Indian Journal of Fibre & Textile Research
Vol. 45, September 2020, pp. 305-311

Compression behaviour of hand-tufted carpets: Part II—Effect of cyclic compressive load

Bhavna Choubisa[1], S K Sinha[1,a] & R Chattopadhayay[2]

[1]Department of Textile Technology, Dr B R Ambedkar National Institute of Technology, Jalandhar 144 011, India
[2]Department of Textile Technology, Indian Institute of Technology Delhi, New Delhi 110 016, India

Received 20 February 2019; revised received and accepted 25 September 2019.

The effect of cyclic compressive load on compression characteristics of wool and acrylic hand-tufted carpets has been studied. Wool carpets exhibit higher compression and recovery than the acrylic carpets with similar construction. Compression and matting decrease with an increase in pile density. Percentage recovery of the carpets is found to increase with increase in the number of compression cycle.

Keywords: Acrylic, Cotton, Carpet consolidation, Compression, Compression hysteresis, Hand-tufted carpets, Matting, Wool

1 Introduction

Carpet is a specific category of textile, which finds its application in indoor floor covering. Besides thermal regulation and sound insulation, its appearance and walking comfort are important attributes. Forces of varying magnitude and repetitive or static nature act on it during its use. Besides the nature of force, its duration also varies. Retention of aesthetics and walking comfort decides the useful life of a carpet. The useful life of carpet is determined by its ability to retain thickness and hence the resilient characteristics. Besides the type and duration of the applied load, the pile characteristics [constituent fibre, type of pile yarn (cut or loop), pile density and pile height] and the nature of support by the backing fabric influence its performance in long run. Onder *et al.*[1] reported the pile material to have a strong effect on the loss of carpet's appearance. Wool has always been a choice due to its natural resilient character; however the advent of synthetic fibres has increased variety of available fibres for carpet production. Thus, it has become pertinent for the researchers to understand the behaviour of fibre spectrum under different conditions of loading and unloading.

Compression resiliency, as assessed by the tuft recovery behaviour, has been reported to be important to optimize the carpet geometry[2]. However, resiliency can also be denoted as the amount of work, which the pile under load is capable of doing in returning to its unstrained state and is known as potential energy due to strain[3]. A tuft may recover from deformation if the energy stored in deformation is higher than the energy dissipated. In carpets with low pile density, pile deforms quickly, and the relatively immovable backing absorbs most of the applied force. An increase in density leads to force dissipation by the resistance of the pile to bending[4].

Onder *et al.*[1] reported an increased pile height to cause more energy absorption by the pile yarn in comparison to the backing material, thereby influencing the carpet's performance. Laughlin *et al.*[5] reported an increase in the pile recovery with increase in compression cycle. Barach[6] had developed a method for measurement of energy absorption ability of carpets and stated that the elastic constant depends on the load involved in deformation. Khavari *et al.*[7] had analysed three different mechanical models to explain the compression, decompression and recovery of cut-pile carpets under constant rate of compression and suggested a nonlinear three element model for best fit of experimental data. An increase in compression and matting and reduction in elastic recovery of pile yarn was reported as a result of an increase in slip wool percentage[8, 9]. A finer wool carpet was also reported to remain more resilient[10-12].

Besides the constituent fibre, yarn structure and properties, the post spinning treatments of pile yarn have also been reported to influence the carpet performance[13-17]. Dayiary *et al.*[18] reported the physical and mechanical properties of pile yarn as important factors influencing the pile deformation. Further,

[a]Corresponding author.
E-mail: sinhask@nitj.ac.in

Grover *et al.*[19] reported the resiliency to decrease due to the use of plied yarn.

The present investigation is aimed at studying the influence of fibre type in pile yarn, pile height, pile density and number of cycle on compression, recovery and matting of carpets. This study also elaborates the hysteresis effect during compression cycle for both wool and acrylic carpets.

2 Materials and Methods

2.1 Materials

Eighteen hand-tufted carpets, varying in pile material, pile height and pile density were prepared from local industry. Pre-woven cotton fabrics were used for primary and secondary backing of the carpets. The carpet samples were produced by tufting the pile yarn into primary backing fabric through tufting gun. Primary and secondary backings were then bonded by latex during finishing. The specifications of carpets are given in Table 1.

For both wool and acrylic carpets, staple fibre yarns of linear density 2 Nm were used as pile. The fineness of wool and acrylic fibres were kept 13.3 denier (38 microns) and 7.5 denier (30 microns) respectively.

2.2 Testing Methods

The carpet samples were conditioned at a tropical atmosphere of 27±2°C and 65±5% RH for 24 h. To study the compression characteristics of carpets, cyclic compression test was performed. Detail of test procedure is given hereunder.

The study of stress-strain behaviour of carpets during cyclic compression was carried out on Zwick Universal testing machine. The compression load was cycled between 2 kPa (0.25 psi) and 83 kPa (12 psi) for five cycles without any delay time during and between cycles. The cross-head speed was maintained at 5mm/min[5]. Five tests were performed for each sample. A typical compression-recovery curve is shown in Fig. 1, while Fig. 2 is a schematic representation of the changes occurred during the compression cycle.

Points A, B and C on the curve represent the thickness at compression loads 2kPa, 83 kPa and 2 kPa (after decompression) and are represented by t_i, t_c & t_d respectively. Using the corresponding thickness values, the following parameters were calculated:

$$\text{Compression (\%)} = \frac{t_i - t_c}{t_i} \times 100$$

$$\text{Recovery (\%)} = \frac{t_d - t_c}{t_i - t_c} \times 100$$

$$\text{Matting (\%)} = \frac{t_i - t_d}{t_i} \times 100$$

where t_i is the carpet thickness at 2 kPa; t_c, the carpet thickness at 83 kPa; and t_d, the carpet thickness after decompression at 2 kPa.

Table 1 — Specifications of carpets

Sample code	Pile material	Carpet thickness mm (at 2kPa pressure)	Pile height mm	Pile density tufts/dm^2	Pile weight g/m^2
1	Wool	12.46	6	387	232.2
2	Wool	12.36	6	465	279.0
3	Wool	13.46	6	558	334.8
4	Wool	14.46	7.5	387	290.3
5	Wool	14.16	7.5	465	348.8
6	Wool	14.76	7.5	558	418.5
7	Wool	15.92	9	387	348.3
8	Wool	15.06	9	465	418.5
9	Wool	15.90	9	558	502.2
10	Acrylic	11.62	6	387	232.2
11	Acrylic	12.15	6	465	279.0
12	Acrylic	11.77	6	558	334.8
13	Acrylic	11.69	7.5	387	290.3
14	Acrylic	11.82	7.5	465	348.8
15	Acrylic	11.85	7.5	558	418.5
16	Acrylic	13.69	9	387	348.3
17	Acrylic	13.52	9	465	418.5
18	Acrylic	13.49	9	558	502.2

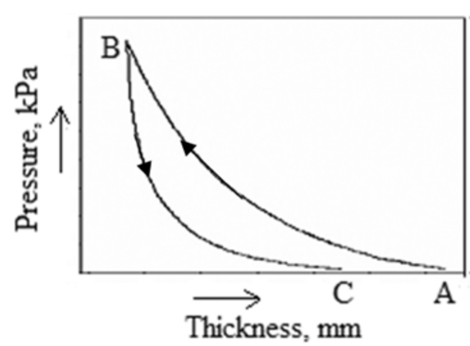

Fig. 1 — Typical compression recovery curve

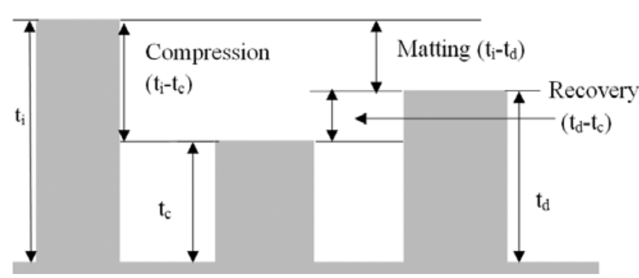

Fig. 2 — Schematic diagram of changes during compression cycle

3 Results and Discussion

The performance and useful life of a carpet is influenced by its behaviour under repeated loading. Percentage compression, percentage recovery and percentage matting parameters for the first and fifth cycle have been calculated for the assessment of performance.

3.1 Compressive Load – Thickness Curve

Typical compression curves for deformation and recovery of both wool and acrylic carpets are shown in Fig. 3. With increased compression, thickness reduces and force recorded rises. The rise of force is nonlinear in nature. After attaining a pre-set level of load (83kPa), the jaw movement is reversed to allow recovery. During recovery phase, the force can be seen to decline with decrease in deformation. The deformation and recovery curves are not same and a hysteresis can be seen for both the carpets. The hysteresis loop is formed which indicates loss in compression energy due to either permanent deformation of fibres, friction and slippage of fibres within the structure[20].

The hysteresis area reduces with increase in compression cycles for both the carpets. Surprisingly, the hysteresis loss is more in the case of wool carpet. The scales in wool fibres probably leads to more frictional energy loss. With increased compression cycling, both the carpets become structurally more consolidated due to gradual compaction and therefore resist further deformation. After five cycles, the thickness loss in acrylic carpet is more than in wool carpet. The acrylic carpet quickly gets consolidated and loses ability to absorb energy.

3.2 Statistical Analysis

The influence of experimental variables (pile material, pile density, pile height and cycle number) on compression, recovery and matting of carpet

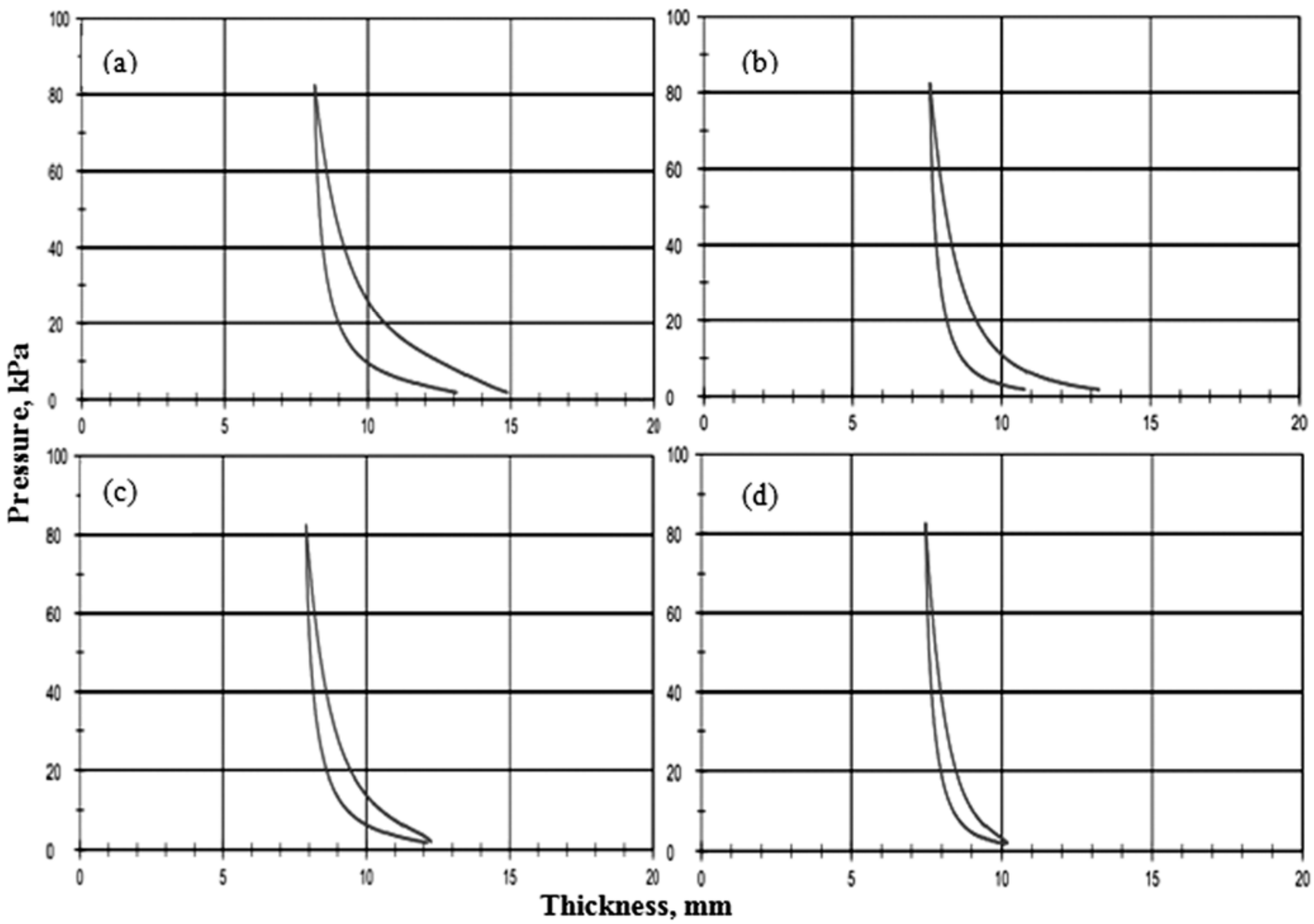

Fig.3 — Compression-thickness curves of carpets (a) wool carpet 1st cycle, (b) acrylic carpet 1st cycle, (c) wool carpet 5th cycle and (d) acrylic carpet 5thcycle

Table 2 — ANOVA test results

Variables	Compression, %		Recovery,%		Matting, %	
	p- value	Effect	p- value	Effect	p- value	Effect
Cycle number	0.00	S	0.00	S	0.00	S
Pile material	0.00	S	0.00	S	0.00	S
Pile height	0.00	S	0.17	NS	0.00	S
Pile density	0.00	S	0.00	S	0.00	S
Cycle number*Pile material	0.00	S	0.00	S	0.08	NS
Cycle number*Pile height	0.00	S	0.24	NS	0.00	S
Pile material*Pile height	0.00	S	0.30	NS	0.00	S
Cycle number*Pile density	0.39	NS	0.27	NS	0.20	NS
Pile material*Pile density	0.20	NS	0.64	NS	0.33	NS
Pile height*Pile density	0.18	NS	0.28	NS	0.01	S

S- Significant; NS- Non-significant

during cyclic compression test has been assessed for significance by using analysis of variance. The results are obtained at 95% level of significance and shown in Table 2.

It is observed from the above table that the effect of main variables on compression and matting is significant. However, the effect of pile height on recovery is not significant.

3.3 Compression

Figure 4 represents the effect of number of cycles and pile yarn composition on carpet compression characteristics under cyclic compression. This figure shows the characteristics in carpets of different pile densities with 7.5 mm pile height. The following observations are made from Fig.4 (a):

- Appreciable difference in the percentage compression during the first cycle for both wool and acrylic carpets is not observed.
- For the 5^{th} cycle, percentage compression values of acrylic carpets are lower than that of wool carpets.
- An increase in pile density leads to decrease in percentage compression for all the carpets during both 1^{st} and 5^{th} cycle.
- For both wool and acrylic carpets, the percentage compression in 1^{st} cycle is higher than that in the 5^{th} cycle.

The influence of pile height on compression is shown in Fig. 5 (a). An increase in pile height leads to an increase in percentage compression for both wool and acrylic carpets in the 1^{st} cycle. In the 5^{th} cycle, compression percentage has been found to increase with pile height for wool carpet. However, increase in compression has been found to be less prominent for acrylic carpet.

The thickness change is primarily considered as the effect of bending of the pile yarns on application of repetitive compression force. The critical load for buckling of a material can be given by[21]:

$$P_{cr} = \frac{\pi^2 EI}{L^2}$$

where *E* is the bending modulus; *I*, the moment of inertia; and *L*, the height of the column.

For a specific yarn, both *E* and *I* remain constant. An increase in height of pile (L) reduces the critical load required to bend the pile yarn. Accordingly, longer length of pile yarns is likely to bend and compress easily. Hence, the percentage compression of longer pile is high. For an unused carpet, the inter loop spacing is greater than that in a used carpet, which is evident from its higher value of porosity. The pile yarns during first cycle, thus, face less resistance from the neighbouring yarns during bending and its deflection from the initial position is expected to be the maximum. Hence, percentage compression in 1^{st} cycle is higher. During subsequent compression cycle, the consolidation and flattening of yarn help in resisting the bending. It is possible that the already bent yarns act as cushion, thereby helping recovery on withdrawal of load. Further, repetitive loading causes mechanical conditioning of pile yarns. The magnitude of permanent deformation is, thus, eliminated and recoverable deformation is left, leading to a lower compression during 5^{th} cycle. Repeated compression consolidates acrylic carpet quickly and makes the structure more elastic. As a result, the hysteresis loss reduces for acrylic carpet.

When the pile density increases, a pile yarn gets support from the neighbouring yarns in resisting bending. The applied force also gets distributed; thereby a reduction in force per pile yarn takes place. Accordingly, compression is less when the pile density increases.

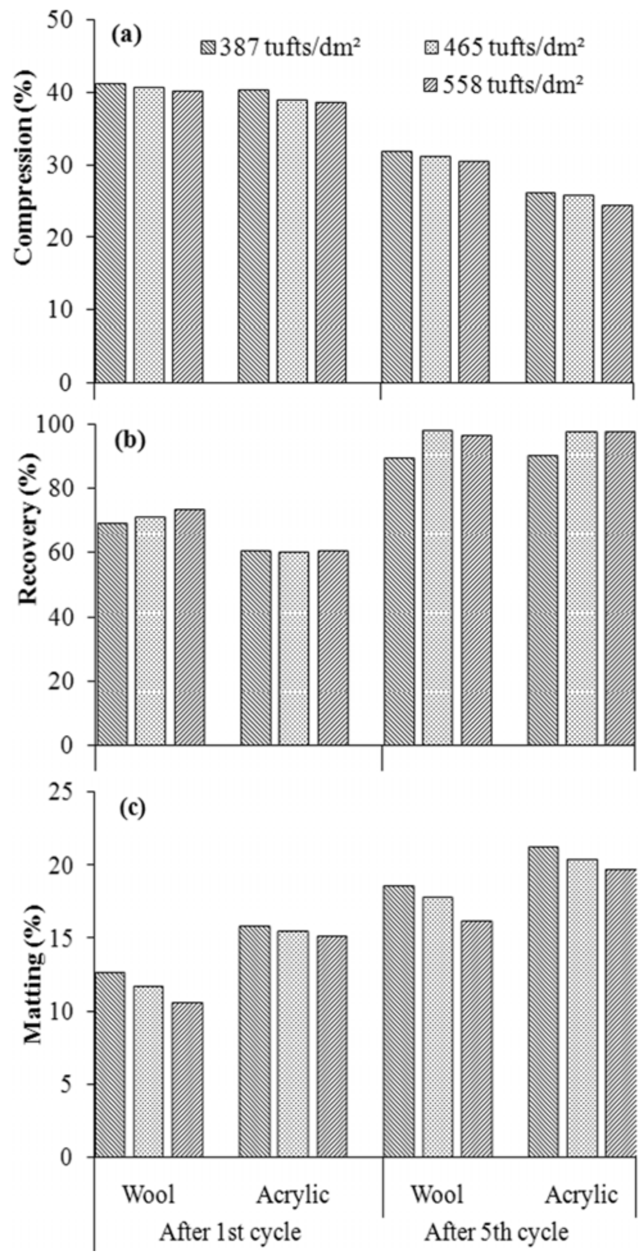

Fig.4 — Effect of compression cycle and pile density on percentage (a) compression, (b) recovery and (c) matting in wool and acrylic carpets for pile height 7.5 mm

3.4 Recovery

The recovery of the pile height is one of the key factors governing the useful life of a carpet. Figure 4 (b) and Fig.5 (b) represent the effect of cycle number and fibre type on carpet recovery during cyclic compression. Figure 4 (b) represents the recovery of carpets having three different pile densities with 7.5 mm pile height. The observations from the Fig. 4 (b) are as follows:

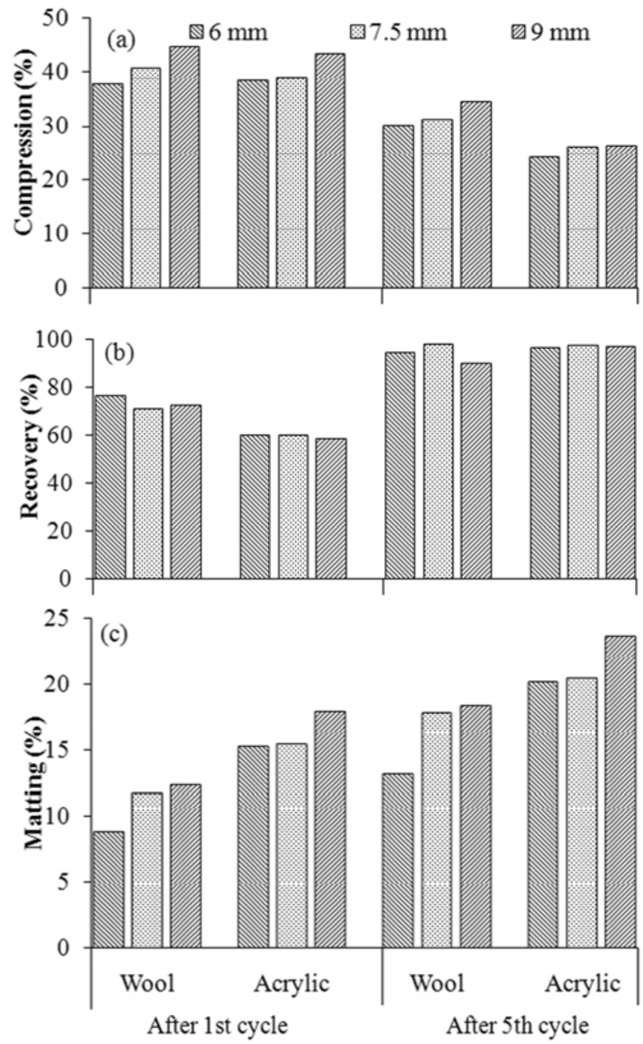

Fig.5 — Effect of compression cycle and pile height on percentage (a) compression, (b) recovery and (c) matting of wool and acrylic carpets for pile density 465 tufts/dm^2

- The percentage recovery of wool carpets is more than that of acrylic carpets for the 1st cycle.
- An increase in pile density leads to increase in percentage recovery.
- For both wool and acrylic carpets, the percentage recovery in 5th cycle is greater than in 1st cycle.
- The percentage recovery ranges from 90% to 98% in both wool and acrylic carpets for the 5th cycle.

Figure 5 (b) represents recovery of both wool and acrylic carpets with pile density of 465 tufts/dm^{2}for three different pile heights. It is observed that the pile height does not have any significant effect on recovery.

Wool by virtue of helical arrangement of its molecules shows higher resilient characteristics. High recovery in 5th cycle is the result of mechanical conditioning of pile yarns due to repetitive loading and structural consolidation as well. It has already been observed that higher pile density reduces the compression during loading. Presence of additional number of pile yarns provides a cushion and assists in recovery.

3.5 Matting

Matting is a wear-induced characteristic that is seen as the merging of carpet tufts to the stage where they become less defined. Matting results in irrecoverable loss of thickness and is undesirable. Figure 4 (c) shows the matting results after different compression cycles for wool and acrylic carpets. This figure also shows the matting behaviour of carpets having different pile densities with 7.5 mm pile height.

The observations from Fig. 4 (c) are as follows:

- The percentage matting of wool carpets is lower than that of acrylic carpets in both the cycles.
- An increase in pile density leads to decrease in percentage matting values of the carpets in both 1st and 5th cycles.
- The percentage matting in 1st cycle is lower than that in 5th cycle for both wool and acrylic carpets.

The influence of pile height on matting for both wool and acrylic carpets for a particular tuft density is shown in Fig.5 (c). An increase in pile height leads to increase in percentage matting.

Carpet matting can be viewed as result of permanent deformation and frictional slippage of fibres inside yarns due to repeated axial loading. The recovery from deformation is due to elastic nature of fibre. This recovery is restricted by the frictional forces between deformed and neighbouring fibres that oppose recovery. The interlocking between the neighbouring yarns as they are buckled also adds to the matting.

With increased pile height, deformation becomes easy. Inter fibre and inter yarn contact in deformed state also increase. Thus, frictional forces opposing recovery rise, resulting in matting. At the initial cycle of deformation, the possibility of pile interlocking is less due to availability of more inter-yarn spaces, as carpet volume is more. At the later stage of loading cycles, progressive decrease in thickness increases compactness of pile surface, which brings yarns closer to each other, enhancing interlocking possibility that results reduced recovery. Hence, percentage matting is greater after fifth cycle of compression. At higher pile density, the applied load is distributed that reduces the load per pile yarn. Thus, the compressibility reduces and recovery is assisted. For a particular load, the possibility of interlocking of pile yarn is less due to reduction in the load per yarn. Thus, higher pile density reduces matting.

4 Conclusion

The performance, aesthetic and hence the useful life of a carpets are influenced by their ability to retain the dimension under repeated loading. In the present study, a cyclic compression has been employed as a test for evaluating carpet performance. The performance is evaluated in terms of compression, recovery and matting on application of cyclic compressive load. The composition of pile yarns and construction parameters of carpet are found to have significant influence on the above performance characteristics. The conclusions from the study are summarized below:

4.1 The wool carpets show both higher compression and recovery characteristics than the acrylic carpets.

4.2 An increase in pile height causes higher percentage compression, which leads to higher matting propensity.

4.3 Increased pile density results in less compression, higher recovery and lesser degree of matting

4.4 The percentage compression and percentage matting decrease with increase in pile density.

4.5 The percentage compression reduces with increase in number of cycle, while the percentage recovery and percentage matting increase with increase in number of cycle during cyclic compression test

References

1 Onder E & Berklap O B, *Text Res J,* 71(6) (2001) 549.
2 El-Shiekh A & Hersh S P, *Text Res J,* 39(12) (1969) 1134.
3 Fox K R & Schwarz E R, *Text Res J,* 11(5) (1941) 227.
4 Beckwith O P & Barach J L, *Text Res J,* 17(6) (1947) 305.
5 Laughlin K C & Cusick G E, *Text Res J,* 38(1) (1968) 72.
6 Barach J L, *Text Res J,* 19(6) (1949) 355.
7 Khavari S & Ghane M, *Fibres Polym,* 18(1) (2017) 190.
8 Moghassem A R & Gharehaghaji A A, *Int J Eng Trans B: Appl,* 21(3) (2008) 303.
9 Mirzalili S A & Sharzehee M, *J Text Inst,* 96(5) (2005) 287.
10 Gupta N P, Shakyawar D B & Sinha R D, *Indian J Fibre Text Res,* 23(1) (1998) 32.
11 Arora R K, Bapna, D L, Patni P C & Batra, H S, *Indian J Fibre Text Res,* 14 (2) (1989) 77.

12 Patni P C, Arora R K, Dhillon R S & Bapna D L, *Indian J Fibre Text Res*, 21 (3) (1996) 189.
13 Nilgün Ö, Faruk B, Gonca Ö & Gamze S M, Teks *Tekstilve Konfeksiyon*, 22(3) (2012) 203.
14 Arora R K, Patni P C, Dhillon R S & Bapna D L, *Indian J Fibre Text Res*, 24 (2) (1999) 111.
15 Ishtiaque S M, Sen K & Kumar A, *J Text Inst*, 106(11) (2014) 1190.
16 Javidpanah M, Najar S S & Dayiary M, *J Text Inst*, 105(12) (2014) 1265.
17 Javidpanah M, Najar S S & Dayiary M, *J Text Inst*, 106(3) (2015) 236.
18 Dayiary M, Najar S S & Shamsi M, *J Text Inst*, 100(8) (2009) 688.
19 Grover G, Zhu S & Twilley I C, *Text Res J*, 63(5) (1993) 257.
20 Morton W E & Hearle J W S, *Physical Properties of Textile Fibres* (The Textile Institute, Manchester), Student edn,1986, 322.
21 Roylance D, in *Stresses in Beams*, edited by D Roylance (John Wiley and Sons Ltd., New York), 1996, 7.