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# Elastic characteristics of hand-tufted carpets under compressive load

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This paper reports the study on dynamic-mechanical properties of nine hand-tufted cut pile carpet samples (80/20 wool/nylon blended pile yarn) *w*ith different structural parameters. The influence of two structural parameters, viz. carpet pile density and pile height on the carpet pile deformation properties has been studied. Carpet samples are tested for compression and thickness recovery, considering pressure ranging from 2 kPa to 200 kPa. The findings are statistically analyzed using general linear model through regression analysis. It is observed that both these structural parameters have a significant influence on compression and recovery properties of selected carpet samples.

**Keywords**: Compression property, Cut pile, Recovery property, Resilience, Tufted carpets, Wool/nylon blend

## 1 Introduction

Handmade Tufted carpets are distinguishable from their woven counterparts on the basis of their greater scope in keeping the pile heights higher with more varied designs[1]. In general, the performance of a carpet is assessed based on the human activities, such as standing and walking by reducing impact and minimizing consequence of potential falls and the increase in comfort[2]. The evaluation of carpet performance has been suggested through some specific characteristics, such as compression, recovery, flattening, resilience and energy absorption. According to Kimura and Kawabata[3], the compression phenomenon in carpets occurs in three sequential stages, namely bending, sliding and jamming of fibres. Distinguishable features intrinsic to compression phenomenon are inelastic mechanism and fatigue mechanism. Inter-fibre and inter-yarn frictional sliding during yarn bending, and visco-elastic properties of pile yarns are inelastic mechanisms which influence the flattening of carpets. Using a rheological model, Carnaby and Wood[4] pointed out that the inelastic properties of fibres become prevalent with increasing compression release cycles. A carpet's fatigue mechanism is one of the pile losses from the carpet's surface due to abrasive wear. If the fatigue regions are not partial and distributed along the pile length, the pile weight left after walking on the carpet depends on the number of repetition cycles, the pile density, the linear density of fibres, and the per cent of damaged fibres[4].

Mechanism of carpet compression has been explained[5,6] both theoretically and experimentally through analysis of force, wherein it was established that the total energy of deformation comprises elastically stored bending energy and frictional loose energy. Wool and nylon fibres are linearly viscoelastic at low bending strains (usually <1%), and the carpet having 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[7]. In this context, El-Shiekh and Hersh[8] explained that a pile returns to its original state, if the energies preventing its recovery are smaller than the elastic energy released during yarn bending.

Patni *et al.*[9] have also indicated the importance of constructional parameters like pile density and pile height in influencing the functional properties of carpet such as thickness loss, its variation and durability. According to Dubinskaite *et al.*[10], the pile height and density are the most critical construction parameters influencing the compression and thickness recovery characteristics.

However, to the best of our knowledge the study on the behaviour of hand-tufted wool-nylon blended cut-pile carpets under compressive load in relation to constructional parameters is still limited. Therefore, present study has been aimed at investigating the elastic characteristics of wool-nylon blended hand-tufted cut-pile carpets under compressive load.

## 2 Materials and Methods

The blended spun pile yarns of 80% wool and 20% Nylon 6, having 4 Nm linear density and ~ 95 TPM,

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were used to prepare nine hand-tufted cut-pile carpet samples. Pile yarn was subjected to the test method, IS 2006:1988 (Wool) & IS 2005:1988 (Nylon) pertaining to blend ratios of wool and nylon fibres. Nine hand-tufted carpet samples of size 24×24 inch were prepared using a tufting gun for pile yarn insertion in the primary backing. Carpet samples were prepared with three different pile heights and pile densities (Tables 1and 2). *T*he warp and weft raw material used in the primary backing was 100% cotton with plain weave.

Pile height was measured according to test method ASTM-D5823-00. In order to determine the compression and thickness recovery properties, carpets samples were tested in accordance with test method BS 4908, which is equivalent to ISO 2094. In this method, the initial thickness of the conditioned carpet specimens was measured under a pressure of 2 kPa before application of the dynamic loads. Thickness of specimens at various deformation levels (2, 5, 10, 20, 50, 100, 150 and 200 kPa) and the corresponding compression and recovery values were studied using load-compression and load-recovery curves. The pile thickness of the unworn and worn carpet specimens was measured using a WIRA digital thickness gauge (Fig. 1), and all these observations were carried out under standard lab conditions of 22 ± 2 °C and 65 ± 2% RH.

From Fig. 2, the compression parameters of a particular carpet sample were calculated numerically using the following equations:

Table 1 — Description of independent variables and their coded levels

| Variable | Coded level | | |
|---|---|---|---|
| | -1 | 0 | +1 |
| Pile density (*X1*), no. of tufts/m² | 145000 | 170000 | 195000 |
| Pile height (*X2*), mm | 10 | 12 | 14 |

Table 2 — Specifications of hand-tufted cut-pile carpet samples

| Sample code | Pile density (*X1*) No. of tufts/m² | Pile height (*X2*) mm |
|---|---|---|
| S1 | 145000 | 10 |
| S2 | 145000 | 12 |
| S3 | 145000 | 14 |
| S4 | 170000 | 10 |
| S5 | 170000 | 12 |
| S6 | 170000 | 14 |
| S7 | 195000 | 10 |
| S8 | 195000 | 12 |
| S9 | 195000 | 14 |

$$\text{WC} = \text{Area under compression curve (Work done during 2-200 kPa)} \quad \ldots (1)$$

$$\text{WR} = \text{Area under recovery curve (Work done in recovery during 200-2 kPa)} \quad \ldots (2)$$

$$\text{RC} = (\text{WR}/\ \text{WC}) \times 100 \quad \ldots (3)$$

$$\text{CF} = (1 - \text{T200}/\text{T2}) \times 100 \quad \ldots (4)$$

where WC is the elastic energy of compression; WR the decompression energy; RC the compression resilience; CF the compressibility factor; T2 the initial carpet thickness at pressure 2kPa; and T200 the thickness when specimen is compressed at pressure 200kPa.

## 3 Results and Discussion

The experimental results (Table 3) of carpet compression and recovery properties have been statistically analyzed through regression equations using general linear model and ANOVA on statistical analysis software SYSTAT-12. A summary of the

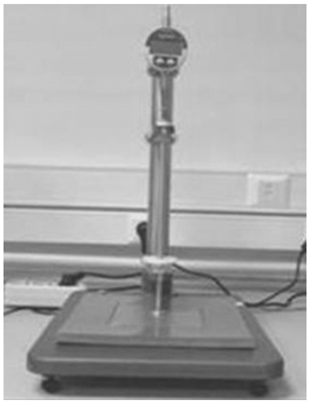

Fig. 1 — WIRA digital thickness gauge (Source: WRA manual)

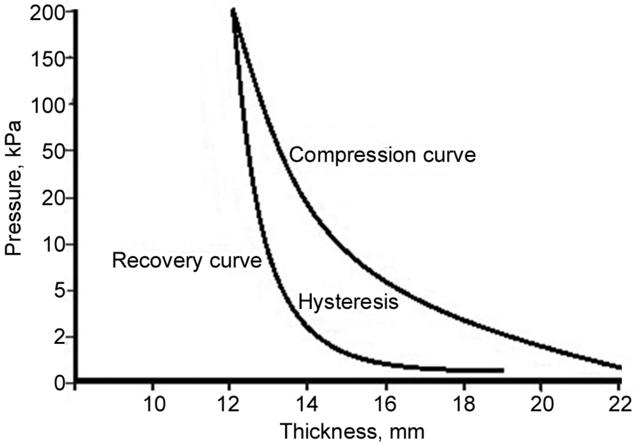

Fig. 2 — Thickness-pressure curve

Table 3 — Experimental results of carpet compression

| Sample code | Compression energy (WC), kPa.mm | Decompression energy (WR), kPa.mm | Compression resilience (RC), % | Compressibility factor (CF), % |
|---|---|---|---|---|
| S1 | 1643.9 | 1321.3 | 79.8 | 55.4 |
| S2 | 1650.7 | 1303.7 | 78.2 | 57.1 |
| S3 | 1659.4 | 1285.1 | 76.9 | 58.6 |
| S4 | 1632.4 | 1335.4 | 80.3 | 53.3 |
| S5 | 1639.8 | 1318.6 | 79.4 | 55.7 |
| S6 | 1645.3 | 1301.2 | 78.2 | 56.4 |
| S7 | 1621.2 | 1351.4 | 80.9 | 51.9 |
| S8 | 1630.4 | 1335.1 | 80.1 | 53.5 |
| S9 | 1637.3 | 1318.3 | 79.6 | 54.7 |

Table 4 — Results of simple regression analysis[1]

| Parameter | Regression equation | Squared multiple coefficient ($R^2$) | Standard error | F-ratio |
|---|---|---|---|---|
| Compression energy (WC) | $WC = 1640.044 + 7.417 \times X1 - 10.850 \times X2 + 0.150 \times X1 \times X2$ | 0.992 | 1.293 | 206.742 |
| Decompression energy (WR) | $WR = 1318.000 - 17.250 \times X1 + 15.783 \times X2 + 0.775 \times X1 \times X2$ | 0.999 | 0.541 | 3744.962 |
| Compression resilience (RC) | $RC = 79.267 - 1.050 \times X1 + 0.950 \times X2 + 0.400 \times X1 \times X2$ | 0.996 | 0.100 | 422.333 |
| Compressibility factor (CF) | $CF = 55.178 + 1.517 \times X1 - 1.833 \times X2 - 0.100 \times X1 \times X2$ | 0.985 | 0.325 | 107.508 |

[1] P-value (up to 3 decimal) – 0.000

Table 5 — Analysis of variance (ANOVA) from experimental results

| Process parameters | Compression energy (WC) | Decompression energy (WR) | Compression resilience (RC) | Compressibility factor (CF) |
|---|---|---|---|---|
| Pile density (*X1*) | s | s | s | s |
| Pile height (*X2*) | s | s | s | s |
| *X1* × *X2* | ns | ns | ns | ns |

S – Significant, ns – Non-significant; Significance level is $\alpha = 0.05$ i.e. 95% confidence level.

regression analysis and ANOVA of experimental results is shown in Tables 4 and 5 respectively**,** which indicate that both the structural parameters (pile height and density) significantly influence carpet compression behaviour at a significance level( $\alpha = 0.05$).

### 3.1 Compression and Recovery properties

The results of carpet compression properties, including compression energy (WC), decompression energy or work of recovery (WR), compression resilience (RC) and compressibility factor (CF) versus the pile density *X1* and pile height *X2* are illustrated in Figs 3(a) - (d) respectively.

A carpet that absorbs more elastic energy indicates that it is more compressible. Figure 3(a) shows that that with the increase in pile density, due to more no. of fibre tufts per unit area, the carpet compression energy goes on decreasing, while simultaneously, with an increase in pile height, compression energy in carpet specimen increases, as more length of pile is available for bending which is the initial step of carpet compression phenomenon.

Decompression energy (WR), also known as work of recovery, refers to the work done on a carpet when the pressure is released from 200 kPa to 2 kPa. Thus, with an increase in decompression energy, the energy loss or damping is reduced, leading to more compression resilience. Further, Fig. 3(b) shows that decompression energy also follows the similar trend, but is not the same due to viscoelastic nature of wool fibre, hundred per cent recovery in the carpet specimen does not take place, and some energy is lost to overcome the frictional slippage effects of fibres in pile yarn during recovery cycle.

Compression resilience (RC), expressed in %, shows the ratio of decompression energy to elastic

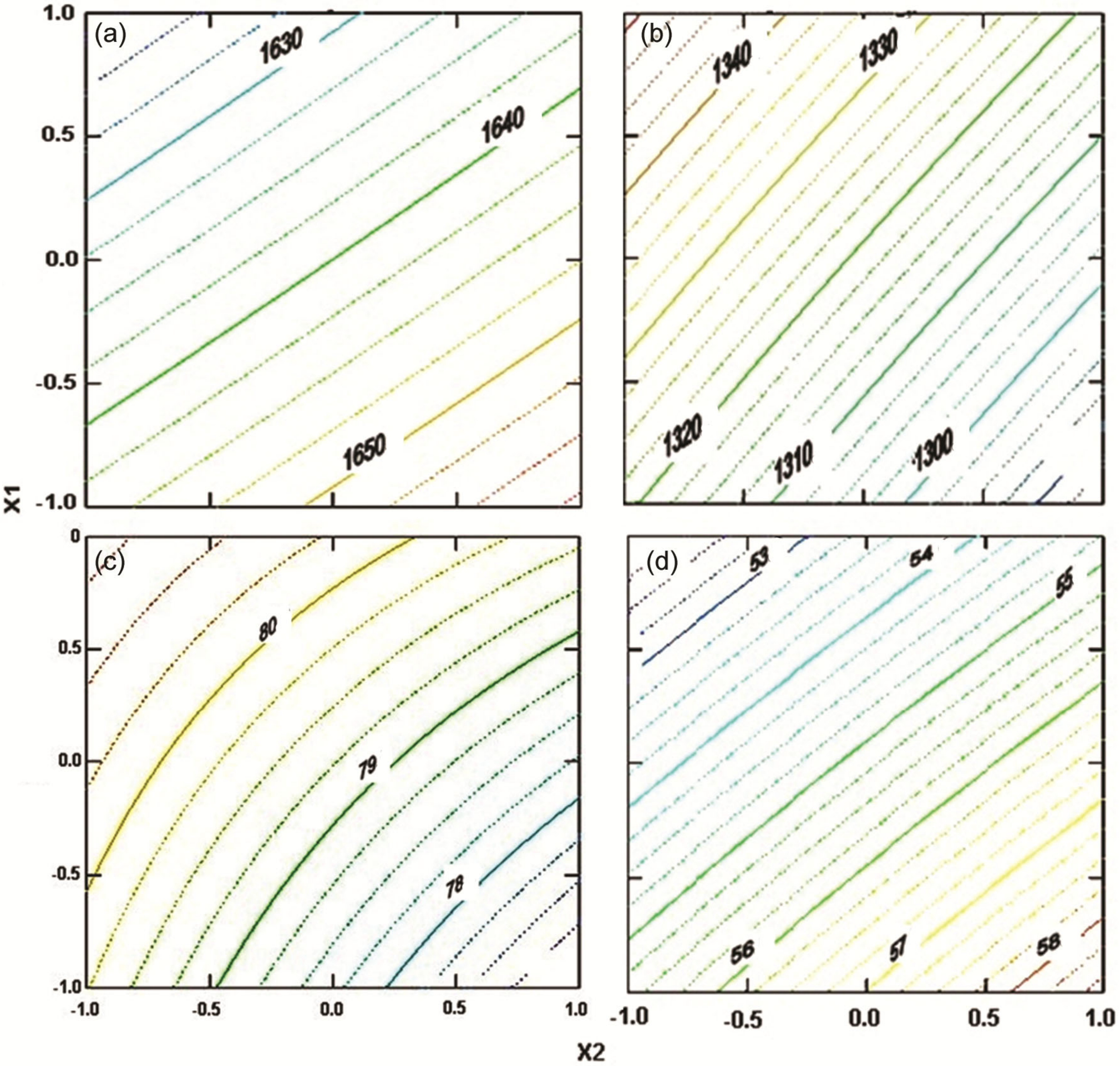

Fig. 3 — (a) Compression energy, (b) decompression energy, (c) compression resilience and (d) compressibility factor, *vs.* pile height and pile density

energy of compression, or work done by the textile floor covering when the pressure is reduced from 200 kPa to 2 kPa, expressed as a percentage of recovery from 2 kPa to 200 kPa pressure i.e. ratio of area under load-recovery curve to area under load-compression curve. This means that if a carpet has a higher resilience to static pressure, it resists more against damping and the pile demonstrates better recovery. Figure 3(c) shows that compression resilience is much affected by both pile height and pile density. With an increase in pile density, number of fibres in the tuft provides more resistance to compression, while high pile height facilitates easy and more resilience during compression.

Compressibility factor (CF) expressed in %, indicates the compression deformation. This means that if a carpet has lower compressibility, it has higher resistance against pressure, resulting in a harder carpet. Figure 3(d) shows that with an increase in pile height, compression deformation or compression recovery decreases, because higher pile height allows more compression along its length but due to viscoelastic nature, the deformation in fibre tuft is not fully recoverable and vice-versa. As the pile density increases, compressibility of carpet specimen is lowered. This is attributed to entanglement of fibres in the pile yarn during bending, sliding and friction stages in compression phenomenon. During recovery cycle, fibres in the pile yarn have to overcome all the bending and frictional effects, due to which recovery in compression is lesser for denser carpets.

## 4 Conclusion

Based on the experimental results, for the above studied hand-tufted cut-pile carpets, it is concluded that:

**4.1** Both the structural parameters viz. Pile height and pile density have significant effect on carpet compression and recovery behavior. Carpet samples having higher pile height and lesser pile density exhibit higher elastic energy of compression .i.e. work of compression. It means that such type of carpets are more comfortable and provide better cushioning effect while walking and at the time of fall.

**4.2** Decompression recovery is higher for carpet samples having lower pile height and higher pile density. It means that denser carpets with low pile heights recover more and faster because higher pile density provides more resistance to compression along with similar effect of lower pile height.

**4.3** Compression resilience for denser carpets having lower pile height is found more. For such a given carpet sample, it recovers very well in comparison to its compression. This flexibility of recovery of such carpet samples makes them preferable over other type of rugs along with their unmatched and varied aesthetics.

**4.4** Compressibility factor (compression deformation) is higher for less denser carpets having higher pile height. In simple terms, it can be said that carpet samples having more cushioning comfort (i.e. higher pile height) are deformed more easily and faster. Such deformation can be avoided by taking optimum levels of pile height and pile density.

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