MULTI-OBJECTIVE OPTIMIZATION OF MACHINING PARAMETERS ON DRILLING OF GFRP COMPOSITES USING HYBRID GRA-PCA TECHNIQUES

K. SIVA PRASAD¹ & G. CHAITANYA²

¹Research Scholar, Mechanical Engineering Department, Acharya Nagarjuna University, (ANU) Guntur-522510

¹Assistant Professor, Mechanical Engineering Department, V R Siddhartha Engineering College, Vijayawada-520007, India

²Associate Professor, Mechanical Engineering Department, R V R & J C College of Engineering, Guntur-522019, India

ABSTRACT

In this research, exhibits an optimal combination of process parameters so as to minimize the surface roughness and circularity deviation during conventional drilling of GFRP composites. In order to multi-objective optimization of process parameters, taguchi based Grey relational analysis (GRA) coupled with principal component analysis (PCA) methodology has been proposed in this work. The number of experiments confirmed is based on L9 orthogonal array as per the taguchi method, depends on the control factors such as cutting speed, feed, specimen thickness and fiber orientation. From the ANOVA it reveals that cutting speed and feed are the most influencing parameters on surface roughness and circularity error. Using GRA multi response parameters are normalized and further applied PCA to evaluate the weighting values of corresponding responses. From the analysis the optimal combination of process parameters are selected.

KEYWORDS: Surface Roughness, Circularity, Grey Relational Analysis, Principal Component Analysis, Multi-Objective Optimization

NOMENCLATURE

- Speed s
- Feed f
- Thickness t
- Fiber orientation f_o

Received: Jun 08, 2020; **Accepted:** Jun 28, 2020; **Published:** Sep 11, 2020; **Paper Id.:** IJMPERDJUN20201168

INTRODUCTION

In recent years Glass fiber reinforced composites (GFRP) are widely using in different fields of engineering applications such as automobiles, aircrafts, marine and chemical industries due to having major advantages like high strength to weight ratio, chemical resistance, excellent corrosion and thermal resistance. Conventional machining of composites is a complex task due to anisotropic and hard reinforced fibers thereby affecting the surface roughness, circularity.

Multi-performance characteristics are optimized using Grey relational analysis and found that surface roughness is highly affected by the feed rate and thrust force during conventional drilling of GFRP composites [1]. T. Rajmohan, 2019[2] examined the influence of machining parameters to obtain better surface finish during drilling of fly ash filled carbon fiber reinforced polymer composites and applied multi-objective optimization technique of grey relational analysis and found that the wt % of fly ash and drill diameter are the most significant factors which affect the performance.

VijayanKrishnaraj, 2012, [4] analysed hole quality includes hole diameter, circularity and delamination by performing drilling operation on CFRP composites using carbide K20 drill. The machining parameters are optimized using Genetic algorithm and found that feed rate having high influence on delamination, thrust force and hole diameter. Also observed that circularity error is strongly influenced by the spindle speed. H. RezghiMaleki, M. Hamed, 2019, [3] studied quality of hole during drilling of natural fiber composites and observed that drill bit has great impact on surface roughness.

C.L. Tan 2016,[5] conducted conventional drilling operation on hybrid carbon/glass composite to study the influence of process parameters on surface roughness and delamination. From the experimental results it is observed that surface roughness and delamination damages are severely affected by the feed rate.

Khaled Giasin 2017, [6] investigated machinability of fiber metal laminates during drilling operation and found that circularity error increases with increase in feed rate and thickness of the specimen. M. S. Sureshkumar, (2014), [7] experimental investigation carried for analysis of surface roughness and circularity error. From the experimental results it is concluded that low feed rate is preferable for improve the hole quality.

Eshetu D Eneyew, (2014) et.al,[8] conducted drilling operation on carbon fiber reinforced polymer (CFRP) composites to analyze the quality of hole by surface roughness and surface damage through the scanning electron microscopy (SEM). From the result analysis, high cutting speed and low feed rate is suggested to produce the minimal surface roughness.

T. Rajmohan, (2012) et.al, [9] studied influence of drilling parameters using the Box–Behnken experimental design (BBD) on Al 356-aluminum alloy reinforced with silicon carbide material to investigate the surface roughness and burr height. The results reveals that low feed rate, medium spindle speed and high wt% of SiC is giving optimum surface roughness and burr height.

C.C. Tsao, (2008) et.al, [10] Studied the effect of process parameters on surface roughness and thrust force by taguchi method and artificial neural network and found that speed and feed are strongly effecting the surface roughness whereas thrust force affected by feed and drill diameter. Also established a correlation between the process parameters and performance characteristics using multi-variable regression analysis and radial basis function network (RBFN). The results indicated that RBFN is more effective than multi-variable regression analysis.

From the literature review, most of the authors investigated the effect of process parameters on surface roughness, delamination and thrust force. Selected optimal process parameters for individual performance measures. From the literature the gaps are observed as very little literature is available for influence of process parameters on circularity errors. The present work focusing on the influence of process parameters on surface roughness and circularity error by applying the Taguchi's ANOVA. In addition to that carried multi-objective optimization of process parameters using GRG coupled PCA approach.

EXPERIMENTAL DETAILS

Selection of Material & Process Parameters

The material selected for conventional drilling operation as E-Glass/138 with Epoxy resin /LY556. For the experimentation GFRP specimens are laminated by the hand layup method. Each specimen having size of 3 cm x 4 cm. in addition to that specimen thickness varies to 4 mm, 6 mm and 8mm.

The process parameters selected for the experimentation are spindle speed, feed, specimen thickness and fiber orientation. Experiments are designed as per the taguchi's orthogonal array and each process parameter having 3 levels of design.

Experimental Setup

Drilling operation carried over specimen by CNC vertical milling machine (Model KMV-8VC) made by KENT-India Co. Ltd, Taiwan. The speed of the machine is varied from 30 rpm to 8000 rpm. The drill size of 10 mm is considered for all the experiments. After machining operation the drilled hole surface roughness is measured by the talysurf meter with an accuracy of 0.3 microns. Circularity error of the drilled hole measured by the Co-ordinate Measuring Machine (CMM) (Model-LKV 8.7.6) made by the METRIS Company.

Figure 1: (a) Experimental Setup for Drilling Operation. (b) Coordinate Measuring Machine [11].

MULTI-OBJECTIVE OPTIMIZATION USING HYBRID GRA-PCA TECHNIQUES

In this chapter proposed multi-objective optimization with grey relational analysis (GRA) and principal component analysis (PCA) to study the optimization problem in conventional drilling of GFRP composites. The methodology consists of a number of steps as follows:

Normalization

In grey relational analysis, the ranges of response variables are larger and the functions of variables are neglected this is due to the response variables functions and their units are different, so that it is necessary to preprocess the response variables to normalize the numerical values between the 0 and 1. The normalization for output response is calculated based on the requirement. They are smaller is the better (SB) and larger is the better (LB).

The equation for Smaller the better as follows

$$x_i^*(k) = \frac{\max x_i^o(k) - x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)} \quad (1)$$

Where $x_i^*(k) = x_i^o(k) - \min x_i^o(k)$

The equation for Larger the better as follows,

$$x_i^*(k) = \frac{x_i^0(k) - \min x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \quad (2)$$

Where, $i=1, \dots, m$; $k=1, \dots, n$. m is the number of experimental data items;

$x_i^0(k)$ Denotes the original sequence; $\min x_i^0(k)$ is the smallest value of $x_i^0(k)$;

$\max x_i^0(k)$ is the largest value of $x_i^0(k)$; Normalized values are calculated by using the equation (1) and tabulated in table 1.

Table 1: Normalized Values and Deviational Sequence for Surface Roughness and Circularity

S. No.	Normalized Values		Deviational Sequence	
	Surface Roughness	Circularity Error	Surface Roughness	Circularity Error
1	0.302478	0.944238	0.697522	0.055762
2	1	0.851301	0	0.148699
3	0.634443	0.959108	0.365557	0.040892
4	0.637301	0.126394	0.362699	0.873606
5	0.695698	0.189591	0.304302	0.810409
6	0.344885	1	0.655115	0
7	0	0	1	1
8	0.604347	0.055762	0.395653	0.944238
9	0.129017	0.579926	0.870983	0.420074

Determination of Grey Relational Co- Efficient (GRC)

After normalization, the grey relation coefficient $\xi_i(k)$ for the k^{th} quality characteristics in the i^{th} experiment can be articulated as

$$\xi_i(k) = \frac{\Delta_{\min} + \zeta \Delta_{\max}}{\Delta_{0i}(k) + \zeta \Delta_{\max}} \quad (3)$$

Where $\Delta_{0i}(k)$ is the offset in the absolute values flanked by the reference series $y_0^*(k)$ and the comparability series $y^*(k)$, ζ is the characteristic coefficient which is generally taken as 0.5, $\Delta_{\min}$ is the least value of $\Delta_{0i}(k)$, and $\Delta_{\max}$ is the biggest value of $\Delta_{0i}(k)$

Calculation of Grey Relational Grade (GRG)

After the grey relational coefficient, $\xi_i(k)$, is derived, the grey relational grade (GRG) δ_i , is determined as the mean value of the grey relational coefficients.

$$\delta_i = \frac{1}{n} \sum_{k=1}^n Q_j \xi_i(k) \quad (4)$$

Where, δ_i representing weighted GRG varying from 0 to 1, n is the number of experiments conducted. Among all the attainments, the highest value of GRG indicates best optimal process parameters to achieve the multi –objective optimization of various response parameter values.

Principal Component Analysis (PCA)

PCA is the statistical approach that converts a set of observations of most likely correlated variables into a set of values of uncorrelated variables. The main advantage of PCA is that once the patterns in data are identified, the data can be compressed, i.e. reducing the number of dimensions, without much loss of information. The steps involved in PCA are discussed below:

Step (i) Formation of multi-objective response matrix (M):

PCA explains the structure of variance-covariance matrix (M), which is formed from Equation (5) as given.

$$M = \begin{bmatrix} m_1(1) & m_1(2) & \dots & m_1(n) \\ m_2(1) & m_2(1) & \dots & m_2(n) \\ \dots & \dots & \dots & \dots \\ m_o(1) & m_o(1) & \dots & m_o(n) \end{bmatrix} \quad (5)$$

where form $i(j)$, $i = 1, 2, 3, \dots, n$ number of trials, $j = 1, 2, 3, \dots, n$ number of output response parameters. In this present research, $O = 27$, $n = 2$ and M are the GRC of individual response parameters

Step (ii) Formation of correlation matrix P_{ji} :

Now, the correlation matrix P_{ji} is attained from Eq. (6)

$$P_{ji} = \left(\frac{\text{Cov}(x_i(j), x_i(l))}{\sigma_{x_i(j)} \times \sigma_{x_i(l)}} \right) \quad (6)$$

Where $j = 1, 2, \dots, n$, and $l = 1, 2, \dots, n$.

Herein, $\text{Cov}(x_i(j), x_i(l))$ is the co-variance of sequences $x_i(j)$ and $x_i(l)$;

$\sigma_{x_i(j)}$ is the standard deviation of the sequence $x_i(j)$;

and $\sigma_{x_i(l)}$ is the standard deviation of sequence $x_i(l)$.

Eigen vectors and Eigen values are obtained from correlation coefficient matrix presented as Eq. (7)

$$(R - \lambda_k I_m) \cdot V_{ik} = 0 \quad (7)$$

Where, $k = 1, 2, \dots, n$,

$V_{ik} = [ak1, ak2, \dots, akn]^T$ Eigen vectors corresponding to the Eigen value λ_k .

Here the response parameters such as surface roughness and circularity error are analyzed by using ANOVA. The multi-objective optimization of process parameters are carried using GRA coupled PCA. The response quality decides weighting value ω_k for each parameter is estimated via PCA. The GRG-PCA value is expressed as in table 2.

Table 2: Eigen Values and Explained Variation for PCs

Principal Component	Eigen Values	Explained Variation %
First	0.8015	45.08
Second	0.9762	54.91

Table 2 shows that the first principal component carries Eigen value of 0.8015 followed by second PC of 0.9762. The first PC contributes 45.08% of the total and rank as one followed by the second PC contributes 54.91% and holding

the second rank. The eigen vectors are used to transforming the data into principal components. The eigen vectors define only directions they are of arbitrary length. The sign of the eigenvectors is arbitrary. Generally negative values are preferred.

Table 3: The Eigenvectors for Principal Components and Contribution

Response Variable	Eigen Vectors		Contribution
	First Principal Component	Second Principal Component	
Surface Roughness	-0.7071	0.7071	0.49999
Circularity Error	0.7071	0.7071	0.49999

As per the PCA, contribution of surface roughness and circularity error are considered as 0.4999 from the table 3. In addition, variance contribution for the first principal component characterizing the two responses is as high as 54.91%. Therefore, in the present work, the squares of its subsequent eigenvectors are preferred as weighing values of the associated responses, and coefficients of GRG.

RESULTS AND DISCUSSIONS

Conventional drilling on GFRP composite material is performed as per the taguchi design of experiments to minimize the number of experiments. The multi- objective optimization is performed by taguchi based GRG coupled PCA which is the indicating response parameter for the two experimental results. The experimental results of GRC and GRG are listed in table 1.

Table 4: GRC, GRG and Rank of the Surface Roughness and Circularity Error

Exp. No.	Grey Relational Coefficient (GRC)		Grey Relational Grade (GRG)	Rank
	Surface Roughness	Circularity Error		
1	0.417529	0.899666	0.658584	4
2	1	0.770774	0.885369	1
3	0.577663	0.924399	0.751016	2
4	0.579576	0.364005	0.471781	6
5	0.621657	0.38156	0.501599	5
6	0.432857	1	0.716414	3
7	0.333333	0.333333	0.333327	9
8	0.558252	0.346203	0.452219	8
9	0.364702	0.543434	0.454059	7

GRA coupled PCA based optimization method has been adopted in sequence to achieve least surface roughness and circularity error. From the table 1 it is observed that higher the GRG value is considered as rank one, which shows the optimal combination to achieve the minimum surface roughness and circularity error. The corresponding optimal process parameters setting shows the cutting speed at level 1(400 rpm), feed at level 2(0.04 mm/feed), thickness at level 2 (6 mm) and fiber orientation at level 2 (45°). From the response table it is observed that cutting speed assigned as rank 1 which means that cutting speed is the most significant parameter affecting the response parameters as surface roughness and circularity error, later followed by the feed, fiber orientation and material thickness.

Table 5: Response Table for Means

Level	Speed(rpm)	Feed(mm/rev)	Thickness(mm)	Fiber Orientation(Degree)
1	0.7650	0.4879	0.6091	0.5381
2	0.5633	0.6131	0.6037	0.6450
3	0.4132	0.6405	0.5286	0.5583
Delta	0.3518	0.1526	0.0804	0.1070
Rank	1	2	4	3

Figure 1: Main Effects Plot for GRG.

Optimal process parameters can be selected from the fig. 1 to minimize the surface roughness and circularity error such as speed at level 1 (400 rpm), feed at level 3 (0.06 mm/rev), specimen thickness at level 1 (4 mm) and fiber orientation at level 2 (45°). Finally ANOVA analysis (95% confidence level) was conducted to know the most significant process parameter and percentage contribution of each parameter on GRG. Among all the selected process parameters, cutting speed is the most significant factor affecting the roughness and circularity error with 72.42 % of contribution this is observed from the table 6, followed by contribution of feed (at 15.38%), fiber orientation (at 7.50%) and specimen thickness (at 4.70%).

Table 6: Analysis of Variance

Source	DF	Seq SS	Adj SS	Adj MS	Contribution
Speed (rpm)	2	0.18697	0.18697	0.093483	72.42%
Feed (mm/rev)	2	0.03971	0.03971	0.019853	15.38%
Thickness (mm)	2	0.01214	0.01214	0.006068	4.70%
Fiber Orientation (degree)	2	0.01937	0.01937	0.009683	7.50%

Figure 2: Interaction Effects of Process Parameters.

Fig.2 shows the interactive effects of process parameters on surface roughness and circularity error. Non-parallelism of lines in interaction plot having significant effect on response parameters. It can be seen that combinations of speed & feed, speed& thickness, speed & fiber orientation, feed & thickness and thickness & fiber orientation having much influence on response parameters.

Regression Equation

$$\text{GRG} = 0.890 - 0.000440 s + 3.81 f - 0.0201 t + 0.000225 f_o \quad R\text{-Sq}=89.43 \quad (8)$$

Figure 3: Probability Plot for GRG.

Fig. 3 shows the normal probability plot for standardized residual. The model adequacy (Eq. 8) is checked by using normal probability plot. It is evident that the process follows the normal distribution without any deviation (no outlier). Hence, it may be concluded that the proposed model performs satisfactory.

CONCLUSIONS

This paper highlights the applications of multi-objectives optimization techniques (hybrid approach) such as grey relational analysis (GRA) amalgamated with principal component analysis (PCA) to identify the optimal process parameters. The contributions of this paper have been summarized as follows.

- From the experimental studies it is found that surface roughness and circularity error of the drilled hole is severely affected by the cutting speed of spindle followed by feed rate. Also found that thickness of material having least effect on the circularity and roughness.
- Multi-objective optimization is carried to select the Optimal process parameters such as speed at level 1 (400 rpm), feed at level 3 (0.06 mm/rev), specimen thickness at level 1 (4 mm) and fiber orientation at level 2 (45°), to optimize the surface roughness and circularity error.
- The significant effect of each process parameter is analysed using ANOVA and observed as cutting speed is having highest contribution of 72.42% and thickness having least contribution of 4.70%

REFERENCES

1. K. Palanikumar, B. Latha, 2012, *Analysis on Drilling of Glass Fiber-Reinforced Polymer (GFRP) Composites Using Grey Relational Analysis, Materials and manufacturing processes*, 27: 297–305, 2012.
2. Raja, R., and SabithaJannet. "Experimental investigation of high speed drilling of glass fiber reinforced plastic (GFRP) composite laminates made up of different polymer matrices." *Int. J. Mech. Prod. Eng. Res. Dev* 7.6 (2017): 351-358.
3. T. Rajmohan, 2019 , *Experimental Investigation and Optimization of Machining Parameters in Drilling of Fly Ash Filled Carbon Fibre Reinforced Composites*, *Journal of Particulate Science and Technology* , Volume 37, 21-30.
4. H. RezghiMaleki, M. Hamed, 2019, *Experimental investigation on drilling of natural flax fiber-reinforced composites*, *Material science and manufacturing*, Volume 34, 283-292.
5. Mohan, Nanjangud., Sathyashankara Sharma, and Ritesh. Bhat. "A comprehensive study of glass fibre reinforced Polymer (gfrp) drilling." *International Journal of Mechanical and Production Engineering Research and Development* 9.1 (2019): 1-10.
6. VijayanKrishnaraj, 2012, *Optimization of machining parameters at high speed drilling of carbon fiber reinforced plastic (CFRP) laminates*, *Composites: Part B* 43, 1791–1799.
7. C. L. Tan, A. I. Azmi, N. Muhammad, 2016, *Delamination and surface roughness analyses in drilling hybrid carbon/glass composite*, *Materials and Manufacturing*, Volume 31, P: 1366-1376
8. Khaled Giasin & Sabinosoberians, 2017, *An Investigation of Burrs, Chip formation, Hole Size, Circularity and Delamination during Drilling Operation of GLARE using ANOVA*, *Composite Structures Volume*, Pages 745-760.
9. Chinta, Venkata Sushma, Y. Nagini, and V. Sandhya. "Investigation of mechanical properties of bidirectional carbon/glass reinforced epoxy hybrid composites." *Int J Mech Prod Eng Res Dev* 8.3 (2018): 449-456.
10. M. S. Sureshkumar, D. Lakshmanan& A. Murugarajan (2014) *Experimental investigation and mathematical modelling of drilling on GFRP composites*, *Materials Research Innovations*, 18:sup1, S1-94-S1-97.
11. Eshetu D Eneyew, MamidalaRamulu, 2014, *Experimental study of surface quality and damage when drilling of unidirectional CFRP composites*, *journal of materials research and technology*, 3(4): 354-362
12. Rout, Arun Kumar, and Jitesh Kumar Singh. "An Overview of Advanced Fiber Reinforced Polymer Composites and It's Applications." *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)* 8 (2018): 311-318.
13. T. Rajmohan& K. Palanikumar (2012) *Optimization of Machining Parameters for Surface Roughness and Burr Height in Drilling Hybrid Composites*, *Materials and Manufacturing Processes*, 27:3, 320-328

14. C.C. Tsao, H. Hocheng, [2008], *Evaluation of thrust force and surface roughness in drilling composite material using Taguchi analysis and neural network (ANN)*, *journal of materials processing technology* 203 (2008) 342–348.
15. K.Siva Prasad, G. Chaitanya, *Selection of optimal process parameters for surface roughness and circularity for Drilling GFRP composites using Taguchi Technique*, *International Journal of Pure and Applied Mathematics*, Volume 118 No. 24 2018.