

## Utility-Taguchi based hybrid optimization approach in machining of graphite composites

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### Abstract

In the present scenario, composites material is widely used in various engineering areas like satellite components, aircraft parts, chemical and sports industries. Graphite is an allotrope of carbon that possesses various electrical and mechanical properties. In this paper, graphite is taken as reinforcement into the epoxy matrix. In this study, the hybrid optimization module is developed to tackle multi-objective machining performance optimization issues. Utility concept coupled Taguchi approach is used to find out optimum values of responses in three input factors i.e., drill speed, feed rate and fiber volume percentage varied at four discrete levels and surface roughness (Ra) and material removal rate (MRR) are taken as process response. Taguchi  $L_{16}$  OA has been used to perform the machining operation. Multiple responses aggregated into a single function i.e., overall utility (U) and finally optimized by the Taguchi concept. Utility embedded Taguchi approach determined the favorable machining setting which the confirmatory test has verified shows satisfactory results. ANOVA outcomes reveal that feed rate (73.37%) is the most important factor trailed by drill speed (3.44%) and fiber volume percentage.

**Keywords:** CNC, Graphite Reinforced Polymer Composite, Surface roughness, ANOVA.

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### 1. Introduction

Composite is the combination of two or more constituents that outcome best properties and high performance parametric than the individual materials. Basically, the constituents divided into two terms, reinforcements and matrix. The reinforcement phase provides the base for composite materials, so it very harder than the matrix phase. Polymer-based composite materials have less capability to sustain heat and are unable to plain thermal application. The various researchers have been distracted from improving the polymer composite's thermal properties. So, there have various filler materials used to increase the thermal as well as mechanical properties. Due to its superior properties like high strength, stiffness reduced weight composite materials are used in various fields such as aircraft, automotive and several other industries. Thus, it is necessary to machine the material at various stages. The graphite-polymer composite's basic characteristics have a 10 times higher rigidity than the glass fiber and density ( $1.8-2 \text{ g cm}^{-3}$ ) half of Gfs. It has excellent thermal and electrical properties and less in rupture compared to Gfs and aramids material.

(Bhatnagar et al., 2004) studied critical issues related to the machining of graphite-reinforced polymer composites and investigated the relationship among the point geometry, cutting speed, hole diameter, feed, point geometry, thrust force & material width during the drilling process. Finally, established a mathematical model to assess the damage due to cutting speed and feed. (Krishnaraj et al., 2012) concluded experimentally optimal cutting situations at speed and feed for CFRP drilling and illustrated the “peel up - push out” concept in the epoxy matrix. Finally, carried out the variance contribution rate using the ANOVA. Yu et al reported a procedure to convert natural graphite into graphite Nano polymer composite to enhance the thermal conductivity using acid intercalation. (Ganguli et al., 2008) prepared a graphite-epoxy composite with a different weight of percentage of graphite filled epoxy and enhanced the thermal, electrical properties over the pure epoxy. (Choi and Chang, 1992) Chang carried out a robust model to predicted damage stress analysis of graphite-epoxy composite and finally verified the tested data. (Tserpes et al., 2002) applied a FEM solution to predict the failure analysis under a bolted joint's strength in graphite-epoxy composites material. They were concluded that the failure of the joint affected by the failure degradation law and result was well agreed within 7% to the experimental.

(Kumar and Singh, 2019) conducted an experimental procedure to study a mechanism of cutting force and tool geometry of graphite-epoxy composites. (Verma et al., 2017) reported the optimized machining parameter to improve the productivity and the quality using the utility concept-based Taguchi approach. Taguchi L16 orthogonal array used for the design of the experiment at different levels of process parameters. (Hansda and Banerjee, 2014) reduced the delamination factor by the selection of optimized process parameters with the help of the utility-based Taguchi approach. (Vasudevan et al., 2014) applied a hybrid optimization technique to optimize the machining process parameter to improve productivity and quality of the product. (Krishnamoorthy et al., 2012) optimized the graphite-reinforced polymer composite drilling performances using a fuzzy concept. The combined approach of the Fuzzy and Taguchi process was used for machining characteristics optimization. (Kim, 2016) employed High-Speed Steel & carbide drills during drilling of GrBi (graphite fiber bisimide) complex and titanium alloy (Ti-Alloy) stacks. Carbides consuming greater hot toughness were found to accomplish better than consistent High-Speed Steel drills.

**2. Methodology**

**2.1 Taguchi Approach**

Taguchi based design of experiments (DOE) array was used to execute the machining operation. Taguchi concept is used to examine the machining parameter's influence over the lowest number of experimentations(Biswas et al., 2012; Rahul et al., 2018). The Taguchi method is used for the single response's statistical scale and used for computing the signal to noise ratio (S/N ratio)(Goswami and Kumar, 2014). Finally, the S/N ratio gives the optimal setting from the graph. In this study, the MRR of the process used as maximizing factor and surface roughness is considered lower than the better (LB) type.

Higher the Better (HB):

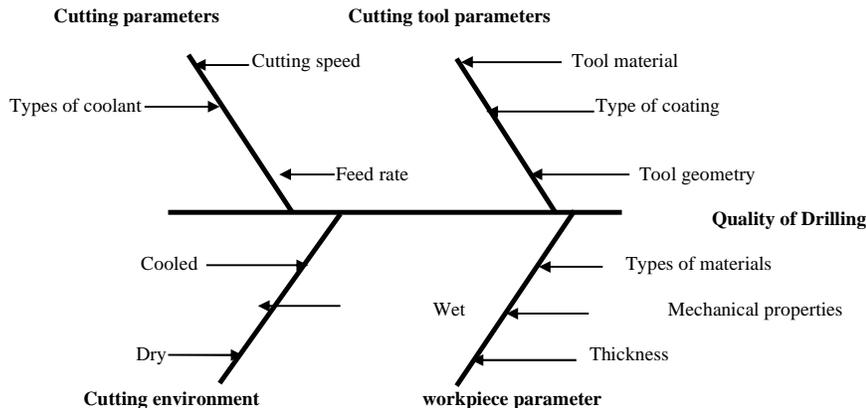
$$(S/N)_{ij} = -10 \log \left( \frac{1}{n} \sum_{j=1}^n 1/X_{ij}^2 \right) \tag{1}$$

Lower the Better (LB):

$$N_{ij} = -10 \log \left( \frac{1}{n} \sum_{j=1}^n X_{ij}^2 \right) \tag{2}$$

Where (S/N)<sub>ij</sub> is S/N ratio, X<sub>ij</sub><sup>2</sup> is measured significance data of the i<sub>th</sub> experimentation at the j<sub>th</sub> assessment.

A cause-effect diagram Fig 1, recognizes direct and indirect probable factors that affect the machining process. From the above literature survey on drilling, a total of three numbers machine parameters were selected at four discrete levels.



**Fig. 1.** Causes and effect diagram of the drilling process

**2.2 Utility Concepts**

The Utility concept is defined as a selection of performance numbers based on a logarithmic scale. This scale is falling under the specific range and converts the individual response into degrees performance utilities. Thus, it is useful to optimization the multi-objective response parameter. The concept of utility theory consists of the following steps:

- 1) Suppose  $K_i$  describes the preference number from given a choice and applying utility concept, then expression becomes as
- $$U(K_1, K_2, K_3, \dots, K_n) = f\{U_1(K_1), U_2(K_2)\} \tag{3}$$

Where  $U_1(K_1)$  = utility  $i^{th}$  function of choices.

- 2) find out the overall utility of specific utility expression as given
- $$U(K_1, K_2, \dots, K_n) = \sum_{i=1}^n U_i(K_i) \tag{4}$$

- 3) The stipulated weight on to emphasis, after deciding the weight and overall utilities expressed as
- $$U(K_1, K_2, \dots, K_n) = \sum_{i=1}^n W_i U_i(K_i) \tag{5}$$

Here, let summation of weight is 1 choice scale denote between two numbers 0 to 9 for accepted quality.

- 4) Calculated preferential number  $P_i$
- $$P_i = C \times \log\left(\frac{K_i}{K_i^*}\right) \tag{6}$$

Therefore  $C = \frac{9}{\log\left(\frac{K^*}{K_i}\right)}$

Where,  $A$  = constant and  $K^*$  = Best values

- 5) Finally, find out the overall utility expressed by the equation
- $$U = \sum_{i=1}^n W_i P_i \tag{7}$$

**3. Experimental Details**

**3.1 Work and Tool Materials**

The drilling was performed on CNC setup and the rate of material removal (MRR) and roughness of surface were considered as machining performances. The machine parameters namely, feed rate, spindle speed, and the fiber volume percentage are used in current work. The experiment has been conducted on a vertical CNC machine, using the HSS drill bit ( $\phi$  10 mm). It has maximum spindle speed 2500 rpm with a 4.5 KW motor as shown in Fig 2. Surface roughness measured by Taylor Hobson Surtronic S128 roughness tester and MRR measured by general mathematical formulae. The graphite-reinforced polymer composite was made of 70gm epoxy resin using graphite content (by weight varying as 10%, 20 %, 30 %, 40). The specimen is manufactured by heating and pouring of materials into the mold. The prepared sample as shown in Fig 3. This method is known as a casting method that can be made a variety of shapes or thicknesses with varying graphite weight percentages. Graphite (Mesh size 200) was supplied by Aakar carbon Pvt Ltd Jharkhand, India. Sample (7.8x8x1 cm) was prepared by combining LAPOX epoxy, hardener K-6, and graphite varying weight percentages (Fig 4).



**Fig. 2.** CNC vertical drilling machine



Fig. 3. Graphite reinforced a composite specimen



Fig. 4. Composite sample after machining

### 3.2 Design of experiments

In order to recognize the process parameter that affects the drilling parts to influences the quality of the drill part. There are three input parameters viz; drill speed, feed rate and fiber volume percentage with four different levels as depicted in Table 1. The experimental input parameter was listed in Table 2. In the present work, Taguchi-based  $L_{16}$  orthogonal array (Mini tab18) has considered for the experiment as depicted in Table 2 and the overall utility Table 3, respectively.

**Table 1:** Process parameters for different level

Factor	Units	Significance of Level			
		Level 1	Level 2	Level 3	Level 4
Drill speed	Rpm	1000	1500	2000	2500
Feed rate	mm/rev	150	200	250	300
FVP	%	10	20	30	40

**Table 2:** Taguchi  $L_{16}$  orthogonal array

Exp. No.	Drill rotational speed (rpm)	Feed rate (mm/rev)	FVP (%)	MRR ( $\text{mm}^3/\text{sec}$ )	Ra (avg) ( $\mu\text{m}$ )
1	1000	150	10	10.98	1.8
2	1000	200	20	12.27	1.3
3	1000	250	30	16.36	0.6
4	1000	300	40	19.21	1.3
5	1500	150	20	7.587	1.1
6	1500	200	10	12.35	1.5
7	1500	250	40	16.42	1.8
8	1500	300	30	19.90	1.0
9	2000	150	30	8.01	1.3
10	2000	200	40	12.06	0.9
11	2000	250	10	16.47	1.7
12	2000	300	20	20.63	1.9
13	2500	150	40	8.29	1.9
14	2500	200	30	12.30	2.5
15	2500	250	20	18.16	1.0
16	2500	300	10	19.61	1.0

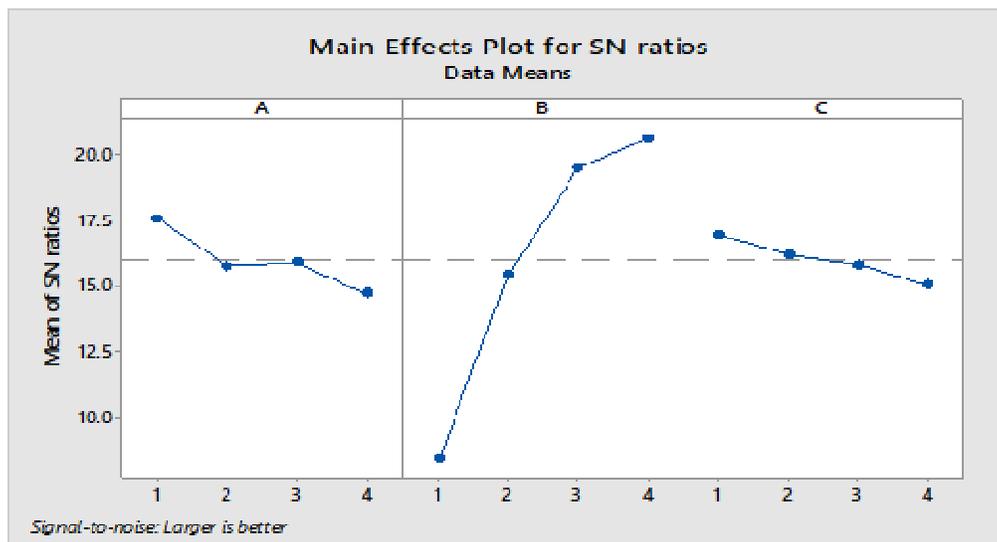
**Table 3:** Overall utility with S/N ratio

Exp. No.	Pi MRR	Pi Ra	U overall	S/N RA	P S/N RA
1	3.325721409	2.0716857	2.698704	8.6231	18.2781
2	4.32514792	4.1239372	4.224543	12.5156	
3	6.913484004	9.0000000	7.956742	18.0147	
4	8.358360801	4.1239372	6.241149	15.9053	
5	0.000000000	5.177451	2.588725	8.2617	

**Table 3 (cont'd):** Overall utility with S/N ratio

Exp. No.	Pi MRR	Pi Ra	U overall	S/N RA	P S/N RA
6	4.383619029	3.2214827	3.802551	11.6015	
7	6.946420747	2.0716857	4.509053	13.0817	
8	8.675861148	5.7785173	7.227189	17.1794	
9	0.488139185	4.1239372	2.306038	7.2573	
10	4.169828473	6.4429653	5.306397	14.4960	
11	6.973776227	2.4321509	4.702964	13.4474	
12	9.000000000	1.7307149	5.365357	14.5920	
13	0.797276203	1.7307149	1.263996	2.0349	
14	4.34711914	0.0000000	2.17356	6.7434	
15	7.85263118	5.7785173	6.815574	16.6700	
16	8.543781278	5.7785173	7.161149	17.0997	

The Taguchi approach transforms the machining characteristic values into the S/N ratio using the desired criteria of the responses i.e., higher the better or lower is better. From Fig. 5 the optimum parameter setting is found as A1B4C1. The predicted S/N ratio of overall utility are observed as 18.2781 which the highest among all the sixteen performed experiments. This higher value of the S/N ratio is highly desired for an efficient machining environment for drilling of graphite-epoxy composites. Also, the outcomes of the confirmatory test satisfactory agreement with the actual ones.

**Fig. 5.** Optimal setting by Utility-Taguchi theory

### 3.3 ANOVA test

The performance of the model has been verified with the help of R-Sq. value after the evaluation of the sum of squares (SS) and mean square (MS)(Gupta and Kumar, 2015). The R-sq. quantity is termed as the coefficient of determination which is used to examine the performance of the regression model developed(Abhishek et al., 2014; Panda et al., 2016).  $0 \leq R-Sq. \leq 1$ . ANOVA has been carried out to determine the significant contribution of process parameters at the confidence level of 95 % of the experimented results shown in Table 4. From the ANOVA result, it is remarked that the feed rate recognizes as the most effective parameter consisting of the contribution 73.37%, drill speed 3.44% and FVP 1.16% of the overall utility. The ANOVA residual plot is shown in Fig 6.

**Table 4:** ANOVA for overall utility

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
S	3	2.2074	3.44%	2.2074	0.7358	0.31	0.816
F	3	47.0393	73.37%	47.0393	15.6798	6.66	0.024
FVP	3	0.7444	1.16%	0.7444	0.2481	0.11	0.954
Error	6	14.1253	22.03%	14.1253	2.3542		
Total	15	64.1164	100.00%				

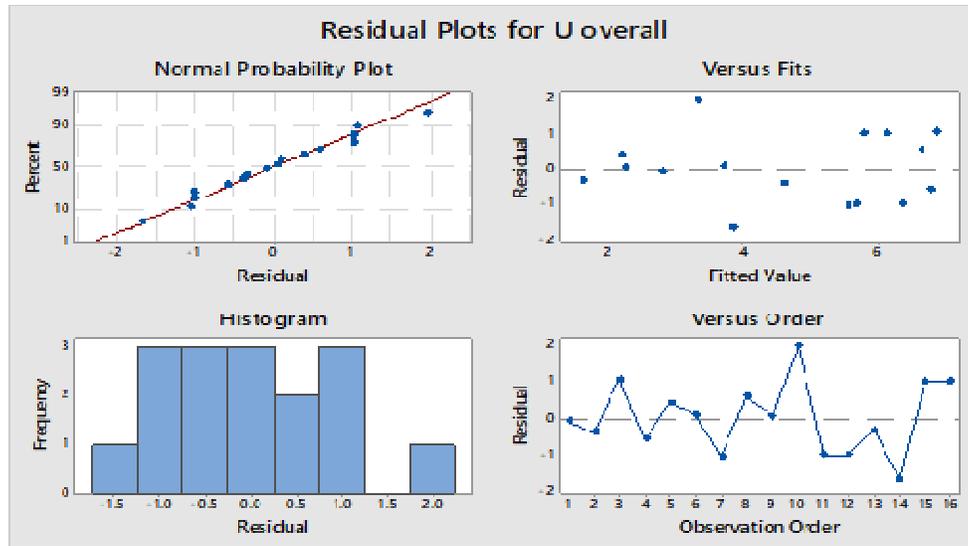


Fig. 6. Analysis of Variance plot

#### 4. Conclusion

The work computed the favorable parameter setting to enhance the overall performance of the machined product. This fabrication work has been carried by a molding technique to develop a graphite-epoxy sample and performed drilling operation in a Vertical milling CNC machine. The output characteristics are MRR and Surface roughness. A hybrid optimization technique is used (utility-based Taguchi) to formulate into a single objective function. Based on the obtained results, the conclusion of the work can be drawn as:

- The Utility-based Taguchi method effectively aggregated the conflicting machining characteristics during drilling of graphite composites into a single objective function which is not feasible by the traditional Taguchi method.
- This hybrid approach's optimal parametric setting is observed as A1B4C1 with a good predicted S/N ratio value.
- ANOVA plot depicted that the percentage of contribution in the machining of graphite composites is the most prominent factor that affects the process i.e., feed rate (73.37%) and drill speed (3.44%), respectively.
- The proposed optimization module is found as robust, sustainable, and dominant in producing the optimal process parameters. This proposed hybrid module can be recommended for online and offline quality monitoring of the other conventional and non-conventional manufacturing processes.

#### Nomenclature

OA	Orthogonal array
$R_a$	Surface roughness
MRR	Material removal rate
$U$	Utility
HB	higher is better
LB	Lower is better
ANOVA	Analysis of variance.

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