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ORIGINAL RESEARCH ARTICLE

Abrasion behaviour of wool-viscose hand tufted carpets using response surface methodology

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ABSTRACT

The effect of viscose blend in pile yarn, pile height and pile density on abrasion resistance of hand tufted carpets has been studied. The interaction between the process variables has been analyzed by using response surface methodology based on the Box-Behnken design of experiment. Overall, higher percentage (%) of viscose in the blend, lower pile height and lower pile density yield the minimum abrasion loss for the hand tufted carpets.

Keywords: calligraphy; painting; handmade papers; evolution of handmade paper; sorting and pulping

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1. Introduction

Indian carpet industry is the number one in the international handmade carpet market both in term of value and volume. India exports 90% of its total handmade carpet production. Indian handmade carpet industry is highly labour intensive and provide employment to about 20 lakh workers. Most of the weaver employed are from the weaker section of the society and this trade provide extra and alternate ocupation to them[1]. A carpet is a textile floor covering typically consisting of an upper layer of pile attached to a backing[2]. Handmade carpets are classified into three different types like knotted (Persian, Tibetan, Turkish etc.), tufted (hand tufting and needle tufting) and flat woven (broad loom carpets, saggy, durry, etc.)[3–5]. Wool, silk, polypropylene and nylon fibres are used as pile fibres; whereas cotton, jute, polyester and polypropylene fibres are used as backing in manufacturing of handmade carpets. Wool as pile yarn is generally used in handmade carpets due to its outstanding properties such as hand, durability, stain resistance, dyeability, flame resistance, insulation, static generation and biodegrability. The woollen pile yarns usually consist of twisted tufts which are typically heat-treated to maintain their structure[6].

Carpet durability is defined as the wear life of a carpet in specified situations. Durability property is important for carpet manufacturers to meet the customer requirements on the basis of their end-uses. Gupta et al.[7] reviewed various methods for measuring carpet durability like abrasion resistance, compression and recovery characteristics, tuft withdrawal force, thickness loss under dynamic loading, thickness loss and recovery after prolonged heavy static loading, surface pile mass density factor, appearance retention etc. Among these, abrasion resistance is one of the most important properties of carpet durability. WIRA carpet abrasion machine is extensively used to judge the abrasion behaviour of carpets. Abrasion behaviour of carpets is collectively influenced by fibre, yarn and carpet constructional parameters. Gupta et al.[8] studied the influence of fibre diameter and medullation on abrasion behavior of hand-knotted carpets and found that the abrasion loss increases with the increase in fibre diameter and medullated fibre content in carpet. Shakyawar et al.[9] also reported that the abrasion loss of carpets depends on fibre diameter and number of medullated fibres present in the yarn. Arora et al.[10] studied the influence of tuft constitution (the number of threads assembled together to form a tuft whether single or plied) on the performance parameters of hand-woven carpets. They found lower abrasion loss in carpets having more regular pile surface (when using single ply yarn) than in carpets having reduced regularity in pile surface (when using plied yarn).

The influence of carpet constructional parameters on the abrasion behaviour has been reported by some researchers[9,11–14]. It has been found that pile density and pile height play an important role in determining carpet abrasion behaviour.

In these days, viscose fibre is gaining its popularity for using in hand made carpet as a pile yarn. But there is hardly any reference about the basic characterstics of wool-viscose handmade carpets in terms of its abrasion behaviors. In this research; the influence of three variables (blend percentage (%) of viscose and wool, pile height and pile density) and their interaction have been studied by developing a model using Box-Behnken response surface methodology. The abrasion behaviour of hand tufted carpets has been investigated to explore its possibility as a new generation product in various product mix.

2. Materials and methods

2.1. Box Behnken methodology

In statistics, Box-Behnken design (BBD) is most common experimental design for responce surface methodology (RSM), devised by Box and Behnken in 1960[15]. Each factor or independent variable is placed at one of the three equally spaced value usually coded as –1, 0, +1. The design should be sufficient to fit a quardratic model, that is one containing linear, square and interaction terms. In three factors and three levels BBD, 15 experiments are conducted whereas in a full factorial design 27 experiments will be needed.

2.2. Sample preparation

Three types of pile yarns were used for the manufacturing of hand tufted carpet samples by using 40%, 60% and 80% of viscose fibres blend with wool fibres. The specifications of wool and viscose fibres are depicted in **Table 1**. Pile yarns of 2.0 metric counts (Nm) with 3.5 twists per inch (tpi) were produced by woollen spinning system.

Table 1. Specifications of wool and viscose fibre.

Specification of wool fibre	
Mean fibre diameter	32 micron
Fibre diameter (CV %)	21%
Mean fibre length	70 mm
Fibre length (CV %)	22.5%
Specification of viscose fibre	
Mean fibre diameter	12 micron
Fibre diameter (CV %)	9%
Mean fibre length	44 mm
Fibre length (CV %)	8%

A three factor three level Box-Behnken experimental design was used for this research. The coded and actual levels of variables are given in **Table 2**.

Table 2. Coded and actual levels of variables.

Variable code	Variables (unit)	Levels		
		–1	0	+1
x_1	Viscose bl end (%)	40% viscose 60% wool	60% viscose 40% wool	80% viscose 20% wool
x_2	Pile height (mm)	9	12	15
x_3	Pile density (tufts/square inch)	16	20	24

Carpet samples were manufactured by hand tufting process. It is processed to manufacture the carpet by the insertion of pile yarn into primary backing fabric with the help of tufting gun (**Figure 1**).

Figure 1. Tufting process.

Specification of primary backing fabric used in this research is depicted in **Table 3**.

Table 3. Specification of primary backing fabric.

S. No.	Parameter	Value
1.	Warp count	2/10 double
2.	Weft count	2/10 double
3.	Reed count	14 to 16 Nos
4.	Picks/Inch	14 minimum
5.	Length	as desired
6.	Width	12½’ to 20’ as desired
7.	Square meter weight	300 gm.
8.	Weaving defects	Nil

2.3. 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.

Abrasion resistance: The abrasion resistance of carpets was tested by rubbing the carpet samples against a standard abraded fabric for 5000 number of rotations. The WIRA abrasion tester (**Figure 2**) 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 weight loss per 1000 number of rotations was calculated as per IWS/TM – 283: 2000 standards. For each sample 5 readings were taken and then the average was calculated. **Figure 3** depicts samples no 11 (before and after abrasion).

Figure 2. WIRA abrasion tester.

(a) Before abrasion (b) After abrasion

Figure 3. Images of sample number 11.

3. Results and discussion

3.1. Response surface model for abrasion loss

Table 4 presents the details of experimental and predicted results for the abrasion loss of hand tufted carpets.

Table 4. Abrasion loss of hand tufted carpets.

S. No	Viscose blend (%)	Pile height (mm)	Pile density (tufts/square inch)	Actual abrasion loss	Predicted abrasion loss	Error (%)
1	80	12	16	36.3	34.93	3.77
2	60	9	16	40.8	40.27	1.30
3	60	15	16	42.8	41.59	2.83
4	60	12	20	47.0	45.89	2.36
5	60	15	24	49.8	48.11	3.40
6	40	9	20	53.4	53.07	0.61
7	80	12	24	40.1	39.02	2.70
8	40	15	20	56.2	56.15	0.10
9	80	9	20	37.6	35.39	5.87
10	40	12	24	61.4	60.50	1.47
11	60	12	20	47.0	45.89	2.36
12	60	12	20	47.0	45.89	2.36
13	80	15	20	37.4	35.35	5.50
14	60	9	24	47.4	46.41	2.10
15	40	12	16	53.2	51.93	2.39

From the experimental results reported in **Table 4**, the following response surface Equation (1) was obtained. This equation contains 9 terms arising from 3, 3 and 3 linear, interaction and quadratic terms respectively.

The coefficient of determination (R2) of the aforesaid model is 0.997. This implies that the model can explain around 99% variability present in the experimental data. All carpet samples are showing less than 6% prediction error. Therefore, it can be inferred that the derived model is perfect in terms of prediction accuracy.

$$y = 9.250 - 0.285x_1 + 5.408x_2 + 1.775x_3 - 0.013x_1x_2 - 0.014x_1x_3 + 0.008x_2x_3 + 0.002x_1^2 - 0.189x_2^2 - 0.006x_3^2 \quad (1)$$

The ANOVA results of the regression model are shown in **Table 5**. The significance of the entire model and each of the coefficients was checked by using F-test and its associated p-value. If the p-value is less than 0.05 then the model is statistically significant at 95% level. The model F-value of 182.87 indicates that it is significant and there is less than 0.01% chance that F-value this large could occur due to chance.

Table 5. Analysis of variance for abrasion loss.

Source	Sum of squares	Degrees of freedom	Mean square	F-value	P-value Prob > F
Model	771.90	9.00	85.77	182.87	<0.0001
x_1-Viscose blend	662.48	1.00	662.48	1412.54	<0.0001
x_2-Pile height	6.13	1.00	6.13	13.06	0.0153
x_3-Pile density	81.92	1.00	81.92	174.67	<0.0001
x_1x_2	2.25	1.00	2.25	4.80	0.0801
x_1x_3	4.84	1.00	4.84	10.32	0.0237
x_2x_3	0.04	1.00	0.04	0.09	0.7820
x_1^2	2.67	1.00	2.67	5.69	0.0628
x_2^2	10.00	1.00	10.67	22.75	0.0050
x_3^2	0.04	1.00	0.04	0.08	0.7903
Residual	67.00	5.00	0.47		
Cor total	774.25	14.00			

In this case, all terms are statistically significant except x_2x_3 (interaction term of pile height and pile density) and x_3^2 (quadratic term of pile density). If the p-value is greater than 0.1 then that model term is not significant.

3.2. Analysis of contour graphs

Figure 4 depicts the effect of pile height and viscose blend on abrasion loss of hand tufted carpets. The carpet pile abrasion loss is lowest at the maximum blend % of viscose and minimum blend % of wool. It may be due to when the content of wool fibres is lowest in the blend then extraction of short fibres from pile yarns is minimum. The abrasion loss of carpets increases with the increase in pile height. It has been reported that small fibres are constantly removed from the exterior of the carpet pile yarns during abrasion[12]. When pile height is increased, then the possibility of fibre loss increases causing higher abrasion loss[14].

Figure 5 shows the effect of pile density and viscose blend on the abrasion loss of hand tufted carpets. It is noted that abrasion loss is minimum when viscose blend is at maximum level and pile density is at minimum level. Abrasion loss increases with the increase in pile density due to the drastic increase in the number of piles per unit area[14].

Figure 6 depicts the influence of two carpet construction parameters (pile density and pile height) on abrasion loss. It is observed that abrasion loss is lowest at the minimum levels of pile density and pile height. With the increase in pile density, abrasion loss increases due to the increase in the number of piles per unit area.

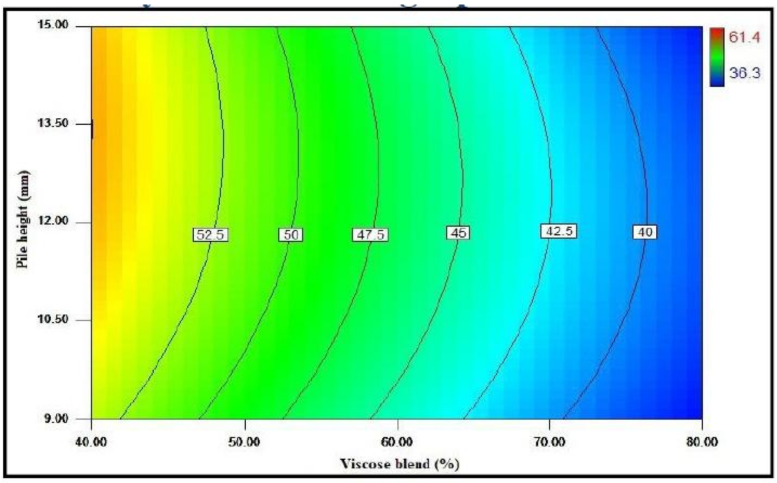

Figure 4. Effect of pile height and viscose blend on abrasion.

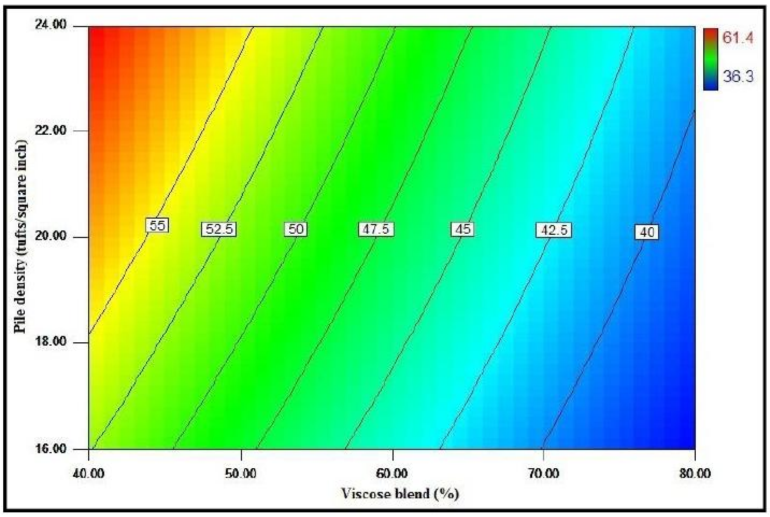

Figure 5. Effect of pile density and viscose blend on abrasion.

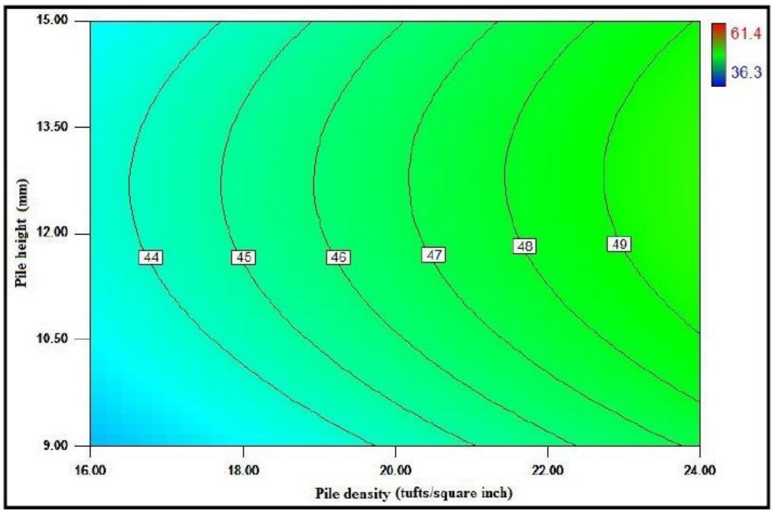

Figure 6. Effect of pile height and pile density on abrasion.

4. Conclusion

The influence of viscose blend, pile height and pile density on the abrasion loss of hand tufted has been investigated. All terms except x_2x_3 (interaction term of pile height and pile density) and x_3^2 (quadratic term of pile density) are found to be statistically significant. The abrasion loss decreases with the increase in blend % of viscose. The abrasion loss of wool-viscose hand tufted carpets increases significantly with the increase in pile height and pile density. Overall; higher % of viscose in the blend, lower pile height and lower pile density yield the minimum abrasion loss for the hand tufted carpets.

Conflict of interest

The authors declare no conflict of interest.

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