OPTIMIZATION OF MACHINING PERFORMANCE DURING THE TURNING OF GFRP COMPOSITES:TOPSIS BASED TAGUCHI METHOD

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Certificate of Approval

This is to certify that the thesis entitled Optimization in Machining of GFRP Composites: Topsis based taguchi method submitted by K.Sudheepth has been carried out under my sole supervision in fulfillment of the requirements for the award of the Degree of Bachelor of Technology (B.Tech.) in Mechanical Engineering at National Institute of Technology, Rourkela, and this work has not been submitted elsewhere before for any other academic degree/diploma.

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Abstract:

GFRP (Glass Fibre Reinforced Polymer) composites are emerging material in engineering field mainly in aerospace and automobile sector because of their excellence properties such as high toughness, low weight to volume ratio, high rigidity, strength, etc., to be widely used in various engineering application. However, the machinability of such composites is difficult to form desired shape. This thesis presents a TOPSIS Taguchi approach for parametric optimization of Glass fiber reinforced polymer bars.

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1. Introduction:

Fiber reinforced polymer (FRP) composite is comprised of a polymer matrix (it might be either a thermoplastic or thermoset resin, for example, polyester, vinyl ester, epoxy, phenolic) joined with a reinforcing material like glass, carbon, aramid and boron and so on which have adequate perspective proportion (length to thickness) to give a discernable fortifying capacity in one or more headings. A few times in FRP composite center materials and added substances are additionally added to enhance properties of the last item. In machining of FRP composites numerous issues emerges, for example, fiber pull out, burr, delamination and so on it is because of the non-homogeneity of the constituent of the composite materials. GFRP (Glass Fiber Reinforced Plastic) composites are the most well-known utilized FRP composites. The major advantages of GFRP are its low cost, high tensile strength, high chemical resistance and excellent insulating properties.

It has, therefore, become essential for the manufacturing industries to give emphasized on machining as well as machinability aspects to those composites in order to achieve high product quality and satisfactory machining performance. The machining behaviour and the ease of machining of Glass fibre composite materials are dissimilar to machining of conventional metals.

2. Literature Review:

Sl .No	Journal	Author	Title	Findings
Composite materials machining (GFRP)				
1.	Composite Structures (2004)	El-Sonbaty, I., Khashaba , U. A., Machaly, T.	Factors affecting the machinability of GFR/epoxy composites.	➢ The drilled holes of GFREC with lower V_f ratio at lower feed have greater roughness than that drilled at higher

				feed.
2.	International Journal of Advance Manufacturing Technology (2005)	Davim, J. P, Francisco, M.	Optimization of surface roughness on turning fiber-reinforced plastics (FRPs) with diamond cutting tools.	➢ To obtain a certain surface roughness (R_a and R_t /R_{max}), corresponding to international dimensional precision (ISO) IT7 and IT8 in the FRP work pieces, using multiple analysis regression (MRA).
3.	International Journal of Machine Tools & Manufacture (2005)	Tsaoa, C. C., Hochengb, H.	Effects of exit back-up on delamination in drilling composite materials using a saw drill and a core drill.	➢ The critical drilling thrust force at the onset of delamination is calculated and compared without backup. ➢ The threshold thrust force at the onset of delamination is increased making the delamination less induced.
4.	Journal of Materials Processing Technology (2005)	Davim, J. P., Mata, F.	A new machinability index in turning fiber reinforced plastics.	➢ Evaluated the machinability of FRP manufacturing process i.e. (filament winding and hand lay-up).
5.	Composite Structures (2005)	Mohan, N. S., Ramachandra, A., Kulkarni, S. M.	Influence of process parameters on cutting force and torque during drilling of glass fiber polyester reinforced composites.	➢ Speed and drill size shows more significant influence on cutting thrust than the specimen thickness and the feed rate.
6.	International Journal of Advance Manufacturing Technology (2006)	Bagci, E. Isik, B.	Investigation of surface roughness in turning unidirectional GFRP composites by using RS methodology and ANN.	➢ The ANN and RSM models for GFRP turned part surfaces are compared with each other for accuracy and computational cost.
7.	Materials and Manufacturing Processes (2006)	Palanikumar, K., Karunamoorthy, L. and Karthikeyan, R.	Multiple Performance Optimization of Machining	➢ Machining performance in the composite machining process can be improved effectively

			Parameters on the Machining of GFRP Composites Using Carbide (K10) Tool.	by using Grey relational analysis.
8.	Journal of Reinforced Plastics and Composites (2008)	Palanikumar, K.	Surface Roughness Model for Machining Glass Fiber Reinforced Plastics by PCD Tool using Fuzzy Logics.	➢ The use of fuzzy logic for modeling machining parameters in machining of GFRP.
9.	International Journal of Advance Manufacturing Technology (2008)	Sait, A. N., Aravindan, S. and Haq, A. N.	Optimization of machining parameters of glass-fiber reinforced plastic (GFRP) pipes by desirability function analysis using Taguchi technique.	➢ Application of desirability function analysis in Taguchi technique. ➢ A new approach for optimizing the machining parameters on turning (GFRP) pipes.
10	Procedia Materials Science (2014)	Sonkar V,Abhishek K, Datta S, Mahapatra SS	Multi-Objective optimization in drilling of GFRP composites: a degree of similarity approach	➢ Application of TOPSIS and degree of similarity in Taguchi technique in machining of GFRP
11	Turkish Journal of Fuzzy Systems (2011)	Verma RK,Abhishek K, Datta S, Mahapatra SS	Fuzzy Rule Based Optimization in Machining of FRP Polyester Composites	➢ Fuzzy has been used to evaluate optimal parametric combination in GFRP turning

3. Methodology:

3.1 Taguchi Method

Taguchi method (originated by Dr. Genichi Taguchi in the late 1940’s) is a popular robust design philosophy which enhances engineering productivity [Dean, 1992; Roy, 2001]. Most of the designers are utilizing this approach for executing experimentation to obtain optimum settings of design parameters for quality and cost very efficiently. In this methodology, Orthogonal arrays are used to analyze a large number of variables with a fewer number of experiments. The Taguchi method utilizes a statistical measure of performance called Signal-to-Noise (S/N ratio to investigate the experimental results. S/N ratio is a loss function which describes the deviation from the target value. The transformed S/N ratio is also defined as quality evaluation index. The least variation and the optimal design are obtained by analyzing S/N ratio.

There are three S/N ratios of common interest for optimization of static problems;

Nominal-the-Best (NB)/ Target-the-Best (TB): In this approach, the closer to the target value, the better and the deviation is quadratic. The formula for these characteristics is:

$$ {}^{S}\!/_{N} = -10 \log \frac{y}{S_y^2} \tag{1} $$

Lower-is-Better (LB): The Lower-is-Better (LB) approach held when a company desires smaller values. The formula for these characteristics is:

$$ {}^{S}\!/_{N} = -10 \log \frac{1}{n} \sum y^2 \tag{2} $$

Higher-is-Better (HB): Higher-is-Better (HB) is required when a manufacturer desires higher values of a characteristic. The formula for these characteristics is:

$$ {}^{S}\!/_{N} = -10 \log \frac{1}{n} \sum \frac{1}{y^2} \tag{3} $$

Here,

$y =$ Average of observed values;

$S_y^2 =$ Variance of y ;

$N =$ Number of observations

However, Taguchi method is considered only for single objective optimization problems. It cannot be utilized for getting the single optimal setting of process parameters considering more than one performance parameter.

3.2 TOPSIS

Hwang and Yoon (1981) proposed TOPSIS for evaluating the alternatives before the multiple attribute decision making; based on fact that chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from negative ideal solution. Positive ideal solution defines the best performance values demonstrated (in the decision matrix) by any alternative for each attribute whereas negative ideal solution can be defined as worst performance values. Following are steps involved in TOPSIS:

Step 1: Formation of decision Matrix:

$$D=\begin{array}{cc} \begin{array}{c} A_1\\ A_2\\ .\\ A_i\\ .\\ A_m \end{array} & \begin{bmatrix} x_{11} & x_{12} & . & x_{1j} & x_{1n}\\ x_{21} & x_{22} & . & x_{2j} & x_{2n}\\ . & . & . & . & .\\ x_{i1} & x_{i2} & . & x_{ij} & .\\ . & . & . & . & .\\ x_{m1} & x_{m2} & . & x_{mj} & x_{mn} \end{bmatrix} \end{array} \tag{4}$$

Here, $A_i\ ((i=1,2,.......,m)$ represents the possible alternatives; $x_j\ \left(j=1,2,........,n\right)$ represents the attributes relating to alternative performance, $j=1,2,..........,n$ and x_{ij} is the performance of A_i with respect to attribute $X_{j.}$

Step 2: Normalization of matrix:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{5}$$

Here, r_{ij} represents the normalized performance of A_i with respect to attribute $X_{j.}$

Step 3: Weighted Decision matrix:

$$V = \lfloor v_{ij} \rfloor V = w_j r_{ij}$$

$$D = \begin{bmatrix} y_{11} & y_{12} & . & y_{1j} & y_{1n} \\ y_{21} & y_{22} & . & y_{2j} & y_{2n} \\ . & . & . & . & . \\ y_{i1} & y_{i2} & . & y_{ij} & . \\ . & . & . & . & . \\ y_{m1} & y_{m2} & . & y_{mj} & y_{mn} \end{bmatrix} \tag{6}$$

Here, $\sum_{j=1}^{n} w_j = 1$

Step 4: Determine the positive ideal and negative ideal solutions:

a) The positive ideal solution:

$$A^{+} = \left\{ \left(\max_{i} y_{ij} \,\middle|\, j \in J \right), \left(\min_{i} y_{ij} \,\middle|\, j \in J' \,\middle|\, i = 1, 2, ..., m \right) \right\} \tag{7}$$

$$= \left\{ y_1^{+}, y_2^{+}, ..., y_j^{+}, ...y_n^{+} \right\}$$

b) The negative ideal solution:

$$A^{-} = \left\{ \left(\min_{i} y_{ij} \,\middle|\, j \in J \right), \left(\max_{i} y_{ij} \,\middle|\, j \in J' \,\middle|\, i = 1, 2, ..., m \right) \right\} \tag{8}$$

$$= \left\{ y_1^{-}, y_2^{-}, ..., y_j^{-}, ...y_n^{-} \right\}$$

Here,

$J = \{ j = 1,2,......., n | j \}$: Associated with the beneficial attributes

$J^{'} = \{ j = 1,2,......., n | j \}$: Associated with non beneficial attributes

Step 5: Determine the distance measures. The separation of each alternative from the ideal solution is given by n- dimensional Euclidean distance from the following equations:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(y_{ij} - y_j^+ \right)^2} \quad i = 1, 2, ..., m \tag{9}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(y_{ij} - y_j^- \right)^2} \quad i = 1, 2, ..., m \tag{10}$$

Step 6: Calculate the Overall performance coefficient closest to the ideal solution:

$$C_i^+ = \frac{S_i^-}{S_i^+ + S_i^-}, \; i = 1, 2, ..., m; 0 \le C_i^+ \le 1 \tag{11}$$

3.3 Experimentation:

Sample of Glass fibered reinforced polymer (GFRP) bars having dimension of diameter 50 mm and length of 150 mm has been used as work-piece material. Single point HSS tool has been used during experiments. Taguchi method has been implemented to generate the orthogonal array for diminishing the number of experiments. For turning of GFRP, three process parameters: spindle speed, feed rate and depth of cut have been selected and varied in three different levels as shown in (Table 1). An L_9 orthogonal array has been chosen for this experimental procedure and furnished in Table 2. Here, only the main effects of machining parameters i.e. spindle speed, feed rate and depth of cut has been considered for assessing the optimal condition and their interaction effects has been considered as negligible. The surface roughness has been measured by Mitutoyo Surf Test (SJ -210). Tool-tip temperature has been measured by using non- contact infrared thermometer (Model: AR882 and temperature range -18 to 150 ^{0}C), supplied by Real Scientific Engineering Corporation, New Delhi).

Table 1: Level values of input parameters

S.No	Parameter	Unit	Level 1	Level 2	Level 3
1	Spindle Speed (N)	rpm	465	605	787
2	Feed Rate (f)	mm/rev	0.06	0.07	0.08
3	Depth of Cut (d)	mm	0.6	0.9	1.2

Table 2: L_9 Design Matrix

Sl. No.	N	f	d
1	465	0.06	0.6
2	465	0.07	0.9
3	465	0.08	1.2
4	605	0.06	0.9
5	605	0.07	1.2
6	605	0.08	0.6
7	787	0.06	1.2
8	787	0.07	0.6
9	787	0.08	0.9

4. Results and Discussion:

In this thesis, the output response characteristics (tool tip temperature and surface roughness) have been evaluated and shown in Table 3. The experimental data have been normalized into a single dimensionless scale in between 0 to 1. These normalized data have been tabulated in Table 4. Here, each response parameters has been supposed to equally important so they have been assigned equal priority weight. Table 5 presents the weighted normalized decision matrix.

Positive ideal solution and negative ideal solution are expressed in order to evaluate separation distance which is furnished in Table 6. Finally, overall performance index (OPI) has been computed by TOPSIS has been shown in Table 7. Taguchi utilizes the S/N ratios (shown in Table 8) concept to determine the optimal parametric combination as $N_1f_1d_1$. S/N ratio plot for evaluating optimal setting has been shown in Figure 1.

Table 3: Experimental data

Sl. No.	Ra (μm)	Tool tip temperature (^{0}C)
1.	6.418	50.4
2.	6.715	77.5
3.	5.183	110
4.	7.018	68.8
5.	6.591	92.6
6.	5.733	117
7.	6.183	88.9
8.	5.686	65.8
9.	7.738	85

Table 4: Normalized experimental data

Sl. No.	N-Ra	N-Tool tip temperature
1.	0.334043	0.196352
2.	0.349501	0.30193
3.	0.269764	0.428546
4.	0.365272	0.268036
5.	0.343047	0.360758
6.	0.29839	0.455818
7.	0.321812	0.346343
8.	0.295944	0.256349
9.	0.402746	0.33115

Table 5: Weighted experimental data

Sl. No.	w-Ra	w-Tool tip temperature
1.	0.167021	0.098176
2.	0.174751	0.150965
3.	0.134882	0.214273
4.	0.182636	0.134018
5.	0.171524	0.180379

6.	0.149195	0.227909
7.	0.160906	0.173172
8.	0.147972	0.128174
9.	0.201373	0.165575

Table 6: Positive Ideal and negative ideal solution

Negative ideal sol	0.201373	0.227909
Positive ideal sol	0.134882	0.098176

Table 7: Calculated distance measure and OPI

Sl. No.	D+	D-	C+
1.	0.032139	0.134204	0.806788
2.	0.066153	0.081419	0.551725
3.	0.116097	0.067875	0.368941
4.	0.059708	0.095742	0.615901
5.	0.09	0.056126	0.384092
6.	0.13052	0.052178	0.285597
7.	0.079383	0.068072	0.461646
8.	0.03273	0.113131	0.775609
9.	0.094677	0.062334	0.397006

Table 8: Calculated OPI and corresponding their S/N ratios

N	f	d	C+	S/N	Predicted S/N ratio
465	0.06	0.6	0.806788	-1.8648	-2.02500
465	0.07	0.9	0.551725	-5.1655	
465	0.08	1.2	0.368941	-8.6609	
605	0.06	0.9	0.615901	-4.2098	
605	0.07	1.2	0.384092	-8.3113	
605	0.08	0.6	0.285597	-10.8849	
787	0.06	1.2	0.461646	-6.7138	

787	0.07	0.6	0.775609	-2.2071	
787	0.08	0.9	0.397006	-8.0241	

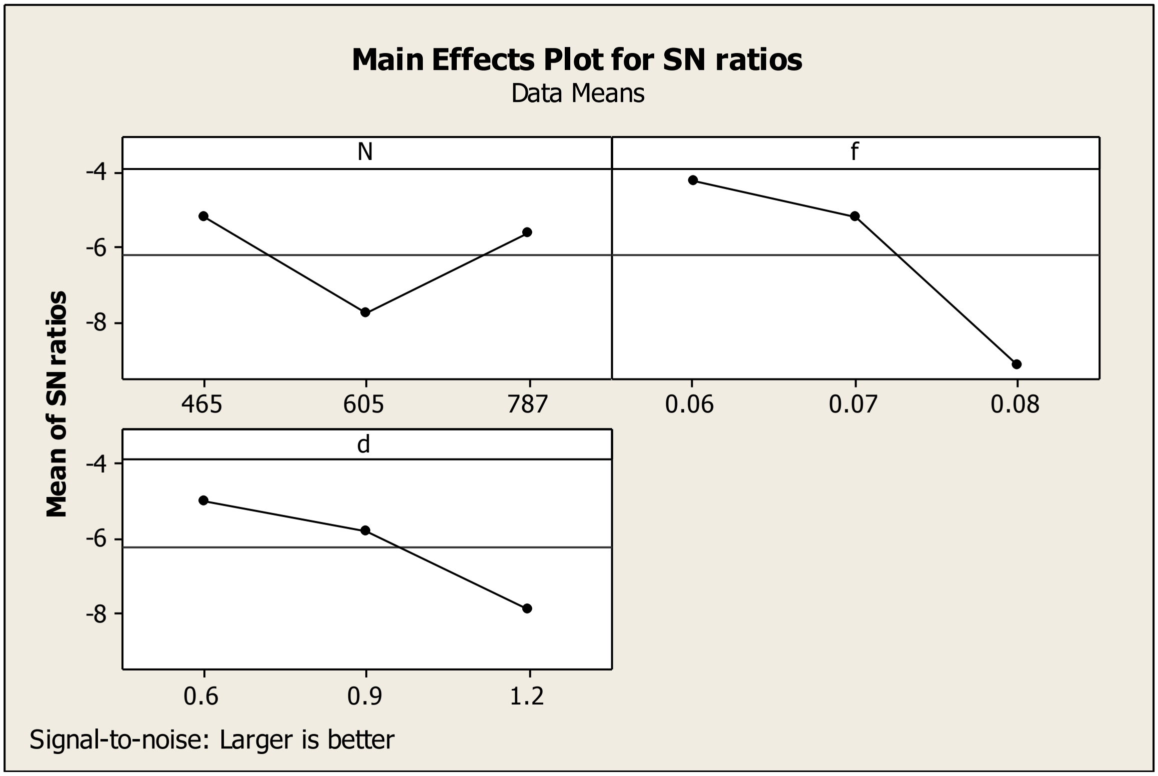

Figure 1: Evaluation of optimal setting

5. Conclusions:

This thesis presents an integrated optimization philosophy using TOPSIS concept aggregated with Taguchi method for optimizing the performance characteristics in machining of GFRP composites. The study illustrates the effectiveness of the proposed method as well. Here, Taguchi's quadratic loss function and TOPSIS concept can be efficiently integrated towards a flexible compatible multi-response optimization methodology. The traditional Taguchi method deals with single response problem whereas TOPSIS is capable of dealing with multi dimensional problem (multiple criteria attribute). TOPSIS is used to multi responses into single performance index (MPCI). MPCI can easily be optimized to determine the optimal process environment which facilitates in mass production and consequently product quality improvement.

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