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Process Parameters Optimization for Surface Roughness and Metal Removal Rate During Turning of MWCNTs-Al$_2$O$_3$/ Epoxy Hybrid Nanocomposites

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Abstract: The high quality of the machined components is a research challenge to improve the operational efficiency of such components. This problem can be overcomed by optimizing machining operations and choosing the cutting parameters correctly. This work, therefore, proposes an optimization approach to the process parameters of epoxy hybrid nanocomposites strengthened by multi-wall carbon nanotubes (MWCNTs) and Al2O3. The machining parameters were rotational speed (n), feed rate (F), insert nose radius, and depthof cut (D). Metal removal rate(MRR) and surface roughness (Ra) were selected as parameters for the process response control. The optimization techniques involved were the Response Surface Method (RSM) and with Analysis of Variance (ANOVA).The results of RSM optimization and ANOVA showed that the most important factors influencing Ra are the insert nose radius and feed rate andfor MRR are feed rate, rotational speed, and depth of cut.

KEYWORDS: Metal Removal Rate, Surface Roughness, Response Surface Method (RSM), Turning, Hybrid Nanocomposites.

1. INTRODUCTION

Today, the manufacturing processes focuses on good product quality and enhanced surface finishing. In machining processes, the dimensions, form, and surface characteristics of the machined parts are modified by cutting the excess material. The mechanism is regarded as a relatively costly process to be decided only when high precision and a proper surface finish are needed[1]. Because of its exceptional mechanical and physical properties, the use of more than one reinforcement is commonly referred to as hybrid composites. Hybrid composites are known to be a good alternative for single composites. Matrix and reinforcements in particulate form are known as particulate metal matrix composites (PMMCs) offer superior manufacturing capability than other manufacturing methods[2].

However, such machining operations were necessary for products made of particulate metal matrix composites to achieve better dimensional tolerance and surface finish. Turning is the most significant cutting and finishing process. Consistency of surface roughness is important considerations during the machining operations of many aspects of the turning process and is the key to quality attributes of the turned product[3].Rotational speed, feed, cutting depth, workpiece materials, temperature cutting, material type, tool geometry, and environmental conditions are the key factors influencing the quality of the machined parts and the selection of optimum machining parameters are very critical to achieve high cutting performance in metal matrix composites (MMCs)[4]. Epoxy resin, owing to its superior thermal, mechanical, and electrical properties, it is most widely used as a matrix for advanced composites; dimensional stability and chemical resistance. Epoxy resin is commonly used in the electrical, aeronautical, and astronautically industries as high-quality synthetic resin[5].The use of CNT in polymers has received substantial attention due to exceptional rigidity, excellent strength, and low CNT density, among the many possible applications of carbon nanotubes. This provided a variety of possibilities for the invention of new material structures for applications requiring high strength and high modulus[6].Polymer-reinforced matrix composites are widely used by industry, especially in space and aviation, automotive, or sports equipment because of their high mechanical characteristics, including a high strength-to-weight ratio, and their high stiffness-to-weight ratio[7].RSM is a collection of statistical and mathematical techniques that can be used to model and analyze problems where different variables influence the response of interest and try to optimize that response. The factor level can be determined by RSM to satisfy the necessary dimensions. Additionally, on each input parameter, to detect response relationships. RSM helps to predict the properties of the product and classify the responses when settings are obtained, and to classify all the conditions suitable for process stability. Hence, based on the above uses, RSM is a better method to optimize accurately predicting the impact of parameters on response.

Ravuri et al.[8] studied the effect of process parameters such as feed rate, depth of cut, feed rate, and nose radius on surface roughness during the turning operation of EN 31 steel. The response surface method based on the L27 orthogonal array was used to study and optimized the effect of process parameters. The results indicated that they succeeded in the optimization of process parameters and got the optimal values of it. Asiltürk[9] investigated the effect of cutting parameters; speed, feed, depth of cut, and tooltip radius on surface roughness (Ra) and Rz of Co28Cr6Mo medical alloy machined on a CNC lathe by using Design of Experiments DOE Response Surface Methodology (RSM) that is based on the Taguchi orthogonal test design. The results showed thatthe most effective parameters on Ra and Rz wasthe tool tip radius.

The literature review revealeda few studies in which the optimization of the MWCNT-Al2O3 / epoxy hybrid nano composites was investigated. In this study, the statistical approach optimization (ANOVA) techniques for reacting surface method (RSM) with an analysis of variance were used to achieve optimum conditions of machining. In addition, the degree to which machining cutting parameters influence the removal speed and surface resistance of the MWCNT-Al2O3 / epoxy hybrid nano composites during the turning process should be assessed.

2. Experimental Procedures

2.1 Materials

Epoxy resin (KEMAPOXY 150) was used as a matrix material. The average diameter of Al2O3 particles was 60±5 nm Figure1a. The MWCNTshave average inner and outer diameters of 40±3 and 80±5 nm, respectivelyFigure1b. The MWCNTs and Al2O3 were dispersed into the epoxy matrix with 1% by volume of each.

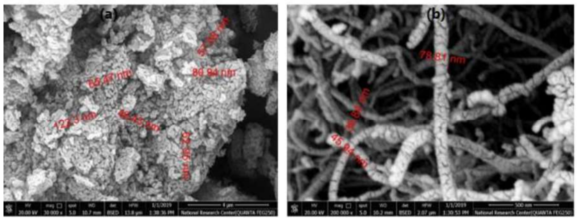
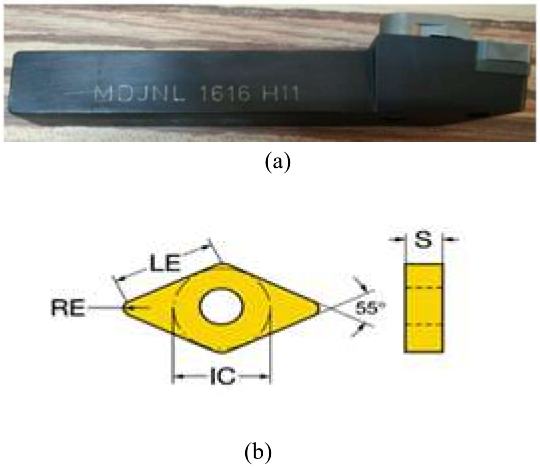


Fig1. SEM photography of the (a) Al2O3and (b) MWCNTsparticles.

2.2 Cutting tool specification

Coated carbide tip inserts with specifications provided in Figure 2 in the turning process. And it was included in Table 1. It was mounted on an MDJNL 1616 H11 tool holder. According to the KORLOY production catalog, the insert tips were selected. The ranges of cutting conditions were chosen according to the specification of the workpiece material and the insert. Two inserts with different radii of the nose (T1=0.8 mm and T2=0.4 mm) were used in this analysis.



(a)

(b)

Fig 2. (a) Carbide inserts geometry and (b) tool insert holder.

Table 1. Carbide inserts specification.

Tool code	**Tip**	**Dimension (mm)**			
		L	**IC**	**T**	**S**
T1	Coating **CVD TICN+AL2O3+TIN**	**10.828**	**9.525**	0.8	**4.763**
T2	Coating **CVD TICN+AL2O3+TIN**	**11.228**	**9.525**	0.4	**4.763**

2.3 Fabrication of the hybrid matrix nanocomposites

Hybrid matrix Nanocomposites MWCNTs-Al2O3 / epoxy weremade using a mechanical stirring technique. Epoxy resin was combined and mechanically stirred with MWCNTs and Al2O3 nanoparticles in a plastic mold. The volume fraction of both MWCNTs and Al2O3 was the same and equivalent to 1%. The hardener was applied by 2:1 by volume to the mixture after the mixing phase. Then the mixture was mechanically stirred for 3 min. Finally, the hybrid nanocomposite mixture was poured into a plastic mold with a cylindrical shape with an inner diameter of 25 mm and a length of 100 mm, which was then completely hardened at room temperature. Sample of the workpiece is shown in figure 3.

Fig 3.Sample of workpiece.

2.4 Design of experiments(DOE)

In this study, a mathematical model was chosen for the RSM-based central composite design with complete factorial design (DOE). It was used to evaluate the effect of many process parameters with different machining requirements, for example, rotational speed, feed rate, the nose of the tool, and depth of cut. Moreover, the effect on output response Ra and MRR of these input process parameters were determined. Table 2 offers a plan of experiments with valued input combinations.

Table 2. Turningparameters and their levels

Parameter	Unit	Level 1	Level 2	Level 3
Rotational speed(n)	rpm	1000	1500	2000
Insert code	mm	T1	T2	
Depth of cut (D)	mm	0.5	0.75	1
Feed rate (F)	mm/rev	0.08	0.12	0.16

2.5 Turning Process

The processing parameters established by DOE (Table 2) were used for the turning process by using EMCO 105 CNC turning machine.

2.6 Rameasuring

Using the surface roughness tester (Mitutoyo Surftest SJ-310) Figure3, the Ra of the workpiece was determined after machining.

Fig 4.Surface roughness measurement device (MitutoyoSurftest SJ-310)

3 Results and discussion

3.1 Ra and MRR results

Table 3 displays the estimated Ra and MRR.The minimum Ra was obtained using the tool insert type T1; depth of cut=1 mm, rotational speed=2000 rpm and feed rate =0.08 mm / rev. T2, depth of cut= 1 mm, feed rate = 0.16 mm / rev and rotational speed = 2000 rpm should be used for maximum MRR

Table 3.Measurement results of Ra and MRR.

Run	**F (mm/rev)**	**n (rpm)**	**D (mm)**	**Insert code**	**Ra (µm)**	**MRR (mm3/min)**	**Run**	**F (mm/rev)**	**n (rpm)**	**D (mm)**	**Insert Code**	**Ra (µm)**	**MRR (mm^3/min)**
1	0.12	1500	0.75	T2	6.1615	10178.8	**21**	0.12	1500	0.75	T2	6.2150	10178.8
2	0.08	1000	1.00	T1	3.4495	6031.9	**22**	0.16	1000	0.50	T2	6.9320	6031.6
3	0.16	1000	1.00	T1	5.3875	12063.7	**23**	0.12	1000	0.75	T2	6.4720	6785.8
4	0.16	1500	0.75	T1	5.1190	13571.7	**24**	0.16	2000	1.00	T2	6.8050	24127.4
5	0.08	1000	0.50	T1	3.5915	3015.9	**25**	0.08	2000	1.00	T2	3.8785	12063.7
6	0.08	2000	0.50	T2	3.8360	6031.9	**26**	0.12	1500	0.50	T2	5.7040	6785.8
7	0.12	1500	1.00	T2	6.6705	13571.7	**27**	0.08	1500	0.75	T2	3.9600	6785.8
8	0.12	1000	0.75	T1	4.3420	6785.8	**28**	0.12	1500	0.75	T2	6.2970	10178.8
9	0.12	1500	0.75	T2	6.1860	10178.8	**29**	0.16	2000	0.50	T2	6.7645	12063.7
10	0.08	1000	0.50	T2	4.0455	3015.9	**30**	0.08	1500	0.75	T1	3.4465	6785.8
11	0.12	1500	1.00	T1	4.3285	13571.7	**31**	0.08	2000	1.00	T1	3.3205	12063.7
12	0.12	1500	0.75	T1	8.2135	10178.8	**32**	0.12	2000	0.75	T2	5.6225	13571.7
13	0.12	2000	0.75	T1	7.5645	13571.7	**33**	0.16	1000	1.00	T2	7.4400	12063.7
14	0.12	1500	0.75	T1	4.3885	10178.8	**34**	0.08	1000	1.00	T2	4.1105	6031.9
15	0.12	1500	0.75	T1	4.1985	10178.8	**35**	0.16	1500	0.75	T2	6.8885	9047.8
16	0.12	1500	0.75	T1	4.2515	10178.8	**36**	0.12	1500	0.75	T1	4.4270	10178.8
17	0.08	2000	0.50	T1	3.1420	6031.9	**37**	0.12	1500	0.75	T1	4.4295	10178.8
18	0.12	1500	0.50	T1	4.1345	6785.8	**38**	0.12	1500	0.75	T2	6.3080	10178.8
19	0.16	2000	0.50	T1	4.7390	12063.7	**39**	0.16	1000	0.50	T1	5.5445	6031.6
20	0.16	2000	1.00	T1	5.0960	24127.4	**40**	0.12	1500	0.75	T2	6.3930	10178.8

3.2 Response surface optimization (RSM) by ANOVA

3.2.1Analysis of main effect for Ra

Figure5. Shows the main effects plots for Ra with parameters feed rate, rotational speed, depth of cut, and insert type. Table 4 summarizes the results of the ANOVA analysis of Ra. Figure 5 and Table 4 revealed that the insert type and feed rate were the most significant factors on Ra, while the depth of cut and rotational speed were insignificant parameters.

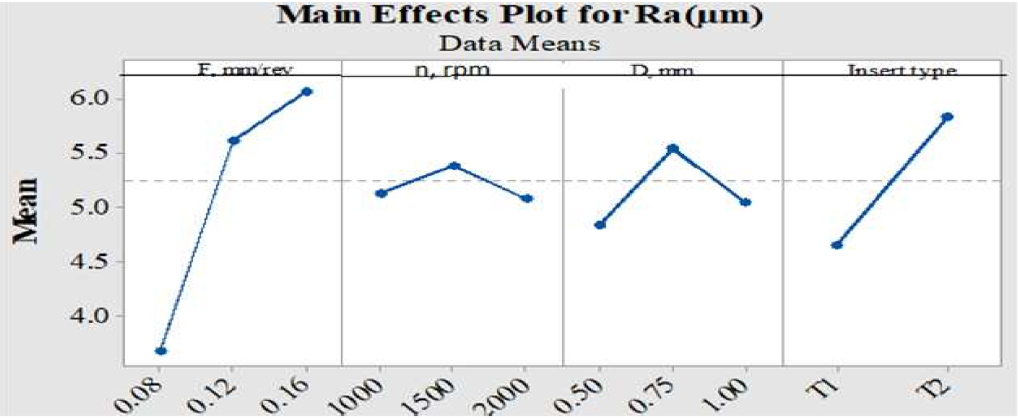
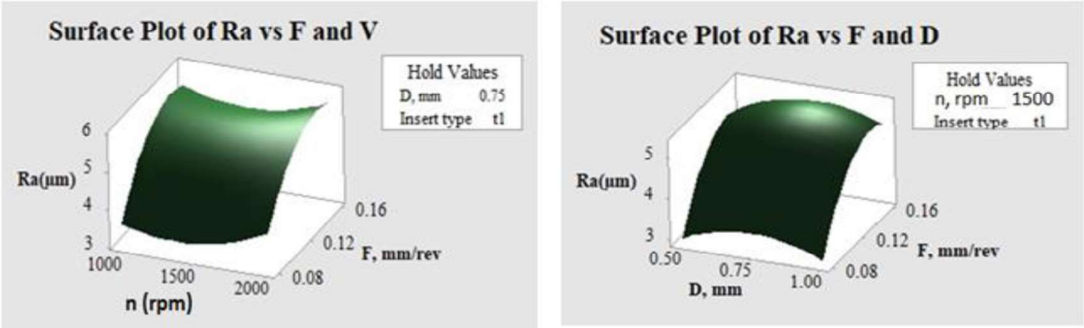


Fig 5. Main effects plot for mean surface roughness (Ra).

Table 4. The results of ANOVA for Ra

Source	**DF**	**Adj SS**	**Adj MS**	**F-Val**	**P-Val**
Feed rate (F, mm/rev)	2	31.7097	15.8548	22.16	0.00
Rotational speed (n, rpm)	2	0.8964	0.4482	0.63	0.541
Depth of cut(D, mm)	2	1.0496	0.5248	0.73	0.488
Insert type	1	13.8957	13.8957	19.42	0.000
Error	32	22.9002	0.7156		
Lack-of-Fit	22	10.3061	0.4685	0.37	0.975
Pure Error	10	12.5941	1.2594		
Total	39	72.4025			

Figure 6 (a) shows the surface plot of Ra vsrotational speed and feed rate at hold values of depth of cut = 0.75 mm and machined by insert type t1. It showed that Ra increased with increasing the feed rate and, conversely, for rotational speed until the rotational speed reached 1500 rpm, then increased to a high max when the rotational speed reached 2000 rpm, (b) shows the surface plot of Ra vs depth of cut and feed rate at hold values of rotational speed = 1500 rpm and machined by t1 insert. It showed that Ra increased with an increase in depth of cut and feed rate until the depth of cut reached 0.75 mm and then decreased until the depth of cut reached 1 mm.



(a) (b)

Fig 6. Surface plot of Ra (a) vs feed rate and rotational speed, (b) vs depth of cut and feed rate

3.2.2 Analysis of main effect for MRR

Figure 7. Shows the main effects plots for MRR with parameters feed rate, rotational speed, depth of cut, and insert type. Table 5 summarizes the results of the ANOVA analysis of Ra. Figure 7 and table 5 revealed that the feed rate, rotational speed, and depth of cut were significant factors on MRR, while the insert type was insignificant parameters.

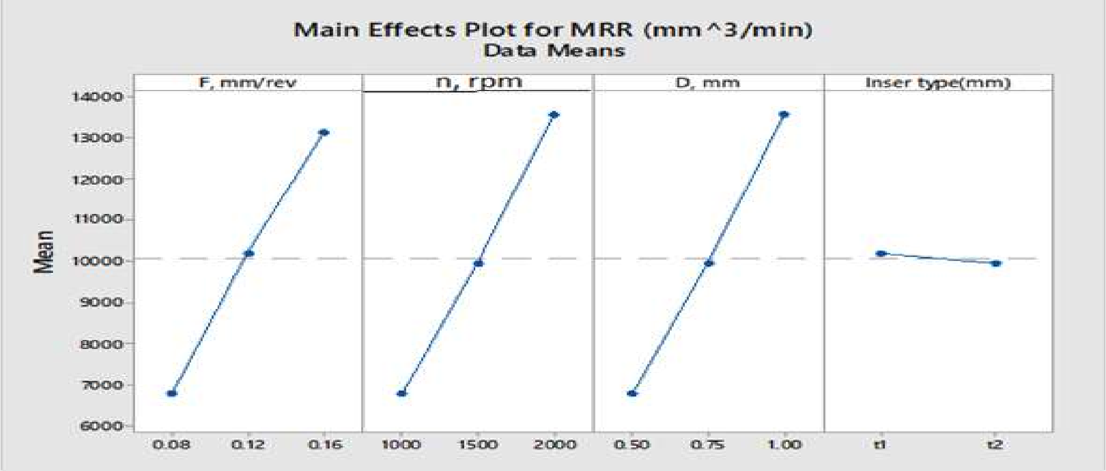
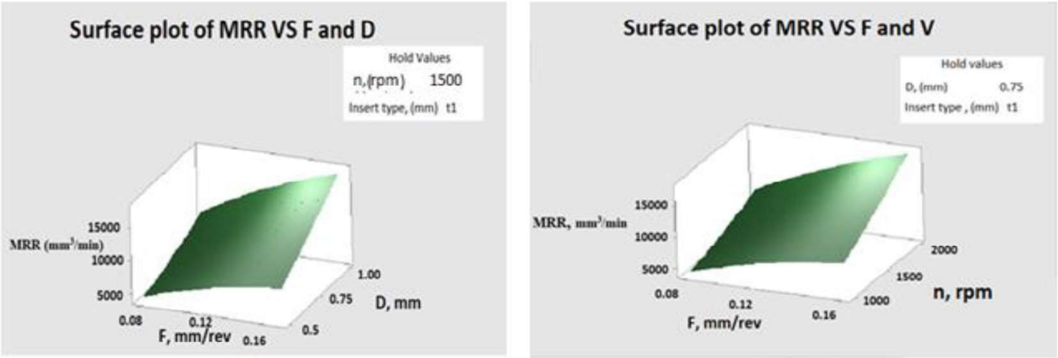


Fig 7. Main effects plot for mean for MRR.

Table 5. The results of ANOVA for MRR

Source	DF	Adj SS	Adj MS	F-Val	P-Val
Feed Rate(F, mm/rev)	2	203408149	101704074	41.41	0.00
Rotational speed(n, rpm)	2	231172457	115586228	47.06	0.00
Depth of cut (D, mm)	2	231172321	115586161	47.06	0.00
Insert type (mm)	1	511637	511637	0.21	0.651
Error	32	78601848	2456308		
Lack-of-Fit	22	78601848	3572811		
Pure Error	10	0	0		
Total	39	743645410			

Figures 8(a) shows the surface plot of the MRR vs feed rate and depth of cut at hold values of rotational speed 1500 rpm and machined by t1 insert.it showed that MRR Fits a proportional fit with the feed rate and depth of cut at hold values of rotational speed =1500 rpm and T1.(b) Shows the surface plot of the MRR vs feed rate and rotational speed. It showed that MRR fits a proportional fit with the feed rate and rotational speed at hold values of depth of cut =0.75 mm and T1.



(a) (b)

Fig 8. Surface plot of (MRR), (a) vs feed rate and depth of cut, (b) vs depth of cut and rotational speed.

4 CONCLUSION

Through optimization approaches, RSM with ANOVA analysis, the turning process parameters of the investigatedMWCNTs-Al2O3/ Epoxy hybrid nanocomposites, depth of cut, feed rate, rotational speed, and rotational insert type were optimized. Metal removal rate and surface roughness are set as the control parameters. Based on the results we can conclude that:

1. RSM optimization approach and ANOVA revealed that the insert type and feed rate were the most significant factors that affect Ra.
2. RSM optimization approach and ANOVA revealed that the most significant factors influencing the MRR the feed rate, rotational speed, and depth of cut.
3. The optimal combination level of cutting parameters obtained by the main effect plot for the lowest Ra were feed rate=0.08mm / rev, rotational speed=2000 rpm, depth of cut=0.5 mm, and insert type T1=0.8.
4. The optimal combination level of cutting parameters for the maximum MRR was feed rate=0.16mm / rev, rotational speed=2000 rpm, depth of cut=1 mm, and insert type T1=0.8.

5. References

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