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Parametric Optimization in Machine Made Tufted Carpets for Abrasion Wear and Tuft Withdrawal Force

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ABSTRACT

This present study highlights optimization problem for selection of optimal parameters in manufacturing of machine made tufted carpet using Taguchi optimization module technique. In this study, Tufting speed (N), Stitch Rate (SR), Gauge size (G) have been considered, for optimizing quality characteristics such as Abrasion Wears (mg) tuft withdrawal force (kgf) based on Taguchi L_9 orthogonal array experimental design. Lower the better criteria for Abrasion Wears and higher the better criteria for 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 Abrasion wears and tuft withdrawal force (kgf). 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. The study proposed the optimization for performance characteristics by determining the optimal setting. The aim is also to identify the significant factor and their effect on quality characteristics. The results obtained thereof have been compared with the predicted results followed by confirmatory test.

Keywords: abrasion wear, gauge, stitch rate, tuft withdrawal force, tufting speed

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PRIOR STATE OF ART

In today's competitive world, customers are demanding better quality products with fast and reliable deliveries. To meet this demand, new manufacturing technologies are developing rapidly, resulting in new products and improvements in manufacturing processes. Carpets can be classified into two types on the basis of its manufacturing techniques i.e. machine made and hand-made carpets. Machine made carpet can be manufactured by using tufting, weaving, knitting, braiding, needle felting, fusion bonding and flocking. Handmade carpets are produced in three different types, namely knotted, flat woven and tufted [1–3]. Machine-made rugs also are sometimes called power-loomed rugs. When you see the words “Wilton Woven” to describe a rug, this means that they are made on machine-operated Wilton looms. These rugs are usually made in Europe, often Belgium, and are made from the same fine wools that are used for hand-knotted rugs. Synthetic rugs are made in the same way Wilton Woven rugs are, except that they are made from synthetic fibers such as rayon, nylon and polypropylene blends. These rugs have a latex backing that is sprayed on. Typically, synthetic rugs are durable and are good for high-traffic areas. Machine-made rugs can withstand high traffic, and will begin to wear out after 12–20 years of use. High traffic areas include hallways, family room and entryway. Medium traffic areas include the dining room and home office. Low traffic areas include bedrooms and formal living room. Carpet is a common three-dimensional indispensable floor covering in today's homes and offices. The first carpets characterized by pile surfaces were probably cured animal skins laid on the dwelling floors of early hunters. Those floor coverings served many of the functions that floor coverings serve today – protection from hard and cold floors, providing a pleasing tactile surface, and decoration. The introduction of synthetic yarn and needle tufting through a pre-woven backing as a manufacturing process was developed after World War II and is responsible for the majority of carpet production in the world. Many pioneer researchers have studied about the wear and abrasion, compressibility behavior of carpets and rugs but very limited work have been carried out in the area of multi objective optimization of quality and productivity characteristics of machine made carpet. Multiple attribute decision making (MADM) is used to deal with the problems of finding a desirable solution from a finite set of feasible alternatives assessed on multiple attributes. The present research aimed to develop a quantitative analysis framework to evaluate optimal parametric combination.

Verma et al. [4] applied Fuzzy embedded Taguchi approach for multi response optimization in machining of glass fiber reinforced composites. It has been observed from drilling experiments that PCA-fuzzy (integrated with Taguchi method) has provided better result as compared to WPCA (Weighted Principal Component Analysis) based Taguchi method. Process parameters viz. spindle speed, feed rate, and depth of cut have been considered to investigate multiple process responses viz. Material Removal Rate (MRR), surface roughness (Ra), tool-tip temperature (maximum temperature generated during machining at tool-tip) and resultant cutting force whilst turning of GFRP (epoxy) composite specimens.

Gupta et al. [5] applied Box Behnken design plan and optimized the parameters such a knot density, pile height, number of plies per yarn and pile yarn twist of Persian hand knotted carpets by using desirability functions approach (DFA) and found that durability can be improved by combination of abrasion wear and compression behavior.

Berkalp [6] investigated the mechanical properties such as wear and abrasion resistance, impact loading. Wear resistance, of carpets produced from acrylic, wool propylene fibers in two different pile heights and loop density has been observed. It was found that weft thread density, raw material and loop height had statistically important effect on wear resistance.

Thilavagathi et al. [7] studied about the acoustic properties and sound insulation of natural fiber (banana, bamboo and jute) nonwoven fabrics blended with polypropylene for four-wheeler vehicles. They found that a bamboo/polypropylene nonwoven provided the maximum sound absorption coefficient for all levels of sound frequencies.

Kucuk et al. [8] studied the sound absorption properties of various nonwoven fabrics and effect of bonding, thickness, fiber composition and air permeability. They found that the thermal bonded nonwoven fabrics made from a blend of natural and synthetic fibers provided improved sound absorption properties than a commercial needle-punched nonwoven fabric made from meta-aramid fibers.

Yilmaz et al. [9] analyzed various properties of needle-punched nonwoven fabrics and effects of porosity, fiber fineness, and layering sequence on sound absorption performance. Their results indicated that air flow resistivity increased with decrease in fiber diameter and porosity. A strong relationship between the layering sequence and air flow resistivity was also observed. In this study, the interaction effects of process parameters were not considered.

Verma et al. [10] developed an optimization module embedded with fuzzy logic tools to assess the effects of machining variables such as spindle speed, feed rate and depth of cut on machining performance evaluation characteristics mainly material removal rate and surface roughness in turning of GFRP composites.

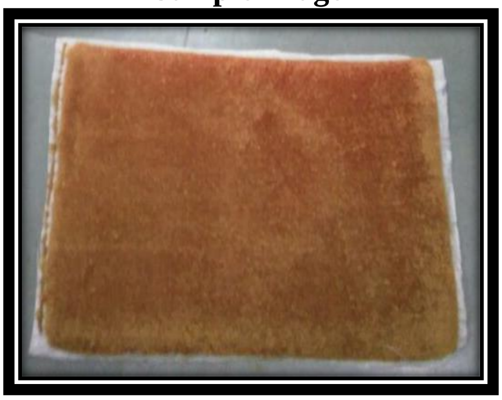
The quality of carpet is characterized by several characteristics; hence it is not easy to achieve all the properties simultaneously, in terms of mechanical and physical aspects. A limited amount is research work is carried out on quality and productivity improvement of machine made carpet. A detailed literature survey has been carried out in the area/areas relevant to the present work including machine made carpet parameters selection and its optimization; it has been found that the work is not sufficiently flourished. Research gap still exists for in-depth understanding in respect of selection of optimal parametric conditions for achieving best durability and compression performance for machine made carpets. Therefore, in this study an attempt has been made to develop an efficient and integrated optimization module module, which can systematically avoid/overcome various assumptions/limitations of existing Taguchi based optimization approaches.

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 MTUFT range of machines is an innovative solution for product development of tufted carpet. The M-Tuft has set the benchmark for performance and flexibility, while saving clients time and money (Figures 1, 2).

Mtuft Machine (Modra)

Sample image



Wear abrasion tester (digital)	Tensometer
	

Fig. 1. *Experimental setup and apparatus used.*

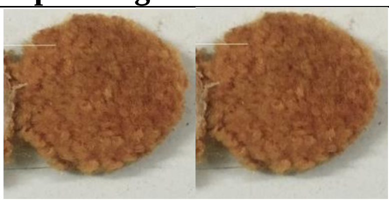
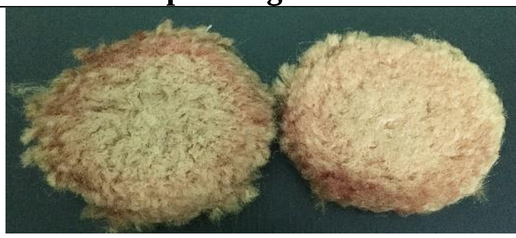
Test sample image before the test	Test sample image after the test
	

Fig. 2. *Image for abrasion wear test.*

TAGUCHI OPTIMIZATION PHILOSPY

Dr. Genichi Taguchi, a Japanese management consultant established an efficient methodology to optimize quality characteristic and is widely being applied now-a-days for continuous improvement and off-line quality control of any manufacturing/production process or product. Taguchi's concepts are as follows:

- Quality should be designed into the product and not checked into it.
- Quality is best achieved by diminishing the deviation from the target. It is immune to uncontrollable environmental factors.
- The cost of quality should be measured as a function of deviation from the standard and the losses should be measured by system-wide.

Dr. Genichi Taguchi is regarded as the foremost proponent of robust parameter design, which is an engineering method for product or process design that focuses on minimizing variation and/or sensitivity to noise. When used properly, Taguchi designs provide a powerful and efficient technique for designing products that operate consistently and optimally over a variety of conditions. 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 always be better 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.

The change in the quality characteristic of a product responsive to a factor introduced in the experimental design is termed as the Signal of the desired effect. The effect of the external factors of the outcome of the quality characteristic under test is denoted as Noise. To use the loss function as a figure of merit an appropriate loss function with its loss constant must be established which is not always cost effective and easy. The experiment results are then changed into a Signal-to-Noise (S/N) ratio. Taguchi recommends the use of S/N ratio to measure the quality characteristics deviating from the desired value. The S/N ratio for each level of process parameters is computed based on the S/N analysis and converted into a single metric. The aim in any experiment is to regulate the highest possible S/N ratio for the result irrespective of the type of the quality characteristics. A high value of S/N implies that signal is much higher than the random effect of noise factors. In Taguchi method of optimization, the S/N ratio is used as the quality characteristic of choice. 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:

$$\frac{S}{N} = 10\log\frac{y}{S_y^2} \qquad (1)$$

(2) Lower-the-Better (LB): The formula for these characteristics is:

$$\frac{S}{N} = 10\log\frac{1}{n}\Sigma y^2 \qquad (2)$$

(3) Higher-the-Better (HB): The formula for these characteristics is:

$$\frac{S}{N} = 10\frac{1}{n}\Sigma\frac{1}{y^2} \qquad (3)$$

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

This study will focus on the optimization of abrasion wear affecting the quality and productivity of MMC. For this purpose, the Taguchi experimental design technique, and signal-to-noise (S/N) ratio were used. The Taguchi method focuses on improving the fundamental function of a product or process, thus facilitating flexible designs and concurrent engineering. Indeed, it is the most powerful method offered for reducing product costs, improving quality, and simultaneously reducing development time A detail study will be done on the process parameters and response to determine the favorable parametric optimal setting (speed, stitch gauge, etc.) in machine made carpet (M-tuft at hi-tech lab of IICT). The productivity of the machine-made carpet is improved with the experiments performed on optimal parametric setting. The results obtained thereof will be compared with the predicted results followed by confirmatory test.

RESULTS AND DISCUSSION

Taguchi optimization module has been used to analyze and optimize the process parameters and response, in which the first stage is to identify the process parameters and their limits as shown in Table 1. Taguchi L9 orthogonal array has been used to construct the design matrix for preparation of samples as shown in Table 2. Three factors are varied at three different levels according to Taguchi L9 Orthogonal Array (OA). Process parameters considered are Tufting speed (N), Stitch Rate (SR), Gauge (G) and process response are Tuft withdrawal force (kgf) and abrasion wears (mg). According to Taguchi L9 OA experiments has been perform and nine samples (Figure 2) are prepared on M-tuft machine (Figure 1). The observed data for Tuft Withdrawal Force (kgf) and abrasion wears (mg) is shown in Table 3. The signal to noise ratio (Table 4) for Tuft Withdrawal Force (kgf) and abrasion wears (mg) were calculated based on the Equations 2 and 3, it is followed by larger the better characteristics for Tuft Withdrawal Force (TWF) and abrasion wears (mg) were calculated based on the Equation 2 because of it is the "smaller the better" characteristics. Response Table for signal to noise ratios for Tuft withdrawal force (kgf) and abrasion wears (mg) are depicted in Tables 5 and 6. From this, it has been found that Stitch Rate (SR) is the most significant factor for controlling Tuft withdrawal force followed by Speed of Motor (N) and gauge (G). Similarly, for abrasion wears (mg) speed of motor (N) is the most dominating factor and then stitch rate and gauge is required to controlled for quality and productivity improvement. The optimal setting for setting Tuft withdrawal force (kgf) and abrasion wears is shown in Figures 3 and 4. The larger the S/N ratio, the better is the process response; therefore, the optimal parametric setting for TWF is speed of motor at 14 RPS, stitch rate as 31.5/10 cm and gauge at 1/10 inch. The optimal parametric setting for abrasion wear is speed of motor at 14 RPS, stitch rate at 31.5/10 cm and gauge 1/10 inch. The result obtained and optimal setting obtained has been verified by confirmatory test which shows the satisfactorily results.

Table 1. *Process parameters.*

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

Table 2. *Design of experiments (L9 orthogonal array).*

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.*

Sample no.	**Tuft withdrawal force (kgf)**	**Abrasion wear (mg)**
Sample no.1	1.76	8.7
Sample no.2	1.75	6.4
Sample no.3	1.86	7
Sample no.4	2.20	8.5
Sample no.5	1.81	13.9

Sample no.6	1.69	9.7
Sample no.7	1.96	4.3
Sample no.8	2.23	7.9
Sample no.9	1.75	6

Table 4. *Signal to noise ratio for tuft withdrawal force (TWF) and abrasion wears (AW).*

Serial no.	**SNRA TWF**	**SNRA AW**
1.	4.91025	–18.7904
2.	4.86076	–16.1236
3.	5.39026	–16.9020
4.	6.84845	–18.5884
5.	5.15357	–22.8603
6.	4.55773	–19.7354
7.	5.84512	–12.6694
8.	6.96610	–17.9525
9.	4.86076	–15.5630

Table 5. *Response table for signal to noise TWF ratios.*

Level	**Speed of motor (N)**	**Stitch rate (SR)**	**Gauge (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	0.060
Rank	2	1	3

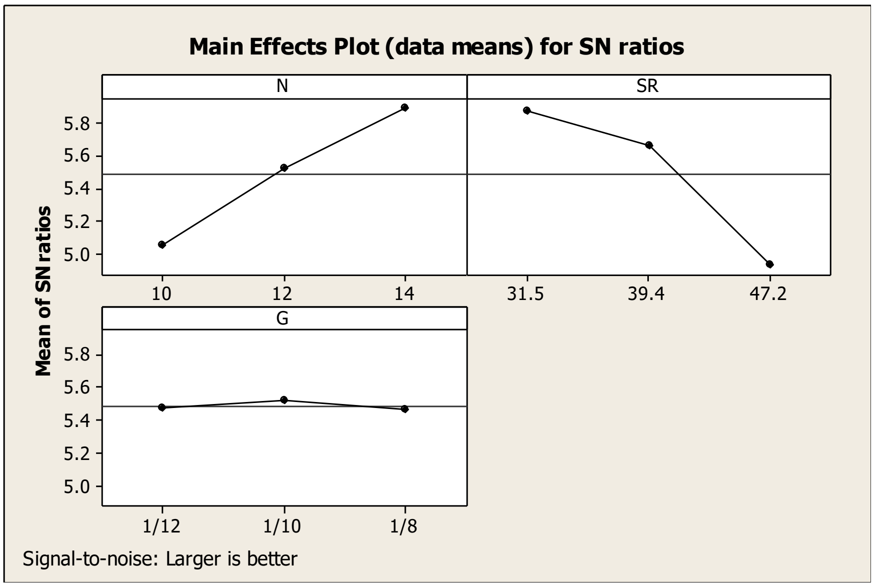


Fig. 3. *Evaluation of parametric optimal setting of Tuft withdrawal force.*

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

Level	**Speed of motor (N)**	**Stitch rate (SR)**	**Gauge(G)**
1	–17.27	–16.68	–18.83
2	–20.39	–18.98	–16.76
3	–15.39	–17.40	–17.48
Delta	5.00	2.30	2.07
Rank	1	2	3

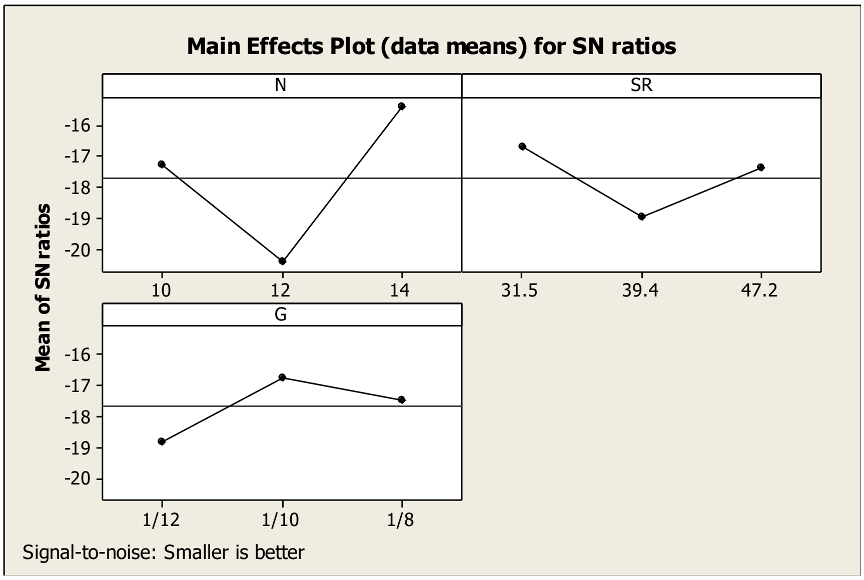


Fig. 4. *Evaluation of parametric optimal setting for abrasion wear.*

CONCLUSION

1. It has been observed that the confirmatory test shows the satisfactory results; therefore, it has been proved that the Taguchi Technique is the effective method to provide the better solution for the single objective optimization problem.
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 more useful to be used in a specific and straightforward process.
3. Taguchi optimization approach can be recommended for continuous quality improvement and off–line quality control of a process/product.

REFERENCES

[1] G.H. Crawshaw. Carpet manufacture, *Private Bag 4749*. Christchurch, New Zealand: Wronz Developments; 2002, 158–63p.

[2] F. Liu, A.P. Maher, J. Lappage, E.J. Wood. The measurement of the tuft–withdrawal force in machine–made and hand–knotted carpet, *J Text Inst.* 2002; 93: 276–282.

[3] M. Topalbekiroglu, A. Kireçci, C.L. Dülger. Design of a pile–yarn manipulating mechanism, *Proc Inst Mech Eng, Part B: J Eng Manuf.* 2005; 219: 539–45p.

[4] R.K. Verma, A. Kumar, S. Datta, P.K. Pal, S.S. Mahapatra. Multi–response optimization in machining of GFRP (epoxy) composites, *Integr Approach J Manuf Sci Prod*. 2015; 15(3): 267–92p.

[5] S.K. Gupta, K.K. Goswami, A. Mazumdar. Optimization of durability of Persian hand knotted wool carpets by using desirability functions, *Text Res J*. 2016; 1–10p.

[6] Ö.B. Berkalp, E. Önder. Effects of different structural parameters on carpet physical properties, *Text Res J*. 2001; 71(6): 549–55p.

[7] G. Thilagavathi, E. Pradeep, T. Kannaian, L. Sasikala. Development of natural fiber nonwovens for application as car interiors for noise control, *J Ind Text*. 2010; 39(3): 267–78p.

[8] M. Kucuk, Y. Korkmaz. The effect of physical parameters on sound absorption properties of natural fiber

mixed nonwoven composites, *Text Res J*. 2012; 82(20): 2043–53p.

[9] N. Yilmaz, P. Banks-Lee, N. Powell, S. Michielsen. Effects of porosity, fiber size, and layering sequence on sound absorption performance of needle–punched nonwovens, *J Appl Polym Sci*. 2011; 121: 3056–69p.

[10] R.K. Verma, K. Abhishek, S. Datta, S.S. Mahapatra. Fuzzy rule based optimization in machining of FRP composites, *Turk J Fuzzy Syst*. 2011; 2(2): 99–121p.