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ORIGINAL CONTRIBUTION

Cost–Benefit and Performance of Handmade Carpets Produced with Wool, Untreated and Chemical Treated Jute Pile Yarns

Shravan Kumar Gupta[1] · **Kamal Kanti Goswami**[1]

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Abstract Jute is a natural fibre which is used to make different type of products due to low cost, easy availability and eco-friendliness. However, the stiffness and harshness of jute fibre affect the use of jute in many products like pile yarns in hand knotted carpets. In this research, a study has been done on the application of jute pile yarns in Persian hand knotted carpet. Three types of commercial yarns (wool, untreated jute and woollenized jute) as well as three types of chemical treated jute yarns (hydrogen peroxide bleached, softened bleached and woollenized yarns) have been applied as pile yarns in Persian hand knotted carpets. Cost–benefit analysis of hand knotted carpets shows that manufacturing cost of wool carpet is lower than others. The contribution of manpower charges is higher than material cost during carpet manufacturing. Hand knotted carpet shows the lowest pile abrasion loss and highest compression recovery when wool is used as pile. Wool hand knotted carpet shows higher compression than untreated and treated jute carpets.

Keywords Abrasion test of carpet · Handmade carpet · Compression · Compression recovery · Jute yarn

Introduction

Carpets are three-dimensional home textile products. These consist of two parts, namely backing and pile. The carpet backing is produced by warp and weft yarns. The piles make actual functioning face of the complete carpet with desired design and pattern. Fundamentally, carpets are grouped into two categories on the basis of its producing systems: machinemade and handmade carpets. Machine-made carpet producing systems comprise tufting, weaving, knitting, braiding, needle felting, fusion bonding and flocking. Handmade carpets are manufactured in three different ways, namely knotted, flat woven and tufted. Persian or Sehna, Tibetan, Turkish or Ghiordes, Spanish and Kiwi knots are used in manufacturing of hand knotted carpets. Among these, Persian knot is extensively used in handmade carpet segment [1–4]. Raw materials commonly used for manufacturing of handmade carpets are wool, silk, polypropylene and nylon as pile fibres whereas cotton, jute, polyester and polypropylene fibres are used as carpet backing. Wool in pile yarn is extensively used in handmade carpets because of its excellent properties in terms of hand, durability, stain-resistance, dyeability, flame resistance, insulation, and biodegradability [2].

Carpets are costlier products than normal apparel. Carpet manufacturers are always trying to reduce carpet manufacturing cost by using cheap raw materials. Jute is bio-degradable, recyclable, environment friendly and cheapest vegetable fibre procured from the bast of the plant's stem. It is the second most important vegetable fibre after cotton, in terms of usage, consumption, production and availability globally [5]. Jute materials are used in packaging, sacking, ropes, twines and home textiles including carpet backing etc. [6, 7]. The presence of wax, pectin and mineral matters creates problems during dyeing, printing and finishing of jute materials [8]. It is also physically coarse, harsh and stiff [9]. As a result, this natural fibre needs proper chemical processing (pretreatment and after treatment) to make it attractive to consumer and to improve its functional properties. It has been

✉ Shravan Kumar Gupta
shravangupta79@rediffmail.com

[1] Indian Institute of Carpet Technology, Chauri Road, Bhadohi 221 401, Uttar Pradesh, India

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observed that jute yarns improve its lustre, dyeing and moisture absorptive properties after the treatment with 18% (w/w) sodium hydroxide (NaOH) solution. Wool like crimps is developed in the jute fibre due to non-uniform swelling of the fibre cell wall so that this process is called woollenization or mercerization of jute yarns [10].

When jute yarn is used in carpet pile, it possesses poor resilience and high fibre shedding behaviour in comparison to wool carpets. Rahman et al. [11] treated jute carpet pile yarns with dimethylol dihydroxy ethylene urea (DMDHEU) using magnesium chloride as catalyst. The test results showed improvements in the performance characteristics of the treated jute carpets than untreated jute carpets.

The main aim of this research is to study the cost–benefit analysis of Persian hand knotted carpets by using wool, untreated jute and chemical treated jute pile yarns. The performance properties (abrasion and compressional behaviours) of Persian jute hand knotted carpets are also investigated and compared with wool carpet.

Materials and Methods

Four types of yarns were used for the manufacturing of Persian handmade carpets namely pile, warp, thick weft and thin weft yarns. Among these, six types of pile yarns were used for manufacturing of Persian hand knotted carpet samples. Three types of commercial pile yarns (wool, untreated jute and woollenized jute), warp, thick weft and thin weft yarns were purchased from Bhadohi local market. Another three types of pile yarns were produced in house by hydrogen peroxide bleaching then softening of woollenized and bleached jute yarns.

Hydrogen Peroxide Bleaching

The chemical constituents and process parameters during hydrogen peroxide bleaching of jute yarn are depicted in Table 1 [12].

Table 1 Hydrogen peroxide bleaching solution constituents [chemical percentage (%) used on the basis of weight of material (owm)]

Hydrogen peroxide (50 volume)	6% (owm)
Sodium silicate	6% (owm)
Caustic soda	0.5% (owm)
Non-ionic detergent	0.5% (owm)
Temperature	80–85 °C
Time	2 h
M:L ratio	1:20
pH	8

Softening of Jute Yarns

The chemical constituents and process parameters during softening of jute yarns are depicted in Table 2 [13].

Specifications of Yarns

The specifications of commercial and chemical treated pile, warp, thin weft as well as thick weft yarns are presented in Table 3.

Manufacturing of Persian Hand Knotted Carpet Samples

The sequence of operations for manufacturing of Persian hand knotted carpets is shown in Fig. 1.

First of all, cotton yarns in hank form were converted into a ball shape for easy warping. This was done with the help of iron wheel with stand, which revolves smoothly around its axis. After that two iron rods (traditionally called "Ramba") are fixed into ground using iron hammer. The distance between rods is equal to the carpet size plus allowances for fringes and unutilized wrappings on to the upper beam. After that, warp yarn was brought from one rod to other. At the end of this operation all the warp yarns will be on the rods. Then warps were transferred from thick iron rod to a thin steel rod. Thin steel rod was folded and carried to the loom for mounting. Two steel rods along with warp yarns were fixed on to the hook provided in the upper and lower beam of the carpet loom. After that warps were set at equal distance as per the required quality. Then healds were prepared for each warp thread. After that warps were tied onto cylindrical wooden sticks traditionally called "Gulla" and "Kamana". Shedding of warp yarns was achieved with these wooden sticks. A support for the pile yarns was achieved by inserting cotton yarns in the weft direction. It was a process of putting a base to the carpet, traditionally known as "Khati-Chunan". The pile yarns were introduced into the carpet by means of tying the Persian knot. After tying each knot weavers cut the pile yarn with a knife. There is necessity of weft yarn insertion to keep the knotted pile intact and fixed. In this regard, thin weft (traditionally called "lachchi") and thick weft (traditionally called "tharri") were added in two lines after a line of pile knotting. Thick weft was added in the same

Table 2 Softening solution constituents

Luxil (Zydex Industries, Vadodara)	8% (owm)
DCB (Sachdeva Chemicals, Moradabad)	8% (owm)
M:L ratio	1:20

Heated water till 50 °C then added 1% (owm) acetic acid solution to water after that jute yarns were dipped for 2 h

Table 3 Specifications of pile yarns

S. no.	Yarn	Material	No. of plies	Count, tex (CV %)	Twist, inch^{-1} (CV %)	Twist direction
1.	Pile	Wool	1	452.55 (7.03)	3.00 (12.05)	"S"
2.	Pile	Jute	1	592.90 (13.70)	2.47 (25.60)	"S"
3.	Pile	Woolenized jute	2	407.30 (6.09)	4.00 (5.20)	"Z"
4.	Pile	Bleached jute	1	949.40 (8.50)	4.00 (12.04)	"S"
5.	Pile	Woolenized softened jute	2	429.40 (4.70)	4.00 (3.33)	"Z"
6.	Pile	Bleached softened jute	1	855.95 (13.20)	2.40 (20.36)	"S"
7.	Warp	Cotton	6	656.11 (0.30)	5.50 (2.60)	"S"
8.	Thin weft	Cotton	2	369.06 (1.40)	5.10 (2.10)	"S"
9.	Thick weft	Cotton	12	4633.80 (2.51)	1.33 (6.02)	"S"

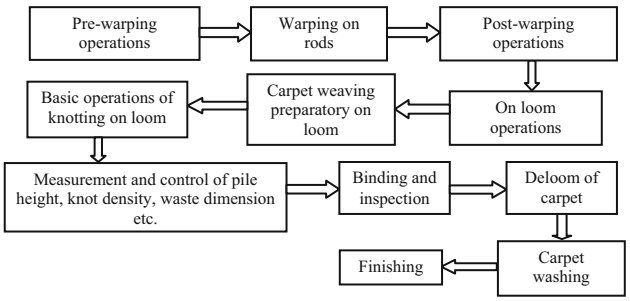

Fig. 1 Operations sequence for manufacturing of Persian hand knotted carpets

position of pile knotting and thin weft was added after changing the shed. The initial lines of pile height in knotted carpets were checked by the weaver with the help of pile height gauge. After setting the initial lines, weavers wove the remaining carpet following the earlier height level. The knot density was as per the quality required and was already taken care of while making the warp. However, this only dealt with the horizontal knot setting; the vertical knot setting was done with the help of a beater. The lengthwise sides of the carpet were bound on the loom itself. The widthwise sides have fringes which were later finished by knotting the warps. When the knotting procedure was completed, khati chunan was constructed again. After that carpet was separated from the loom by cutting the warp sheet widthwise.

Six Persian hand knotted carpet samples were developed by varying pile yarns as shown in Table 4.

Sample Testing

Pile Height

The pile height of carpets was measured as per IS: 7877 (Part IV)—1976 (Reaffirmed 1997) using flat metal gauges of known height as shown in Fig. 2.

Table 4 Persian hand knotted carpet samples

Sample no.	Pile yarns
HK 1	Wool
HK 2	Jute
HK 3	Woolenised Jute
HK 4	Bleached Jute
HK 5	Woolenised and softened Jute
HK 6	Bleached and softened Jute

Fig. 2 Metal gauges

Knot Density

Number of knots in Persian handmade wool carpets was determined as per IS: 7877 (Part III)—1976 (Reaffirmed 1997), which is equivalent to ISO 1763-1973, by using a rule (Fig. 3) capable of measuring to the nearest millimeter. This parameter was measured at the back of carpet in length-wise and width-wise directions.

Abrasion Resistance

The abrasion resistance of carpets was measured by rubbing the carpet samples against a standard abrading fabric for 5000 number of cycles. The WIRA abrasion tester

Fig. 3 Rule

Fig. 4 Carpet wear and abrasion tester

Fig. 5 SDL carpet thickness gauge (digital)

(Fig. 4) was used for conducting this test, based on the Schiefer principle of offset heads rotating in the same direction at the same speed. The rate of mass loss per 1000 number of cycles was calculated as per IWS/TM—283: 2000 standards. For each sample five readings were taken and then the average was calculated.

Compression Properties

The thickness of carpet samples was measured as the distance between the reference plate on which carpet was kept and a circular presser-foot on which pressure was applied. Carpet sample size for this test was 125 mm × 125 mm. The sample was placed on the base plate so that no part of the presser foot would be within 20 mm of the edge of the specimen or within 75 mm of any previous measurement. The presser foot was lowered slowly on the sample to apply a pressure of 2 kPa and after 30 s gauge reading was noted. Without raising the presser foot, extra mass was carefully added to increase the pressure to 5 kPa and gauge reading was again noted after 30 s. This process was continued to raise the pressure in steps to 10, 20, 50, 100, 150 and 200 kPa and the corresponding thicknesses values were recorded after 30 s of pressure application. Immediately after noting the gauge reading at the highest pressure i.e. 200 kPa, the pressure was reduced to 150 kPa. Thickness gauge reading was noted after 30 s and this recovery cycle was continued till the initial pressure of 2 kPa is reached. For each sample five readings were taken and then the average was calculated. SDL Carpet Thickness Gauge (Digital) as depicted in Fig. 5 was used for conducting this test as per BS 4098: 1975 (Reaffirmed 1982) standards. Figure 6 depicts the thickness-pressure curve during compression and recovery cycle for carpet sample HK1.

Here t_2 is initial carpet thickness at 2 kPa pressure (point A).

t_{200} is carpet thickness at 200 kPa pressure (point B).
t_r is recovered carpet thickness at 2 kPa pressure after loading to 200 kPa pressure (point C).

Following parameters were calculated with the help of the aforesaid readings.

- *Compression* $(t_2 - t_{200})$ The change in thickness of carpet when the pressure is increased from 2 to 200 kPa.
- *Percentage compression recovery* The change in thickness when the pressure is diminished from 200

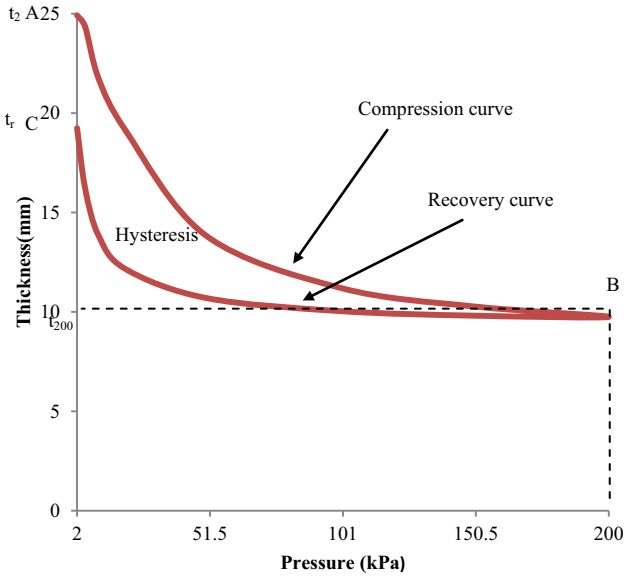

Fig. 6 Thickness-pressure curve for carpet sample HK 1

to 2 kPa expressed as a percentage of the compression. Numerically it is expressed as $\left(\frac{t_r - t_{200}}{t_2 - t_{200}}\right) \times 100$.

Results and Discussion

Cost–Benefit Analysis of Persian Hand Knotted Carpets

Current market rates of yarns (pile, thick weft, thin weft and warp yarns), chemicals for treatment of jute yarns and man power charges for manufacturing of Persian handmade carpet samples are depicted in Table 5.

Table 5 Current market rates of materials, chemicals and man power charges

S. no.	Materials/chemicals/man power charges	Rate in INR (inclusive of all taxes)
1.	Wool (as pile yarn)	504.00 (per kg)
2.	Jute (as pile yarn)	161.00 (per kg)
3.	Woollenised jute (as pile yarn)	168.00 (per kg)
4.	Cotton (as thick weft)	84.00 (per kg)
5.	Cotton (as thin weft)	84.00 (per kg)
6.	Cotton (as warp)	136.50 (per kg)
7.	Hydrogen peroxide	210.00 (per litre)
8.	Sodium silicate	236.00 (per kg)
9.	Caustic soda	79.00 (per kg)
10.	Non ionic detergent	257.00 (per kg)
11.	Softener	630.00 (per kg)
12.	Man power charges	497.00 (per day)

Table 6 Cost of chemicals used for treatment of jute yarns

Sample no.	Chemical cost (Rs.)
HK 4	29.00
HK 5	95.00
HK 6	123.00

Table 7 Raw material consumption and engaged man power days for manufacturing of hand knotted carpet samples

S. no.	Pile (g)	Thick weft (g)	Thin weft (g)	Warp (g)	Days
HK 1	760	300	60	356	4
HK 2	754	370	116	360	6
HK 3	852	410	211	362	7
HK 4	968	262	170	362	9
HK 5	940	280	122	360	6
HK 6	1222	102	280	360	7

Cost involved in chemical treatment of jute yarns are shown in Table 6.

Quantity of raw materials consumed and numbers of man power days for developing Persian hand knotted carpet samples are presented in Table 7.

Total manufacturing cost of 6 hand knotted carpet samples was calculated on the basis of rates mentioned in Table 5, cost involved in chemical treatment of jute yarns mentioned in Table 6, amount of consumed raw materials and numbers of days of engaged man power for each samples mentioned in Table 7. Total cost of each hand knotted carpet sample (sample size: 1.5 feet × 2.0 feet) is depicted in Table 8 and Fig. 7.

Percentage wise material cost and man power charges of six hand knotted carpet samples are shown in Table 9.

Table 8 and Fig. 7 show that the cost in the preparation of sample HK1 is lowest. Raw materials used in this sample are wool as pile and cotton as thick weft, thin weft as well as warp. Although jute is cheaper as compared to wool but knotting of wool is easier so that man power charges are minimum. The manufacturing cost of jute hand knotted carpets is higher than wool carpets because jute yarns create problem in knotting and pile cutting due to its stiffness.

Table 9 shows that average material cost percentage of six hand knotted carpets is 9.70% and average man power charges percentage is 90.30%. It indicates that manufacturing of hand knotted carpets are more labour intensive. Material contribution of total cost decreases when jute yarns were used as pile.

Abrasion Behaviour of Persian Hand Knotted Carpets

Table 10 presents the details of experimental results (pile height, knot density and abrasion loss) of six hand knotted carpet samples.

Table 8 Total manufacturing cost of carpet samples

Sample no.	Pile cost (INR)	Thick weft cost (INR)	Thin weft cost (INR)	Warp cost (INR)	Chemical cost (INR)	Man power charges (INR)	Total cost (INR)
HK 1	Wool 383.04	Cotton 25.20	Cotton 5.04	Cotton 48.60	–	1988	2449.88
HK 2	Jute 121.39	Cotton 31.08	Cotton 9.74	Cotton 49.14	–	2982	3193.35
HK 3	Woolenized jute 143.14	Cotton 34.44	Cotton 17.72	Cotton 49.41	–	3479	3723.71
HK 4	Bleached jute 155.85	Cotton 22.01	Cotton 14.28	Cotton 49.41	29.0	4473	4743.55
HK 5	Softened woolenized jute 157.92	Cotton 23.52	Cotton 10.24	Cotton 49.14	95.00	2982	3317.86
HK 6	Bleached soften jute 196.42	Cotton 8.56	Cotton 23.52	Cotton 49.14	123.00	3479	3879.64

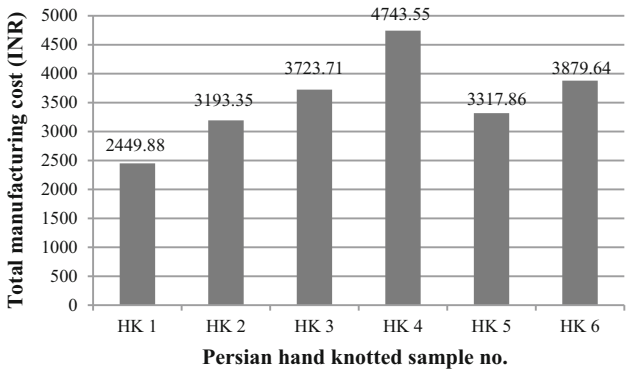

Fig. 7 Total manufacturing cost of carpet samples

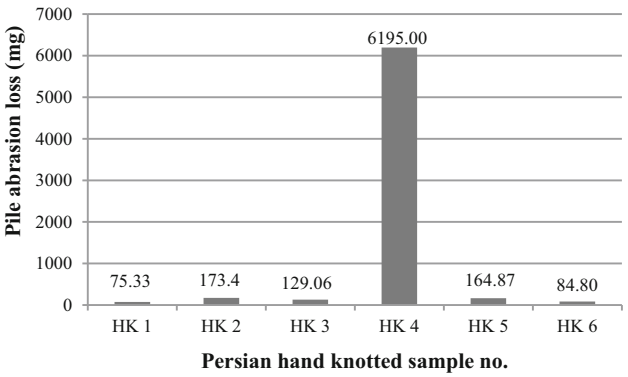

Fig. 8 Abrasion loss of hand knotted carpets

Table 9 Percentage wise cost of material and man power charges

S. no.	Material cost (%)	Man power charges (%)
HK 1	18.85	81.15
HK 2	6.62	93.38
HK 3	6.57	93.43
HK 4	5.70	94.30
HK 5	10.12	89.88
HK 6	10.33	89.67
Average	9.70	90.30

Table 10 Pile height, knot density and abrasion loss of hand knotted carpets

S. no.	Pile height (mm)	Knot density (inch^2)	Abrasion loss (mg)
HK 1	13.33 (2.63)	42.65	75.33 (12.92)
HK 2	14.96 (5.12)	37.20	173.40 (10.20)
HK 3	13.23 (3.25)	41.08	129.06 (25.66)
HK 4	13.66 (6.17)	40.46	6195.00 (4.29)
HK 5	13.20 (4.40)	39.79	164.87 (23.36)
HK 6	14.16 (3.75)	36.94	84.80 (13.73)

Values in parenthesis indicate CV %

Table 11 Compression and compression recovery of hand knotted carpets

S. no.	Compression (mm)	Compression recovery (%)
HK 1	15.17 (4.67)	60.93 (5.19)
HK 2	12.59 (3.18)	35.42 (14.18)
HK 3	9.37 (11.55)	19.45 (21.22)
HK 4	12.20 (7.74)	28.40 (10.87)
HK 5	8.30 (6.93)	22.14 (3.39)
HK 6	11.52 (12.18)	28.53 (9.40)

Values in parenthesis indicate CV %

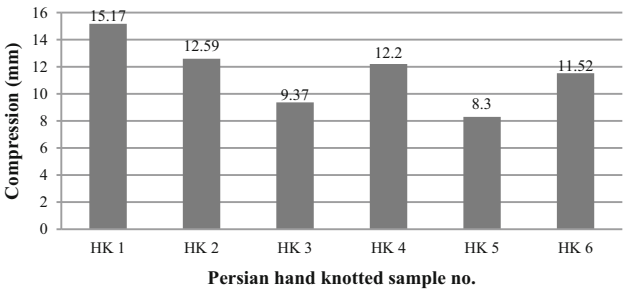

Fig. 9 Compression of hand knotted carpets

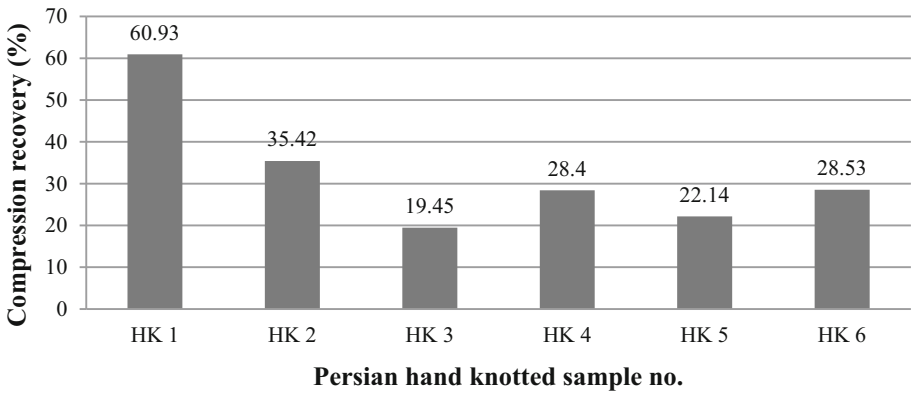

Fig. 10 Compression recovery of hand knotted carpets

Table 10 and Fig. 8 show that the highest pile abrasion loss occur in sample HK4 where hydrogen peroxide bleached jute yarn is used as pile. Hydrogen Peroxide causes partial removal of hemicellulose which is a cementing material for the ultimate cells of jute fibre [14]. Abrasion loss of jute carpet is comparable to wool carpet, when softened and bleached jute yarn is used as pile (sample HK 6).

Compressional Behaviour of Persian Hand Knotted Carpets

Table 11 presents the detail of experimental results for compression and compression recovery of hand knotted carpets.

Table 11 and Fig. 9 show that compression is the lowest for carpet HK 5. Pile material used in this sample is softened woollenised jute. Hand knotted carpets prepared from untreated and treated jute as pile give lower compression than wool carpet due to more stiffness of jute than wool.

Table 11 and Fig. 10 show that the compression recovery of hand knotted carpets prepared from wool as pile is maximum (HK1). Carpets made from untreated and treated jute (HK2–HK6) show minimum compression recovery due to inherent property of used textile fibres.

Conclusions

Although jute is cheaper material as compared to wool but it creates problem in knotting and cutting of pile during manufacturing of hand knotted carpets. However, material contribution of total carpet manufacturing cost decreases when jute yarns were used as pile. Manufacturing of Persian hand knotted carpet is more labour intensive because contribution of man power charges is much higher than material. Persian hand knotted carpet shows the lowest pile abrasion loss and highest compression recovery when wool used as pile. Jute hand knotted carpets show lower compression than wool carpets.

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