OPTIMIZATION OF MACHINING PERFORMANCE YIELDS DURING TURNING OF GFRP COMPOSITES: A GREY BASED TAGUCHI APPROACH

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Certificate of Approval

This is to certify that the thesis entitled Optimization in Machining of GFRP Composites: Case Experimental Research submitted by Ranjan Mahananda 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:

Glass fiber-reinforced polymer (GFRP) composites have made their applications increasingly noticeable mainly in the aerospace and automotive industries due to its lighter in weight and excellence mechanical properties. It has been found very difficult to assess the optimum process parameters responsible for machining. The thesis focuses on machining (turning) aspects of GFRP composites by using single point HSS cutting tool. The optimal setting i.e. the most favourable combination of process parameters (such as spindle speed, feed rate and depth of cut) has been obtained in view of multiple requirements of machining performance yields viz. tool tip temperature and surface roughness by using a grey Taguchi approach.

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1. Introduction:

In recent years, GFRP composite materials are widely being used in various engineering applications such as automobile, aerospace industries, spaceship and sea vehicle industries because of their unique properties such as high specific stiffness, high specific strength, high specific modulus of elasticity, high damping capacity, good corrosion resistance, good tailoring ability, excellent fatigue resistance, good dimensional stability and a low coefficient of thermal expansion. In aforesaid fields, turning and drilling of GRFP composite materials is a common machining operation.

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 quite difficult as compared to machining of conventional metals.

2. Literature Review:

Sl .No	Journal	Author	Title	Findings
Composite materials machining (GFRP)				
1.	International Journal of Advance Manufacturing Technology (2008)	Palanikumar, K.	Application of Taguchi and response surface methodologies for surface roughness in machining glass fiber reinforced plastics by PCD tooling	➢ The predicted values and measured values are close due to the use of Taguchi and response surface methodologies.
2.	Journal of materials processing technology (2008)	Palanikumara, K., Matab, F., Davim, J. P.	Analysis of surface roughness parameters in turning of FRP tubes by PCD tool.	➢ Empirical models are developed to correlate the machining parameters with surface roughness.
3.	Journal of	Patnaik, A.,	A Taguchi Approach	➢ Glass-reinforced-polyester

	Reinforced Plastics and Composites (2008)	Satapathy, A., Mahapatra, S. S., Dash, R. R.	for Investigation of Erosion of Glass Fiber – Polyester Composites.	composites exhibit mostly semi-ductile erosion response.
4.	Journal of Reinforced Plastics and Composites (2008)	Patnaik, A., Satapathy, A., Mahapatra, S. S., Dash, R. R.	Implementation of Taguchi Design for Erosion of Fiber-Reinforced Polyester Composite Systems with SiC Filler.	➢ Development of a multi-component composite system. ➢ Optimal factor settings for minimum wear rate results using a genetic algorithm.
5.	Materials and Design (2009)	Davim, J. P., Silva, L. R., Festas, A., Abrao, A. M.	Machinability study on precision turning of PA66 polyamide with and without glass fiber reinforcing.	➢ The radial force component presented highest values, followed by the cutting and feed forces. ➢ The PCD tools give the lowest force values with best surface finish.
6.	Journal of Materials Processing Technology (2009)	Palanikumara, K., Davim, J. P.	Assessment of some factors influencing tool wear on the machining of glass fiber reinforced plastics by coated cemented carbide tools.	➢ Cutting speed is a factor which greatly influence tool flank wear, followed by feed rate. ➢ To optimize the chosen factors to attain minimum tool wear.
7.	Advances in production engineering and management (2009)	Naveen , Sait, A., Aravindan, S., NoorulHaq, A.	Influence of machining parameters on surface roughness of GFRP pipes.	➢ Machining parameters are optimized using simple regression and cross product regression method.
8.	European Journal of Scientific Research (2010)	Hussain, S. A., Pandurangadu, V., Palanikumar, K.	Surface Roughness Analysis in Machining of GFRP Composites by Carbide Tool (K20).	➢ A second order mathematical model was developed using RSM.
9.	American J. of Engineering and Applied Sciences (2010)	Suhail, A. H., Ismail, N. , Wong, S.V. and Jalil, N. A. A.	Optimization of Cutting Parameters Based on Surface Roughness and Assistance of Work piece Surface Temperature in Turning Process	➢ To optimize the cutting parameters using two performance measures. ➢ It is possible to increase machine utilization and decrease production cost.
10	Materials and Design (2010)	Kini, M. V., Chincholkar, A. M.	Effect of machining parameters on surface roughness	➢ Overlaid contour graph help in obtaining value of roughness for different values of M.R.R.

			and material removal rate in finish turning of ±30° glass fiber reinforced polymer pipes.	➢ Development of an empirical model for turning GFRP utilizing factorial experiments.
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
12	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

3. Experimentation:

3.1 Work piece and Tool material

In this work, 9 pieces 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.

3.2 Design of Experiment (DOE)

Taguchi method has been implemented to generate the orthogonal array for minimizing the number of experiments. 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) in turning of GFRP. 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.

3.3 Performance characteristics measurements

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

Sl. No	Parameter	Unit	Level 1	Level 2	Level 3
1	Spindle Speed (N)	rpm	605	787	1020
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	605	0.06	0.6
2	605	0.07	0.9
3	605	0.08	1.2
4	787	0.06	0.9
5	787	0.07	1.2
6	787	0.08	0.6
7	1020	0.06	1.2
8	1020	0.07	0.6
9	1020	0.08	0.9

4. Methodology:

4.1 Taguchi Method

Taguchi method (originated by Dr. Genichi Taguchi in the late 1940's) is a popular robust design philosophy which enhances engineering productivity. 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.

4.2 Grey Relation Analysis:

The Grey theory established by Dr. Deng includes Grey relational analysis, Grey modeling, prediction and decision making of a system in which the model is unsure or the information is incomplete. Grey Relation Analysis is based on the degree of similarity or difference of development trends among elements to measure the relation among elements.

Step 1: Data pre-processing

In this step, normalize the random grey data with different measurement units to transform them to dimensionless parameters which range within 0 to 1. Following are equation which is used for data normalization:

For Lower-is-Better (LB) criterion:

$$y_{ij} = \frac{x_{ij} - \max x_{ij}}{\min x_{ij} - \max x_{ij}} \qquad (4)$$

For Higher-is-Better (LB) criterion:

$$y_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \qquad (5)$$

Where, x_{ij} is the experimental data.

Step 2: Individual Grey Relation Grade

$$\gamma_{ij} = \frac{\Delta_{min} + \tau\Delta_{max}}{\Delta_{0i}(j) + \tau\Delta_{max}} \qquad (6)$$

Step 3: Overall Grey Relation Grade

$$R_i = \frac{1}{n}\sum_{j=1}^{n}\gamma_{ij} \tag{7}$$

5. Results and Discussion:

In this thesis, the output response characteristics (tool tip temperature and surface roughness) have been evaluated and shown in Table 3. For the data pre processing, lower-is-better criterion has been taken in consideration. The experimental data have been normalized into a single dimensionless scale in between 0 to 1which are presented in Table 4. After that, individual grey coefficient has been determined and shown in Table 5. Table 5 also presents the overall grey relation coefficient. Finally, overall grey relation grade (OG) has been evaluated and has been shown in Table 7. Taguchi used the S/N ratios (shown in Table 6) concept to determine the optimal parametric combination as $N_2f_3d_3$. S/N ratio plot for evaluating optimal setting has been shown in Figure 1.

Table 3: Experimental data

Sl. No.	Tool tip temperature (^{0}C)	Ra (µm)
1.	43.78	5.248
2.	55	6.549
3.	42.3	7.814
4.	84.2	5.182
5.	84.3	7.259
6.	76.5	7.776
7.	92.9	5.459
8.	79.2	5.686
9.	86.1	6.998

Table 4: Normalized experimental data

Sl. No.	N-Tool tip temperature	N-Ra
1.	0.970751	0.974924
2.	0.749012	0.480623
3.	1	0
4.	0.171937	1
5.	0.16996	0.210866
6.	0.324111	0.014438
7.	0	0.894757

8.	0.270751	0.808511
9.	0.134387	0.31003

Table 5: Individual Grey coefficient and Overall Grey Coefficient

Sl. No.	Grey coefficient 1	Grey coefficient 2	Overall Grey (OG) coefficient
1.	0.339962	0.339001	0.339481
2.	0.400316	0.50988	0.455098
3.	0.333333	1	0.666667
4.	0.744118	0.333333	0.538725
5.	0.746313	0.703367	0.72484
6.	0.606715	0.971935	0.789325
7.	1	0.358485	0.679243
8.	0.648718	0.382114	0.515416
9.	0.788162	0.617261	0.702711

Table 6: Calculated OG and corresponding their S/N ratios

N	f	d	OG	S/N	Predicted S/N ratio
465	0.06	0.6	0.339481	-9.38369	
465	0.07	0.9	0.455098	-6.83790	
465	0.08	1.2	0.666667	-3.52182	
605	0.06	0.9	0.538725	-5.37266	
605	0.07	1.2	0.72484	-2.79516	
605	0.08	0.6	0.789325	-2.05488	
787	0.06	1.2	0.679243	-3.35950	
787	0.07	0.6	0.515416	-5.75684	
787	0.08	0.9	0.702711	-3.06446	

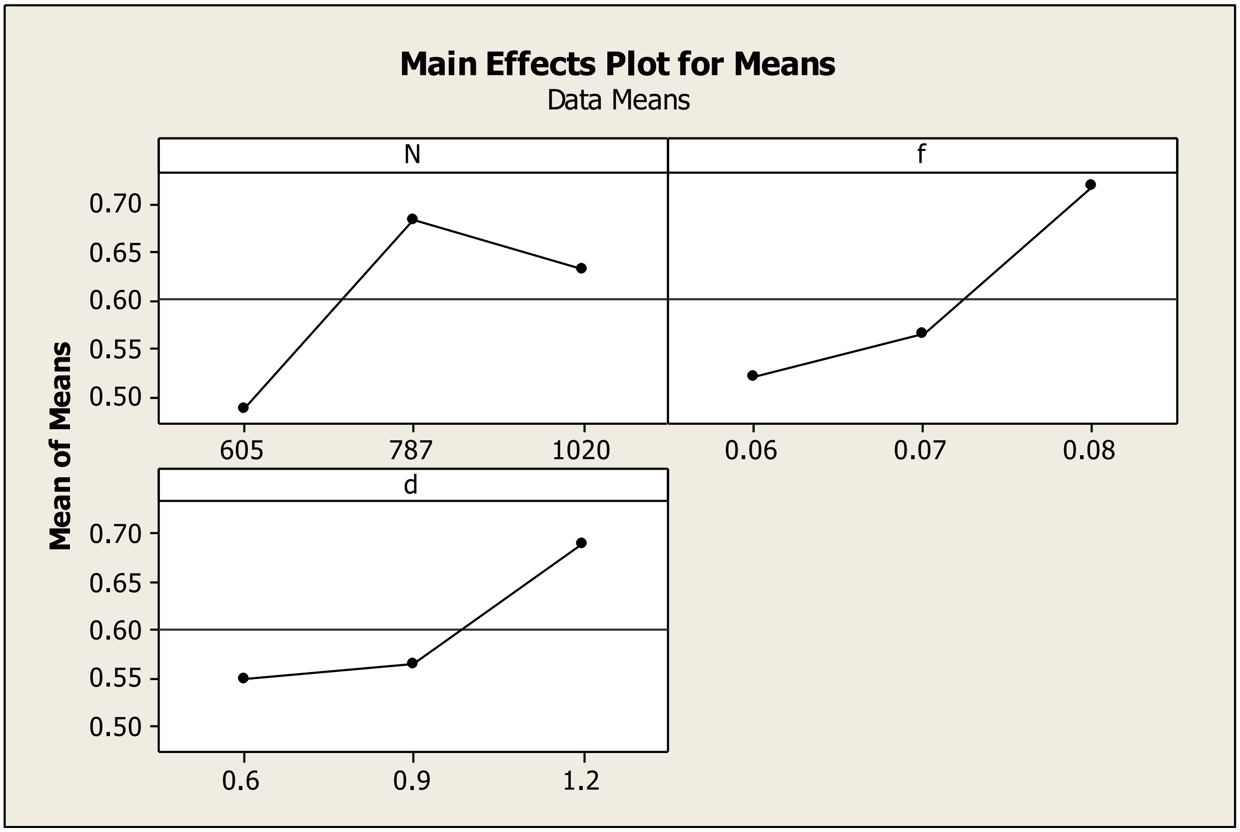

Figure 1: Evaluation of optimal setting

6. Conclusions:

This thesis presents an integrated optimization philosophy using Grey relation analysis integrated with Taguchi method for optimizing the performance characteristics in turning of GFRP composites. The study illustrates the effectiveness of the proposed method as well. The traditional Taguchi method deals with single response problem whereas Grey relation analysis is used to aggregate the multi responses into single response i.e. overall grey relation coefficient (OG). OG can easily be optimized to determine the optimal process environment which facilitates in mass production and consequently product quality improvement.

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