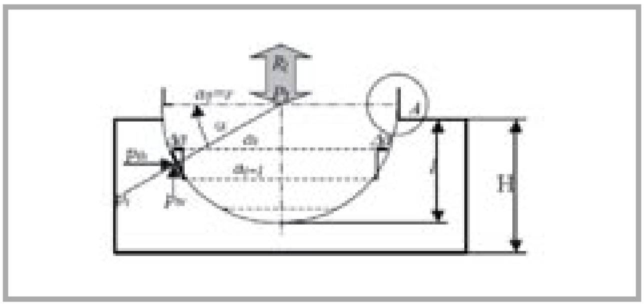

Figure 5. Ball indentation and indenting force distribution.

gravity than other parts of the body; a pressure peak always occurs on this part. Distribution of contact pressure p_i depends on the radius a_i of the ball.

Model of the monofilament spacing

We assume that the monofilament is a beam and regard it as an uniaxial element with tension, compression, and bending capabilities. The element has three degrees of freedom at each node: translations in the nodal *x* and *y* directions and rotation about the nodal z-axis.

The most critical assumptions are made concerning the bending behaviour of the monofilament spacing when the spacer fabric is compressed. Here, Love's "ordinary approximate theory" [7] can be used to describe the monofilament spacing. Every erect monofilament is assumed to be an elastic rod as described in the Bernoulli-Euler theory [2], which for an initially straight rod assumes the following linear relations between the moments in the rod and the curvatures:

$$M = Gp + G'q + Ht \qquad (4)$$

where

$$G = Ak,\ G' = B\lambda,\ H = C\tau. \qquad (5)$$

t is directed along the tangent to the centre line of the monofilament and *p* and *q* are normal to t such that $p \times q = t$.

Here *A*, *B* are the bending stiffness and *C* is the torsional rigidity and *G*, *G'*, *H* are local components or the internal moment. For isotropic materials,

$$A = Eak^2 \quad B = Eak'^2 \qquad (6)$$

E is Young's Modulus for the monofilament, *a* is the cross-sectional area, and *k* and *k'* are the radius of the cross-section. In the special case of kinetic symmetry, where $A = B$, the moments *G*, *G'* are equivalent to a single couple of magnitude *Bk* directed along the binormal *b*, so the moment equation becomes :

$$M = Bkb + C\tau t \qquad (7)$$

According to the virtual, initially bending of the monofilament in the spacer fabric, the constitutive equation adapted to the case of a rod that is initially curved, is a more appropriate assumption for a monofilament bonded. Love modified Equation 5 to the following:

$$G = A(\kappa - \kappa_0),\ G' = B(\lambda - \lambda_0),\ H = C(\tau - \tau_0), \qquad (8)$$

where κ_0, λ_0, τ_0 are the initial (unstressed) values of κ, λ, τ. Thus, in general for an initially curved rod there is nothing analogous to formula 7, and all three components of the moment must be included.

Conclusions

The stress-strain behaviour of WKSF in compression was discussed, and the collapse stage of the three important stage was especially regarded as the most crucial one in studying the compression behaviour of WKSF. Formulas were brought forward to calculate the contact pressure of the WKRC under the plane plate and ball. Furthermore, the spacer filament was assumed as an elastic rod, and primary analysis was given to this model. This research is a basis for further research on pressure distribution and contributes to finding the relationship between the construction parameters and indentation hardness or other factors of compression behaviour.

A lot of experiments should be undertaken to validate the model and future work should be focused on the computer simulation of the deformation of warp knitted spacer fabric by the finite element method.

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