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Parametric Appraisal for Compression Behaviour of Machine Made Carpet: Exploration of Taguchi Optimisation Techniques

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ABSTRACT

Carpets and rugs are mainly classified into two types as hand-made carpets and machine-made carpets, in present; various machine carpets are available produced with needling and bonding techniques. In this study, an attempt has been made to identify the significant factor affecting the compression behavior of machine made carpets manufactured by M-Tuft hi-tech machine with exploration of Taguchi robust design philosophy for quality and productivity characteristics optimization. Lower the better criteria for compression and higher the better criteria for compression recovery (%) and tuft withdrawal force, are desirable to achieve better quality of carpets. The study aims at evaluating the most favorable process environment followed by an optimal parametric setting for improved quality and productivity. Process parameters considered are tufting speed (N), stitch rate (SR), Gauge size (G) and process response analyzed are compression recovery (%), compression (mm) and tuft withdrawal force (Kgf). Taguchi design of experiments based L16 orthogonal array has been used to perform the experiments. One of the most important mechanical properties of carpet is pile strength and thickness loss in terms of tuft withdrawal force and compression behavior respectively. This study focuses on improving the fundamental function of a product or process, thus facilitating flexible designs and concurrent engineering for reducing product costs, improving quality/productivity. The results obtained thereof have been compared with the predicted results followed by confirmatory test.

Keywords: Gauge, stitch rate, Taguchi optimization, tufting speed

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INTRODUCTION

As indispensable home decoration textile materials, carpets should have high durability during usage. One of the performance tests that affect the usage of carpets in our life are thickness recovery after static and dynamic loading. This study deals with the structural properties, compressibility and thickness recovery properties of machine made carpets. Various pioneer researches have studied about the chemical and physical properties of carpets but very limited work have been done in the area of parametric appraisal and response optimization of machine made carpets. Erkesim (1995) investigated some of the important quality characteristics of the carpets, such as wear resistance, thickness loss, and thickness recovery, appearance changing under mechanical impact, dimensional stability, snagging, contamination, wire resistance and static electricity [1]. It was stated that tufting carpets have better snagging load compared to Wilton type carpets. Berkalp (2001) investigated the structural properties and behavioral characteristics of the carpets against mechanical impacts.

Wear resistance, appearance, snagging characteristics of carpets produced from acrylic, wool and polypropylene fibers in two different pile height and loop density were measured [2-5]. It was found that weft thread density, raw material and loop height had statistically important effect on wear resistance. Tekin (2002) investigated the production stages of Wilton type woven carpets. In the study, after short term static loading, the thickness loss of acrylic carpets was found higher compared to wool and polypropylene carpets, however after dynamic loading opposite results were obtained. Koç et al. (2005) evaluated the thickness loss under static loading, deformation resistance, and elasticity and resilience properties of carpets. The thickness loss of acrylic carpets after static loading was found higher compared to wool and polypropylene carpets. Korkmaz (2010) searched the effect of pile density and number of loops per unit area on the short and long term static loading. It was reported that after short term loading the length of carpet piles reached to 80–90% of its initial length and after long term loading 74–89% of its initial length. Dalcı (2006) investigated the effects of carpet production parameters on carpet performance by using 16 carpet samples having acrylic and polypropylene piles in two different pile densities and four different pile heights. Experiments of tuft withdrawal strength, appearance, pilling, losses of thickness under dynamic loading, loss of thickness in short and long term under static loading were done. In this study an attempt has been made to identify the significant factor and their effect on machine made carpet.

EXPERIMENTATION

M-Tuft is a tufted carpet making machine in which all the system is controlled by the software and design is feed by Ned Graphics software. The M-Tuft range of machines is an innovative solution for product development of tufted carpet as it is very fast to set up and flexible in usage. The M-Tuft has set the benchmark for performance and flexibility, while saving clients time and money. It has maximum speed straight stitch is up to 20 per second, maximum sample width of 1 mt. and maximum pile height of 19 mm [6-8].

METHODOLOGY APPLIED: TAGUCHI'S OPTIMIZATION PHILOSOPHY

In Taguchi method, parameter design is utilized to reduce the source of variation in the quality characteristics and achieve the target. For whom orthogonal array forms the basis for the experimental analysis in the Taguchi method. It reduces the large number of variables with small number of experiments. Total degree of freedom is required for selecting the appropriate orthogonal array in the experiment. The degrees of freedom are defined as the number of comparisons between process parameters which determines the better level for the conduction of the experiment. The degree of freedom for the orthogonal array should be greater than or at least equal to those of the process parameters. The minimum number of trials (N) in the array is:

$$N = (L-1)F + 1$$

Here, (L) is the number of level defined, (F) define the number of factors taken in the experiment.

There is a loss function which describes the deviation from the target and further transformed into an S/N ratio. The transformed S/N ratio is also defined as quality evaluation index. The least variation and the optimal design are obtained by the S/N ratio. The higher the S/N ratio, the more stable the achievable quality. It reduces the sensitivity of the system performance to source of variation. The different S/N ratio characteristics are given as:

(1) Nominal-the-Best (NB): The formula for these characteristics: $\frac{S}{N} = 10\log\frac{y}{S_y^2}$

(2) Lower-the-Better (LB): The formula for these characteristics is: $\frac{S}{N} = 10\log\frac{1}{n}\Sigma y^2$

(3) Higher-the-Better (HB): The formula for these characteristics is: $\frac{S}{N} = 10\frac{1}{n}\Sigma\frac{1}{y^2}$

Here, y = Average of observed values, S_y^2 = Variance of y, N = Number of observations.

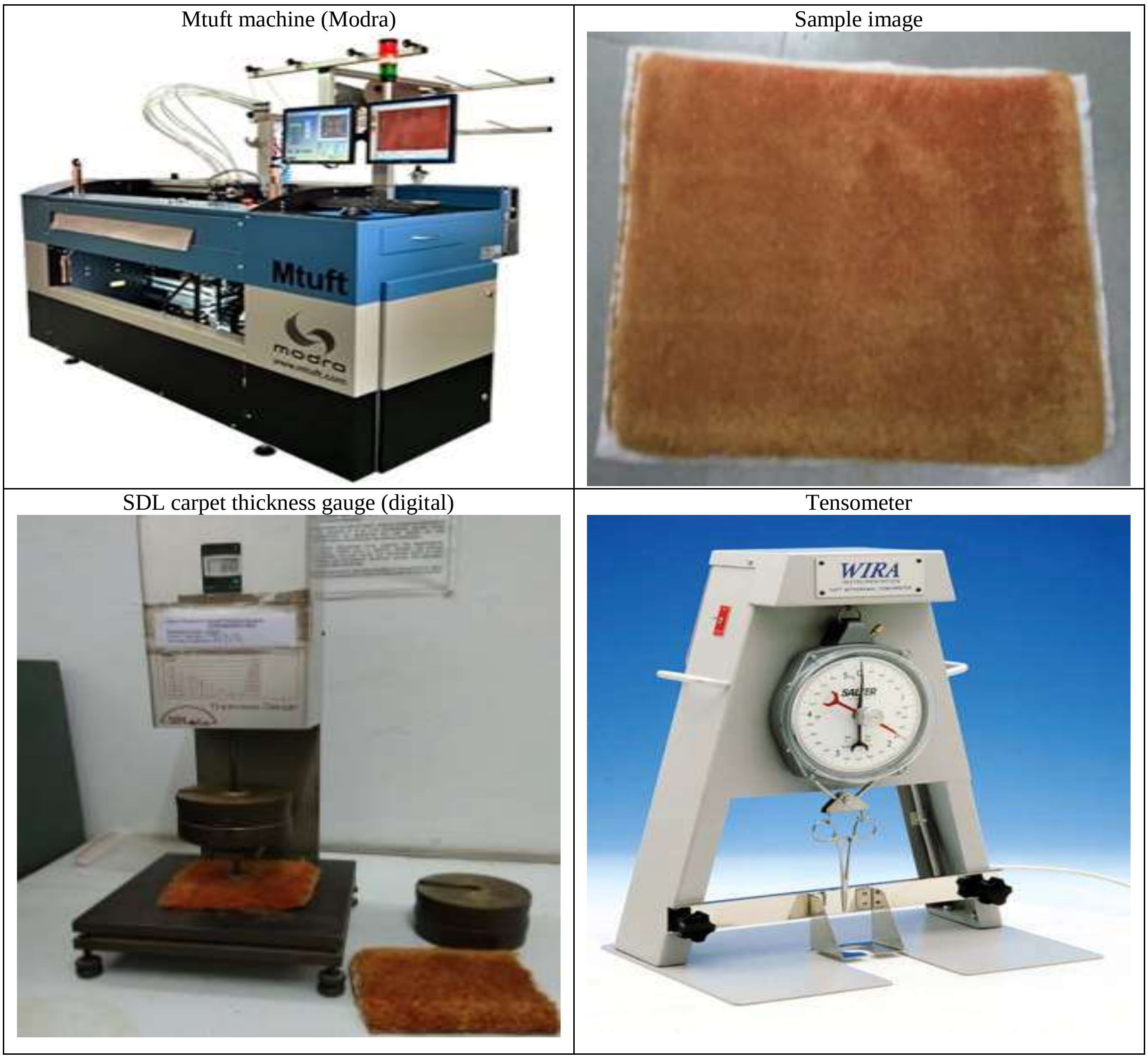

Fig. 1. *Experimental setup.*

RESULTS AND DISCUSSION

A Taguchi optimization module has been used in which the first stage is to identify the process parameters and their limits as shown in Table 1. Three factors and three levels are used according to Taguchi L9 Orthogonal Array (OA) has been used to construct the design matrix for preparation of samples as shown in Table 2. Process parameters considered are tufting speed (N), stitch rate (SR), Gauge (G) and process response are Tuft withdrawal force (kgf), compression (mm) compression recovery (%).

The signal to noise ratio for compression recovery (CR) and tuft withdrawal force (TWF) were calculated based on the equation of Taguchi selection criteria, it is followed by larger the better characteristics for compression recovery (CR) and tuft withdrawal force (TWF) and compression were calculated based. The S/N ratio for compression recovery (CR), compression (C) and tuft withdrawal force (TWF) are shown in Table 4.

The response tables for S/N ratio of compression recovery, compression and tuft withdrawal force are shown in Tables 5–7, respectively from this it is observed that the stitch rate is most significant factor for compression recovery. For compression speed of motor is most significant factor and for TWF the most significant factor is Stitch rate. It is very important to control these significant factors to improve the quality and productivity of machine made carpets. The compression recovery is higher in sample run no. 6 and minimum in sample run no.5.

It has been found (from Figures 2–4) that larger the S/N ratio, the better is the process response, therefore, the optimal parametric setting for TWF are speed of motor at 14 RPS, stitch rate as 31.5/10cm and gauge at 1/10 inch and similarly the optimal parametric setting for compression recovery are speed of motor at 14 RPS, stitch rate as 47.2/10 cm and gauge at 1/12 inch and for Compression the optimal parametric setting is speed of motor at 12 RPS, stitch rate at 39.4/10 cm and gauge 1/8 inch.

Table 1. *Process parameters.*

Factors	Unit	Level 1	Level 2	Level 3
Tufting speed (N)	[RPS]	10	12	14
Stitch rate (SR)	[/10cm]	31.5	39.4	47.2
Gauge (G)	[inch]	1/12	1/10	1/8

Table 2. *Design of experiments.*

Exp. run order	Tufting speed (N)	Stitch rate (SR)	Gauge (G)
1.	10	31.5	1/12
2.	10	39.4	1/10
3.	10	47.2	1/8
4.	12	31.5	1/10
5.	12	39.4	1/8
6.	12	47.2	1/12
7.	14	31.5	1/8
8.	14	39.4	1/12
9.	14	47.2	1/10

Table 3. *Experimental data for compressibility behavior, compression and tuft withdrawal force test.*

S. no	Sample no.	Compression recovery (%)	Compression (mm)	Tuft withdrawal force (kgf)
1	Sample No.1	52.91	11.71	1.76
2	Sample No.2	51.25	9.55	1.75
3	Sample No.3	58.89	10.39	1.86
4	Sample No.4	50.84	9.19	2.20
5	Sample No.5	48.58	8.83	1.81
6	Sample No.6	65.91	11.04	1.69
7	Sample No.7	58.32	10.93	1.96
8	Sample No.8	56.47	11.87	2.23
9	Sample No.9	56.47	11.48	1.75

Table 4. *Signal to noise ratio for compression recovery (CR), compression (C) and tuft withdrawal force (TWF).*

Sample. no	SNRA-CR	SN-C	SNRA-TWF
1.	34.4708	-21.3711	4.91025
2.	34.1939	-19.6001	4.86076
3.	35.4008	-20.3323	5.39026
4.	34.1241	-19.2663	6.84845
5.	33.7292	-18.9192	5.15357
6.	36.3790	-20.8594	4.55773
7.	35.3164	-20.7724	5.84512
8.	35.0364	-21.4890	6.96610
9.	35.0364	-21.1988	4.86076

Table 5. *Response table for S/N ratio of compression recovery.*

Level	N	SR	G
1	34.69	34.64	35.30
2	34.74	34.32	34.45
3	35.13	35.61	34.82
Delta	0.44	1.29	0.84
Rank	3	1	2

Table 6. *Response table for signal to noise ratios for compression.*

Level	N	SR	G
1	-20.43	-20.47	-21.24
2	-19.68	-20.00	-20.02
3	-21.15	-20.80	-20.01
Delta	1.47	0.79	1.23
Rank	1	3	2

Table 7. *Response table for S/N ratio of TWF.*

Level	N	SR	G
1	5.054	5.868	5.478
2	5.520	5.660	5.523
3	5.891	4.936	5.463
Delta	0.837	0.932	0.023
Rank	2	1	3

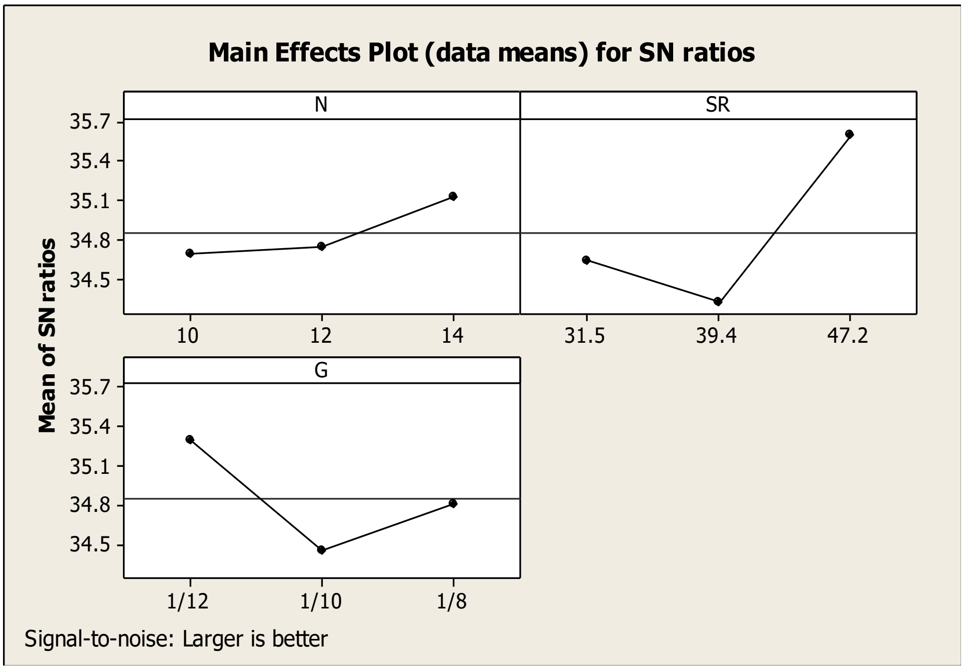

Fig. 2. *Evaluation of optimal setting for compression recovery.*

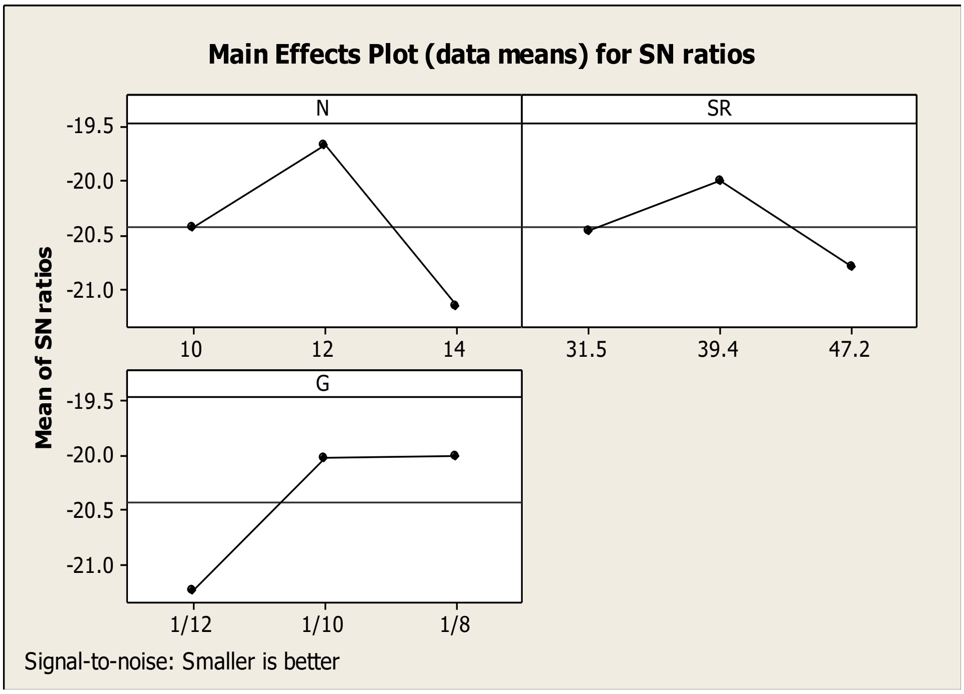

Fig. 3. *Evaluation of optimal setting for compression.*

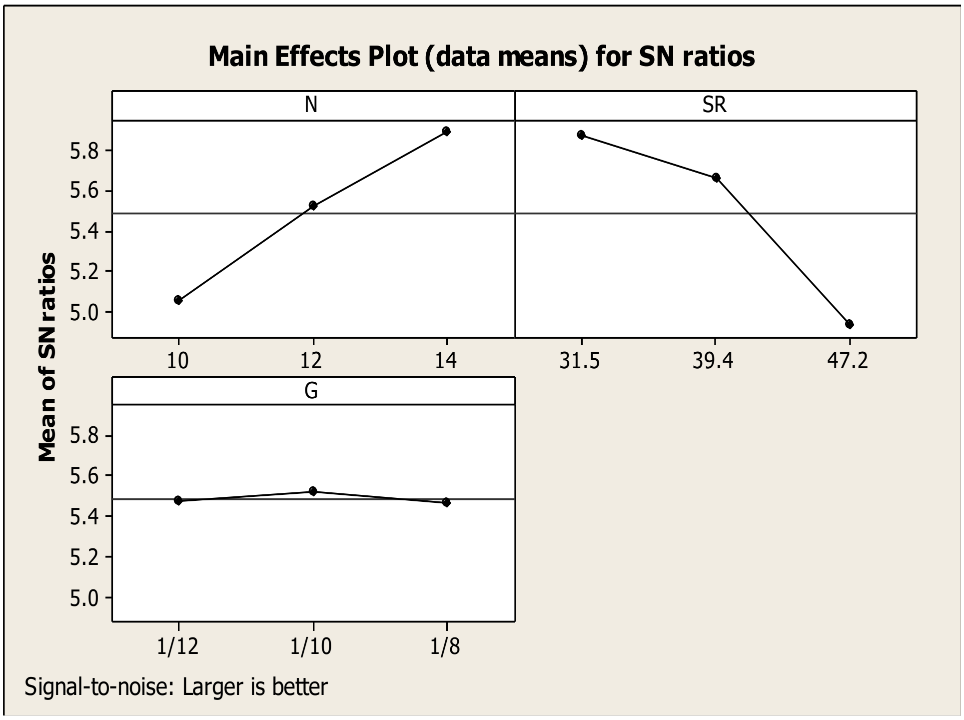

Fig. 4. *Evaluation of optimal setting for TWF.*

CONCLUSION

(1) The Taguchi approach to design of experiments is an effective strategy in product and process optimization. The approach of Taguchi method is able to improve the process performance when optimum parameters setting used in the process give better output performance in terms of quality and productivity. Taguchi method will identify the possible factors for the significant effect to response variable.

(2) It is strongly recommended to use Taguchi method in industry as one of the design experiment methodology in improving the product and process quality. The great importance of its approach will enhance the production performance in quality product with minimal operating cost. Taguchi approach will result in fast decision making and are very much useful to be used in a precise and simple process.

(3) Taguchi optimization approach can be recommended for continuous quality improvement and off-line quality control of a process/product.

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