Experimental Investigations and Multiple criteria Optimization during Milling of Graphene Oxide (GO) doped epoxy/CFRP Composites Using TOPSIS-AHP hybrid Module

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The present study developed a robust hybrid module for multi-criteria optimization of conflicting machining performances during milling of GO doped Epoxy/CFRP composites. Doping of GO radically increased the dispersion ratio which creates a better interaction of matrix and reinforcement. The machining behavior of these polymers significantly differs from metals and their alloys. The process constraints were considered as spindle speed (S), feed rate (F), depth of cut (D) and GO wt. percent (GO). Taguchi L9 OA was used in the combined optimization approach of AHP and TOPSIS. The optimum parametric combination was obtained as S2F2D1GO1 which shows substantial improvement in desired machining characteristics. The optimal results were verified through a confirmatory test, which shows good agreement with actual ones. The minimum roughness, cutting force and maximum MRR are found as 0.730 μm, 4.706 N, and 17.0484 mm^3/s, respectively. The ANOVA inferred that S (79.55%) and F (4.80%) are the most important parameters for overall assessment value.

Keywords: *TOPSIS, AHP, Taguchi, Graphene, Optimization.*

1. INTRODUCTION

Now-a-days, Polymeric materials are receiving more attraction for a wide range of applications in aircraft, biomedical, automobile, marine, gas and chemical trades due to elevated specific strength, resistance to corrosion and relatively low strength-weight ratio. But due to anisotropic inhomogeneity structures, the manufacturer is facing some restrictions such as the method of weave, fiber pull, matrix debonding, delamination, surface issues, etc during fabrication and machining of polymeric materials. Therefore, machining of FRP materials becomes a critical task for manufacturing industries, practicing engineers and academia. [1]. Also, these crucial machining issues result in rapid tool wear at lowered temperatures, thus increasing the machining costs and the tool costs. Unconventional machining processes are developed to address the limitations of traditional machining processes. CNC milling is one of the primarily used unconventional machining methods that has pioneered the manufacturing and industrial sector[2]. The performance of milling mainly depends on the proper range of input constraints for maximizing material removal rate (MRR), minimizing surface roughness (SR) and cutting force (Fc)[3]. The novelty of this paper solves this problem for the first time with TOPSIS-AHP methods for GO-CF reinforced epoxy composites. The MCDM method is the most effective tool for resolving tangled optimization problems in the machining/manufacturing industry[4]. Milling is commonly used in manufacturing processes because it provides significant advantages such as good quality material, customer satisfaction, cost-effectiveness and relatively easy application[5]. Majumder et. al. [6] developed a hybrid approach of MOORA embedded PCA using Taguchi L27 OA for Turning on ASTM A588 mild steel to determine the optimum combination of input parameters (spindle speed, cutting depth and feed rate) for the given output response. With ASTM A588 mild steel, the optimal combination of parameters with multi-performance characteristics is found as spindle speed 160 rpm, cut depth 0.1 mm and feed rate 0.08 mm / rev. Singaravel et al. [7] experimental study were carried out to determine optimal processing parameters for turning EN25 steel by use of a combined TOPSIS and the Analytical Hierarchical Process (AHP) technique with coated carbide tools. They found a multi-objective optimization approach for reducing microhardness, surface roughness and optimizing MRR simultaneously. Yih-Fong et. al. [8] experimental study of the high-speed CNC milling process was carried out to enhanced process efficiency, durability, and robustness. They have successfully applied Taguchi dynamic method in combination with the proposed ideal design to create an optimized high-speed CNC milling process through high-dimensional performances. Besides, three common geometries, square, circle, and triangle were considered to essentially geometrical variations in the mold and die for use in all experimental activities. Experimental results have shown that optimum conditions greatly enhance the

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dimensional accuracy of the machined product. Kumar et al [9] described optimizing process parameters for CNC milling to ensure better surface finishing and a high MRR. Taguchi's concept was used to perform the experiments and machining parameters optimization. They selected the different machining parameters such as speed, feed rate and depth of cut over the response of MRR and surface finish. They found that the speed was the influenced value for Ra, Feed, and Depth of Cut (DOC) for MRR. Krishnamoorthy et al. [10] were taken an attempt with surface response technique to develop the delamination factor and surface roughness model in GFRP composite machining. They were considered the experimental work with three-factors and five-level used the central composite design (CCD). Finally, concluded that feed rate is the factor that has higher influence in drilling of GFRP composites on the delamination and surface roughness. It also described the response surface plots and three-dimensional interaction plots for better data prediction. Ragunath et al**.** [11] presented machining study on the fiber-reinforced composites. The study was mainly covering delamination factor during the machining on FRP composites. They considered the process parameters, material parameters, types of fabrication and optimization techniques were discussed. From the study, the feed rate was one of the most influential controllable factors among all the process parameters such as applied load, sliding distance, drill bit diameter, point angle, and chisel edge. The work on fiber-reinforced polymer composites under the influential factor was effectively studied. Wang et al. [12] investigated properties like surface energy and roughness using the SEM, TEM and AFM techniques through increasing the interfacial strength as well as tensile strength in the modified carbon fiber graphene reinforced polymer composite. The author revealed the outbalance by 86.1 % tensile strength while introducing graphene to the Carbon fiber by a chemical vapor deposition method. Ning et al. [13] conducted experimental work and prepared composite using a novel graphene material with the continuous CFs sheet with epoxy hardener. Results were demonstrated using FEM technique which indicates an enhancement in mechanical toughness and increment of fracture properties by 170.8%, 108% respectively with a comparison to a plain sample. Jiang et al. [14] synthesized graphene-coated onto the carbon fiber composite using the EPD technique for improvement of the interfacial bond. Finally, the result revealed 46.4% tensile strength in graphene multiwall carbon fiber composite. They proposed the mechanical method for mixing of multiwall graphene and CFs sheet. Chi et al. [15] prepared composite by directly growing GNWs on the CFs using the CVD method. They claimed that the bonding between them was very strong by consideration of a robust model through the SEM technique and concluded that the interfacial strength increased by 173 % as compared to without using GNWs composites. Dichiara et al. [16] negotiated hybrid reinforced composite by the growth of CNTs on GNPs within the epoxy matrix. The result was increased by 36%, 40% tensile strength and the young modulus of elasticity respectively. They have also performed the modeling technique to predict the combination of CNTs and GNPs composite. Li and Chem [17] proposed a new composite material adjoining graphene oxide and CFs via chemically grafted. They made a final decision that feasible composite materials became higher in performance and enhanced in surface properties as well as interfacial adhesion. Huang et al. [18] introduced the graphene on CFs using EPD method for preparation of composite. The presented sample possessed enhanced surface tropology that leads to increment in shear strength and the interfacial adhesion between them. Zhang et al. [19] used an experimental method to improve the properties of carbon fiber polymer composites; they exfoliated the graphene oxide directly to the carbon fiber and used the technique (AFM, SEM) to verify the surface morphology, also investigated the interfacial bonding between them. Thus, results demonstrated, increased strength as well as interlaminar adhesion with 5 wt.% graphene oxide while introduced on carbon fiber. Kumari and Kumar [20] examined the competency of CFs graphene reinforced at a Nanoscale. They synthesized composite by hand layup method with a sonicate equipment in the vacuum chamber under different graphene 2%-10% weight of epoxy-hardener and analyzed using tension test, three-point bending. The result was presented as reduced deformation and increment in strength as well as stiffness. Kumar and Singh [21] find out and illustrates the problem formulation during the cutting of Multi CFRP composite material. They have faced the delamination problem while the drilling of sample. Rajkumar et al. [22] optimized the cutting process parameter of CFRP composite material using the Taguchi based desirability module to get a significant parameter like MRR and Ra. The experiment was conducted on CNC machine for requirement of micro-drilling. Desirability concept has very useful functional analysis to optimized multiple response problem. In this machining procedure are considered the cutting speed, depth of cut and feed rate as input process parameters. Finally, they conducted ANOVA for analysis a covariance of the process parameter and performance characteristics and also concluded that the drilling parameter influenced feed rate, spindle speed and air pressure by 39.21%, 49.32% and 8.58% respectively. Pathak et al. [23] investigated enhanced properties of polymer composite using a different weight percent (0.1 to 0.6 %) of graphene oxide as a filler material combined with the CFRP and they used the FTIR, XPS and Raman Spectroscopy for characterization of graphene oxide. Finally, they concluded that the strength of composite materials was increased by 66% and modulus of elasticity was increased by 72%.

Previous studies demonstrate that optimizing machining performances of carbon fibers reinforced polymers is still a critical and challenging task to obtain better performance and meet the industrial requirements of the produced parts. The purpose of this paper is to improve surface quality through the use of the SiC (TiAlN coated) tool in the face milling process. This paper focuses on the optimization of the four process parameters viz, spindle speed, feed rate, depth of cut and wt. % of GO. Performance characteristics taken into consideration are material removal rate, surface roughness and cutting force. The optimization process was performed using TOPSIS embedded AHP. An attempt has been made to study the machining aspects of GO doped polymeric material and also, to overcomes the drawbacks and limitations of existing optimization techniques by implementing the combined approach of TOPSIS-AHP.

2. EXPERIMENTATION

The experimentation was performed on a vertical CNC milling (Figure 1) machine. Silicon carbide coated TiAlN cutter having a 05 mm diameter was used.

Table 1 shows the limits of machining parameters and the number of levels considered during the milling operation. In the current research, three machining characteristics i.e. MRR (mm3/s), cutting force (N) and Ra (μm) has been considered as quality and productivity concerns (depicted in Table 2).

Figure 1. Milling setup

Figure 2. Surface roughness setup

The MRR is computed by using the expression:

$$MRR = \frac{Initial\ weight - Final\ weight}{density \times Time} \quad (1)$$

The Surface Roughness Tester (Taylor Hobson) measured (Figure 2) Ra of the machined surface. The cut-of-length of 5 cm was chosen, each specimen was cleaned before measurement, and for each surface, the average Ra values were decided. The measurements are taken on the machined surface at three different locations and finally, the mean values were considered.

Table 1. Domain of experiemet

Parameters	Symbol	Level 1	Level 2	Level 3
Spindle Speed	S	800	1600	2400
Feed Rate	F	80	160	240
Depth of cut	D	0.5	1	1.5
Wt.%	GO	1	2	3

Table 2. Taguchi L_9 experimental array and corresponding observed data

S. No	Process parameter				Machining response		
	S	F	D	GO	MRR	F_c	R_a
1	800	80	0.5	1	3.7936	15.7799	1.1200
2	800	160	1	2	11.7803	42.5790	1.4866
3	800	240	1.5	3	11.1813	60.0751	1.3966
4	1600	80	1	3	10.7820	17.7565	1.3133
5	1600	160	1.5	1	12.3793	16.7800	1.4833
6	1600	240	0.5	2	15.9733	5.6020	0.7833
7	2400	80	1.5	2	9.1846	53.6754	1.5400
8	2400	160	0.5	3	4.5923	9.5343	1.0200
9	2400	240	1	1	7.5873	4.7354	1.9300

3. PARAMETRIC OPTIMIZATION

3.1 Single objective optimization: Taguchi Approach

The Taguchi philosophy is a very effective statistical technique used when interacting with varying process parameters influencing the machining performances. It is a systematic approach that designs and analyzes the tests used to enhance the quality of the product at a low cost. It is designed to optimize a single characteristic of output [24]. By this technique, the multiple machining response evaluations become arithmetically simple. In this study, spindle speed 800-2400 rpm, feed rate 80-240 mm, depth of cut 0.5-1.5 mm and GO wt. percent of 1-3 percent were selected as input system constraints, based on the existing literature survey; accordingly, Taguchi L9 OA has been used to perform the experimentation work. The signal-to-noise (S/N) ratios were determined from experimental data. MRR is considered as "higher the better" (HB) criteria, and SR and Fc are taken as "lower the better" (LB) criteria. Optimization of one response may adversely affect other function and the overall function becomes undermined. Because of these causes, it is more difficult to optimize the correlated multiple performances than to optimize a single performance. The hybrid AHP – TOPSIS approach is used in this study to investigate the various conflicting machining characteristics of the milling process.

3.2 Multi-objective optimization: TOPSIS- AHP Hybrid approach

AHP is an efficient MCDM module for multi-response aggregation and complex issues of optimization engineering. AHP is considered as one of the most prominent analytical methods of multi-objective functions developed by Thomas (1970) for solving complicated decision-making (DM) problems. AHP is commonly used as a DM tool because it can manage subjective judgment decision conditions and deliver preferential consistency [25]. The following step has been taken for the weight calculation in AHP:

Step 1: Matrices have been developed to accomplish the pair-wise evaluations as defined in Eq. (2). In the corresponding level, the decision criteria are compared using an important comparison scale. The reference scale used by AHP is shown in Table 3.

$$A_{ij} = \begin{bmatrix} 1 & a_{12} & a_{13} \\ a_{21} & 1 & a_{23} \\ a_{31} & a_{32} & 1 \end{bmatrix}, i = 1,...,m; j = 1,...,n \quad (2)$$

Step 2: The scales for attributes are extracted from Table 3, as can be seen in the above matrix. The three functions are taken as MRR, SR, and Fc. The attribute's weight hereby is measured using geometric mean methods. Table 4 displays the geometric mean of the reference matrix and the values observed.

Table 3. The fundamental scale

The intensity of the absolute scale	Description
1	Identical significance
3	Modest significance of one over other
5	Key robust significance
7	Very strong significance
9	Intense significance
2,4,6,8	Intermediary values between the two contiguous

Table 4. Pair-wise comparison matrix

Response	MRR	Ra	Fc	The third root of the product	Priority vector
MRR	1	7	5	2.3513	0.4364
Ra	1/7	1	6	1.9258	0.3575
Fc	1/5	1/6	1	1.1097	0.2060

$$MRR: (1+7+5)^{\frac{1}{3}} = 2.351$$

$$Ra: \left(\frac{1}{7}+1+6\right)^{\frac{1}{3}} = 1.9258$$

$$Fc: \left(\frac{1}{5}+\frac{1}{6}+1\right)^{\frac{1}{3}} = 1.1097$$

$$2.3513 + 1.9258 + 1.1097 = 5.3868$$

$$MRR: \frac{2.3513}{5.3868} = 0.4364$$

$$Ra: \frac{1.9258}{5.3868} = 0.3575$$

$$Fc: \frac{1.1097}{5.3868} = 0.2060$$

$$MRR: (1+1/7+1/5) \times 0.4364 = 0.5860$$

$$Ra: \left(7+1+\frac{1}{6}\right) \times 0.3575 = 2.9195$$

$$Fc: (5+6+1) \times 0.2060 = 2.472$$

$$\lambda_{\max} = 0.5860 + 2.9195 + 2.472$$

$$\lambda_{\max} = 5.9775$$

Step 4: Measurement of Inconsistency

$$Consistency\ index(CI) = \frac{(\lambda_{\max} - n)}{(n-1)}$$

$$CI = \frac{5.9775 - 3}{3-1}$$

$$CI = 1.4887$$

$$CR = \frac{CI}{RI} = \frac{1.4887}{0.52}$$

As we have taken three process response, the pair comparisons of the decision-maker are quite constant. The achieved weights are as follows: W_{MRR} = 0.4364, W_{Ra} = 0.3575 and W_{Fc} = 0.2060.

4. TOPSIS TECHNIQUE

The TOPSIS approach was established by Hwang and Yoon (1981) for computation of the distance between the two types of solutions. The data calculates alternatives nearest to the ideal positive solution and far away from the ideal negative solution. The behaviors of ideal positive solutions maximize profit criteria and minimize cost criteria, while in the case of ideal negative solution maximizes cost criteria and minimizes profit criteria. The following step was considered for the desired optimal solution.

Step 1: Initially defining the objective function and classify all the alternatives as MRR, SR, and Fc.

Step 2: Select the decision matrix using Eq. (3) consisting of alternatives m and n attributes:

$$D_m = \begin{bmatrix} x_{11} & x_{12} & x_{13} \\ x_{21} & x_{22} & x_{23} \\ \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & x_{mn} \end{bmatrix} \quad (3)$$

Step 3: Normalized process performance is using Eq. (4) as depicted in Table 5

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (4)$$

where x_{ij} denotes the authentic value of the ith value of jth trial.

Step 4: The weighted normalized decision matrix (Vij) is calculated as the product of the normalized decision matrix r_{ij} with its associated weights (Wj) and depicted in Table 6.

$$V_{ij} = W_i \times r_{ij}$$

Step 5: Positive and negative ideal solutions are estimated:

$$V_j^+ = \left\{ \sum_{i=1}^{\max} \left(\frac{V_{ij}}{j} \in j \right), \sum_{i=1}^{\min} \left(\frac{V_{ij}}{j} \in J^1 \right) \right\} \quad (6)$$

$$V_j^- = \left\{ \sum_{i=1}^{\min} \left(\frac{V_{ij}}{j} \in j \right), \sum_{i=1}^{\max} \left(\frac{V_{ij}}{j} \in J^1 \right) \right\} \quad (7)$$

The separation from the positive ideal solution is analyzed by using Eq. (8)

$$S_j^+ = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - V_j^+ \right)^2} \quad i= 1,2,\ldots..m \quad (8)$$

The separation from the negative ideal solution is analyzed by using Eq. (9)

$$S_j^- = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - V_j^-\right)^2} \quad i= 1,2,\ldots..m \tag{9}$$

Step 6: In this step, the relative proximity M_i^+ of a alternative to the ideal solution can be expressed

$$M_i^+ = \left(\frac{S_i^-}{S_i^+ + S_i^-}\right) \tag{10}$$

It has performed to aggregate responses for each alternative into one output response value Table 7 Shows positive or negative ideal solution relative closeness values to its ranks.

5. RESULTS AND DISCUSSION

Machining parameters considered in this study are S, F, D, and GO wt. %, while MRR, Ra, and Fc are machining characteristics. Among these performances, MRR is beneficial where a higher value is desirable and, Ra and Fc are assumed as not beneficial, i.e. a lower value is desirable. The S / N ratio of the Taguchi model is used to determine the optimal setting of machining constraints for an individual attribute S, F, D and GO respectively are shown in Fig. 3–5.

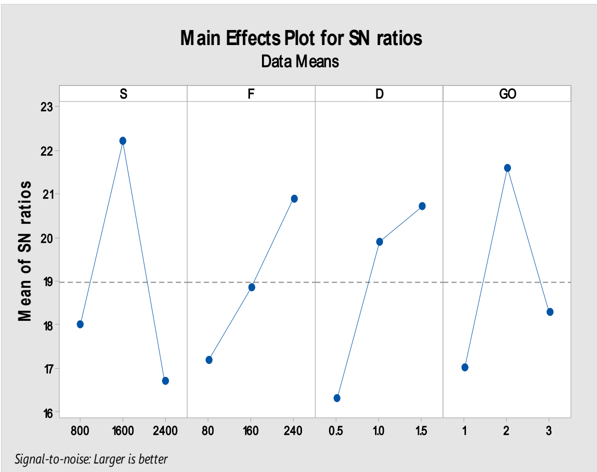

Figure 3. S/N ratio for MRR

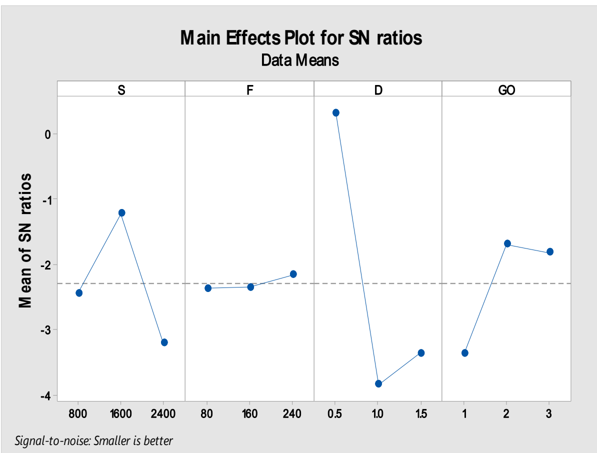

Figure 4. S/N ratio for Ra

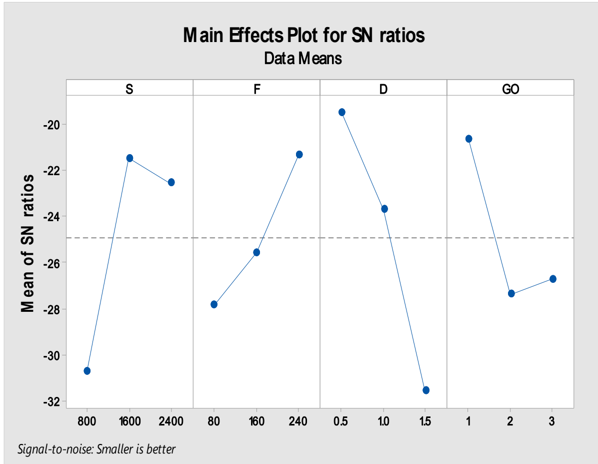

Figure 5. S/N ratio for Fc

It is observed that separate response has a specific combination of parameters. In this way, the optimum input constraints defined by the Taguchi (Fig. 3) for the higher MRR are S=1600 rpm, F=240 mm, D=1.5 mm, and GO=2%. The optimum input parameters calculated by the Taguchi S / N ratio (Fig. 4) for the smaller Ra are S=1600 rpm, F=240 mm, D=0.5 mm, and GO=2%. For the smaller Fc, the optimum input parameters calculated by the Taguchi technique (Fig. 5) are S=1600 rpm, F=240 mm, D=1 mm, and GO= 1%.

In the TOPSIS technique, initially, the decision matrix data was first altered into dimensional values by Eq. (4), and the uniform value of each output variable normalized value was determined as shown in Table 5. AHP approach was implemented in the next step, and the relative weights of each performance characteristic were calculated and accordingly weightage matrix (Tables 6) was developed for which specific contributions for MRR, Ra, and Fc are taken as 0.4364, 0.3575 and 0.206 respectively. Finally, the overall performance in terms of relative proximity (M_i^+) was calculated using Eq. (10) as depicted in Table 7. Evaluation value arranges in descending, and ranking has performed according to the TOPSIS method. In Taguchi L9 OA, experiment number six shows maximum value and corresponding setting of machining constraints as S2F3D1GO2 (S = 1600, F = 240, D = 0.5 and GO = 2%.). The optimal setting from S/N ratio plot (Fig 6) of TOPSIS-AHP aggregated function value is found as S2F2D1GO1 (S = 1600, F = 1600, D = 0.5 and GO = 1%.). Table 8 shows the response table for means which determine the delta value of process parameters.

Table 5. Normalized values for optimal machining

Exp. No	Normalized		
	MRR	Fc	Ra
1	0.122069	0.163687	0.270917
2	0.379055	0.441675	0.35961
3	0.359781	0.623164	0.33784
4	0.346932	0.18419	0.317682
5	0.398329	0.17406	0.358803
6	0.513973	0.05811	0.18948
7	0.295534	0.556779	0.37251
8	0.147767	0.0989	0.246728
9	0.244137	0.049122	0.466847

Table. 6. Weightage matrix

Exp. No	Weight matrix		
	MRR	Fc	Ra
1	0.279717	0.794596	0.757809
2	0.868595	2.144054	1.005901
3	0.824429	3.025066	0.945006
4	0.794986	0.894126	0.888621
5	0.912761	0.844952	1.003645
6	1.177756	0.282087	0.530015
7	0.67721	2.702811	1.041987
8	0.338605	0.480098	0.690147
9	0.559434	0.238454	1.305867

Table 7. Overall assessment value

Exp. No	S^+	S^-	M^+
1	1.080583	2.296816	0.680054747
2	1.988306	1.101335	0.326089782
3	2.839412	0.6534	0.193462621
4	0.839653	2.231703	0.660775855
5	0.813872	2.290193	0.678093686
6	0.043633	2.988705	0.884913283
7	2.566265	0.575744	0.170469717
8	0.887812	2.619053	0.77546468
9	0.992103	2.800615	0.829222715

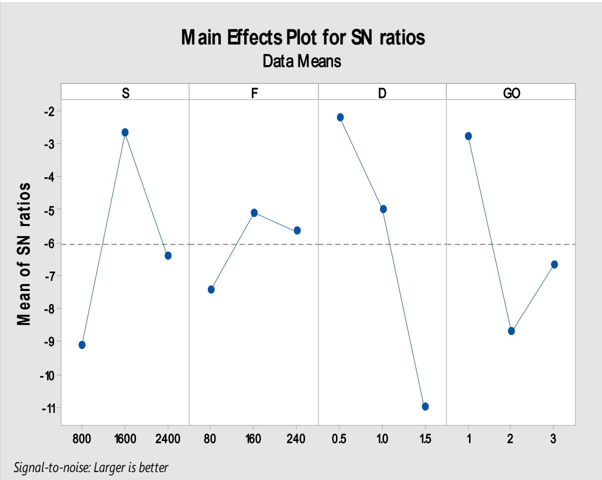

Figure 6. S/N ratio for the overall assessment

Table 8. Response Table for Means

Level	S	F	D	GO
1	0.3999	0.5038	0.7801	0.7291
2	0.7413	0.5932	0.6054	0.4605
3	0.5917	0.6359	0.3473	0.5432
Delta	0.3414	0.1321	0.4328	0.2686
Rank	2	4	1	3

6. ANOVA TEST

ANOVA is used to identify the effects of the most influencing factor for machining performances. Table 9 provides the ANOVA results for TOPSIS embedded AHP aggregated optimized function of MRR, Ra, and Fc inferred that factor S is the most important parameter for the milling operation with 79.55% of the contribution, feed rate (4.80 %), depth of cut (2.84 %) and wt. % (0.03%) for the maximization of the MRR and minimization of the cutting force & surface roughness.

Table 9. ANOVA test for overall assessment (M^+)

Source	DF	Seq SS	Contribution	P-Value
Regression	4	3.14300	87.21%	0.019
S	1	2.86664	79.55%	0.122
F	1	0.17296	4.80%	0.175
D	1	0.10231	2.84%	0.349
GO	1	0.00109	0.03%	0.918
Error	5	0.46076	12.79%	
Total	9	3.60376	100.00%	

7. CONFIRMATION TEST

The confirmation test was carried out to determine the performance characteristics of GO-CFs doped epoxy composites following the optimum setting with their selected levels. Table 6 demonstrates that experiment number 6 has the maximum prefer solution value which corresponds to the optimum input parameter setting of S2F3D1GO2 (according to the orthogonal array). Figure 6 presents the overall assessment value, indicating an optimum setting parameter of S2F2D1GO1 (by the TOPSIS/AHP method). The comparison of the experimental results using the orthogonal array (S2F3D1GO2) and the optimal TOPSIS / AHP design (S2F2D1GO1) of GO-CF doped epoxy composites are shown in Table 10.

Table 10. Confirmatory test outcomes

	Orthogonal setting	Optimal process parameters	Confirmatory
Optimal setting	S2F3D1GO2	S2F2D1GO1	S2F2D1GO1
MRR	15.9733	-	17.0484
Ra	0.78333	-	0.730
Fc	5.602	-	4.706
Overall assesment value	0.8849	1.1109	

The MRR shows an increase from 15.9733 mm3/s to 17.0484 mm3/s, surface roughness (Ra) decrease to 0.7402 µm from 0.7833 µm and a decreased cutting force (Fc) of 5.602 N to 4.706 N. The corresponding increase in MRR is 6.306 %, while Ra and Fc are respectively 5.502 % and 15.994. These improvements in machining characteristics are highly required for a favorable machining (Milling) environment.

8. CONCLUSIONS

In this study, CNC milling operation was performed according to Taguchi L9 orthogonal array on GO doped epoxy/CFs composites using TiAlN milling cutters. The combined approach of TOPSIS and AHP was used to optimize machining performances (MRR, Ra, and Fc). This relatively advanced approach is very effective in eliminating process fluctuations and a more supportive strategy than other MCDM approaches. Each response has been weighted and reduces the versatility of the process of Decision making (DM). Based on the result and discussion of this study following conclusion can be drawn:

(a) The TOPSIS-AHP hybrid MCDM approach consists of less computational efforts and a comparatively simpler calculation than the other traditional optimization methods. Therefore, it can be related to machining situations in which different conflicting responses is to optimized.

(b) Outcomes of TOPSIS coupled AHP reveals that MRR enhanced the value of 1.578 mm^3 / min to 1,826 mm^3 / min, Ra value of 0.331 μm to 0.287 μm is reduced, Fc reduced with the value of 1.867 N to 1.726 N. These desired improvements shows the satisfactory machining background for GO doped epoxy/CFs composites.

(c) The optimal setting obtained by the Taguchi approach is computed by using S / N ratio concept. For a higher value of MRR, the optimal setting is evaluated as S=1600 rpm, F=240 mm, D=1.5 mm, and GO=2 percent. For reduced values of Surface roughness (Ra) and Cutting force (Fc), the optimal setting is found as S=1600 rpm, F=240 mm, D=0.5 mm and GO = 2 percent and S=1600rpm, F=240 mm, D=1 mm, and GO=1 percent respectively.

(d) Overall optimum assessment values are found as 1.1109 and results of ANOVA inferred that spindle speed (79.55%) is the most dominant factor for milling performances trailed by feed (4.80%). The result of the TOPSIS-AHP approach shows the desired improvement in machining performances during milling of GO doped epoxy/CFs composites for online and offline quality monitoring in a very efficient way.

FUTURE SCOPE OF WORK

GO doped epoxy/CFs composites possess a wide range of engineering applications and improved mechanical properties as compared to other polymeric material. Hence machining and machinability aspect of these composites is a potential area of research for industries and academia. Factors such as fiber orientation, tool material, tool wear, mechanics of material removal, etc. can include in the future a better machining environment. TOPSIS-AHP is a generalized optimization method that can be customized for other machining processes (Turning, Drilling, etc.) of GO doped composites and other metal and ceramic matrix materials. Hence, it can be effectively endorsed for other case studies of industrial engineering for quality and productivity concerns of any types of manufacturing processes/products.

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NOMENCLATURE

S	Spindle speed
F	Feed rate
D	Depth of cut
GO	Graphene Oxide
CFs	Carbon fabrics
TOPSIS	Technique for order of preference by similarity to ideal solution
MRR	Material removal rate
Ra	Surface roughness
Fc	Cutting force
MCDM	Multi-criteria decision making
OA	Orthogonal array
CVD	Chemical vapor deposition
CNT	Carbon nanotube
TiAlN	Titanium aluminum nitrite
CR	Consistency ratio
AHP	Analytic Hierarchy Process
RI	Random Index

ЕКСПЕРИМЕНТАЛНО ИСТРАЖИВАЊЕ И ВИШЕКРИТЕРИЈУМСКА ОПТИМИЗАЦИЈА ОБРАДЕ ГЛОДАЊЕМ ЕПОКСИ-CFRP КОМПОЗИТА ДОПИРАНИХ ГРАФЕН ОКСИДОМ КОРИШЋЕЊЕМ TOPSIS-AHP ХИБРИДНОГ МОДУЛА

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Приказан је робустни хибридни модул развијен за вишекритеријумску оптимизацију противречности перформанси обраде приликом обраде глодањем епокси-CFRP композита допираних графен оксидом. Допирање графен оксидом повећава однос дисперзије што доводи до боље интеракције између матрице и ојачања. Понашање ових полимера приликом обраде знатно се разликује од понашања метала и њихових легура. Ограничења процеса представљају брзина вретена, брзина помоћног кретања, дубина резања и тежински проценат графен оксида. За комбиновани приступ оптимизације AHP и TOPSIS коришћен је метод Тагучи L9 OA. Добијена оптимална комбинација параметара је S2F2D1GO1 која показује значајно побољшање пожељних карактеристика обраде. Оптимални резултати су верификовани конфирматорним тестом и показују добро слагање са постојећим резултатима. Вредности минималне храпавости, силе резања и максимална брзина скидања материјала су: 0,730 μm, 4706 N и 17,0484 mm3/s. ANOVA је показала да су за укупну процену вредности најважнији параметри брзина вретена (79,55%) и брзина помоћног кретања (4,80%).