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Effect of the Acrylic Fibre Blend Ratio on Carpet Pile Yarn Compression Behaviour

Abstract
The aim of this research was to investigate the compression properties of acrylic cut-pile carpet consisting of pile yarn with different fibre blend ratios. Acrylic fibres with finenesses of 7.69, 10.99 and 16.48 dtex were selected and then blended at 10 different percentages of blend ratios using the semi-worsted spinning system, and finally 10 two-fold pile yarn samples were produced. In addition typical cut-pile carpet samples with a constant pile density level of 15 pile/cm^2 and pile height of 13 mm were produced by the face to face method. Then the compression behaviour of the carpet samples was evaluated under a constant compression stress of 40.89 kPa using an Instron tensile tester. The cut-pile carpet compression properties were evaluated using different compression parameters including the energy of compression WC, the decompression energy W'C, the resilience of carpet compression RC and relative compressibility EMC. The experimental results were then statistically analysed using ANOVA and Duncan test methods. The results showed that with an increase in the coarse acrylic fibre component ratio (16.48 dtex fibre) the yarn specific volume first decreases and then increases. The results of this research revealed that acrylic cut-pile carpet produced from pile yarn with 16.48, 10.99 and 7.69 denier fibre at a 15%, 67% and 18% blend ratio, respectively, exhibit the highest WC, W'C, EMC and RC values compared with other samples and commercially produced yarn. The statistical regression analysis suggested that the compression behaviour of acrylic cut-pile carpet is extremely close to the two parameter model proposed for woven fabrics.

Key words: *acrylic fibre, blend ratio, compression properties, cut-pile carpets.*

Introduction

Carpet is a three dimensional textile structure commonly widely used in home-furnishing for floor covering. The biggest advantages of carpet are its comfort, thermal and sound insulation properties. One of the most important carpet mechanical properties is thickness loss during use, in general terms the compression property. It has been reported that carpet thickness loss is created as a result of static and dynamic loading exerted thereon [1, 2].

It has been noted that there are two material and structural parameters that influence carpet compression properties [3 - 8]. Laughlin and Cusick [3] evaluated the compression behaviour of loop-pile and cut-pile tufted carpet samples of different fibre content and pile weight under cyclic loading. They found a relationship between the compression force per unit weight of pile yarn and the percent compression of the pile with different fibre materials. However, they found no major difference in the relative compression stress-strain behaviour of the carpets before and after exposure to 100000 revolutions of the Tetrapod Walker. Feather and Settle [4] found that with a decrease in pile density, the thickness of cut pile nylon, acrylic, viscose and wool carpet samples increases. Vangheluwe and Kiekens [5] measured polypropylene pile yarn resiliency under a static load using a carpet simulator and found that with an increase in pile height and density, more compression and resiliency were obtained. Onder and Berkalp [6] compared the thickness loss of acrylic, wool and polypropylene carpets of 7 mm and 9 mm pile height worn by a Hexapod Tumbler. The general tendency results indicated that carpet samples with a shorter pile height and also polypropylene carpet exhibit a higher thickness loss. Koc, et al. [7], studied the thickness loss of wool, acrylic and polypropylene carpets exposed to prolonged heavy static loading and found that acrylic carpet shows a higher thickness loss and hence a lower resilience value than other carpet samples. Celik and Koc [8] confirmed this result from the point of view of compression energy absorption and hysteresis effects. Recently, these authors extended their studies on the thickness loss of previously produced carpets under dynamic loading and found that acrylic carpet exhibited more compression recovery after dynamic loads compared to other carpet samples [9]. Dubinskaite et al. [10], used an orthogonal mathematical plan to investigate compression deformations of wool and polyamide blended carpets. Their results showed that pile density has a great influence on elastic deformation whereas both pile density and pile height have a great effect on the recovered deformation of pile compression under three cycles loading. Later on, the resilience behaviour of woven acrylic carpets under short and long term static loading was studied by Korkmaz and Dalci Kocer [11] and they found that the acrylic carpet structural parameters of pile height and pile density significantly affected the thickness loss recovery. In a recent study, Dayiary et al. [12] experimentally verified their previously proposed theoretical model [13] for cut pile carpet compression based on elastic stored bending energy and found that with an increase in pile density the total compression energy of pile deformation decreases, while acrylic cut pile carpet exhibits a higher total energy of pile compression deformation than polypropylene BCF and heat set polypropylene BCF carpet samples.

It might be noted that acrylic carpet pile yarn usually consists of blended acrylic fibres of different fibre fineness. Fibre producers usually suggest a specific blend ratio to obtain the carpet properties desired. However, there has been no comprehensive research to study carpet compression properties from the point of view of fibre fineness effects. Therefore the aim of this study was to investigate the effect of the acrylic fibre blend ratio in pile yarn on the compression properties of cut-pile carpet properties.

Experimental

Material

In this work, acrylic fibre of three different finenesses (7.69, 10.99 and 16.48 dtex) was used, the fibre specifications of which are listed in ***Table 1***.

Table 1. *Raw material specifications; The figures in brackets are S.D values.*

Parameters	Material, dtex		
	7. 69	**10.99**	**16.48**
Fineness, dtex	8.04 (0.59)	11.38 (1.02)	16.92 (1.10)
Tensile strength, cN/tex	28.64 (3.27)	25.56 (3.27)	25.44 (2.62)
Elongation, %	41.36 (6.37)	41.47 (5.68)	44.25 (5.97)
Length, mm	121.5 (0.27)	121.2 (0.29)	150.0 (0.39)
Length, mm/ Fineness, dtex	15.11	10.65	8.87

Table 2. *Percentage of each acrylic fibre used in the pile yarn samples; *control sample.*

Yarn samples	Fibres fineness, dtex		
	7.69	**10.99**	**16.48**
1	7	93	0
2	11	84	5
3	15	75	10
4	18	67	15
5	22	58	20
6	26	49	25
7*	30	40	30
8	38	22	40
9	42	13	45
10	48	0	52

Table 3. *Main specifications of cut-pile carpet samples.*

Pile yarn linear density, tex	95.24×2
Weft yarn linear density, tex	275×2
Warp yarn linear density, tex	29.5×6
Pile material	acrylic
Pile density, pile/cm^2	15
Pile height, mm	13
Weft density, per cm	9
Warp density, per cm	5

The fibre length was measured using the comb-sorter method. Fibre fineness was obtained using the Vibromat method and 30 fibre samples were used for each fibre type. Single fibre tensile strength and elongation were measured according to ASTMD3822 utilising Fafegraph apparatus. Since fibre stiffness plays a significant role in pile yarn compression properties, the fibre length (mm) divided by the fibre fineness (dtex), known as the fibre stiffness factor [14], is also represented in ***Table 1***.

Yarn processing and cut-pile carpet specifications

In order to determine the acrylic fibre blend ratio, the average fibre fineness and number of fibres in a yarn cross-section of commercially produced yarn (control sample) were calculated at values of 10.68 dtex and 88, respectively [15]. Accordingly the maximum and minimum percentage of each fibre type was calculated as indicated in the following equation:

$$7 \leq 7.69 \text{ dtex} \leq 48$$

$$0 \leq 10.99 \text{ dtex} \leq 93$$

$$0 \leq 16.48 \text{ dtex} \leq 52$$

Thus the fibre blend ratio values were selected in such a way that the average number of fibres in the yarn cross-section was kept constant at a value of 88. The fibre percentage for a fibre fineness of 16.48 dtex was changed from 0 to 52 at a 5% interval value. Therefore the fibre percentages for other fibre types (7.69 and 10.99 dtex) were calculated. ***Table 2*** lists the fibre blend ratio values for different yarn samples.

In the spinning process, the individual acrylic fibre type was processed using the opening, carding and pre-drawing (gill-box machine) processes, and then acrylic fibre slivers with pre-determined linear densities were produced. The slivers produced were then blended on a drawing machine (gill-box I). The blended slivers produced were passed through two drawing passages (gill-box II & III), and finally 10 yarn samples with a yarn count of 10.5 Nm and twist level of 250 t.p.m. were produced on a semi-worsted ring spinning machine. The yarn samples were then folded on a two-for-one twister machine at a twist level of 160 t.p.m. Using the acrylic pile yarns, 10 cut-pile carpet samples were then produced. ***Table 3*** shows the carpet specifications.

Carpet compression testing

Carpet compression properties were measured using an Instron tester Model 5566. To do this test, the compression force exerted by a person's feet was calculated. The person's weight and feet cross-sectional area were considered, 75 kg and 20 × 9 cm^2, respectively. Then the compression pressure was obtained, 40.89 kPa. In this stage, a circular stand of 54 mm diameter was mounted on the Instron tester and the compression force was adjusted to 9.53 kg. The cross-head speed was 0.4 mm/sec., and only one cycle loading was investigated. Five replicates were determined for each carpet sample. A typical compression -recovery curve of acrylic cut-pile carpet for the first cycle compression loading is presented in ***Figure 1***. Based on the compression-recovery curve of individual acrylic cut-pile carpet samples, different compression properties of the carpets were evaluated using various compression parameters (*WC, W'C, RC* and *EMC*). *WC* is the elastic energy of compression, which refers to work done on a carpet created by constant static pressure (4.1 N/cm^2). Moreover the unit of the energy is in N·cm, where the pressure is in N/cm^2 and the deformation in cm. A carpet that absorbs more elastic energy indicates that it is more compressible. *W'C* (expressed in N·cm) is the decompression energy, which refers to work done on a carpet when the static pressure is removed. Thus with an increase in decompression energy, the energy loss or damping is reduced, leading to more compression resilience. *RC* is the compression resilience expressed in %, which shows the ratio of decompression energy to elastic energy of compression, meaning that if a carpet has a higher resilience to static pressure, it resists more against damping and the pile demonstrates better recovery, which leads to a softer carpet. *EMC* is the compressibility factor expressed in %, which indicates the compression deformation. This means that if a carpet has lower compressibility, it has higher resistance against static pressure, which results in a carpet with higher hardness. The compression parameters were calculated and obtained using the following equations:

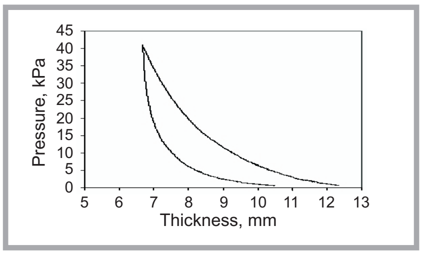

Figure 1. *Typical compression-recovery curve of acrylic cut-pile carpet (Sample 9).*

$$WC = \int_{T_{0c}}^{T_m} p\,dt \qquad (1)$$

$$W'C = \int_{T_m}^{T_{0r}} p\,dt \qquad (2)$$

$$RC = \frac{W'C}{WC} \qquad (3)$$

$$EMC = 1 - \frac{T_m}{T_{0c}} \qquad (4)$$

Where, T_{0c} is the initial carpet thickness, T_m the carpet thickness at maximum pressure, T_{0r} the final carpet thickness in a state of decompression, P the compression function, and dt carpet variations (suffix c refers to the compression and suffix r - to the recovery state). It should be noted that the compression function (P) was determined for individual samples using Matlab software, and then the corresponding compression energy (WC) and decompression energy ($W'C$) were calculated using a written program in the Matlab software [16]. The carpet compression properties are reported in ***Table 4***.

In addition, the carpet thickness under a static pressure (2 ± 0.2 kPa) were obtained on a Shirley digital thickness tester according to ASTM D 1777-96 [17]. The carpet thickness values are listed in ***Table 5***. All experiments were performed under standard conditions of 22 ± 2 °C and 65 ± 2% RH.

Results and discussion

The experimental results of carpet compression properties were statistically analysed using one-way ANOVA and Multiple Range test methods [15]. A summary of the ANOVA statistical analysis results is shown in ***Table 6***, which indicates that the acrylic fibre blend ratio significantly influenced carpet compression behaviour. The results of the work will now be discussed in detail:

Cut pile compression properties

The results of carpet compression properties, including the thickness at the maximum load value, the compression energy (WC), decompression energy ($W'C$), compression resilience (RC) and compressibility factor (versus the acrylic fibre blend ratio for the 16.48 dtex fibre component), are illustrated in ***Figures 2*** to ***5***.

As shown in ***Figure 2***, it can be stated that the lowest carpet thickness is obtained at a 15% fibre blend ratio, while the highest carpet thickness is obtained at a 52% fibre blend ratio. The statistical analysis also confirmed this finding [15]. This result is in agreement with the compressibility factor result, as indicated in ***Figure 3***, which illustrates that the maximum and minimum compressibility factor are found at fibre blend ratios of 15% and 52%, respectively. It is also found that at a 15% fibre blend ratio the com-

Table 4. *Test results of carpet compression properties; S.D values are indicated in brackets, * control sample.*

Percentage of 16.48 dtex acrylic fibre used in the pile yarn samples	Energy of compression, N·cm	Decompression energy, N·cm	Resilience of compression, %	Compressibility factor, %
0	13.25 (0.176)	5.13 (0.104)	38.5 (0.0071)	47.9 (0.016)
5	14.15 (0.315)	5.55 (0.174)	39.1 (0.0057)	50.7 (0.015)
10	14.24 (0.217)	5.56 (0.092)	39.4 (0.007)	52.6 (0.007)
15	14.35 (0.136)	5.74 (0.123)	40.2 (0.002)	53.7 (0.015)
20	14.25 (0.272)	5.49 (0.114)	38.7 (0.0013)	48.8 (0.016)
25	13.87 (0.324)	5.34 (0.102)	38.9 (0.0074)	49.2 (0.015)
30*	13.59 (0.149)	5.38 (0.097)	38.6 (0.0084)	48.3 (0.01)
40	13.69 (0.437)	5.23 (0.212)	38.3 (0.0068)	47 (0.008)
45	13.73 (0.375)	5.31 (0.277)	38.3 (0.0116)	47.1 (0.009)
52	13.57 (0.213)	5.15 (0.189)	37.8 (0.0114)	45 (0.009)

Table 5. *Arithmetic mean thickness of carpet samples; S.D values are indicated in brackets, *control sample.*

Properties	Percentage of 16.48 dtex acrylic fibre used in the pile yarn samples									
	0	5	10	15	20	25	30*	40	45	52
Thickness, mm	12.48 (0.12)	12.53 (0.17)	12.61 (0.11)	12.53 (0.22)	12.58 (0.19)	12.51 (0.15)	12.32 (0.14)	12.63 (0.16)	12.59 (0.24)	12.60 (0.15)

Table 6. *Summary of ANOVA statistical analysis results for carpet compression properties, *P value at 0.05 confidence level.*

Compression parameter	Energy of compression (*WC*)	Decompression energy (*W'C*)	Compression resilience (*RC*)	Compressibility factor (*EMC*)
Acrylic fibre blend ratio	0.000	0.000	0.000	0.000

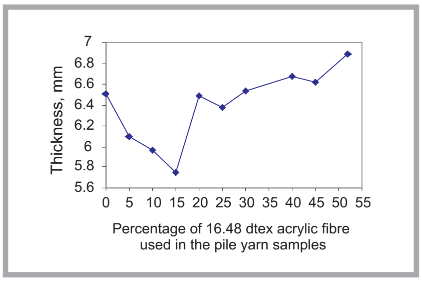

Figure 2. *Carpet thickness variation (at maximum pressure) versus different acrylic fibre blend ratios.*

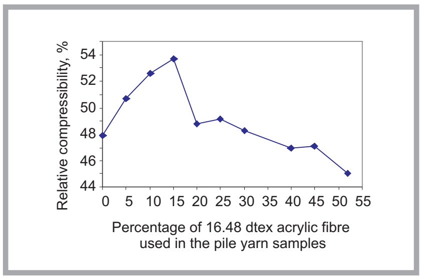

Figure 3. *Compressibility factor variation versus different acrylic fibre blend ratios.*

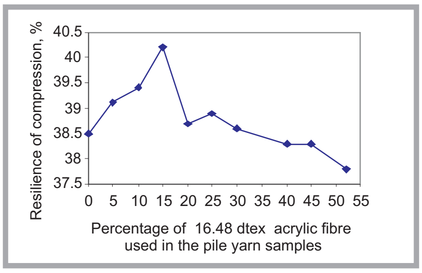

Figure 4. *Resilience of compression variation versus different acrylic fibre blend ratios.*

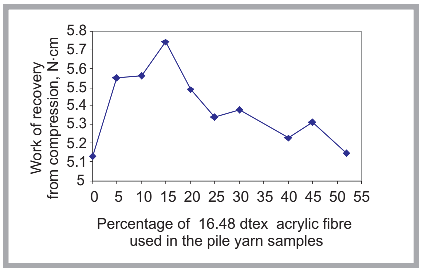

Figure 5. *Decompression energy variation versus different acrylic fibre blend ratios.*

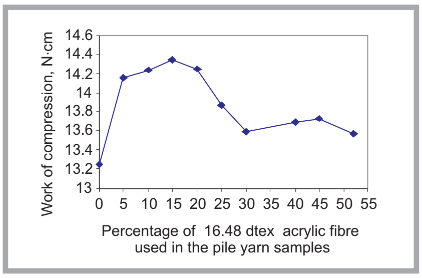

Figure 6. *Energy of compression variation versus different acrylic fibre blend ratios.*

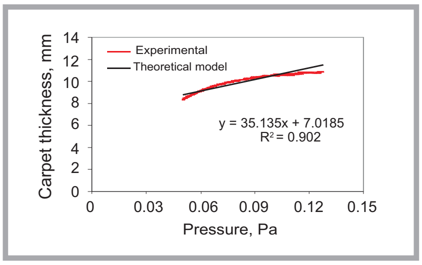

Figure 7. *Typical carpet thickness and pressure relationship (plotted as the inverse cube root).*

pression resiliency and decompression energy values are statistically different from other samples and exhibit the highest values, as shown in ***Figures 4*** and ***5*** (see page 79). However, the statistical analysis indicates that the lowest compression energy is obtained at a 0% fibre blend ratio (sample 1), and the compression energy at fibre blend ratio values of 5, 10, 15, and 20% are similar, showing the highest value as given in ***Figure 6***.

It is reasonable to state that these findings are attributed to the compression properties of individual fibre components and hence also to their interaction effects during the compression process. The distribution of individual fibre components in the yarn cross-section may also play as important a role, which was ignored in this work. The other hypothesis is that, as shown in ***Table 1*** (see page 78), with an increasing 16.48 dtex fibre blend ratio, the 7.69 dtex fibre blend ratio also increases, while the blend ratio for 10.99 dtex fibre decreases, illustrating that the effect of the finer component on pile yarn compression is more dominant than the other components up to a certain point (15% of 16.48 dtex fibre), which in turn leads to a softer carpet with lower compression hardness. However, after this point, the role of the coarser component is more crucial, and as a result more compression resistance will be obtained. As a consequence, more resistance against the compression force and hence a higher carpet thickness will be obtained.

Prediction acrylic cut pile carpet compression

In order to predict the compression behaviour of acrylic cut-pile carpet, the two parameter model proposed by de-Jong *et al.*, [18] with the following equation types was used:

$$P = \frac{a}{(V - V')^3} \qquad (5)$$

$$a = K'Y\left(\frac{W}{\rho}\right)^3 \qquad (6)$$

Where P is the pressure, a a constant, V carpet volume or thickness, V' the limiting carpet volume (thickness) at large pressure, K' a dimensionless constant which depends on fibre orientation and crimp, Y Young's modulus of fibre, ρ the density of fibres, and W is the mass of the fibre assembly.

After the rearrangement of ***Equation 5***,

$$V = V' + \frac{a^{1/3}}{P^{1/3}} \qquad (7)$$

it may be considered that plotting the carpet thickness V against the inverse cube root of the pressure $1/P^{1/3}$ should result in a straight line with intercept V' and slope $a^{1/3}$. In order to verify the validity of this model for the acrylic cut-pile carpet and to determine constants a and V', the individual carpet sample thickness (V) at different pressure values was first read off the compression-recovery curves and then these values were plotted against $1/P^{1/3}$, after which linear statistical regression analysis was performed. A typical acrylic cut-pile carpet thickness and pressure relationship (plotted as the inverse cube root of the pressure $1/P^{1/3}$) is represented in ***Figure 7***. As shown in ***Figure 7***, the behaviour of acrylic cut-pile carpet in compression is extremely close to that of the model proposed by de-Jong *et al.*, [18]. However, at lower and higher pressure values, the experimental results are slightly different from the theoretical results. The determination coefficient (R_c^2 and R_r^2) for both the compression and recovery of compression were obtained at the following values, respectively:

$$0.9020 < R_c^2 < 0.9303$$

$$0.9672 < R_r^2 < 0.9805$$

Conclusions

In this research, the compression properties of acrylic cut-pile carpet consisting of pile yarn with different fibre blend ratios were investigated. The results showed that with an increase in coarser acrylic fibre content (16.48 dtex fibre), the yarn specific volume first decreases and then increases. The results of this research revealed that acrylic cut-pile carpet produced from pile yarn with 16.48, 10.99, and 7.69 dtex fibre at 15%, 67%, and 18% blend ratios, respectively, exhibits the highest compression energy (WC), de-compression energy (W′C), resilience of carpet compression (RC) and relative compressibility (EMC) values compared with other samples and comercially produced yarn. In addition, the compression behaviour of cut-pile acrylic carpet was predicted based on the two parameter model proposed by de-Jong *et al.*, [18]. It is shown that the regression coefficient for both the compression (R_c^2) and recovery of compression (R_r^2) were almost high. This result suggests that for the cut-pile carpet structure, there is an incompressible layer (V') which resists high compression loading. Further experimental research works are needed to investigate the dynamic compression behaviour of acrylic cut-pile carpets produced at different fibre blend ratios.

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