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Optimizing Cutting Parameters of Al_2O_3 Particle Reinforced 6061 Aluminum Alloy Composites in Turning Using Taguchi Method

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Abstract

Today's extremely challenging manufacturing scenario puts a clear impetus on developing newer materials and efficient production methods to process them in order to survive and sustain, which also provides immense research opportunities to constantly upgrade and optimize existing processes. The current study was started with an objective of optimizing cutting parameters in turning operation of Al_2O_3 *reinforced 6061 Aluminum alloy composite (PAMC) such as speed, feed, depth of cut and type of inserts by Taguchi method (robust design) along with resultant cutting force and MRR as two responses of the turning process. The experimental design was done by considering Taguchi L9 array having four parameters at three levels was carried out on a conventional Hi-Tech Lathe. Finally, the work was concluded with optimal parameters for the maximum MRR along with minimum resultant cutting force.*

Keywords: MRR, resultant cutting force, Taguchi method, Al_2O_3 Particle Reinforced 6061 Aluminum Alloy Composites

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INTRODUCTION

In the present day, among the products manufactured with aid of advanced manufacturing technologies, the application of composite materials is gaining a lot of importance as the conventional materials are unable to cater the current requirements in terms of many desired properties. On the other hand the use of composite materials offers wide range of desired properties like larger strength, low density, high wear resistance and elevated stiffness properties.

Thus, because of these reasons the composite materials are preferred choice in many applications such as in automobile and aerospace industries over the conventional materials. As the manufacturing requirements are constantly changing in today's context, the optimization of cutting parameters gains a great significance in the development of aircrafts and automotive structures. The Aluminum alloys were commonly used material before development of composites. Aluminum based composites are considered as base materials for different applications due to their better mechanical and physical properties. [1–9]

Aluminum matrix composites (AMC) had showed considerably higher strength to weight ratios as compared to 100% Al.[2,10] In AMC's particulate reinforced aluminum matrix composites (PAMC) have demonstrated their suitability in automotive industry through their low cost and isotropy in property values. [3, 11]

Among various liquid centered fabrication techniques available for production of PAMC's like spray casting, squeeze casting, powder metallurgy, Lanxide technique and stir casting, for development and processing of aluminum alloy based composite materials, the stir casting is considered economical. [4, 12]

In stir casting, the properties of produced aluminum matrix composite (AMC) depends on control of process parameters like stirring temperature, preheating, stirring rate, stirring time etc., plays a major role for uniform distribution of reinforcement. [5, 13]

In the past, many studies were carried out with the use of Al_2O_3 particles as reinforcements along with 2024 Aluminum Alloy as matrix with different sizes reinforcement and varying the weight fractions up to 30%. It was observed that on increasing mass fraction and reduction of particle size, the stiffness and the tensile strength of the composites can be increased. [6, 14]

The Turning of PAMCs poses a challenge, as the tool wear out early due to hard reinforced particles which makes Poly Crystalline Diamond the best option for AMC's [7,15] over conventional high speed steel (HSS) and carbide tools, but high tooling cost makes its usage difficult. Further, the studies conducted using HSS tools were concentrated on optimizing cutting parameters for reducing machining cost and improving surface roughness. The CNC machines were preferred in the past over conventional machines for Al_2O_3 PAMC's for machinability studies aimed at improving surface roughness. [8, 16]

The optimization of turning process parameters were carried out previously by researcher using Taguchi method. Researchers are also made an effort to optimize the material removal rate by using alloy steel (EN_{24}) as material. They observed that MRR increasing with an increase in speed, feed and depth of cut as well. [17]

The MRR influences the many process parameters either directly or indirectly and with AISI 4130 steel alloy as material, the MRR was principally affected by feed and speed. [18]

Researcher [19] applied Taguchi method to optimize material removal rate and found that the most significant factors for MRR as speed and feed. The cutting parameters like speed, feed and the depth of cut were considered with cutting force as response. The analysis of recorded data using Taguchi approach by the researcher [20] showed that High speed, low feed and low depth of cut led to minimum value of resultant cutting force.

The cutting force is one of the significant indexes of machinability as it finds the power utilization and amount of energy consumed in the process of machining. The magnitude of cutting forces primarily influenced by cutting parameters such as speed, feed rate and depth of cut. In an orthogonal turning process usually the optimal values of cutting speed (rpm), feed (mm/min) and depth of cut (mm) were determined in order to minimize cutting force. [21]

An experimental examination was focused on determining the impact of various cutting conditions on responses of surface roughness and cutting forces during the turning of hardened steel material (X_{38}CrMoV5-1steel) up to 50 HRC by using CBN tool by researcher [22] and shown that the depth of cut exhibited great influence on cutting force components as compared to the feed and speed.

In the review of past studies it was evident that the use of Al_2O_3 particle reinforced aluminum 6061 alloy was not investigated extensively with turning process, thus it provides an opportunity to study further the MRR and resultant cutting forces as responses with varying parameters like type of inserts, cutting speeds, feed rates and depth of cuts in order to optimize the parameters of turning process for these class of materials.

METHODOLOGY AND IMPLEMENTATION

Fabrication of Metal Matrix Composite Specimens by Stir Casting

The present work was initiated with fabrication of Al_2O_3 particle reinforced 6061 Aluminum alloy composite specimen. One kilogram of 6061 Aluminum alloy was melted by heating using a graphite crucible to a temperature 700ºC in an electric induction furnace as shown in Figure 1, aluminum Oxide (Al_2O_3) particles were heated to 300 ºC temperature for a period of 1 hr. in order to eliminate the moisture from the powder. As the melting point of 6061 aluminum alloy reaches 652ºC, the furnace temperature is raised to 700 ºC to liquefy the aluminum. After a gap of 5 min., the liquid Aluminum is cooled to 652ºC to form slurry.

The preheated stirrer (as in Figure 1) was placed in the furnace and the molten aluminum was stirred for 10–15 minutes to obtain a homogenous mixture by employing a stirring rate of 300 RPM. Aluminum oxide particles (preheated) of 10% volume ratio that is 100 gm per 1 kg were introduced in the molten 6061 Aluminum alloy as reinforcement with an average particle size of 32µm at the time of addition of reinforcement, stirring is carried out mechanically for 5 min. The temperature of the furnace was controlled within 700±10 ºC in mixing process. The position of the stirrer was in such a way that it doesn’t touch the bottom of the furnace, that means about 20–30% of material must be placed below the stirrer and rest i.e., 80–70% should be above the stirrer. After the complete addition of reinforcement, the stirring of mixture was continued for 10–15 min.

Fig. 1. *Melting of 6061 Aluminium Alloy and Stir Casting Setup.*

Then the prepared mixture was poured into the preheated cast iron mold (as in Figure 2) at 300ºC to get cylindrical shaped composite bars of ϕ 17 and 260 mm length. The mixture was allowed to solidify for 15–20 min and then the bars were removed from the mold. Figure 2 shows the bars that were cut to length of 60 mm to prepare specimens for experimentation.

Microstructural and Properties Investigations of the Specimens

Soon after the preparation of specimens to analyze the formation of composite structure (Al_2O_3 as reinforcement and Aluminum 6061 alloy as matrix) the microstructural investigations of the test samples were carried out with the aid of an optical microscope. The typical microstructures of Al_2O_3 particle reinforced 6061 Al alloy composite as observed in microscope is depicted as in Figure 3.

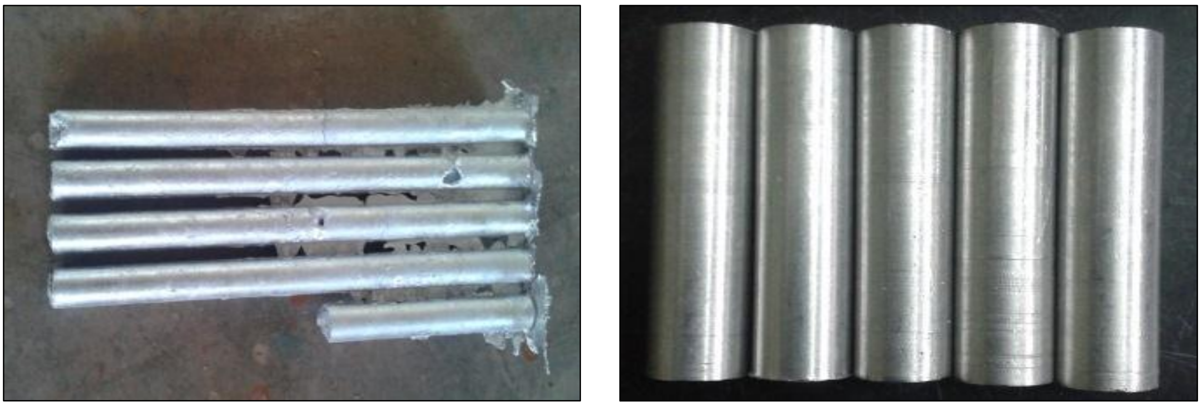
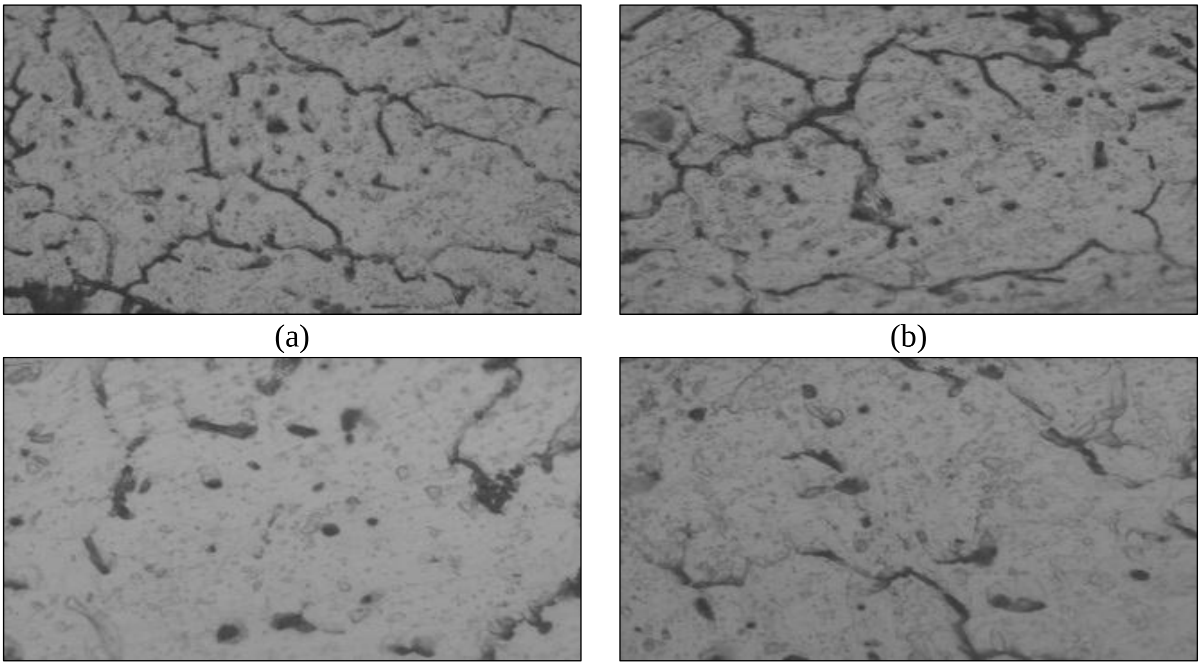


Fig. 2. *Composite After the Solidification.*



(a) (b)

(c) (d)

Fig. 3. *(a) 50x Magnification Without Etchant, (b) 50x Magnification With Kellers Etchant, (c) 100x Magnification Without Etchant and (d) 100x Magnification With Kellers Etchant.*

DESIGN OF EXPERIMENTS USING TAGUCHI METHOD

The Taguchi method was applied for optimizing the turning parameters for effective machining of Al_2O_3 particle reinforced 6061 aluminum alloy composite. The parameters were cutting speed (V) in (Rpm), feed rate (f) in (mm/min), depth of cut (d) in (mm) and Type of inserts (carbide, diamond, ceramic). The responses were MRR and Resultant cutting force. The parameters were taken in 3 levels as in Table 1.

Table 1. *Turning Parameters and Levels.*

Sl. no	Parameters	Parameter designation	Levels		
			1	2	3
1	Cutting speeds (in RPM)	V	112	280	450
2	Feed rates (in mm/rev)	f	0.1	0.2	0.32
3	Depth of cut (in mm)	d	0.5	0.75	1.0
4	Type of inserts	I	Carbide	Diamond	Ceramic

The L9 orthogonal array was considered for experimentation and the experimental design is as in Table 2.

***Table 2.** L9 Orthogonal Array.*

Test no.	Cutting speed	Feed rate	Depth of cut	Type of inserts
1	140	0.096	0.5	Carbide
2	140	0.124	0.75	Diamond
3	140	0.179	1.0	Ceramic
4	224	0.096	0.75	Ceramic
5	224	0.124	1.0	Carbide
6	224	0.179	0.5	Diamond
7	315	0.096	1.0	Diamond
8	315	0.124	0.5	Ceramic
9	315	0.179	0.75	Carbide

Four replications of experiments were carried out in order to account for variability. The plain turning processes were conducted to estimate the MRR and resultant cutting force under different values of turning parameters. A conventional Hi-Cut 3503 lathe machine was utilized for experimentation and cutting force was measured by using lathe tool dynamometer. The MRR (gm/min) was estimated using the formula:

$$\mathrm{MRR} = \frac{(\text{Initial Weight} - \text{Final Weight})}{\text{Time required to turn}} \ [\text{gm/min}]$$

Electronic balance machine was used to weigh the turned specimens and later to calculate the MRR. A length of 30 mm of specimen was turned, and the time required to turn was measured using stop watch.

EXPERIMENTATION AND CALCULATIONS

The turning experiments were conducted on a conventional Hi-Cut 3503 lathe as shown in Figure 4.

***Fig. 4.** Conventional Hi-Cut 3503 Lathe.*

The MRR calculations and experimental outcome of the resultant cutting forces in turning of aluminum composite with different cutting parameters are tabulated below.

***Table 3.** Experimental Results for MRR.*

Exp no.	Cutting parameters				Material removal rate (gm/min)					S/N ratio
	V (rpm)	f (mm/rev)	d (mm)	Inserts	Trials				Average	
					1	2	3	4		
1	140	0.096	0.5	Carbide	0.65	0.64	0.64	0.65	0.645	–3.80959
2	140	0.124	0.75	Diamond	0.79	0.79	0.79	0.77	0.785	–2.10422
3	140	0.179	1.0	Ceramic	1.72	1.67	1.69	1.66	1.685	4.52961
4	224	0.096	0.75	Ceramic	1.27	1.26	1.28	1.24	1.2625	2.022827
5	224	0.124	1.0	Carbide	2.35	2.34	2.27	2.18	2.285	7.165906
6	224	0.179	0.5	Diamond	1.84	1.88	1.84	1.77	1.8325	5.254691
7	315	0.096	1.0	Diamond	2.05	2.00	2.04	2.14	2.0575	6.25891
8	315	0.124	0.5	Ceramic	1.90	1.91	1.90	1.80	1.8775	5.463859
9	315	0.179	0.75	Carbide	2.97	2.80	2.88	3.03	2.92	10.42667

Table 4. *Design of Experiment and Calculations.*

Exp. no.	Cutting parameters				Cutting force (N)					S/N ratio
	V (rpm)	f (mm/rev)	d (m)m	Inserts	Trials				Average	
					1	2	3	4		
1	140	0.096	0.5	Carbide	111.96	108.38	109.50	111.28	110.28	–40.8508
2	140	0.124	0.75	Diamond	103.36	98.27	98.98	99.72	100.08	–40.0087
3	140	0.179	1.0	Ceramic	71.77	79.67	77.74	76.96	76.53	–37.6837
4	224	0.096	0.75	Ceramic	53.98	53.09	52.44	54.90	53.60	–34.5854
5	224	0.124	1.0	Carbide	64.15	61.58	61.96	59.77	61.86	–35.8314
6	224	0.179	0.5	Diamond	48.46	44.09	52.13	47.19	47.97	–33.6346
7	315	0.096	1.0	Diamond	22.65	20.78	19.72	20.81	20.99	–26.4515
8	315	0.124	0.5	Ceramic	21.94	22.82	22.39	26.32	23.37	–27.3959
9	315	0.179	0.75	Carbide	17.13	18.87	16.24	14.15	16.59	–24.4461

ANALYSIS OF VARIANCE

The experimental results were examined using a statistical analysis technique, ANOVA with the objective of recognizing the factors that significantly influencing the MRR and resultant cutting force as well. The results of the ANOVA with the Material removal rates are shown in Tables 5 and 7, and the Resultant cutting forces are shown in Tables 6 and 8 are the corresponding table of responses.

Table 5. *ANOVA Table for MRR.*

Factor	DF	SS	MS	F	P	C
A. Speed	2	95.969	47.985			59.43%
B. Feed	2	42.018	21.009	8.169	0.025	26.02%
C. Depth of cut	2	21.301^{*}	10.651	3.576	0.10	13.19%
D. Type of insert	2	2.196^{*}	1.098			1.36%
Error	0	0	-			
Total	8	161.48				
(Error)	(4)	23.497	5.874			

Table 6. *Response Table for MRR.*

	CS	F	D	Inserts
Level 1	–04614	1.4907	2.303	4.2174
Level 2	4.8145	3.5085	3.071	3.1365
Level 3	7.0062	6.3601	5.984	4.0054
Delta	7.4676	4.8694	3.681	1.0809
Rank	1	2	3	4

Table 7. *ANOVA Table for Means of Resultant Cutting Force.*

Factor	DF	SS	MS	F	P	C
A. Speed	2	277.056	138.53			95.73%
B. Feed	2	10.571	5.286	311.88	0.001	3.65%
C. Depth of cut	2	1.399^{*}	0.699	11.899	0.020	0.48%
D. Type of insert	2	0.377^{*}	0.189			0.14%
Error	0	0	–			
Total	8	289.40				
(Error)	(4)	1.777	0.444			

Table 8. *Response Table for Resultant Cutting Force.*

	CS	**F**	**D**	**Inserts**
Level 1	–39.14	–34.11	–33.84	–33.71
Level 2	–34.44	–34.12	–33.00	–33.36
Level 3	–26.10	–31.92	–33.31	33.22
Delta	13.42	2.49	0.95	0.49
Rank	1	2	3	4

CS-Cutting Speed, DF-Degree of Freedom, F-Feed Rate, D-Depth Of Cut, SS-Sum of Squares, MS-Mean of Squares, F-Statistical parameter, P-Probability Percentage, C-% Contribution.

**Represents least significant parameters and has little effect on the MRR and resultant force. Because it has negligible values compared to the other cutting parameters, hence it was neglected and pooled together to calculate error.*

The Figures 5 and 6 show the plot of mean of S/N ratios and levels of factors for both the responses which assists in identification of optimum condition.

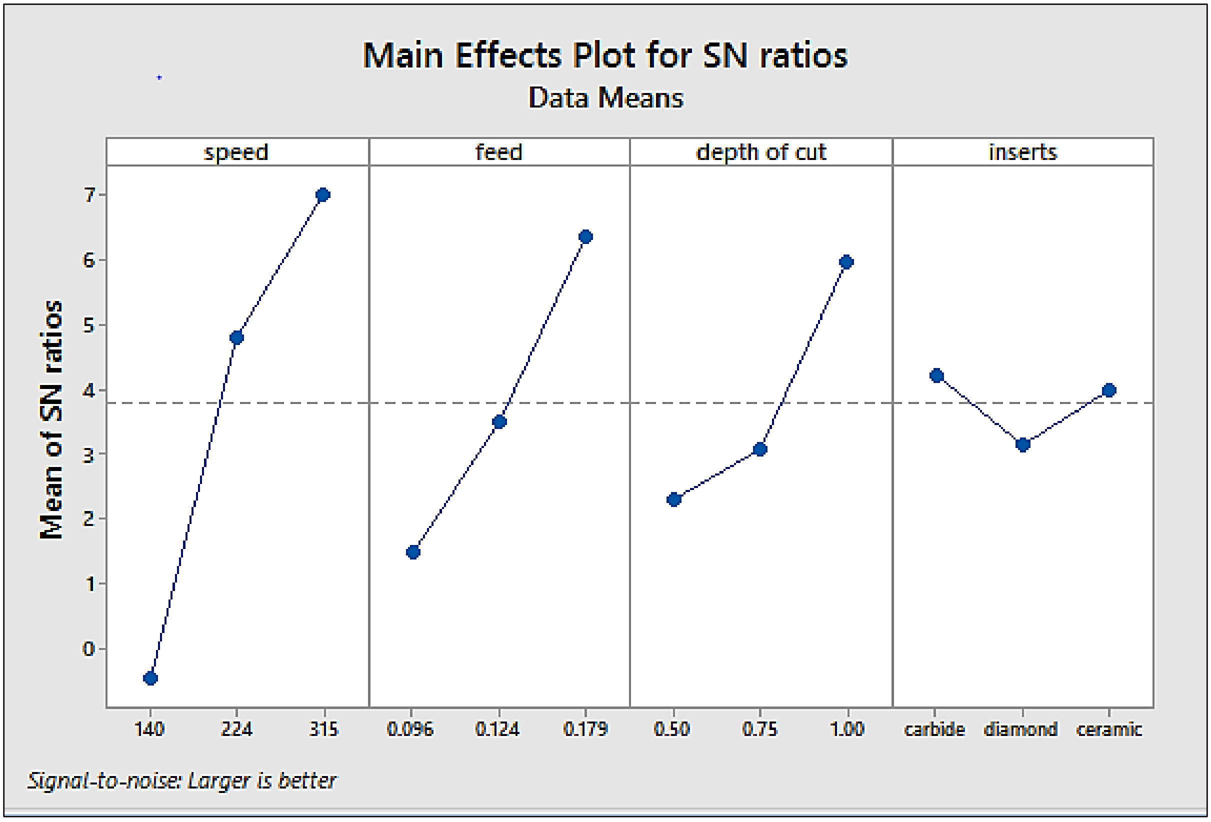


Fig. 5. *Main effect Plot for Means of MRR.*

ESTIMATION OF OPTIMUM CONDITION

For the estimation of optimum condition both response and S/N ratio plays important role. Since for quality feature, larger the better criteria is suitable for MRR and smaller the better criteria is ideal for resultant cutting force. From the plots 5 and 6 it is evident that the optimum condition for MRR was observed at V = 315 rpm, f = 0.179 mm/rev, d = 1.0 mm and with carbide insert. Similarly, for resultant cutting force the optimum condition obtained were V = 315 rpm, f = 0.179 mm/rev, d = 0.75 mm and with ceramic insert.

PREDICTED VALUES AND CONFIRMATION TEST

The obtained values of MRR and resultant cutting force at the optimum conditions are estimated and tabulated as in Table 9.

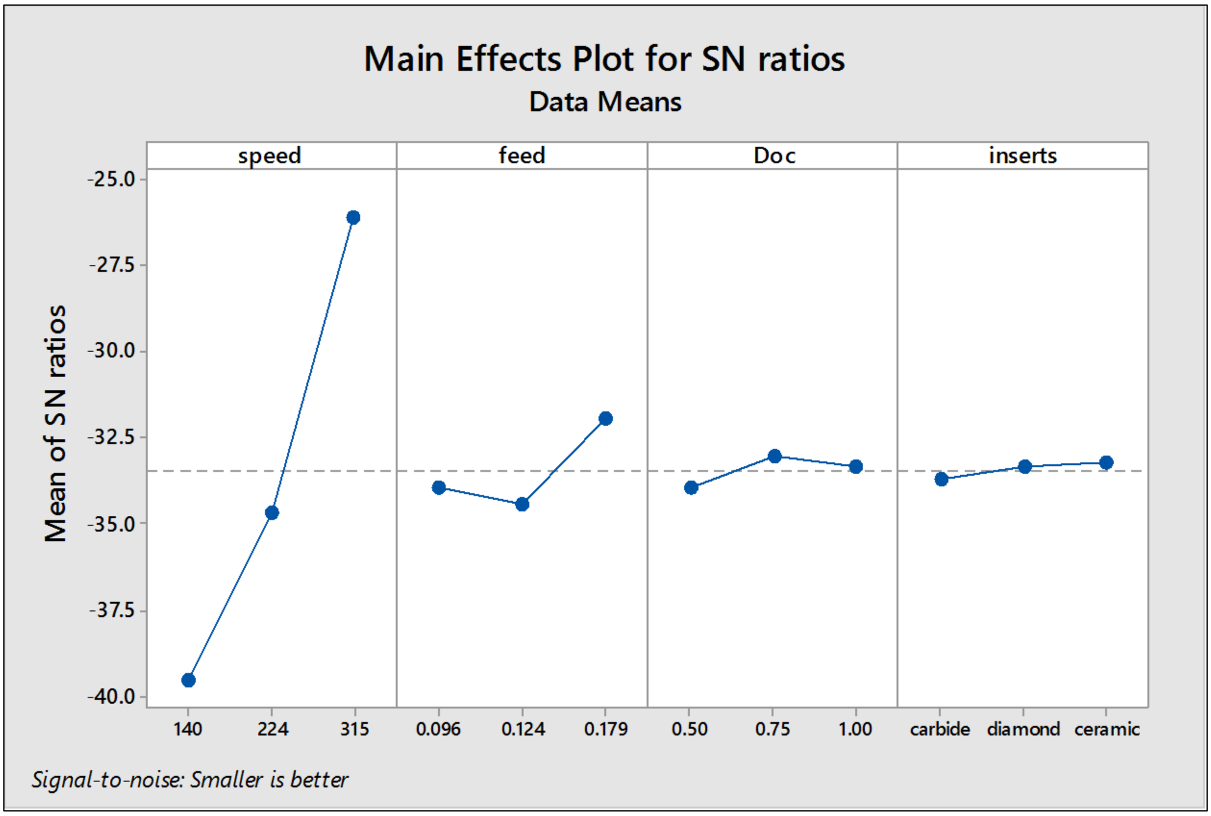


Fig. 6. *Main Effect Plot for Means of Resultant Cutting Force.*

Table 9. *Optimal Cutting Parameters.*

Predicting method	**Cutting parameters**				**Material removal rate (gm/min)**	**Cutting force (N)**
Taguchi analysis	**Cutting speed V (rpm)**	**Feed f mm/rev**	**Depth of cut 'd' mm**	**Type of insert**		
Optimization for Cutting force.	315	0.179	0.75	Ceramic	2.92	16.5972
Optimization for Material removal rate.	315	0.179	1.0	Carbide	2.92	16.5972

The obtained optimal values cutting parameters were obtained statistically by using Taguchi's approach. To verify the optimum condition, the confirmation test was conducted at the obtained optimal cutting parameters.

CONFIRMATION TEST

Finally, the verification test was conducted as part of the Taguchi method based optimization. The aim of this test was to verify the optimum conditions which was in the form of the matrix of experiment, and estimates the closeness of predicted values with real values. The confirmatory tests were carried out by setting optimum cutting parameter values, the two responses were measured and tabulated as in Table 10.

Material Removal Rate (MRR)

The measured MRR during confirmatory test showed a variation of 1.35% with predicted optimal value. The measured value of MRR at the optimal condition was 2.96 gm/min.

Table 10. *Results of Confirmation Experiments.*

Performance measures/responses	Optimal set of parameters	Predicted optimal value	Actual value (confirmation experiments)
Cutting force.	Cutting speed = 315 rpm Feed rate = 0.179 mm/rev Depth of cut = 0.75 mm Insert = ceramic	16.5972 N	17.3461 N
Material removal rate.	Cutting speed = 315 rpm Feed rate = 0.179 mm/rev Depth of cut = 1.0 mm Insert = carbide	2.92 gm/min	2.96 gm/min

Resultant Cutting Force

The measured Resultant cutting force during confirmatory test showed a variation of 4.2% with predicted optimal value. The measured value of Resultant cutting force at the optimal condition was 17.3461 N. A great deal of similarity was observed between the actual and the predicted results. The percentage error between them was less than 5% which shows a fair amount of reproducibility of the outcomes. The results demonstrates that by utilizing the ideal parameter setting a higher MRR can achieved with a reduction in Resultant cutting force.

RESULTS

The effect of cutting parameters i.e. Speed, feed, depth of cut and inserts and their interactions on responses was calculated by analysis of variance (ANOVA) technique using MINITAB 17 software.

The main consideration of ANOVA in current work was to estimate the significant cutting parameters in evaluation of MRR and Resultant cutting force.

CONCLUSION

After the experimentation by varying parameters of cutting speed, feed rate, depth of cut and type of inserts in turning of Al2O3 reinforced 6061 Aluminum alloy composite by Taguchi's method with responses MRR and resultant cutting forces, finally the work was concluded with following observations.

(i) The cutting speed was the main factor that had the highest effect on MRR followed by feed, depth of cut and inserts.
(ii) Optimum machining condition for larger MRR was observed at speed of 315 rpm, feed rate of 0.179 mm/rev and depth of cut of 1.0 mm with carbide insert.
(iii) The cutting speed was the main factor that has the highest effect on cutting force followed by feed, depth of cut and inserts.
(iv) Optimum machining condition for minimum Cutting force was observed at speed of 315rpm, feed of 0.179 mm/rev and depth of cut of 0.75mm with ceramic insert.

REFERENCES

1. Vijaya Ramnath B., *et al*. Aluminum metal matrix composites a review, *Rev Adv Mater Sci*. 2014; 38; 55–60p.
2. Sujan D., *et al*. Physio-mechanical properties of aluminum metal matrix composites reinforced with Al2O3 and SiC, World Academy of Science, *Eng Technol*. 2012; 6–8p.
3. Varuzan K. “Development of Al MMC composites for automotive industry.” Yugoslav Association of Metallurgical Engineers YAME.

4. Valsange M.. *et al*. Stir Casting used in manufacturing of Aluminum Matrix Composite, *Int J Res Technol Stud*. 2014; 1(9).
5. Bhandare R.G., et al. Preparation of aluminum matrix composite by using stir casting method, *Int J Eng Adv Technol*. 2013; 3(2).
6. Kok M. Production and mechanical properties of Al2O3 particle-reinforced2024 aluminum alloy composites, *J Mater Process Technol*. 2005; 161: 381–7p.
7. Kishawy H. A. *Turning Processes for Metal Matrix Composites*. Wood head Publishing Limited; 2012.
8. Kok M. A study on the machinability of Al2O3 particle reinforced aluminum alloy composite, IIBCC, *11th Int. Inorganic – Bonded Fiber Composites Conference*. 2008.
9. Singh Y., *et al*. Forecasting of optimum turning parameter on surface roughness in turning of Al_2O_3 metal matrix composite, *Int J Eng Sci Technol*. 2013; 5(2).
10. Uppinal V.K., Vinoth M.A. Analysis of mechanical properties of pure aluminum based metal matrix composite. 2014.
11. Gupta M.K., Rakesh P.K. Effects of reinforced particulates on properties of aluminum metal matrix composites. 2014.
12. Sujan D., *et al*. Physio-mechanical properties of aluminum metal matrix composites reinforced with Al2O3 and SiC, World Academy of Science, *Eng Technol*. 2012; 68.
13. Bhandare R.G., Sonawale P.M. Preparation of aluminum matrix compositr by using stir casting method & its characterization, *Metal Matrix Compos*. 2014.
14. Najem S.H. Machinability of Al-2024 reinforced with Al_2O_3 and/or B_4C.
15. Mahesh Babu T.S., Muthu Krishnen N. An experimental investigation of turning Al/Sic/B4C hybrid metal matrix composites using ANOVA analysis. 2012.
16. Kadam S.S., Warkhedkar R.M., Kulkarni S.S. Estimating the effect of cutting parameters on surface roughness and tool wear during turning of Al-Sic metal matrix composite. 2013.
17. Krishankant, Taneja J., Bector M., *et al*. Application of Taguchi method for optimizing turning process by the effects of machining parameters. 2012.
18. Bansal G., Sodhi H.S., Singh J. Optimization of Machining Parameters for MRR in Boring Operation Using RSM. 2014.
19. Krishnamurthy K., Venkatesh J. Assessment of surface roughness and material removal rate on machining of TIB2 reinforced aluminum 6063 composites: a Taguchi's approach. 2013.
20. Hanafi I., Khamlichi A., Mata Cabrera F., *et al*. Optimization of cutting parameters in CNC turning operation using Taguchi design of experiments. 2011.
21. Sahoo A.K., Mohanty T. Optimization of multiple performance characteristics in turning using Taguchi's quality loss function: An experimental investigation. 2013.
22. Aouici H., Yallese M.A., Belbah A., *et al*. Experimental investigation of cutting parameters influence on surface roughness and cutting forces in hard turning of X38CrMoV5-1 with CBN tool. 2013.