A STUDY OF THE COMPRESSIONAL PROPERTIES OF TUFTED CARPETS OF DIFFERENT PILE YARNS

دراسة الخواص الانضغاطية للموكيت ذو خيوط مختلفة للوبرة

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خلاصة

يهدف هذا البحث إلى دراسة تأثير بعض خواص خيوط الوبرة مثل نسبة خلط الصوف مع النايلون و البرمات فى الخيط المفرد و المزوى و كذلك بعض الخواص الإنشائية للموكيت مثل إرتفاع الوبرة و كثافة الغرز على الخواص الإنضغاطية للموكيت مثل قابلية الإنضغاط و الصلابة و الطاقة المفقودة فى الإنضغاط و الرجوعية و الفقد فى السمك نتيجة للإنضغاط. لهذا الغرض تم إنتاج ٨١ عينة موكيت مختلفة من حيث الخيوط وضبطات ماكينة إنتاج الموكيت. و لدراسة النتائج فقد أستخدمت طريقة الإنحدار المتعدد نظرا لوجود عدد كبير من المتغيرات ثم عرضت النتائج فى صورة منحنيات المناسيب لإستخلاص التأثيرات المختلفة للمتغيرات المدروسة على خواص الموكيت. و قد أظهرت النتائج أهمية إختيار كل من خواص الخيط المستخدم مع الضبطات الإنشائية لإنتاج الموكيت بما يناسب الغرض المنتج من أجله.

ABSTRACT

This paper aims to study the effect of pile yarn and tufted carpet structure parameters on the behavior of the carpet during successive compression-recovery cycles. Many as 81 different samples were produced form different yarns with different tufting machine parameters. The yarn parameters are blend ratio of wool / nylon and twist in single and plied yarn. The carpet structure parameters are pile height and stitch density.

1. INTRODUCTION

Floorcoverings are used at the beginning of man on the earth. The kind of floorcovering is a good witness on the cultural, economical, technological and religious status during ages. In the last few decades, as a result of globalization, the use of tufted carpets, known as moquette, is increased world wide. For improving carpet properties and durability, the effect of fiber, yarn, and environmental variables on yarn properties and the relation between yarn properties and carpet performance need to be explored further.

The performance of carpets has been an issue of interest to researchers for years. The thickness loss of carpets, carpet durability, changes in appearance and wear in an actual use have been investigated and correlated to inter-laboratory tests on the WIRA Dynamic Loading Machine, Tetrapod Walker and the WIRA Carpet-abrasion Tester [1,2,3]. H. Ebraheem [4] studied the compressional behavior of some moquette floorcoverings. Samples were subjected to repeated compression-recovery test on Shirley Thickness Meter before and after practical use. Mathematical relationships between pressure and thickness were obtained. Reflection of compressional behavior of moquette samples on their behavior in abrasion, soiling, appearance change, and comfort.

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There have been several notable attempts [5 -9] to explain the physics of carpet performance and to correlate yarn properties and carpet properties. El-Shiekh and Hersh [5] analyzed deformations in loop pile carpets, showing that after initial compression, the tufts deflected laterally. If the loop/inch are low in either direction, loops may be squashed rather than laterally deformed. In high loads, pile yarns deflect until jamming occurs. Dynamic mechanical measurements on carpet yarns could present information about tuft recovery behavior. Southern et al. [7] categorized the loss of carpet appearance in synthetic cut pile carpets as resulting from poor recovery and loss of tuft definition. In studies on nylon 66 and polyester carpets, they concluded that increased yarn twist and reduced yarn bulk improved appearance retention, but at the same time also reduced carpet body.

Dynamic mechanical properties of carpet yarns and carpet performance are studied by Grover et al. [8]. The resiliency of nylon, polyester and polypropylene yarns is measured. The effects of fiber drawing, fiber crimp, yarn structure, yarn heat setting, and moisture on yarn resiliency and modulus as measured by the Rheovibron are investigated. Dynamic mechanical measurements on carpet pile yarns are compared with carpet appearance retention performance. They found that the effect of fiber, yarn, and environmental variables on yarn resiliency and the relation between yarn resiliency and carpet performance need to be explored further. Yarn twist is a critical variable affecting resiliency and appearance retention; higher resiliency with higher twist. The effect of moist conditions on the resiliency of carpet yarn depends on polymer type. Yarn resiliency alone cannot predict carpet performance. Differences in carpet construction also influence performance and contribute to carpet appearance retention as well. Dunlop and Sun [9] during their measurements of dynamic mechanical properties of carpets, they indicated that the compression modulus of carpets and the energy dissipation per cycle are affected by the magnitude of the pressures or displacements.

Image analysis is considered to have a promising future as a scientific tool in studying carpet performance, as an objective means of carpet grading, and for product optimization and quality control in carpet manufacture. The carpet appearance, texture and texture changes due to wear are recently quantified by image analysis techniques [10-15].

Appearance loss due to traffic in tufted pile carpets is studied by Wilding et al. [16]. The effect of shading, loss of tuft definition, fiber damage, and other factors were discussed. Optical and scanning electron microscopy were used to assess changes due to wear in pile geometry of nylon and polyester cut-pile carpets following wear trials in traffic. The relative performance of nylon and polyester carpets was discussed in the light of the differing mechanical properties of the fiber types. The observation was that the nylon carpets relatively poor in retention of tuft definition but withstood high levels of wear better than polyester carpets.

Carpet comfort was studied by Michael et al. [17]. Subjective comfort was correlated to the maximum decelerations obtained with an impact instrument specially modified for this application. This was based on the fact that the high rate of strain impact measurements reflects a less satisfactory degree of carpet.

The conclusion from the review of previous literature shows that one of the most important properties characterizing carpet performance and comfort is the compressional behavior that determines carpet thickness and appearance during use. There are many factors that may influence the compressional properties of a carpet, including yarn type and count, type of construction, pile hight and density. Our study is restricted to the resiliency related aspects of carpet performance as measured by carpet compressional properties.

2. EXPERIMENTAL WORK

2.1 Materials

Combinations of cut-pile tufted carpet samples are produced especially for this study. Different pile yarns of Nm 6/2 are made from wool/nylon blends with different blend ratios and twists in single and plied yarn. The relation between plied and single yarn twist multipliers is kept constant. The varying carpet structure parameters are pile hight and stitch density. Other working conditions are kept unchanged. Wool fibers of 36 microns and 94 mm long were blended with Nylon fibers of 12 denier and 135 mm long.

2.2 Experimental Design

In this study, the experimental design uses the all cobinations of the four varying parameters mentioned above, each is changed in three levels. All combinations of the changed four parameters and levels produce 81 carpet samples. Table (1) gives the coded levels (-1, 0, +1) and the corresponding actual values of changed parameters.

Table (1): variables of the experiment and their levels of change

Parameters	Levels		
	-1	0	+1
X_1: blend ratio wool/nylon	0/100	50/50	100/0
X_2: yarn twist Plied / m	180	200	220
X_3: pile height (mm)	6	8	10
X_4: stitch density piles/cm	8	10	12

2.3 Testing

All samples are tested for compressional characteristics, defined next: compressibility, hardness, resilience, hysterisis, and permanent set. The testing instrument is the Shirley Thickness Meter for measuring carpet thickness under any stated pressure. Each carpet sample is subjected to 5 successive compression-recovery cycles at the same place. In one cycle, loading starts from zero and increased in six steps, each step takes about 40 seconds, to create the following pressures: 0, 100, 200, 300, 400, 500 g/cm^2. Unloading follows the inverse way at the same rate. For each cycle, the applied pressure and carpet thickness are recorded during compression and recovery. From the collected data, the compression-recovery curves are obtained. For example, the data of the intermediate sample (at X_1=0, X_2=0, X_3=0, and X_4=0) is given in table (2) and its compression-recovery curves are shown in Fig. (1).

Table (2): A sample of the data of loading unloading cycles

SAMPLE No.(41) : BLEND : 50% WOOL / 50% NYLON TWIST :200 turns/m PILE HIGHET=8 STITCH DENSITY=10										
PRESSURE (gm/cm^2)	THICKNESS (mm)									
	CYCLE 1		CYCLE 2		CYCLE 3		CYCLE 4		CYCLE 5	
	LOAD	UNLOAD	LOAD	UNLOAD	LOAD	UNLOAD	LOAD	UNLOAD	LOAD	UNLOAD
0	10.8	10.00	10.0	9.70	9.70	9.50	9.50	9.30	9.30	9.20
100	9.30	6.50	8.10	6.20	7.60	6.00	7.35	5.90	7.30	6.85
200	7.40	5.60	6.70	5.50	6.30	5.30	6.20	5.30	6.20	5.25
300	6.30	5.30	5.90	5.20	5.70	5.10	5.70	5.10	5.70	5.10
400	5.60	5.20	5.40	5.15	5.35	5.10	5.30	5.10	5.20	5.00
500	5.20		5.15		5.10		5.10		5.00	
Area Under Curve kg/cm^2/mm	3.660	2.500	3.367	2.432	3.235	2.370	3.185	2.350	3.155	2.430
Compressibility = 1.074 cm^2/kg Permanent set. = 14.814814 % Resilience= 68.76 %						Hardness=0.098 kg/cm^2/mm Hysterisis = 1.12 kg/cm^2.mm				

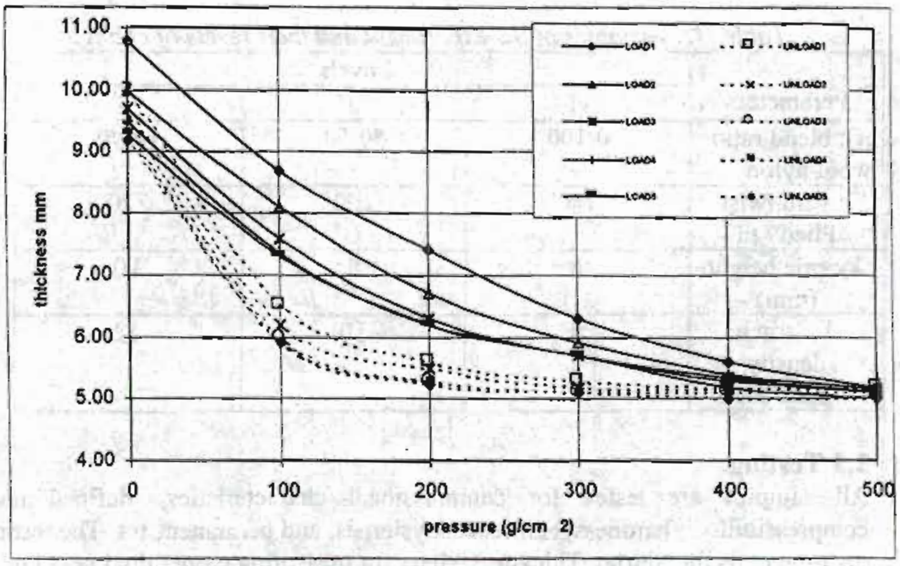

Fig. (1): A sample of Compression- Recovery curves

Although we recorded five compression-recovery cycles, we used in our characterization the compression curve of the first cycle and the recovery curve of the fifth cycle. The following characteristics are obtained:

$$Compressibility = \frac{T_1' - T_2}{T_1'(P_2 - P_1')}$$

$$Hardness = \frac{P_2 - P_1'}{T_1' - T_2}$$

$$Permanent\,Set = \frac{T_1 - T_3}{T_1}.100$$

$$Resilience = \frac{A_r}{A_c}.100$$

$$Hysteresis = A_c - A_r$$

Where:

T_1- original carpet thickness (in mm) at minimum pressure $P_{1=0\ g/cm^2}$,
T'_1- compressed carpet thickness (in mm) at pressure $P'_{1=100\ g/cm^2}$
T_2- compressed carpet thickness (mm) at maximum pressure $P_{2=500\ g/cm^2}$
T_3- recovered carpet thickness (in mm) at minimum pressure of the fifth cycle, P_1.
A_c- area under frist compression curve mm.kg/cm^2,
A_r- area under fifth recovery curve mm.kg/cm^2.

3. RESULTS AND DISCUSSIONS

Testing results (dependent variables) are put in regression equations as functions of varying experiment parameters (independent variables: X_1, X_2, X_3, and X_4) in the following form:

$$y = a_0 + \sum_{i=1}^{4} a_i.x_i + \sum_{i=1}^{4} a_{ii}.x_i^2 + \sum_{\substack{i=j=1 \\ i\neq j}}^{4} a_{ij}.x_i.x_j$$

3.1 Regression Equations

The coefficients of the regression equations, the significant level of each component, and the overall correlation coefficient of the equations are given in Table (3).

3.2 Graphs of Contour Lines

From the obtained regression equations, the contour lines are drawn for the carpet properties via blend ratio and twist of pile yarn once and once more via pile height and stitch density. Samples of these graphs are given in fig. 2 where the curves of carpet property via blend ratio and twist of pile yarn are drawn at middle values of pile height and stitch density (x_3=0 , x_4=0). The curves of carpet property via pile height and stitch density are drawn at middle values of blend ratio and twist of pile yarn (x_1=0 , x_2=0).

Table (3): Regression coefficients and their significant levels of calculated characteristics:

Characteristic	compressibility cm^2/kg		Hardness $Kg/cm^2/mm$		permenant set %		Resilience %		Hystrisis $mm.Kg/cm^2$	
Coefficient	value	sig. %	Value	sig. %	value	sig. %	value	sig. %	value	sig. %
a_o	1.0053	100	0.13876	100	21.2841	100	72.1162	100	0.89248	100
a_1	0.10765	100	-0.02143	100	-1.94058	100	-0.91970	100	0.02546	98.1
a_2	-0.02286	92 *	0.00564	93 *	0.67633	90 *	0.37844	99.1	-0.02118	98.1
a_3	0.01334	70 *	-0.01633	100	3.49033	100	-0.36511	98.9	0.11597	100
a_4	0.03812	99.6	-0.02574	100	-2.48689	100	-1.13000	100	0.14061	100
a_{11}	-0.03474	85 *	-0.00283	37 *	-2.48624	99.9	-0.02662	8.1 *	0.04596	99.4
a_{22}	-0.00039	1.4 *	-0.00022	3.2 *	0.23633	26 *	-0.10689	34*	0.00151	7.8 *
a_{33}	0.00888	31 *	-0.00082	12 *	0.09633	11 *	-0.44556	93*	-0.02126	83 *
a_{44}	-0.02359	71 *	0.01288	98	1.44067	95.8	-0.09622	30 *	-0.03266	96.4
a_{12}	0.00356	15 *	-0.00088	15 *	-0.57586	67 *	-0.10292	38 *	-0.00207	12.6 *
a_{13}	-0.00355	15 *	0.00579	79 *	0.83180	84 *	0.39540	94 *	-0.01614	78.1 *
a_{14}	0.01451	55 *	-0.00077	13 *	1.77749	99.7	-0.97361	100	0.02764	96.4
a_{23}	-0.00882	42 *	0.00300	56 *	0.38517	56 *	-0.20400	76 *	-0.00357	25.6 *
a_{24}	-0.00338	17 *	0.00087	18 *	-0.29367	45 *	0.50633	99.6	-0.02688	98.5
a_{34}	0.06487	100	-0.01633	100	-2.06833	100	-0.23233	82 *	0.04495	100
R	0.58		0.72		0.74		0.71		0.88	

* ***No significant effect***

3.3 Discussions

From the collected data and obtained from the graphs, the following observations can be drawn:

a- Carpet Compressibility:

The shape of contour lines is saddle (min-max), Fig. (2). This means that the increase in the property with the increase of one factor is accompanied with the decrease in the property with the increase of the other factor. At low pile height, as the stitch density increases the compressibility decreases. This is true because the fibers are standing while the short its height makes it difficult the fibers to be buckled or compressed. At the same time, if the pile height is high and stitch density increases, the fibers will be in compact together which makes the fibers difficult to be compressed but laid partially. It must be considered that the compressibility is the relative decrease in carpet thickness to its initial thickness. This interprets the lower values of compressibility of carpets with shorter piles. The phenomenon goes for all blends and yarn twists. As the twist increase the compressibility decreases, which is logic. As the percent of wool increases the compressibility increases. This is interpreted by the superior quality of the natural fibers.

b- Carpet Hardness:

As shown in Fig. (3) the pile height has the major influence on the carpet hardness. As the pile height increases the carpet hardness decreases, i.e., shorter piles give harder carpet. The stitch density increases to a certain limit the carpet hardness increases. Behind this limit the effect of stitch density decreases. This is true because the property depends mainly on stitch density. The shape of contour lines is almost the same for all yarn twists and wool/nylon blend ratios. As the yarn twist increases the carpet hardness increases. This effect is very clear with the increase of wool percentage in the pile yarn. Wool piles have lower hardness than wool/nylon or 100% nylon.

c- Permanent-Set:
As shown in Fig. (4) as the stitch density increase the permanent-set decreases. As the pile height increases the permanent-set increases. This is true because of as the pile height is high, it becomes difficult for the carpet to recover again its original thickness. As the yarn twist increases the structure becomes more c mpact and the permanent-set values increase. From the other side, the values of permanent-set decreases as the percentage of wool fibers in the blended yarn increases.

d- Carpet Resilience:
Resilience is the ability of carpet to retain its original thickness. The graphs in Fig. (5) show that, in general, as the pile height increases the resilience decreases. This effect is very clear for 100% nylon pile yarns. As the percentage of wool increases the pile height is going to have a little effect on the carpet resilience. The same effect is valid also for the stitch density despite the increase of wool percent in the yarn, the stitch density is going to have a stronger effect on the carpet resilience than that of pile height. The increase of wool percentage makes the carpet resilience decreases. The effect of yarn twist is that as the yarn twist increases the resilience increases. This is true and could be interpreted by the effect of twist on the yarn compactness and strength.

e- Hysteresis:
Hysteresis is the difference between energy absorbed by the carpet during loading (compression) and the energy released from it during unloading (recovery). As hysteresis increases the carpet releases less energy than it absorbs during compression-recovery process. The better carpet is that which have low hysteresis values. As shown in Fig. (6), the pile height increases the hysteresis increases. This is may be because of that the recovery depends on the original length where longer yarns are difficult to keep straight. The same effect is also for the stitch density; more dens the stitch density more friction between yarns so, it consumes more energy to return to its original state. The effect of yarn twist on hysteresis is not so high but at any case, as yarn twist increases the hysteresis decreases. More twist means less yarn diameter so it lowers the friction between piles. As the percentage of wool increases the hysteresis decreases. This means that increasing wool percentage gives carpets with better quality.

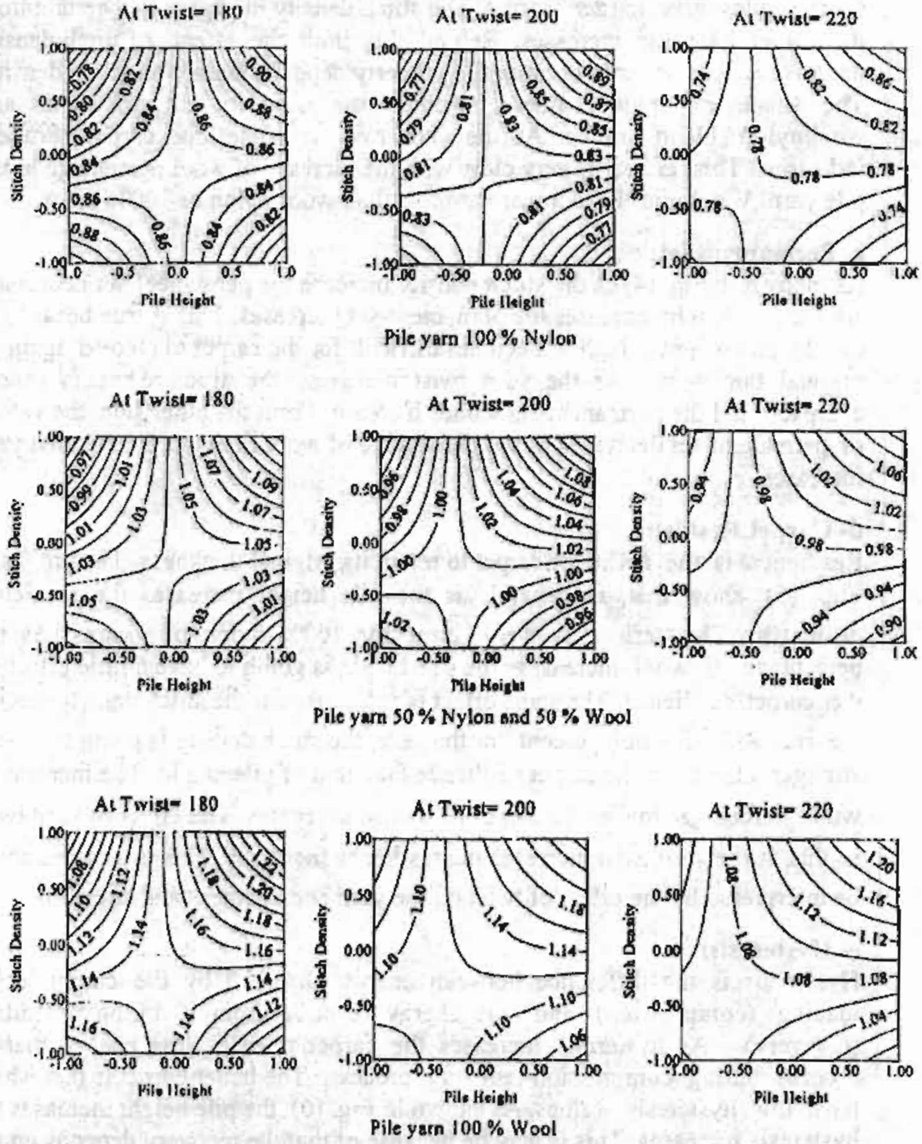

Fig.2: Effect of Pile Height and Stitch Density on Carpet Compressibility at Different Twist Levels and Blend Ratio

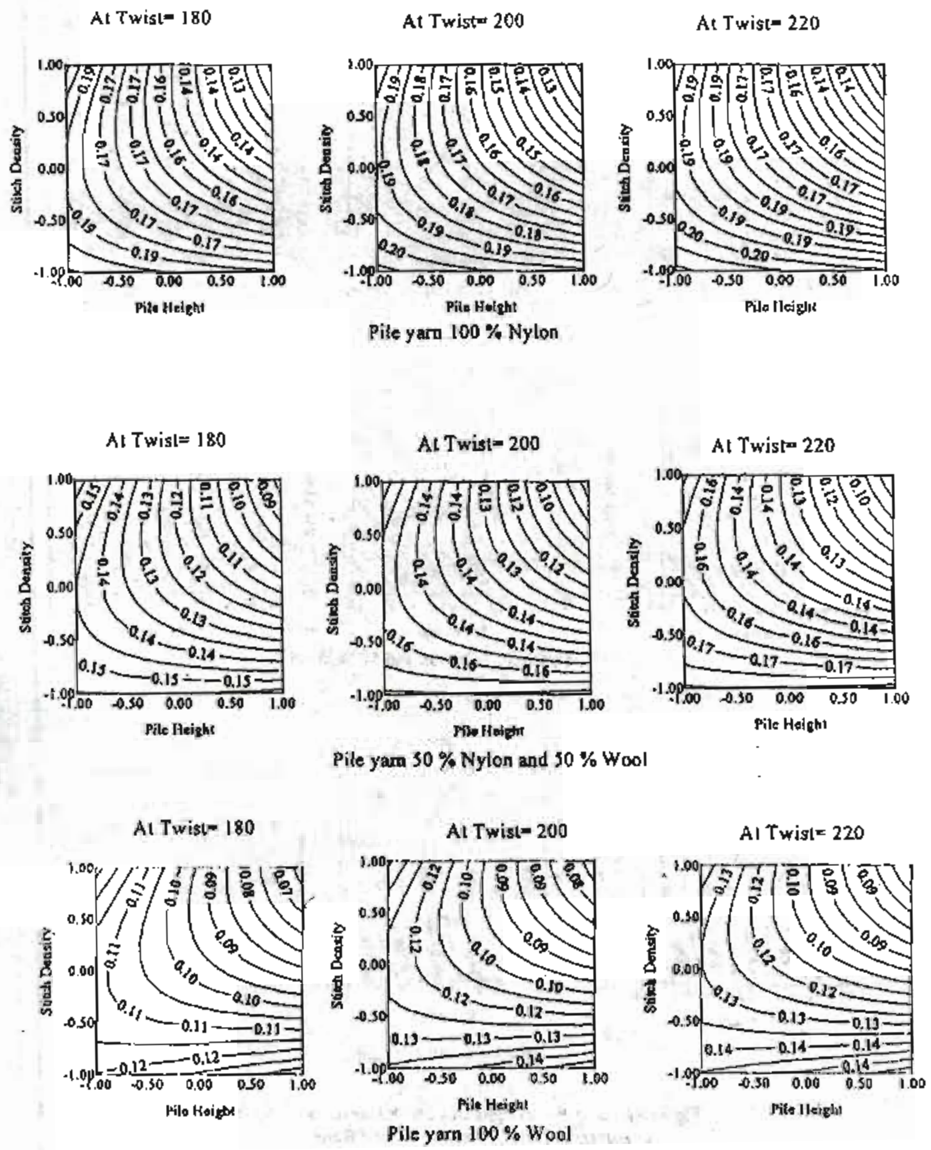

Fig.3: Effect of Pile Height and Stitch Density on Carpet Hardness at Different Twist Levels and Blend Ratio

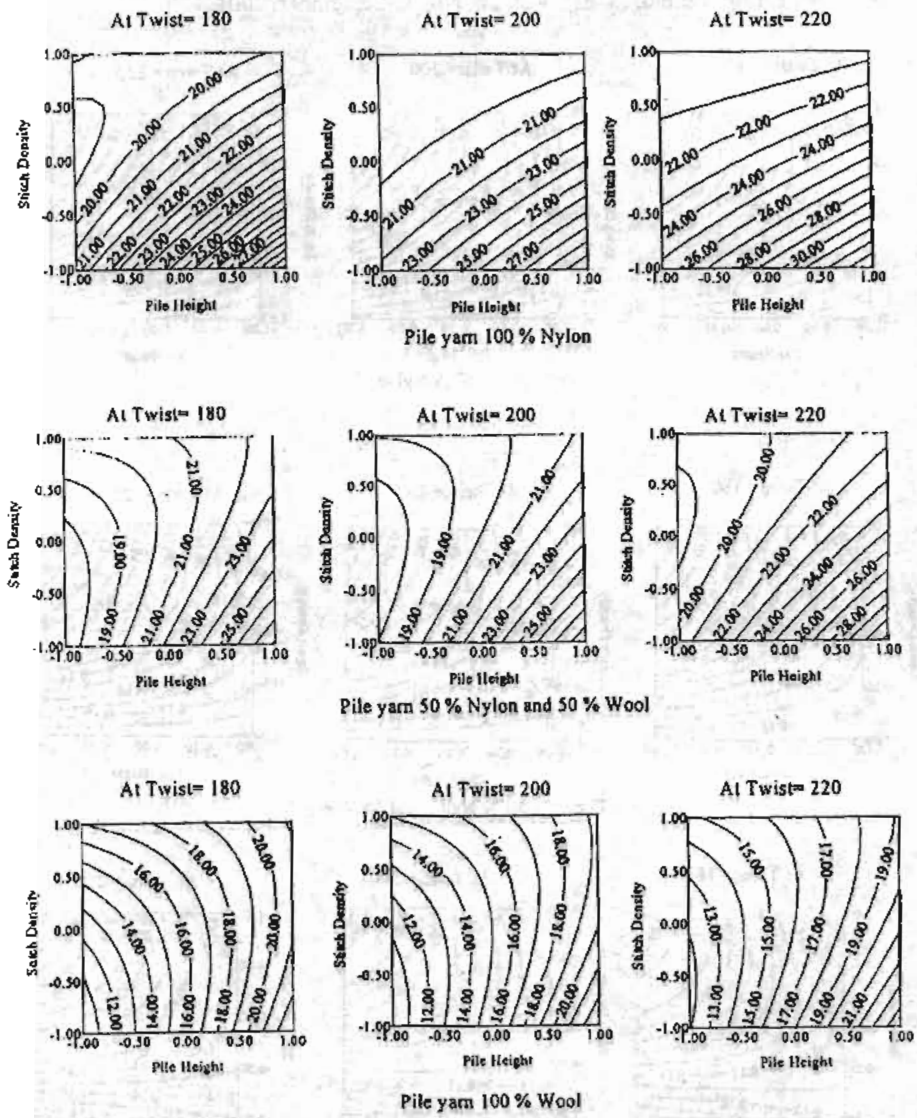

Fig.4: Effect of Pile Height and Stitch Density on Carpet Permanent-Set at Different Twist Levels and Blend Ratio

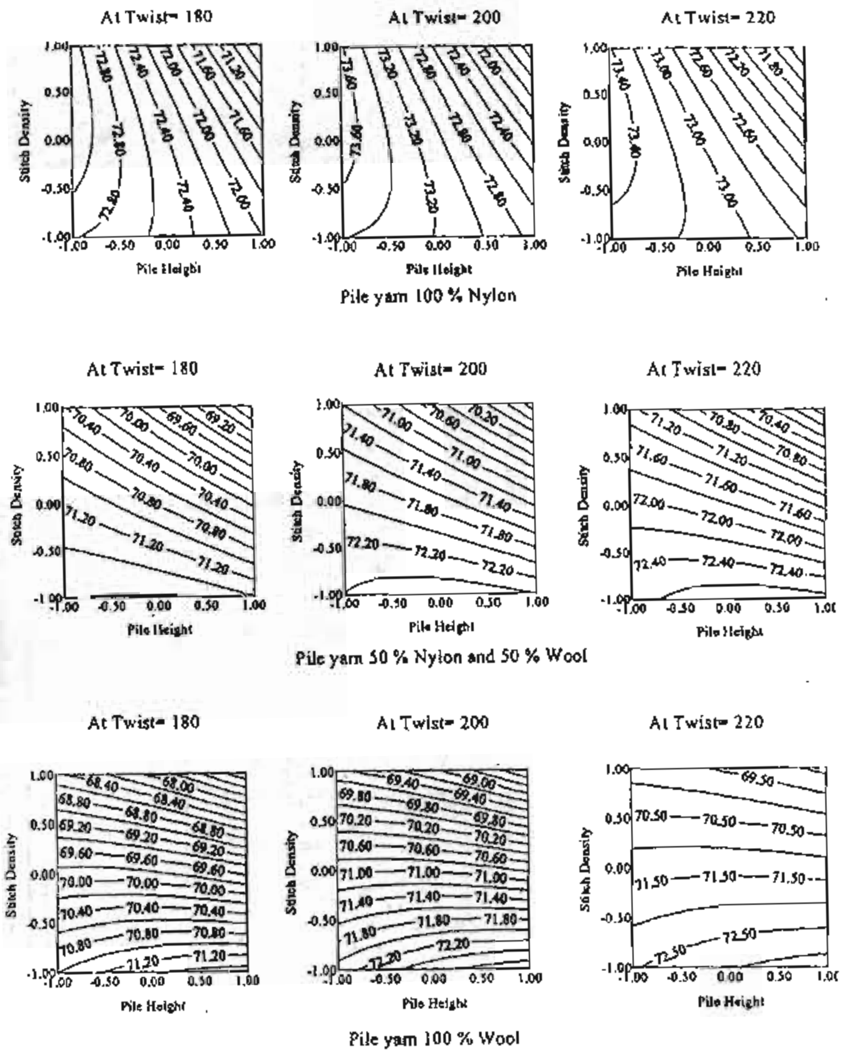

Fig.5: Effect of Pile Height and Stitch Density on Carpet Resilience at Different Twist Levels and Blend Ratio

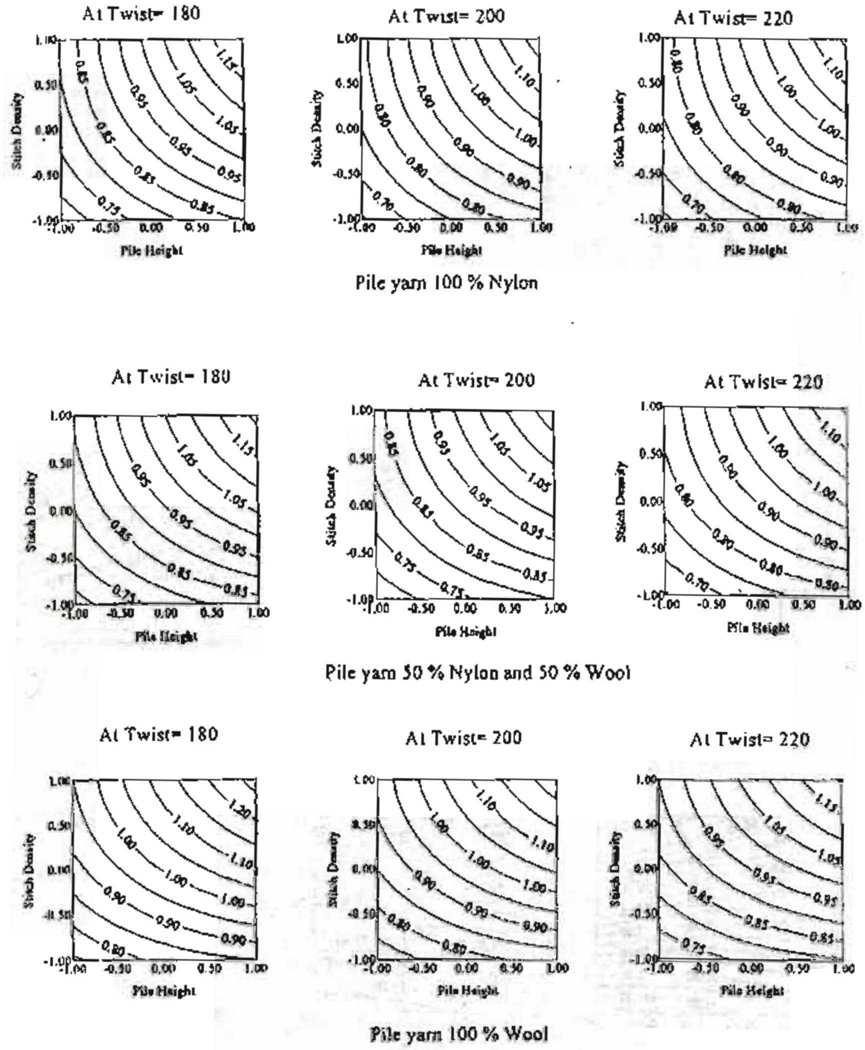

Fig. 6: Effect of Pile Height and Stitch Density on Carpet Hysteresis at Different Twist Levels and Blend Ratio

4. CONCLUSION

- Stitch density and pile height mostly affect carpet characteristics in same power but in opposite way to each other. Carpet compressibility significantly affected by the pile height and stitch density. Increasing stitch density increases carpet hardness, permanent-set. Increasing both pile height and stitch density decreases carpet resilience and hysteresis.
- As the percent of wool increases, carpet compressibility increases, where wool piles have lower hardness. Permanent-set, hysteresis, and resilience decrease as wool percentage increases.
- Yarn twist in the range used in this study showed a little effect on most of carpet properties. As yarn twist increases carpet compressibility decreases, carpet hardness, resilience, hysteresis, and permanent-set increases.

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