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Compression behaviour of hand-tufted carpets: Part I–Effect of short-term static and dynamic loading

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The effect of static and dynamic loading on the compression characteristics of hand tufted carpets has been studied using two types of pile materials. Wool tufted carpets are found to show better retention of thickness. Higher tuft density is found to assist retention of thickness, while higher pile height results in more thickness loss. Thickness loss is also found to be more at the initial impacts, while the recovery rate is found to be more at the initial stage.

Keywords: Acrylic, Carpets, Dynamic loading, Pile density, Static loading, Thickness loss, Wool

1 Introduction

Carpet is a three dimensional textile structure used as floor covering. It is composed of warp, filling and pile yarns. Warp and filling yarns form the carpet backing like a heavy fabric. Pile yarns in the form of cut, loop, or cut-loop remain perpendicular to the backing fabric and constitute carpet surface[1]. Besides aesthetic, walking comfort, sound and thermal insulation are the important attributes of a carpet.

There are several carpet-manufacturing methods, such as knotting, tufting, weaving, knitting, braiding, needle felting, fusion bonding and flocking[2]. Based on manufacturing technique, the carpets are categorized as hand-made or machine-made carpets. Hand-made carpets are further categorized as knotted, tufted and flat woven carpets. Manufacturing of hand-tufted carpet involves the use of tufting gun. Pile yarns are punched into the pre-stretched primary backing fabric mounted on a frame through the needle of tufting gun. After completion of tufting process, the carpet is removed from the frame. In order to increase the useful life and to reduce wear and tear of carpet, a heavy secondary backing fabric is always bonded to the primary backing fabric by latex.

During its lifetime, a carpet is exposed to forces, such as axial compression, bending, flattening, and extension[3]. These forces are applied either by dynamic loading, such as walking or by static loading of variable magnitude and duration[4]. During any type of loading, pile yarns are compressed and try to come back to their initial position on removal of load. Failure of pile yarns to regain their initial position leads to thickness loss of carpet.

The compression behaviour of carpet, a time-dependent phenomenon, plays a special role as one of the most important mechanical properties. It has been noted that carpet compression properties are influenced by the structure and properties of the constituent fibres and yarns, carpet construction parameters, nature and level of loading and time allowed for both loading and recovery[5-19]. An increase in compression and matting, and reduction in elastic recovery of pile yarn has been reported as a result of an increase in slip wool percentage[6, 7]. The properties of carpet have also been reported to be influenced by wool fibre diameter and its percentage medullation[8-10]. A positive correlation of fibre diameter and medullation with carpet compressibility and resiliency was reported by Gupta *et al.*[8]. An increase in yarn linear density affects its thickness and, hence recovery characteristics of carpet[15], while an increase in the number of folds in the yarn increases resiliency and decreases compressibility[16]. Other than process parameters used during yarn formation, the structure of yarn and post spinning operation may also influence the carpet performance[17-19]. Pile height and pile density have been reported to influence the thickness loss, pile recovery and compressibility of carpets[4, 6, 7, 20-26]. Since a carpet is subjected to

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different types of compressive load in use, study of its compression behaviour is very important. The compression of carpet may lead to a loss in its working life and appearance with simultaneous deterioration of walking comfort. Many researchers have investigated the carpet compression behaviour but information on the compression behaviour of hand-tufted carpets is scanty. Therefore, the aim of this study is to investigate the effect of fibre type and carpet constructional parameters on the compression behaviour of hand-tufted carpets. This part of the paper deals with investigation on carpet performance capabilities under static and dynamic loading conditions. An emphasis has been made on thickness loss, as the property is most closely related to consumer acceptance. The study reported here is undertaken to investigate the effect of selected carpet construction variables using short-term static and dynamic loading.

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 joined by latex during finishing. The carpet construction parameters were chosen as per the market demand and being produced in local industries. The construction parameters are given in Table 1.

Staple fibre yarns of linear density 2 N_m (500 tex) from wool and acrylic were used as pile material for the production of the carpets. The fineness of wool was 13.3 denier (38 micron), while that of acrylic fibres was 7.5 denier (30 micron).

2.2 Testing Methods

The carpet samples were conditioned at a tropical atmosphere of 27±2^{o} C and at 65 ± 5% RH for 24 h. To study the compression characteristics of carpets, short-term static loading and dynamic loading tests were performed.

Table 1 — Carpet construction parameters

Factor	Level
Fibre used in pile yarn	Wool, acrylic
Pile height, mm	6, 7.5, 9
Pile density, tufts/dm^2	387, 465, 558

2.2.1 Short-Term Static Loading

The short-term static loading test was performed to determine the percentage thickness loss and thickness recovery for a short interval of time. The thickness of 100 mm^2 sample was measured by digital thickness tester at 0.01 mm accuracy using 2 ±2% kPa pressure. For static loading, a pressure of 220 kPa was applied on the surface of the sample without any shock. The sample was subjected to loading for 2 h. After removal of load, carpet sample was left to recover. The recovered thickness of sample was measured immediately after removing the load and after recovery periods of 15 min, 30 min and 60 min respectively[4]. For each sample, five readings were taken. Following parameters were calculated with the help of observed readings:

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

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

where percentage thickness loss is the change in thickness expressed as a percentage of initial thickness; t_i is the initial thickness of sample before testing; t_d, the sample thickness after recovery period; and t_c, the sample thickness immediately after removal of load.

2.2.2 Dynamic Loading

The dynamic loading tester simulates the treading action on carpets. The action of the machine was developed to imitate two of the main actions of walking, i.e. the compressive effect and shearing effect produced at the boundary of shoe edges[27]. Carpet performance during dynamic loading testing is reported to correlate reasonably well with practical corridor trials[28]. The dynamic loading test was performed following ISO 2094:1999 standard. The thickness of 125 mm^2 sample was measured by digital thickness tester with 0.01 mm accuracy under 2±2% kPa pressure. The thickness of sample was measured as the distance between a reference plate on which carpet rests and a parallel circular pressure foot. The carpet sample was then laid on carpet dynamic loading tester. The carpet samples were then subjected to 50, 100, 200, 500 and 1000 impacts. After each set of dynamic loading impact, sample thickness was measured. Five tests for each type of carpet were carried out. The percentage thickness loss was calculated from the following equation:

$$\text{Thickness loss (\%)} = \frac{t_i - t_x}{t_i} \times 100$$

where t_i is the initial thickness of carpet before dynamic loading test; and t_x (x=1, 2, 3, 4, 5) represents thickness after specified number of dynamic impact test (50, 100, 200, 500 and 1000).

2.3 Mechanism of Pile Deformation and Recovery

2.3.1 Pile Deformation

The pile deformation refers to the change in dimension of a pile on application of compressive load. A reduction in the thickness of carpet for such deformation is inevitable. This in turn, yields a remarkable deterioration in the appearance and walking comfort. To represent the nature of possible deformation of loop pile, following assumptions were made:

- Yarn is uniform and circular in cross-section
- Compression force acts vertically along the axis of the pile.
- There is no interaction of the neighbouring loops during the process of deformation.

Two loops of same yarn length may vary in terms of ratio of loop spacing (S) and loop height (H)[29] as shown in Figs 1(a) and (b).

When a carpet is subjected to compressive stresses encountered during use, the loop will deflect laterally after a possible initial compression. The resultant of twist in pile and the compression stress will tend to shift the plane of the loop, thus causing instability in the tufts helping them to deflect laterally. The loop may either bend, as shown in Fig. 1(e), or get flattened as shown in Fig. 1(f).

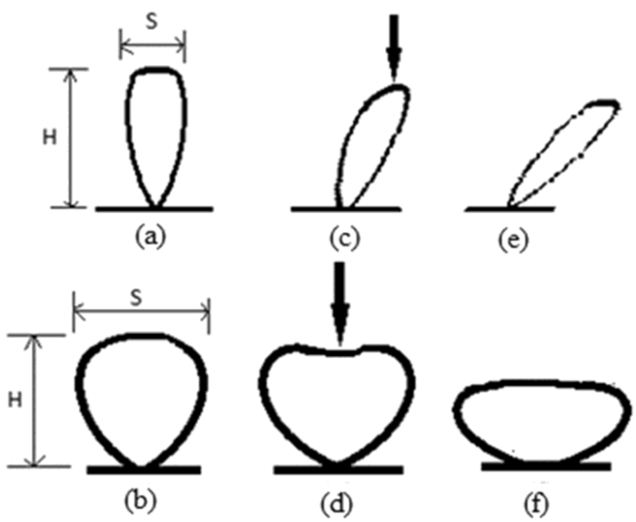

Fig. 1 — (a) loop pile having low S/H ratio, (b) loop pile having high S/H ratio, (c) & (d) commencement of load and pile deflection, and (e) & (f) final position of pile at the end of loading

2.3.2 Pile Recovery

Pile recovery refers to the ability of pile yarn to recover from deformation immediately or with time on withdrawal of compressive load and is measured by the recovered thickness with respect to the thickness loss of pile at the end of loading. The pile recovery on withdrawal of compressive load is expected to be influenced by:

- The property of constituent fibres in pile yarn
- Composition and arrangement of fibres in pile yarn
- Frictional characteristics of pile yarn and its interaction with neighbouring piles
- Carpet construction parameters viz. pile type (cut/loop), pile height and density
- Time allowed for loading and recovery
- Type of loading (dynamic or static)

When a compressive load is applied, the pile deformation or thickness loss in a carpet may occur due to one or both of the following reasons:

(i) Bending of yarns with simultaneous bending of fibres

(ii) Frictional sliding of fibres within pile yarn and frictional sliding between pile yarns

The generation of bending stress and level of induced compression energy will depend on the magnitude of applied load and the interference from the neighbouring piles. Frictional slippage and bending of pile lead to thickness loss of carpets, though induced compression energy will help the structure to recover the thickness on withdrawal of compressive force.

3 Results and Discussion

The tests have been performed under two different loading conditions, viz. static loading (constant load followed by recovery), and dynamic loading (impact load). Both types of loading lead to deformation. The influence of these two types of loading is discussed hereunder.

3.1 Influence of Short-Term Static Loading

The influence of experimental variables, viz. pile material, pile density, pile height and recovery time, on thickness loss and recovery of carpet after short-term static loading has been assessed by analysis of variance. The results at 95% level of significance are given in Table 2. It is observed from the table that the main effect of all the variables on thickness loss and recovery is significant. The interaction effect of pile material - pile density, pile material -pile height and pile density - recovery time are found significant.

Table 2 — ANOVA results for short-term static loading test

Variables	Thickness loss, %		Recovery, %	
	P- value	Effect	P- value	Effect
Pile material	0.00	S	0.00	S
Pile density	0.00	S	0.00	S
Pile height	0.00	S	0.02	S
Recovery time	0.00	S	0.04	S
Pile material*Pile density	0.00	S	0.00	S
Pile material*Pile height	0.00	S	0.00	S
Pile density*Pile height	0.15	NS	0.68	NS
Pile material*Recovery time	0.97	NS	0.08	NS
Pile density*Recovery time	0.00	S	0.00	S
Pile height*Recovery time	0.33	NS	0.03	S

S- Significant; NS- Non-significant

3.1.1 Effect of Recovery Time on Thickness Loss

The effect of recovery time on carpet thickness loss under short-term static loading condition is presented in Figure 2(a) for both wool and acrylic carpets of different tuft densities. Figure 2(a) represents thickness loss in both types of carpets with 7.5 mm pile height and 387, 465 and 558 tufts/dm^2 densities. Following observations have been made from Fig. 2(a):

- An increase in recovery time results in decrease in the thickness loss for both the carpets, i.e. thickness is recovered with time.
- The percentage thickness loss is always little more in acrylic carpets (15 - 28%) in comparison to wool carpets (10 - 24%).
- An increase in pile density leads to decrease in thickness loss for acrylic carpet, irrespective of recovery time. However, for wool carpet, though the high pile density shows less loss at the beginning of recovery, the difference becomes negligible with recovery time.
- None of the carpets could attain their initial thickness even after 60 min of recovery time.
- The thickness loss (%) in first 15 min of recovery time is greater than the rest of recovery period.

Figure 2(b) represents thickness loss with recovery time for both the carpets having 465 tufts/dm^2 density for three different pile heights. It can be seen that the carpets with higher pile height have low resistance to static loading and suffers higher loss in thickness for acrylic carpets. For wool carpets, the pile height does not make any difference.

3.1.2 Influence of Pile Density on Recovery

The effect of time on thickness recovery after removal of load is presented in Fig. 3(a) for both wool and acrylic carpets (pile height 7.5 mm) at different tuft densities. The percentage recovery is found to increase with recovery time. The recovery (%) is always greater in wool carpets. For acrylic carpets, an increase in pile density results in an increase in percentage recovery, which is expected too. However, the trend is opposite for wool carpets. Similar results are seen for other pile heights with different densities.

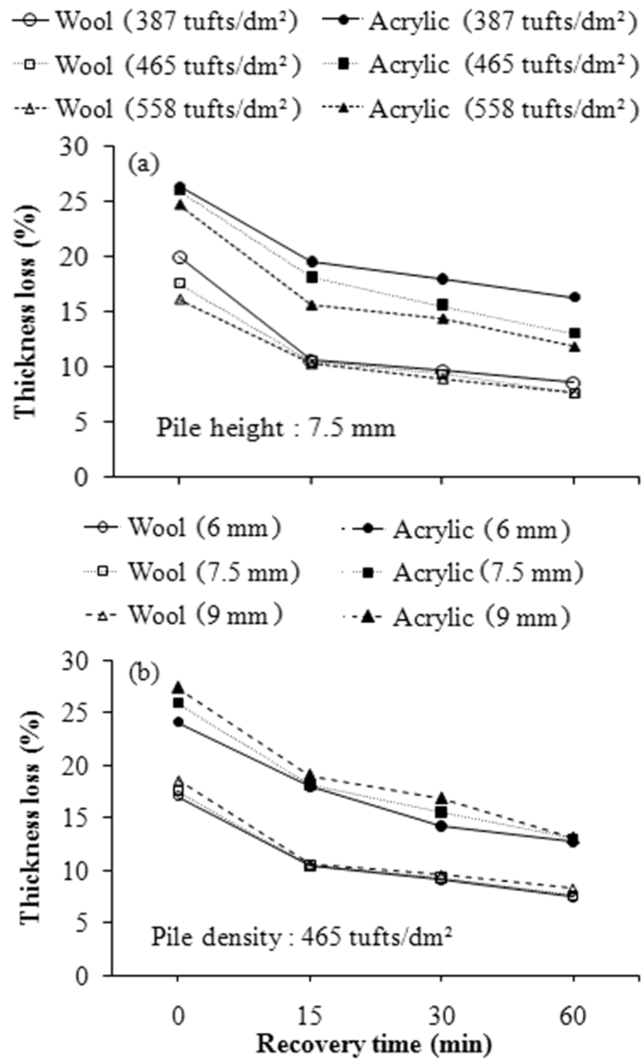

Fig. 2 — Effect of recovery time and pile density (a), and pile height (b), on thickness loss of wool and acrylic carpets

With increase in pile density, load borne by individual pile in carpet at a constant pressure reduces. As a result, the lesser deformation of carpet piles takes place and thus thickness loss becomes less and consequently more recovery (%). The stored elastic energy in deformed pile yarns assists to regain their original configuration after removal of load. If the elastic energies stored during yarn bending are

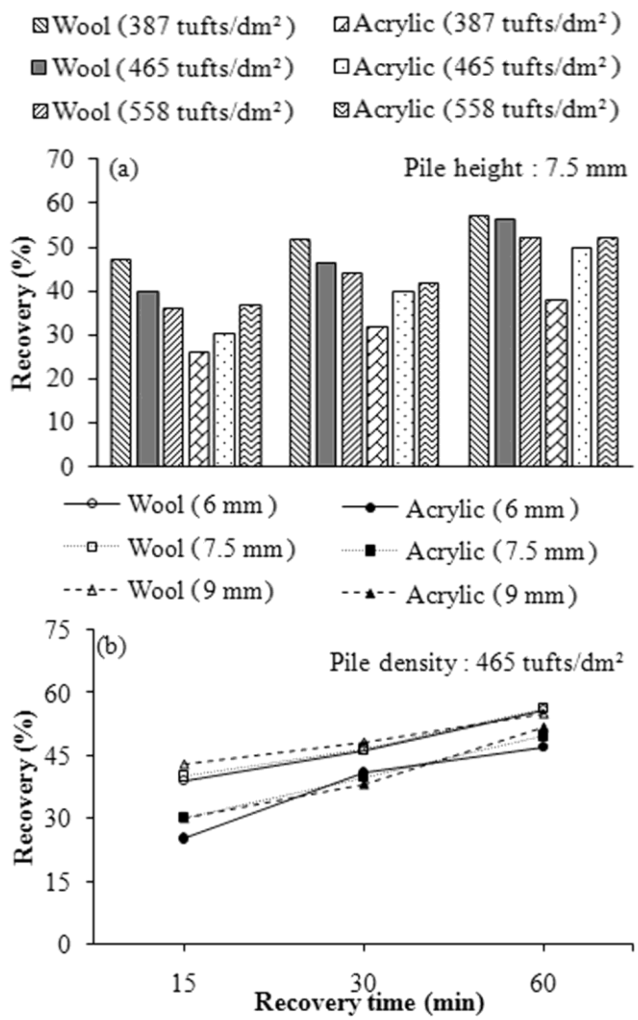

Fig. 3 — Effect of recovery time and pile density (a), and pile height (b), on percentage recovery of wool and acrylic carpets

higher than energies preventing the recovery, a pile returns to its initial form[30,31]. Natural resilience of wool fibres, resulting from the coiled structure of its internal molecules, facilitates better recovery after compression than acrylic fibres.

The possibilities of entanglements between neighbouring pile yarns in compressed state due to presence of scale on fibre surface may restrict recovery when they are too close to each other.

3.1.3 Effect of Pile Height on Recovery

Figure 3(b) represents thickness recovery with recovery time for both the carpets at 465 tufts/dm^2 density for three different pile heights. It may be observed that the influence of pile height on recovery is marginal but statistically significant.

Table 3 — ANOVA results for dynamic loading test

Variables	Thickness loss, %	
	P- value	Effect
Pile material	0.00	S
Pile density	0.00	S
Pile height	0.00	S
Number of impacts	0.00	S
Pile material*Pile density	0.09	NS
Pile material*Pile height	0.48	NS
Pile density*Pile height	0.08	NS
Pile material*Number of impacts	0.00	S
Pile density*Number of impacts	0.44	NS
Pile height*Number of impacts	0.01	S

S- Significant; NS- Non-significant

3.2 Influence of Dynamic Loading

The influence of experimental variables, viz. pile material, pile density, pile height and number of impacts on thickness loss of carpet during dynamic loading has been assessed by using analysis of variance at 95% level of significance and the results are shown in Table 3.

It is observed from the above table that the main effect of all the variables on thickness loss during dynamic loading is significant. The samples are evaluated under dynamic loading condition for impacts varying from 50 to 1000. The thickness loss results are presented in Fig. 4.

The major observations made from the figures are discussed below:

- The thickness loss increases with increase in number of impacts, irrespective of pile material, pile height and pile density.
- The thickness loss (%) is greater in acrylic carpets.
- An increase in pile density leads to decrease in thickness loss, while an increase in pile height leads to increase in thickness loss.
- The extent of thickness loss during the initial impacts is more in comparison to variation occurred in later impacts.

The influence of static and dynamic loading on carpet deformation is similar. High bending rigidity of the yarn and resilient characteristics of constituent wool fibres are responsible for lesser thickness loss in wool carpets. An increase in pile density offers more resistance to deformation since yarns per unit area increases. The easier deformation of higher pile height leads to higher thickness loss in carpets.

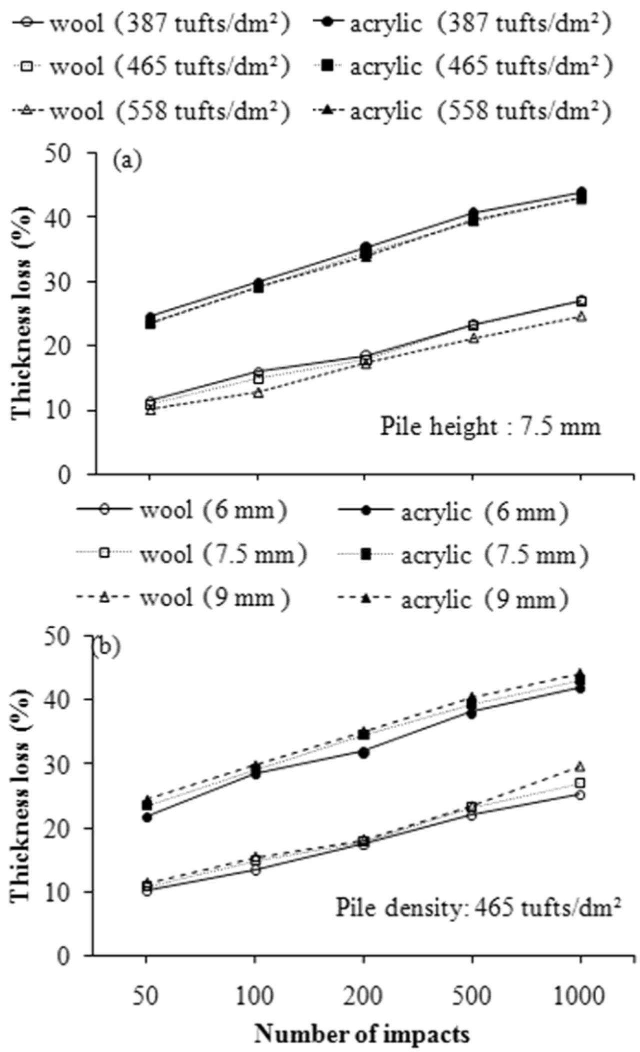

Fig. 4 — Effect of repeated impacts and pile density (a), and pile height (b), on thickness loss of wool and acrylic carpets

4 Conclusion

4.1 The carpets suffer thickness reduction due to static loading to the tune of 15-28% in acrylic carpets and 10-24% in wool carpets. In case of dynamic loading, the corresponding loses are 10-20 % for wool and 20-40 % for acrylic carpets.

4.2 The wool carpets show both lower thickness loss and higher recovery characteristics than the acrylic carpets. Long piles cause higher thickness loss and marginal effect on recovery. The thickness loss decreases with increase in pile density. The thickness loss progressively reduces with impacts in dynamic loading.

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