Optimization of Process Parameters in CNC End Milling of Glass - Fibre Reinforced Plastic

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ABSTRACT

Quality and productivity are the two important conflicting objectives in any machining process. Some extent of quality has to be compromised while assurance giving for high productivity. Similarly productivity will be decreased while the efforts are channelized to enhance quality. To ensure high quality and productivity, it is necessary to optimize the machining parameters. The surface finish and material removal rate in end milling refer to quality and productivity respectively. In this paper Grey relational analysis based Taguchi method is employed for optimizing process parameters in end milling of glass-fibre-reinforced plastic (GFRP). The application of the methodology is demonstrated through an experimental study in which end milling of GFRP is carried on CNC milling machine.

Keywords: End milling, Glass-fibre reinforced plastic, Grey relational analysis, Taguchi method.

1. INTRODUCTION

CNC end milling is extensively used in most of the manufacturing industries due to its capability of producing complex geometric surfaces with responsible accuracy and surface finish along with flexibility and versatility [1]. Studies in end milling of glass fibre reinforced plastics (GFRP) have not yet received its due attention until recently. This is despite being one of the most widely used material removal processes in industry. This machining process is usually employed for trimming of composite parts as well as for removing of the excess material to achieve final shape and dimensional tolerance[2]. In end milling, surface roughness and material removal rate (MRR) refer to quality and productivity respectively. In order to obtain better surface finish, the proper setting of cutting parameters is crucial before the process takes place. Several factors will influence the final surface roughness in CNC milling operation. The natural surface roughness is a result of the irregularities in the cutting operation. Surface quality affects fatigue life of components and influences various mechanical properties and has received serious attention for many years [3]. The factors such as spindle speed, feed rate, tool diameter and depth of cut that control the chip formations or the material properties of both tool and work piece [4]. The MRR is an important control factor of machining operation and the control of machining rate is also critical for production planners. MRR is a measurement of productivity and it can be expressed by analytical derivation as the product of the width of cut, the feed velocity of milling cutter and depth of cut [5]. Yang and Chen [6] attempted to demonstrate how Taguchi parameter design could be used in identifying the significant processing parameters and optimizing the surface roughness of end-milling operations. Mansour and Abdalla [7] studied the roughness in end milling of EN 32 steel in terms of machining parameters using RSM. Lakshmi and Venkata Subbaiah[8] conducted experimental investigations on surface finish and material removal rate during the high speed end milling of EN24 alloy steel in order to develop an appropriate roughness prediction model and optimize the cutting parameters using RSM. Jaya Krishna et al.[9] adopted principal component analysis (PCA) based neural networks for predicting the surface roughness in CNC end milling of P20 mould steel. In the present days, the attention of the researchers turns towards the use of composite materials in various fields. Among many kind of composite materials, polymer composites are the most common material to be used for lightweight structures such as aircraft, marine, construction and automobile industries. Fibrous polymer composite is the material that containing fibre which provide strength and stiffness to it. The use of Glass fibre reinforced plastics (GFRP) in several industries is increased and become important in this decade due to its special mechanical properties. Even though FRP still cannot totally replace the used of steel and aluminium alloy, but its significance of light weight, high specific strength and lower thermal expansion properties had successfully grab the manufacturers' attention. GFRP is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, basalt or aramid, although other fibres such as paper or wood or asbestos have been sometimes used. The polymer is usually an epoxy, vinyl ester or polyester thermosetting plastic, and phenol formaldehyde resins are still in use. Fibre-reinforced plastics are a category of composite plastics that specifically use fibre materials to mechanically enhance the strength and elasticity of plastics. The original plastic material without fibre reinforcement is known as the matrix. The matrix is a tough but relatively weak plastic that is reinforced by stronger stiffer reinforcing filaments or fibres. The extent that strength and elasticity are enhanced in a fibre-reinforced plastic depends on the mechanical properties of the fibre and matrix, their volume relative to one another, and the fibre length and orientation within the matrix. The milling of GFRP composite materials is a rather complex task owing to its heterogeneity and the number of problems, such as surface delamination, which appear during the machining process, associated with the characteristics of the material and the cutting parameters. Optimization of machining parameters is an important step in machining [10]. Babu and Sunny [11] conducted study with a view to determine optimal machining parameters in drilling of GFRP composite materials. Palanikumar et al.[12] studied the effect of cutting parameters on surface roughness on machining of GFRP composites by polycrystalline diamond (PCD) tool by developing a second order model for predicting the surface roughness average. Praveen Raj et al.[13] developed a surface roughness and delamination prediction model in end milling of GFRP using artificial neural network (ANN)technique. The competence of the developed model is verified by using coefficient of determination and residual analysis. Srinivasulu [14] carried experimental study which is focused on the influence of cutting speed, feed rate and depth of cut on the delamination damage and surface roughness on GFRP during end milling. Taguchi design method is employed to investigate the machining characteristics of GFRP. Asokan et al. [15] investigated on optimization of end milling parameters for GFRP. In their work, the GFRP was fabricated by hand layup with 33% fiber and 66% general purpose resin. They determined the optimal level setting of machining parameters such as tool condition, number of flute, cutting speed and feed rate. Azmi and Bhattacharyya [16] demonstrated the development of an indirect approach in predicting and monitoring the wear on carbide tool during end milling of GFRP using multiple regression analysis (MRA) and neuro-fuzzy modelling. Naresh et al., [17] concluded that fibre orientation angle is the most significant parameter and spindle speed is the least significant parameter for milling of GFRP composite with the objective of minimizing surface roughness, machining force and delamination factor. Babur and Mahmut [18] developed a statistical model by response surface methodology for predicting surface roughness in high-speed flat end milling process under wet cutting conditions by using machining variables such as spindle speed, feed rate, depth of cut and step over. They observed that, the order of significance of the main variables is as total machining time, depth of cut, step over, spindle speed and feed rate respectively. In the present work an attempt has been made to apply Grey Relational Analysis (GRA) based Taguchi method to optimize the process parameters in CNC end milling of GFRP. The over view of Taguchi method and GRA are discussed below.

1.1. Taguchi method

Taguchi Method was proposed by Dr. G. Taguchi in the year 1950. This method explores the concept of quadratic quality loss function and uses a statistical measure of performance called signal-to-noise (S/N) ratio. In Taguchi method, the process parameters are divided into two groups such as control factors and noise factors. The control factors are the controllable parameters which affect the process significantly whereas noise factors are the variables that affect the process and are either uncontrollable or more expensive to control. Signal represents the effect on the average response while the noise is a measure of the influence on the deviation from the average response. The S/N ratio is the ratio of the mean (Signal) to the standard deviation (Noise), which indicates the scattering around a target value. This ratio helps to identify the optimum level of process parameters. The combination of parameters with the highest S/N ratio will be the optimum setting of process parameters. A high S/N ratio is desirable as the signal level is much higher than the random noise level that leads to best performance. The calculation of S/N ratio depends on the quality characteristics of the product or process to be optimized. The equation for calculating S/N ratios for "larger is better" (HB), "smaller is better" (LB) and "nominal is best" (NB) types of characteristics are as follows:

- For larger is better

$$(S/N)_{HB} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}(1/y_i^2)\right]$$

- For smaller is better

$$(S/N)_{LB} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}(y_i^2)\right]$$

- For nominal the better

$$(S/N)_{NB} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}(y_i - y_0)^2\right]$$

Where, y_i = experimental value in the i^{th} test

y_0 = target value and

n = number of replications

The signal-to-noise (S/N) ratio for each level of process parameters are computed. The optimum setting of the process parameters contributes the minimization of the effect of noise. It means that the level of process parameters with the highest S/N ratio corresponds to the optimum level of process parameters.

1.2. Grey Relational Analysis (GRA)

In the year 1982, Prof. Deng Julong founded the grey system theory. Since then, it has been widely used in many fields such as agriculture, electric power, IT, transportation, economics, management, etc. The Grey system theory works on unascertained problems which have little research data and poor information. In grey relational analysis, experimental data i.e. measured features of quality characteristics are first normalized ranging from zero to one. The process is known as grey relational generation. Next, based on normalized experimental data, grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall grey relational grade is determined by averaging the grey relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade. This approach converts a multiple response process optimization problem into a single response optimization situation with the objective function is overall grey relational grade. The optimal parametric combination is then evaluated which would result into highest grey relational grade. The optimal factor setting for maximizing overall grey relational grade can be performed by Taguchi method. The application of GRA is carried out in the following steps.

(a) Data Pre-Processing

Different methods are employed to pre-process grey data depending upon the quality characteristics of the original data. If the original sequence data has quality characteristic as 'larger-the-better' then the original data is pre-processed as 'larger the best':

$$x_i(k) = \frac{y_i(k) - \min.y_i(k)}{\max.y_i(k) - \min.y_i(k)}$$

If the original data has the quality characteristic as 'smaller-the-better than the original data is pre-processed as 'smaller-the-best':

$$x_i(k) = \frac{\max.y_i(k) - y_i(k)}{\max.y_i(k) - \min.y_i(k)}$$

Here $x_i(k)$ is the value after grey relational generation, min $y_i(k)$ is the smallest value of $y_i(k)$ for the k^{th} response, and max $y_i(k)$ is the largest value of $y_i(k)$ for the k^{th} response.

(b) Deviation Sequencing

Deviation sequencing is calculated for the obtained pre-processing data by considering ideal value 1. Deviation sequencing can be calculated by using the following formula $\Delta 0i = 1 - x_i(k)$, Where $\Delta 0i =$ Deviation sequencing for the k^{th} pre-process data and $x_i(k)$ is the k^{th} pre-process value.

(c) Calculation of Grey Relational Coefficient

In the next step coefficient ξi is calculated for all the obtained deviational sequencing data individually, Grey relational coefficient $\xi_i(k)$ is calculated using the following formula:

$$\xi_i(k) = \frac{\Delta \min . + \psi \Delta \max}{\Delta 0_i(k) + \psi \Delta \max}$$

Where ψ = distinguishing coefficient ($0 \le \psi \le 1$).

$\Delta 0i(k)$ = Deviation sequencing of k^{th} value

Δmax = Maximum deviation value form the k^{th} deviation values

Δmin = Minimum deviation value form the k^{th} deviation values

(d) Computation of Grey Relational Grade

Grey relational grade is calculated by the following formula

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k)$$

Where n is the number of process responses.

The higher value of grey relational grade corresponds to intense relational degree between the reference sequence $x0(k)$ and the given sequence $xi(k)$. The reference sequence $x0(k)$ represents the best process sequence; therefore, higher grey relational grade means that the corresponding parameter combination is closer to the optimal.

2. EXPERIMENTATION

The present work is carried out with a view to observe the response variables such as material removal rate and surface roughness during CNC end milling of GFRP with the change of cutting parameters at different levels. The experimentation has been conducted through the following step by step procedure.

Step 1: Preparation of work piece

The GFRP is made of glass FRP Woven cloth with epoxy resin with the ratio of 70: 30. First one layer of resin is applied on the plywood and then one layer of GFRP woven cloth laid on the resin layer and hand roller was rolled on it with pressure. The same procedure was repeated to achieve 5mm thickness. Finally job was kept in autoclave for curing for 4 (four) hours. The work piece is ready for milling operation shown in figure 1. The size of work piece is 370mm × 170mm × 5mm. The ultimate tensile strength and density of the work piece are 1770 MPa and 1.8 gm/cm³ respectively. A commercially available solid carbide tool is used for machining.

Fig-1: Work Piece ready for milling

Step 2: Selection of process parameters

The selection of right combination of process parameters and setting the range of the process parameters is very important step in any unconventional machining process. The small changes in process parameters lead to more variation in surface roughness and accuracy of the machined components. In the present work there are two process parameters are considered namely (i) fixed parameters and (ii) controlled parameters. The fixed parameter will not change throughout the investigation. The table 1 shows the fixed parameters considered in the experimentation.

Table1: Fixed parameters for end milling

Fixed Parameters	Description
Milling cutter size	10.0 mm diameter
Shape of the work piece	Rectangular
Size of the work piece	370 × 170×5 mm thick
Location of work piece on working table	Centre of the table
Input voltage	415 V

The change of values of parameters considered during each experiment is known as controlled parameters. The focus of investigation is mainly on these parameters to achieve the desired objective. The table 2 shows the controlled parameters. The levels of the parameters selected as per the CNC machine used in the work.

Table 2: Controlled parameters for end milling

Control Parameters	Symbol	Unit	Levels		
			I	II	III
Speed	A	RPM	2000	4000	6000
Feed	B	mm/min	300	600	900
Depth of cut	C	Mm	1.0	1.5	2.0

Step 3: Taguchi design of experiments

Based on the factors considered and degrees of freedom of all factors appropriate Orthogonal Array may be selected. In the present investigation three controlled process parameters at three levels are considered as shown in the table 3.

Step 4: Selection of milling cutter

The cutting tool used is a commercially available solid carbide tool shown in figure 3.4. The specifications of the cutting tool are as follows: Cutter Diameter = 10 mm; Fluted Length = 75 mm ; Helix Angle = $30°$; No. of flutes = 04.

Table 3: Taguchi Design L27 Orthogonal Array

Exp. Trail No.	Factors			Exp. Trail No.	Factors		
	A	B	C		A	B	C
1	1	1	1	15	2	1	2
2	1	2	1	16	2	3	3
3	1	3	1	17	2	2	3
4	1	2	2	18	2	1	3
5	1	3	2	19	3	1	1
6	1	1	2	20	3	2	1
7	1	3	3	21	3	3	1
8	1	2	3	22	3	2	2
9	1	1	3	23	3	3	2
10	2	1	1	24	3	1	2
11	2	2	1	25	3	3	3
12	2	3	1	26	3	2	3
13	2	2	2	27	3	1	3
14	2	3	2				

Step 5: Performing milling operation

End milling operation on specimens in involving various combinations of input parameters such as cutting speed, feed and depth of cut.

Step 5: Measure the surface roughness with the help of a portable stylus-type Talysurf TR200.

Step 6: Calculate the material removal rate (MRR) using the following formula

$$\text{MRR} = \frac{\text{Intial weight} \;-\; \text{Final weight}}{\text{Density of work piece} \times \text{Machining time}}$$

The experimental results are analyzed and are discussed in the following section.

3. RESULTS AND ANALYSIS

After performing all the 27 experiments, the material removal rate in mm³/min and surface roughness in µm are determined and are shown in table 4.

Table 4. Material removal rate (MRR) and Surface roughness (SR) values

Exp. Trail No.	MRR	Surface roughness	Exp. Trail No.	MRR	Surface roughness
1	3174.60	2.687	15	4529.00	2.993
2	6349.20	2.527	16	18518.5	2.255
3	9259.30	2.131	17	11396.0	2.117
4	9633.90	2.448	18	6006.00	2.696
5	13333.3	2.527	19	3174.60	2.027
6	4529.00	2.690	20	6349.20	2.675
7	18518.5	2.736	21	9259.30	2.372
8	11396.0	2.726	22	9633.90	2.709
9	6006.00	2.547	23	13333.3	2.361
10	3174.60	2.524	24	4529.00	2.533
11	6349.20	2.135	25	18518.5	2.527
12	9259.30	2.751	26	11396.0	2.834
13	9633.90	2.749	27	6006.00	1.894
14	13333.3	2.737			

In order to achieve better surface finish and higher material removal rate simultaneously, GRA based Taguchi method is employed. The step by step procedure of GRA discussed in the section 1 is carried for obtaining optimal set of process parameters. The pre-processing data and the deviation sequencing are presented in table 5.

Table 5: Pre-processing data on MRR and surface roughness

Exp. Trail No.	Pre-processing data on MRR and surface roughness (Ra)		Sequencing deviation (Δ0i)	
	MRR (HB)	Surface Roughness (LB)	MRR (Δ0i)	Surface Roughness (Δ0i)
1	0.0000	0.2784	1.0000	0.7216
2	0.2068	0.4240	0.7932	0.5760
3	0.3965	0.7843	0.6035	0.2157
4	0.4209	0.4959	0.5791	0.4959
5	0.6620	0.4240	0.3380	0.5760
6	0.0882	0.2757	0.9118	0.7243
7	1.0000	0.2338	0.0000	0.7662
8	0.5358	0.2429	0.4642	0.7571
9	0.1845	0.4058	0.8155	0.5942
10	0.0000	0.4267	1.0000	0.5733
11	0.2068	0.7807	0.7932	0.2193
12	0.3965	0.2220	0.6035	0.7798
13	0.4209	0.2220	0.5791	0.7780
14	0.6620	0.2329	0.3380	0.7671
15	0.0882	0.0000	0.9118	1.0000
16	1.0000	0.6715	0.0000	0.3285
17	0.5358	0.7970	0.4642	0.2030
18	0.1845	0.2702	0.8155	0.7298
19	0.0000	0.8789	1.0000	0.1211
20	0.2068	0.2893	0.7932	0.7107
21	0.3965	0.5650	0.6035	0.4350
22	0.4209	0.2584	0.5791	0.7416
23	0.6620	0.5750	0.3380	0.4250
24	0.0882	0.4185	0.9118	0.5815
25	1.0000	0.4240	0.0000	0.5760
26	0.5358	0.1446	0.4642	0.8554
27	0.1845	1.0000	0.8155	0.0000

The grey relation coefficients (GRC) for all the trails are calculated. The values of GRC are further utilized to compute grey relational grades (GRG). The values of GRC and GRG are shown in table 6.

Table 6.The values of GRC and GRG for all the trails

Exp. Trial No	Grey relation coefficient (GRC)		Grey relational grade (GRG)
	MRR	Surface Roughness	
1	0.3333	0.4092	0.37125
2	0.3866	0.4646	0.42560
3	0.4531	0.6986	0.57585

Table 6.The values of GRC and GRG for all the trails (contd..)

Exp. Trial No	Grey relation coefficient (GRC)		Grey relational grade (GRG)
	MRR	Surface Roughness	
4	0.4633	0.5020	0.48265
5	0.5966	0.4646	0.53060
6	0.3541	0.4083	0.38120
7	1.0000	0.3948	0.69740
8	0.5185	0.3977	0.45810
9	0.3800	0.4569	0.41845
10	0.3333	0.4658	0.39955
11	0.3866	0.6951	0.54085
12	0.4531	0.3906	0.42185
13	0.4633	0.3946	0.42895
14	0.5966	0.3946	0.49560
15	0.3541	0.3333	0.34370
16	1.0000	0.6035	0.80175
17	0.5185	0.7112	0.61485
18	0.3800	0.4065	0.39325
19	0.3333	0.8050	0.56915
20	0.3866	0.4129	0.39975
21	0.4531	0.5347	0.49390
22	0.4633	0.4027	0.43300
23	0.5966	0.5405	0.56855
24	0.3541	0.4623	0.40820
25	1.0000	0.4646	0.73230
26	0.5185	0.3688	0.44365
27	0.3800	1.0000	0.69000

From the table 6, it is observed that the combination of speed, feed and depth of cut employed in experiment trail No.16 possesses higher GRG value. Therefore to achieve both good surface finish and better material removal rate, the speed should be in medium level and feed and depth of cut have to be taken at lower level. The optimal process parameters for MRR and surface roughness are speed 4000 rpm, feed 900 mm/min. and depth of cut 2.0mm.

4. CONCLUSIONS

The quality and productivity are the important objectives in any machining process. Surface finish and material removal rate represents quality and productivity respectively. Taguchi method helps to optimize surface roughness and material removal rate individually. But the GRA based Taguchi technique helps to solve the multi – response optimization problem. In the present work experimental investigation is carried to study the effect of process parameters such as speed, feed and depth of cut during CNC end milling of GFRP. On the basis of grey relational grades the optimum levels of speed, feed and depth of cut are identified. In end milling of GFRP, the feed and depth of cut have to be maintained at lower level and speed in medium level yields better material removal rate and good surface finish.

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