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Influence of Pile Height and Density on the End-Use Properties of Carpets

Abstract
Nine different face-to-face cut pile carpets were used for the investigation. The raw material of the carpet pile yarns was wool and polyamide blended yarns. The influence of the different structure parameters (carpet pile density and pile height) on the carpet properties was investigated. The deformations occurring in carpets during compression were determined. A compressive load of 100 N was applied to the surface of the carpets, and three cycles of loading were performed. An orthogonal mathematical plan was used to investigate resulting deformations. As regards the total deformation, results showed that both of the structure parameters of the carpets have an influence – in elastic deformation pile density is the parameter which has the biggest influence, and in unrecovered deformation both of the structure parameters have a great influence.

Key words: *carpets, pile compression, deformation.*

Introduction

The Brussels system, sometimes known as loop-pile Wilton or Brussels Wilton, was the first mechanical system for weaving carpets. When bladed wires were developed, the modified system became known as Wilton. The face-to-face weaving of carpets, developed in the 1940's, is also sometimes regarded as Wilton weaving. The face-to-face system produces two carpets with the same amount of dead yarn as one wire-loom carpets, hence material costs are lower: elaborate designs, such as oriental styles, are therefore most often made by face-to face weaving.

These attributes make wire-loom weaving highly suitable for the production of high-performance wool contract carpets [1].

Wool is the oldest fibre used for carpets. If ordinary wool is stretched, it can be extended up to 50% in water or 100% in steam. It is resilient, has low soiling, pleasing to the touch etc. Polyamide is the most popular carpet fibre, because it is durable, static free, and resistant to soiling, staining mildew and crushing [2]. Many researches have investigated carpets. Most of them have concentrated on the experimental investigation of the end-uses of carpets. To enable carpet performance to be evaluated, the compression, recovery, flattening, resilience and energy absorption have generally been measured from the stress-strain behaviour of carpets [3].

One of the most important quality factors in carpets is thickness loss (i.e. deformation in compression) caused by static and dynamic loads. Due to this loss, the carpet's appearance loses its original form on the face as well as its resilience capability. The factors decreasing the resilience capability are static pressures by massive goods such as walking, running, moving as well as furniture & other household goods that a carpet has to bear during use [4].

Carpet pile density and pile height are the main structure parameters of carpets, which have an influence on resulting deformations during compression. Any variation of these two mechanical parameters has an influence on the end – use properties of carpets. Therefore, these two parameters were taken as the two factors of the experiment plan. Resilience of pile is the ability of pile to return to the original state after applying the load. Our goal was to determine the influence of carpet pile density and pile height on the resilience of the carpets after loading.

Theoretical

Carpet pile compression can be assumed as the compression of filament assemblies. It was assumed that the bending rigidity of wool worsted yarns is estimated from the mean fibre diameter together with four correction factors: diameter distribution, yarn twist, fibre ellipticity and mean fibre length.

Two important parameters in bending behavior were established: the bending or flexlural rigidity represented by a the slope of the hysteresis loop and 'coercive couple' (forced contact of the fibres), which is the width of the hysteresis loop at zero curvature. The bending rigidity was attributed to the elastic properties of the fibre material, and the 'coercive couple' was thought to arise from interfibre friction. Chapman showed that wool and nylon fibres are linearly viscoelastic at low bending strains (usually <1%), and that fabric composed of linear viscoelastic fibres behaves as an anisotropic, linear viscoelastic sheet with an internal frictional moment during bending. Thus, viscoelasticity and fibre friction both contribute to the width of the hysteresis loop during bending [5].

There have been some studies of the compression of fibre assemblies. Norman B. Beil [6] created a model to investigate phenomena related to the compression of fibre assemblies that are not accounted for by the Van Wyk theory of unaxial compression of an initially random fibre assembly. In order to do this, the assembly function is calculated. Realistic looking hysteresis plots are produced, and the model can predict the amount of frictional energy dissipated, as a function of time.

Another approach to carpet compression was formulated by Kimura and Kawabata [7]. According to their theory, the compression process can be divided into the following three stages of deformation

1) Bending deformation region. A region in which only the bending deformation is effective (until neighboring piles come in contact).
2) Mixed region of bending and compressive deformations. A region in which both the bending and compressive deformations are effective, i.e., the concurrence of the bending deformation of piles which do not come in contact with neighboring piles and

the compressive deformation of piles which do.
3) Compressive deformation region. A region in which only the compressive deformation is effective (after all the piles have completely fallen down).

Horino and Shimonishi [8] assumed that when cut pile yarn (a) of apparent diameter d_a and pile length l_p is subjected to a compressive load w, it will take three kinds of deformed modes. If the value lp/d_a is smaller than 3, the cut pile yarn may be deformed, as the twist angle of the yarn varies; but its diameter does not change as in the case of a spring coil.

When lp/d_a is larger than 5, the pile yarn deforms like the buckling of a column, where one end is fixed and other free.

According to Kimura, Kawabata and Kawai [3], the authors have accepted as a model a simple structure in which thin rods are planted in a backing fabric by one and the other and free at an angle of β against the vertical line to the carpet.

The lateral deflection properties caused by bending a single thin rod with a vertical compressive load P may be the basic compressive properties of carpets. But to provide the actual compressive properties of carpets, we have to consider the complex lateral deflection properties incorporating the assembly effect of thin rods, which are fixed in a checkered pattern at equal intervals. A model was assumed in which the thin rods may all be bent in the same direction and their cast shadows be located on the checkered lines on the surface of the carpet. If this model is compressed, the slant angle α will increase, and the upper ends of the contiguous thin rods begin to come in contact with one another.

***Table 1.** Structure parameters of the carpets.*

Density, tufts/m^2	Pile height, mm		
117800	10	8	6
130200	10	8	6
142600	10	8	6

***Table 2.** Matrix of the mathematical plan.*

X_1 (pile density, tufts/m^2)		X_2 (pile height, mm)	
value in matrix	real value	value in matrix	real value
1	142600	1	10
1	142600	0	8
1	142600	-1	6
0	130200	1	10
0	130200	-1	6
-1	117800	1	10
-1	117800	0	8
-1	117800	-1	6

If these thin rods were made of fibre assemblies (yarns), the diameter of a thin rod must be calculated by including the compressive effects of the cross section of the yarns. Also, it was established by F.C. Aarper that there are compressive and shearing forces imposed on the floor during walking [9]. In straight walking, fibre damage is spread fairly uniformly throughout the depth of the pile [10].

Kimura proposed that the compressive deformation curve of cut pile carpets can be calculated from the mechanical properties of pile yarns i.e. compressive properties and bending rigidity [7]. The bending rigidity was attributed to the elastic properties of the fibre material, and the coercive couple was thought to arise from the interfibre friction.

On the basis of experimental were established that the kind of material, the crimp of fibre, the shape of the cross section of the fibre and yarn, the twist structure of the pile yarn and the structure of backing fabric [5]. Influence the carpet structure.

In general, if a carpet is assumed to be made up of a fibre phase and an open air phase, its mechanical properties are considered dependent on the following factors:
1. volume fraction of the fibre phase,
2. original shape of the pile,
3. pile yarn material [8].

As regards the behavior of pile and backing, while measure of the total carpet thickness, the principal factors responsible for the loss in thickness may be as follows:
1. frictional slippage effects,
2. viscoelastic/plastic behavior of fibres,
3. loss of pile by abrasion because of fatigue, cutting and the breaking off of individual fibres, as well as the shedding of unbound fibres [11].

The following assumptions were made: firstly, constituent strands come in contact with each other in a line; secondly, cross sections of strands are circular before and after the bending deformation; thirdly, strands slip by each other throughout their contact line during bending deformation as friction is not high enough to prevent this; fourthly, a lateral compressive force occurs with stress on the strand axis due to bending deformation; fithly, constituent fibres and strands deform elastically, and fibres in the strand deform in in the form of as a solid [12]. The important theoretical mechanical studies postulated that the compressive strain of the assembly of fibres is transformed directily into a bending strains in the individual fibres, and that the resistance of the assembly to an externally imposed stress arises solely from the resulting increase in bending energy in the fibres [13]. When a fibre mass is deformed, the resisting and restoring forces engendered within the structure are sustained and transmitted through the fibre contact points. If the contacts are stable and the fibres elastic, the mass will completely recover its original state. If contacts slip or are created and destroyed, the original state will not be recovered [14].

Many researchers prescribe various methods of explanation for carpet behaviour and their properties during compressional loading. In this article the viscoelastic properties of carpet pile will be considered, i.e. viscoelastic properties of fibres which are constituent of carpet pile yarns.

Methods and materials

There are many methods of investigation of carpet properties - running methods and instrumental methods. Running methods are time consuming, therefore an instrumental method was chosen which simulates the static and dynamic compression of carpets. Nine face-to-face cut pile carpets were woven (***Table 1***). Carpets were manufactured as jaquard face-to face carpets, because weaving allows the pile layer to be denser than that of tufted carpets, which results in the retention of the carpet's appearance.

The raw material of the pile yarns was 80% wool/20% PA6, the weft raw material was 100% jute, the warp raw material was 100% cotton, i.e. yarns which are widely used in the carpet industry.

The carpets were tested on a computer controlled tensile tester (STATIMAT-M, Textechno-Herbert Stein, Germany). The control program was written by L. Vangheluwe [15]. The carpet specimen was put on the plate that is mounted on the holder device, then it was put on the tensile tester in order to perform a compression test. With a speed of 20 mm/min, the loading plate compressed the carpet surface until a force of 100 N was obtained. This compression was maintained for 1 minute (the pause at the lower reversal point was 1 min) for a relaxation force to occur. After one minute, the compression load was released from the carpet surface. Three loading cycles were performed.

An orthogonal mathematical plan was used to investigate resulting deformations. The matrix of the mathematical plan is presented in ***Table 2***.

Results and discussion

The experimental tests were performed according to the orthogonal mathematical plan of the experiment (see ***Table 2***). The relative confidence error of the experiment did not exeedes 5.15%. 2nd order polynomial equations were calculated. The dependences of the investigated properties of the structure parameter are presented in ***Figures 1 - 3***.

The equations were examined with an additional experimental point, when the pile height of the carpet was 8 mm, and the pile density 130,200 tufts/m^2. The difference between the experimental values and those calculated by empirical equations did not exceed 2.4%. Hence, the empirical equations determined can be used for the analysis and prediction of carpet properties.

During the initial stage of deformation, only the pile surface is deformed- first separate tufts are deformed and later, due to increasing deformation, the pile surface is compressed, the interaction forces between tufts increases and loading is transferred to the carpet backing. 10 - 20% of the deformation dissapears during 1 min of relaxation. Later, the process of the vanishing of deformation dramatically eases off.

Analysing the total deformation during compression (***Figure 1***), it is obvious that deformation has only a slight dependence on the number of cycles, i.e. the chain of macromolecules of the fibres' matrix have already changed orientation during the first cycle. Plastic deformation already occurs during the first cycle after 1 min of relaxation. The carpet pile after releasing the load is not totally recovered, and gradually the thickness of the pile surface decreases.

The total deformation is almost independent on the pile height when the pile height is low (6 - 7.5 mm), except for a higher pile of 9 - 10 mm, which makes deformation dependent on the pile height. Deformation becomes dependent on the pile height when the pile density is 117,800 tufts/m^2. Obviously, the total deformation depends on the pile density. The denser is the pile surface of the carpet, the more it resists compressional stress, which is because of an increase in the area of contact, where contacts increase between fibres i.e. tangent resistance increases. It can be seen from ***Figure 2*** that the higher pile density, the lower the values of total deformation are, i.e. the carpet deforms less. It can be stated that the

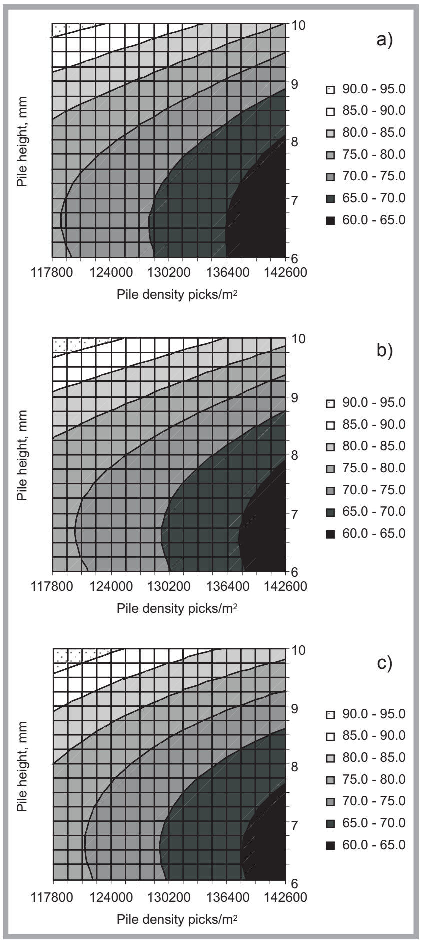

Figure 1. *Total deformation dependence on the pile height and pile density during three cycles of loading; a - at 1 cycle, b - at 2 cycles, c - at 3 cycles.*

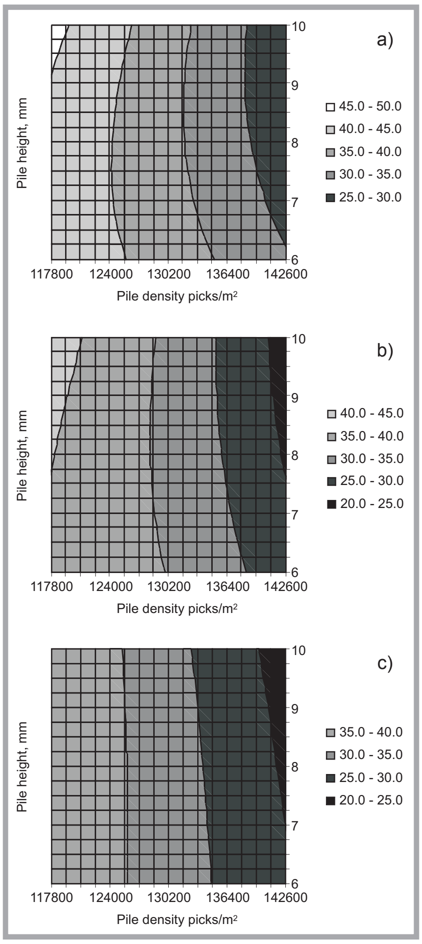

Figure 2. *Elastic deformation dependence on the pile height and pile density during three cycles of loading; a - at 1 cycle, b - at 2 cycles, c - at 3 cycles.*

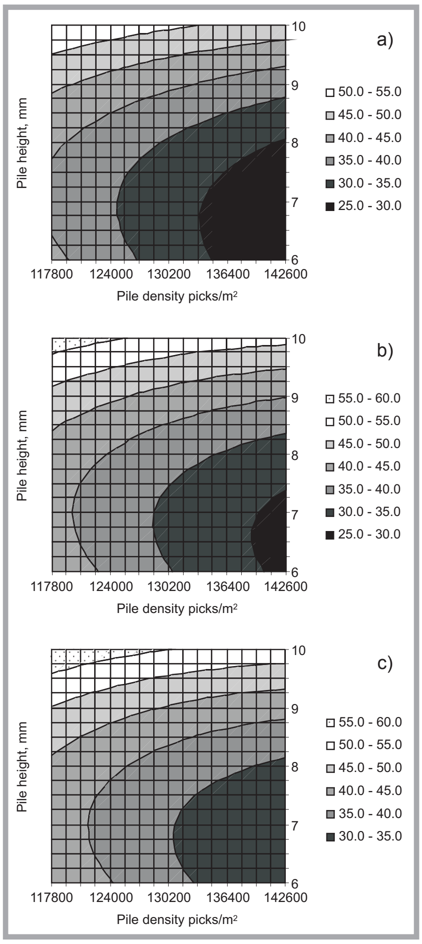

Figure 3. *Unrecovered deformation dependence on the pile height and pile density during three cycles of loading; a - at 1 cycle, b - at 2 cycles, c - at 3 cycles.*

lower the total deformation, the lower the pile height and the higher the pile density are. Furthermore, it can be seen that by increasing the number of cycles, the total deformation also increases, i.e. the area of lowest values of deformation shrinks, whereas the area of the highest values of deformation enlarges.

Elastic deformation also has only a slight dependence on the number of cycles (***Figure 3,*** see page 49), is almost independent of the pile height, and depends only on the pile density. The resilience properties of carpets depend on the pile density- the denser the pile, the straighter the tufts stands in the pile surface are (it has to be considered real pile density because high density may prevent elastic deformation from recovering). The higher the elastic deformation, which is recoverable, the less a carpet deforms. The denser the carpet, the lower the total deformation, therefore its percentage consituents of deformation is lower, henced elastic deformation is lower. By increasing the number of cycles, elastic deformation decreases. When the last cycle ends, the highest values of deformation occur for carpets of the lowest pile density, i. e. elastic deformation decreases by 5%.

Unrecovered deformation depends on the number of cycles, as can be seen it increases by 5% on account of elastic deformation. Unrecovered deformation is almost independent of the pile height when the pile height is 6 - 7.5 mm, while deformation is almost independent of the pile density when the pile height is 10mm, but is strongly dependent on the pile density when the pile height is low (6 - 8 mm).

Although the bending of pile yarns occurs during the initial compression, the pile density has an influence on deformation when the pile height is low, because the distance through which loading has to pass is small. When the pile height is high, pile density will have a slight influence; a high tuft will bend even when the pile density is high.

Conlcusions

- Both structure parameters (pile height and pile density) have an influence on the end-use properties of carpets, but their significance is not the same.
- The total deformation does not have a significant influence on pile height when the pile height is low, although higher pile and lower pile density makes deformation dependent on the pile height. At a lower pile height, the total deformation value is lower, therefore carpet deformation will be lower.
- Elastic deformation is almost independent of the pile height and depends only on pile density.
- Unrecovered deformation does not have a significant influence on pile height when the pile height is low nor on pile density when the pile height is high, but it is strongly dependent on the pile density when the pile height is low.
- Only the investigation of both structure parameters is informative, and its results can be used for designing carpets of particular use and properties for the carpet industry.

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