EVALUATING PILE YARN CHARACTERISTICS IN HAND WOVEN CARPET USING STRESS-STRAIN BEHAVIOR IN COMPRESSION

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Abstract Many factors such as production methods and structural parameters have distinctive influence on the quality and performance of a hand woven carpet. To investigate the effects of some variables, eighteen samples of carpet vary, in knot density, pile height and percentage of slipe wool, were manufactured. Pile yarn performance was assessed by using load-displacement compression curve, obtained from Zwick tensile tester under cyclic loading, up to 30 kPa. Based on the results, compression and matting of the pile yarn decreased and its elastic recovery increased with the increase in knot density. Increase in pile height caused an increase in the degree of variation for carpet samples. Matting of samples decreased with increase in pile height to certain level, but further increase caused increased reduction in matting. Elastic recovery of pile yarn had a reverse trend as the pile height changed. Consequently, increase in percentage of slipe wool caused an increase in compression and matting, and also reduction in elastic recovery of pile yarn.

Keywords Slipe Wool, Virgin Wool, Compression, Elastic Recovery, Matting, Stress-Strain Compression Curves

چکیده بسیاری پارامترها همچون روش تولید، مواد اولیه و فاکتور های ساختاری بر کیفیت و کارایی فرش دستباف موثر است. به منظور مطالعه اثر پاره ای از عوامل، هجده نمونه با در نظر گرفتن تغییر در درصد پشم دباغی، تراکم گره و ارتفاع نخ پرز بافته شد. کارایی نمونه های بافته شده با بهره گیری از منحنی نیرو – جابجایی فشاری تحت بار تکرار شونده به میزان حداکثر ۳۰ کیلو پاسکال در دستگاه آزمایشگاهی زوئیک مطالعه گردید. بر پایه نتایج، افزایش تراکم گره در سطح فرش موجب کاهش درصد قابلیت فشرده شدن و خوابیدگی و افزایش درصد بازگشت پذیری الاستیک نخ پرز شد. تغییرات ارتفاع نخ پرز با افزایش ارتفاع نخ خواب بیشتر گردید. خوابیدگی نخ پرز با افزایش ارتفاع در ابتدا کاهش و برای مقادیر بالاتر ارتفاع، افزایش نشان داد. بازگشت الاستیک پرز دارای رفتاری عکس رفتار خوابیدگی درمقابل تغییر ارتفاع نخ خواب می‌باشد. نهایت آنکه افزایش درصد پشم دباغی موجب افزایش قابلیت فشرده شدن و خوابیدگی و کاهش درصد بازگشت پذیری الاستیک نخ پرز شد.

1. INTRODUCTION

Hand woven carpet is made of two different parts, namely; secondary backing fabric and pile yarns. Horizontal strand is placed between warp yarns usually after each course of knotting to create secondary backing fabric, and to support pile yarns in vertical or near vertical condition. Warp yarn is usually spun from silk, wool or cotton fibers. Silk fibers are used in weft ends and pile yarns, for valuable carpet. In not so expensive carpet, wool and cotton fibers are introduced. However, in spite of the current situation, using cotton yarns as the weft end is highly suitable due to their high tenacity and low strain [1]. For example, despite many advantages of using polyester fiber in thin weft and warp yarn, surface deformation of samples increases when irregular heating is applied to the carpet. The bending length increases in the warp and weft direction when the percentage of polyester fiber in the carpet yarn increases in comparison with samples woven from 100 % cotton warp and thin weft yarns [2].

The most common fiber used for producing pile yarn is wool. Wool fiber can be used as pile yarn when its resiliency, length, number of crimp, percentage of vegetable trash, tenacity, elongation and fineness are suitable [3]. It is clear that, fiber used in the making of a carpet has a significant influence on the carpet properties [4,5]. Nowadays, slipe wool is mixed with virgin wool and used as pile yarn. Based on the effect of wool on the quality of a carpet, Iranian standard organization restricts using of slipe wool because of the lower quality of the wool due to the damage caused by the chemical treatment, during tanning process [6-8]. Researches show that, using slipe wool in the carpet leads to more reduction in pile height after applying compressive load and poor elastic recovery after removing the load [3,7].

The importance of each component and its effect on hand woven carpet properties has been studied. Studies show that, the work frame without a jack has a bending effect on its horizontal bar, like the samples used in Kerman and Khorasan provinces [9]. By studying the effect of knot types, it is shown that the length of the sample woven with symmetrical (Turkish) or asymmetrical (Persian) knot is more than the length in the map. In addition, while using paired knots or using no knots, the length of the carpet sample is less than the length in the weaving map. The percentage of thickness reductions in the carpet samples under a static load, for samples woven by symmetrical, asymmetrical and paired knots are 42 %, 46 % and 56 % respectively. Researches show that the elastic recovery of pile yarn, 60 minutes after removing the load is 98 % for symmetrical and asymmetrical knots, and the amount is 94 % for paired knot under dynamic load [10]. Studies prove that controlling weft yarn tension during weft insertion and stiffness or looseness of warp yarns, affects the quality and appearance of the carpet [11]. Accomplished researches show that, the usage of fine thin weft yarns has a very high influence on the required force for pulling out the pile from the carpet or in another term, the knot strength [12].

Researches indicated that the extent of the loss of carpet thickness in the initial months of use was more in comparison with variation occurred in later months. A linear relationship was found between the thickness and the logarithm of the number of impacts on the carpet or the number of people walking over the carpet [13-16]. However, a dense carpet and short pile will give less compression and less loss of thickness after recovery. Loss of pile height after recovery increased with increase in pile height [14,16]. Study shows that the variation in pile height and density per area, results a change in the amount of resilience and elastic recovery of the pile. An increase in pile height improves the compressibility of the carpet, but there is no observable change in its elastic recovery. Having more pile density, also improves the pile's elastic recovery, reduces the thickness variation of the carpet and increases the stability factor [17,3]. This study has a closer look on the effect of pile height, knot density and percentage of slipe wool, on the quality of Iranian hand woven carpet by using load-displacement compression curves of the pile yarn.

2. MATERIALS AND METHODS

Three woolen yarn samples, containing different percentage of slipe and virgin wool were spun. For this purpose, several skins were prepared from an Iranian wool breeds called Naini. Before tanning processes, wool fibers were removed from parts of skins as virgin wool. Virgin and slipe wools were used in studying and comparing their physical and mechanical properties for producing pile yarn. At the beginning of tanning processes, the skins were rinsed in cold water for 24 hr to remove excess salt, blood and dirt from wool and pelt. Then the skins were rinsed for 15 min in machine. Characteristics of wool fibers from Naini generation have been illustrated in Table 1.

For tanning process, sodium sulfur was added

TABLE 1. Characteristics of the Virgin and Slipe Wool Used in the Structure of Pile Yarn.

Swelling in Diameter %	Drop in Elongation	Drop in Tenacity	Elongation %	Tenacity cN/dtex	Diameter Micron	Length (mm)	Generation of Wool
Virgin Wool Fiber							
----	-----	-----	39.11	1.402	28.22	109.54	Naini Generation
Slipe Wool Fiber							Naini Generation
5.74	7.31 %	22.42 %	41.12	1.148	29.84	109.54	

to the water until the concentration of the solution reached 18˚ Be. After dissolving sodium sulfur, lime was added to the solution in order to obtain a 35˚ Be concentration. After preparing the tanning solution, the skins were laid on each other from their woolen sides and the tanning solution was applied by big brushes on their fleshy sides, correspondingly. The thickness of tanning material layer was approximately 1.5 mm-2 mm based on the activities of industrial unit. After applying the tanning material, skins were fold in the middle and maintained for a specific time. After the said time, skins were laid on a table on their fleshy sides and the wool fibers were extracted by hand and blade. Finally, skins were dried in air and under sunlight. Slipe and virgin wools were transported to the spinning line after dyeing with acid dye and three yarn samples were spun with 0 %, 30 % and 100 % of slipe wool fibers.

To investigate the effects of knot density, pile height and the percentage of slipe wool, on the behavior and performance of carpet, 18 hand woven carpet samples were prepared according to the conditions shown in Table 2. In woven carpets, warp yarn, thick weft and thin weft yarns were from cotton fibers. Specifications of pile yarns, warp yarns, thin and thick weft yarn that were used in carpet weaving have been illustrated in Table 3.

Experiments for the investigation of stress-strain behavior of pile yarns under cyclic loading were performed by Zwick textile tester, equipped with compressive cycling facility. In the experiments, the load was cycled between lower limit 2 kPa and the upper limit 30 kPa. The cross head speed was 5 mm/min. Load-displacement curves were plotted for 5 different places on each sample and in 5 uninterrupted sequences. Finally, defining the parameters of carpet characteristics such as, compression %, elastic recovery % and matting % were calculated based on the equations below and according to Figure 1. Assumption of negligible changes in secondary backing fabric during compression was used for calculation [18]. Results of calculation have been shown in Table 4.

$$\text{Compression \%} = \frac{t_i - t_f}{t_i} * 100 \qquad (1)$$

$$\text{Elastic recovery \%} = \frac{t_d - t_f}{t_i - t_f} * 100 \qquad (2)$$

$$\text{Matting \%} = \frac{t_i - t_d}{t_i} * 100 \qquad (3)$$

t_i Carpet thickness under minimum compression before test’s start or carpet thickness at the beginning of each cycle(A1)

t_f Carpet thickness under maximum compression after a cycle of compressive load (B1)

t_d Thickness after removing the compressive load at minimum load (A2) [15].

3. RESULTS AND DISCUSSION

Based on the obtained curves from the experiment, intensity of thickness reduction in the carpet decreased, as the cycle number increased. The

TABLE 2. Specifications of Carpet Samples.

Sample Code \ Carpet Character	Pile Yarn	Height of Pile Yarn	Knots/6.5 cm	knots/36 cm^2
1	100 % Slipe Wool	13.2	20	462.5
2	100 % Virgin Wool	13.2	20	462.5
3	30 % Slipe and 70 % Virgin Wool	13.2	20	462.5
4	100 % Slipe Wool	10.5	20	462.5
5	100 % Virgin Wool	10.5	20	462.5
6	30 % Slipe and 70 % Virgin Wool	10.5	20	462.5
7	100 % Slipe Wool	6.5	20	462.5
8	100 % Virgin Wool	6.5	20	462.5
9	30 % Slipe and 70 % Virgin Wool	6.5	20	462.5
10	100 % Slipe Wool	13.2	40	925
11	100 % Virgin Wool	13.2	40	925
12	30 % Slipe and 70 % Virgin Wool	13.2	40	925
13	100 % Slipe Wool	10.5	40	925
14	100 % Virgin Wool	10.5	40	925
15	30 % Slipe and 70 %Virgin wool	10.5	40	925
16	100 % Slipe Wool	6.5	40	925
17	100 % Virgin Wool	6.5	40	925
18	30 % Slipe and 70 % Virgin Wool	6.5	40	925

TABLE 3. Specifications of Pile Yarn, Warp Yarn, thin and Thick Weft Yarns used in Carpet Samples Construction.

No of Ply	Nm Ply Yarn	Ply Yarn Twist/m	Single Yarn Twist/m	Yarn was used as:
2	2.75	85	165	100 % Slipe Wool
2	2.80	90	167	100 % Virgin Wool
2	2.47	75	160	30 % Slipe and 70 % Virginl Wool
2	25	400	----	Thin Weft Yarn
4 Thread * 10 Ply	0.645	280	124	Thick Weft Yarn
3 Thread * 3 Ply	3.25	600	---	Warp Yarn

variation of pile height and the extent of poor elastic recovery, were the greatest in the first cycle but they decreased in further cycles. By observeing the ploted lines, after the fifth cycle the lines were all showing the same value and could hardly be used.

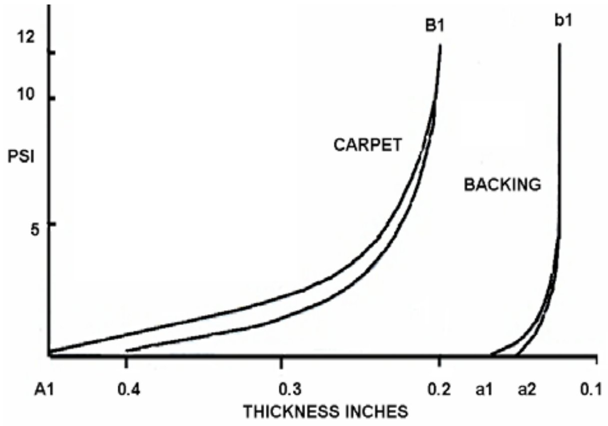

Figure 1. Theoretical load-displacement compression curve of pile yarn under cyclic loading [18].

Results indicated that, most variations and reductions in the hight of the pile yarn toke place at the initial compression cycle and decreased in the next steps. Decrease in the thickness of the carpet during cyclic compression was linear with respect to the cycle number after the initial compression and the slope of the curve was higher at first and decreased toward next steps (Figure 2).

3.1. The Effect of Pile Height on the Carpet Performance

The effect of pile height on the samples' performance has been illustrated in Figure 3. Comparison of carpet samples in order to study the effect of pile height was done according to Table 5. Calculation of the mentioned parameters for each cycle of the tests was also possible. Although, the calculation procedure was the same, but the evaluations were based on the last cycle.

Based on the results, percentage of compression increased as pile height decreased. Data obtained from the experiments showed that, the amount of deformation or reduction in pile height under maximum loading increased by increasing its height. This may be attributed to the easier deformation of the higher pile. Therefore carpet thickness variation increases by increasing the pile height. In spite of the expectancy, maximum compression was observed for carpet sample with pile height of 6.5 mm, because of the special form of calculations. On the other hand, despite low variation in the height of the short pile under cyclic loading, it had a high effect on the carpets' appearance. However, the amount of deformation and reduction of thickness was the highest in carpet samples with the pile height of 13.2 for every cycle, and decreased towards carpet samples with pile height of 6.5 mm.

Based on the results, elastic recovery (%) was the highest in carpet samples with pile height of

TABLE 4. Amount of Compression, Elastic recovery and Matting for Pile Yarn at the end of 5th Cycle of Compression and Decompression.

Parameter / Sample No	Compression %	Elastic Recovery %	Matting %
1	29.9	48.00	17.50
2	22.79	49.80	16.70
3	29.00	48.72	17.00
4	38.48	52.31	14.00
5	32.28	55.10	13.00
6	37.50	53.00	13.50
7	47.07	45.00	25.23
8	41.53	48.70	16.30
9	46.69	45.86	24.15
10	21.50	48.50	12.65
11	19.30	51.00	11.00
12	21.00	49.10	12.35
13	21.45	57.03	11.60
14	20.70	59.96	8.65
15	21.70	58.00	10.00
16	46.15	48.50	20.38
17	36.15	49.50	16.00
18	45.69	46.20	20.00

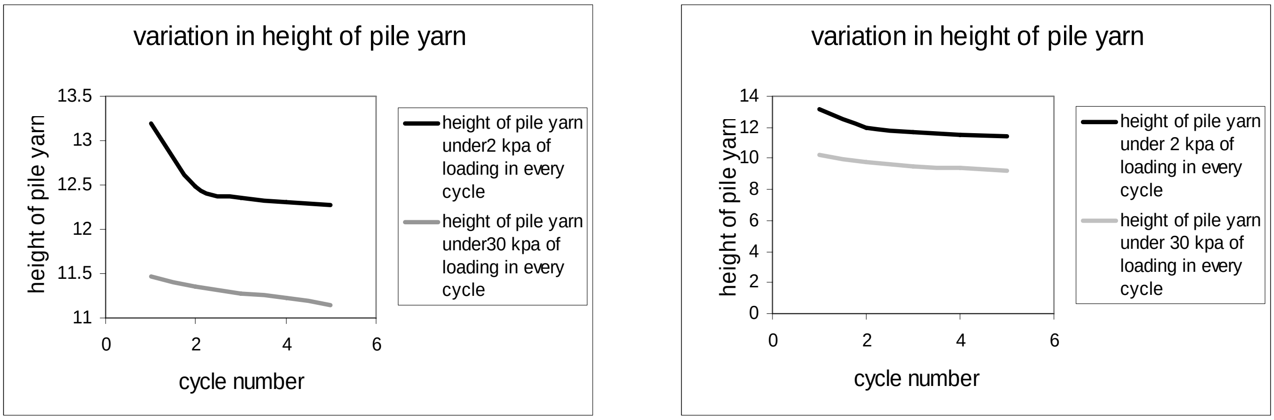

Figure 2. Height of pile yarn at 2 and 30 kPa for five consecutive cycles (sample: left No. 1, right No. 10).

10.5 mm and had the lowest value in samples with pile height of 6.5 mm. Experiments showed that amount of recovery to the original state, after removing compressive load (numerator of the fraction), had the highest value for the carpets with pile height of 10.5 mm. Hence, it may be an optimum value for pile height which has the best and maximum elastic recovery %.

Study on the matting behavior of pile yarn showed that, carpet samples with pile height of 6.5 mm, had the highest, and pile height of 10.5 mm, had the lowest percentage of matting. Based on the experimental data, the shortest pile had the maximum plastic deformation, and pile yarn with the height of 10.5 had the minimum un-recovered deformation for every cycle.

3.2. The Effect of Knot Density on the Carpet Performance The effects of knot density on the quality and performance of carpet samples have been shown in Figure 4. In this step Table 5 was used for comparing carpet samples again. Based on Figure 4 and results, compression % and matting % of pile yarn decreased as knot density increased. The results indicated that, deformation of pile yarn for every cycle was reduced by increasing knot density from 20 knot/6.5 cm in weft direction to 40 knot/6.5 cm. In other word, the reduction in pile height under maximum loading, decreased by the increase in knot density. It may be attributed to more friction between pile yarn and lack of space between fibers which is needed for deformation and displacement in dense carpet samples. In addition, because of low pile yarn deformation, the recovery after removing compressive load improved, and the percentage of elastic recovery increased. In loose carpet samples, recovery to the initial state was lower.

3.3. The Effect of Percentage of Slipe Wool on the Carpet Performance As mentioned, nowadays slipe wool is mixed with virgin wool fibers and used in carpet industry. Fiber damage occurs because of alkali agent during tanning process and undesired contact between tanning solution and wool fibers. Variations in dye absorption and brightness of wool fibers, peeling scale from wool surface, reduction in numbers of peptide bond, increase in the pile yarn imperfecctions and mass variation are some of the damages. Use of pile yarns spun from slipe wool fibers degrades the quality, performance and life expectancy of carpet to a certain extent [13,16,17,3].

Using three different pile yarns containing 0, 30 and 100 % of slipe wool in fiber blend, showed the effect of degradation of slipe wool on the quality of the carpet samples. The results of study based on Table 5 have been illustrated in Figure 5. Increase in percentage of the slipe wool increased compression % of pile yarn under certain load. On the other hand, yarns are easily deformed by increasing slipe wool. It may be attributed to the

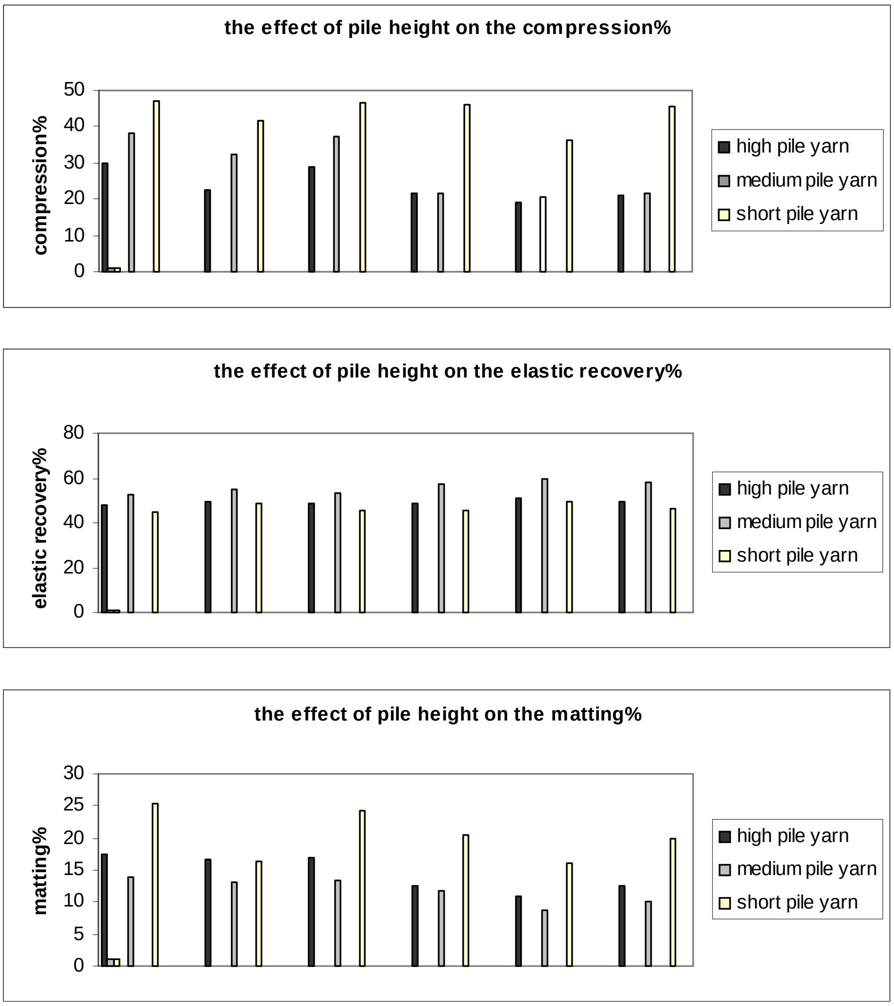

Figure 3. The effect of pile height on the performance and properties of carpet.

TABLE 5. Comparing Carpet Samples in Order to Study the Effect of Pile Height, Knot Density and Percentage of Slipe Wool on the Carpet Performance.

Comparing for the Effect of Pile Height		
3-6-9	2-5-8	1-4-7
12-15-18	11-14-17	10-13-16
Comparing for the Effect of Knot Density		
7-16	4-13	1-10
8-17	5-14	2-11
9-18	6-15	3-12
Comparing for the Effect of Percentage of Slipe Wool		
7-8-9	4-5-6	1-2-3
16-17-18	13-14-15	10-11-12

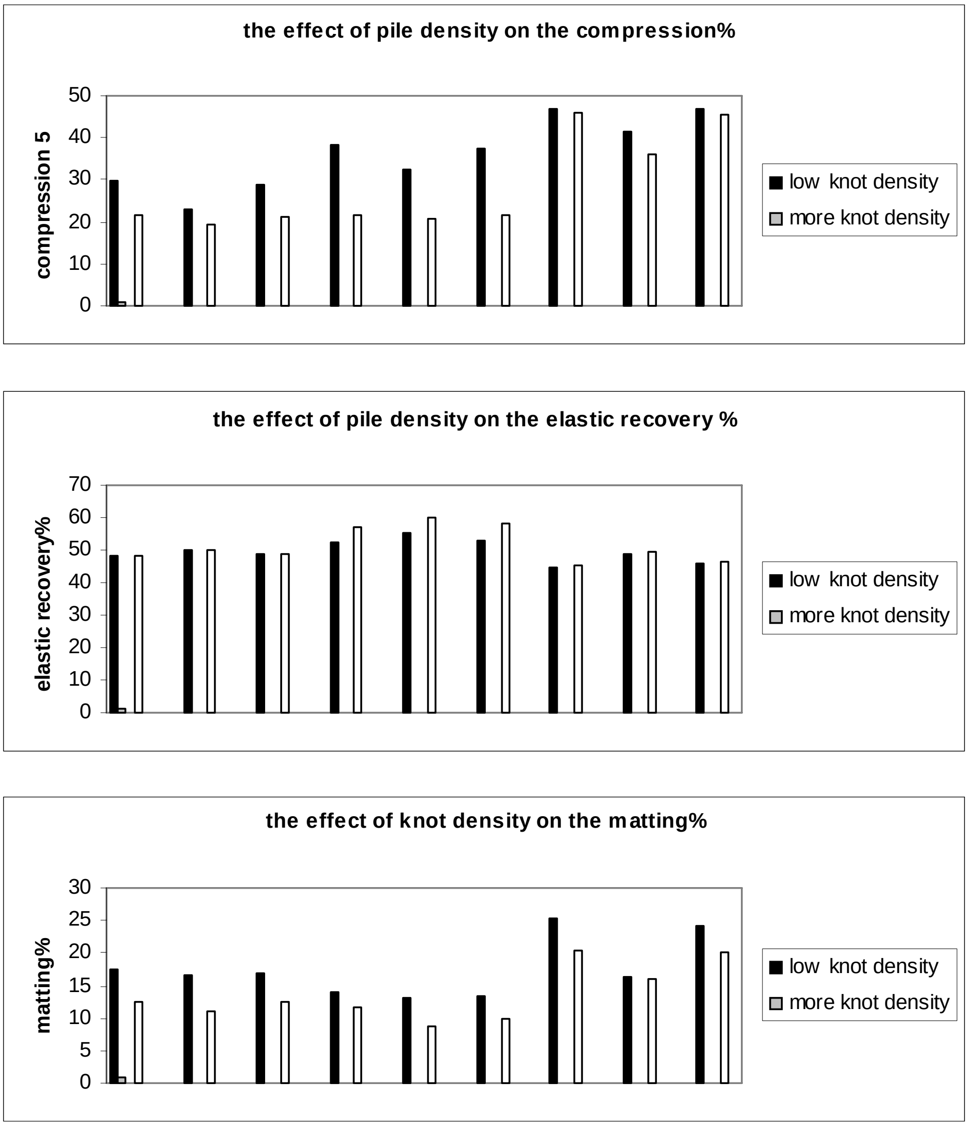

Figure 4. The effect of knot density on the performance and properties of carpet.

damage of slipe wool surface, and various stresses applied on the fibers during spinning operations. Scales are an effective factor for recovery of fibers to the initial state. The percentage of elastic recovery for the pile yarn decreased where matting percentage increased as the percentage of slipe wool increased in fiber blend. Change in fiber surface morphology and its inner structure may be the reason for this phenomenon.

By considering simultaneous effect of all three parameters**,** it is concluded that, carpet sample No14 woven from 100 % virgin wool, more knot density (40 knots/6.5 cm) and pile height of 10.5 mm exhibited the best characteristics. Minimum compression, matting and also maximum elastic recovery was obtained with this sample.

4. CONCLUSIONS

The effect of some fibrous and structural factors on

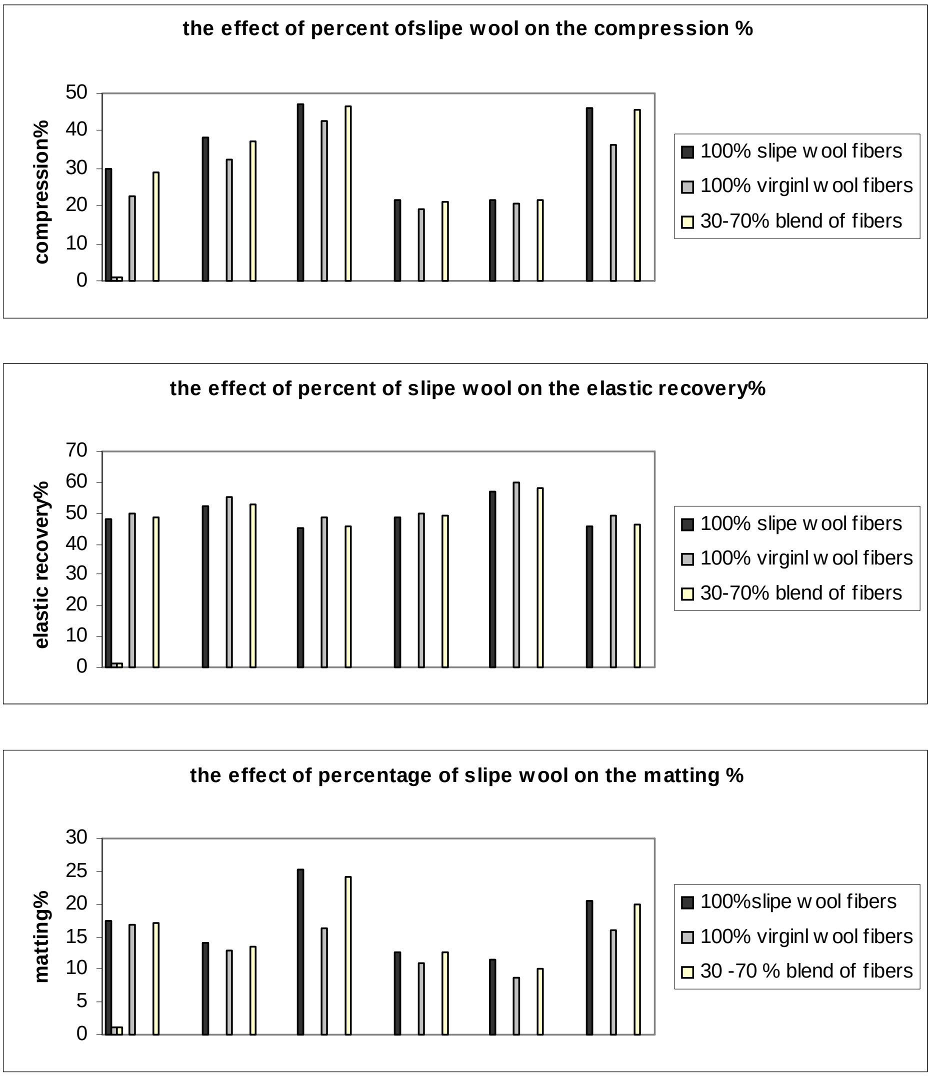

Figure 5. The effect of percentage of slipe wool on the performance and properties of carpet.

the performance and characteristics of Iranian hand woven carpet have been investigated in this study. Because of using slipe wool in Iranian carpet industry, part of research was focused on the disadvantage of these fibers. Therefore several skins from Naini breed were prepared.

Based on the experimental results, an increase in knot density, caused reduction in compression and matting percentage and also an increase in the amount of elastic recovery for the pile yarn. The compression magnitude increased by increasing the pile height. Matting percentage of samples decreased with the increase in pile height to a certain extent and increased for more pile heights. With respect to the trend of matting percentage, elastic recovery had a reverse trend as the pile height changed. Increase in percentage of slipe wool in pile yarn caused an increase in compression and matting percentage and a reduction in elastic recovery of pile yarn. Carpet sample woven from 100 % virgin wool with more knot density and pile height of 10.5 mm exhibited minimum compression and matting and also maximum elastic recovery.

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