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Optimization of Process Parameters in Turning of Aluminium Metal Matrix Composites

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Abstract:

This paper investigates the study of mechanical and machining behavior of Aluminium- 7075- with (0, 2.5, 5 wt%) of TiB2 and TiC. The in-situ composite was prepared by liquid metallurgy route. The composite was prepared with the formation of the reinforcement inside the molten matrix by adding salts of Potassium Tetra fluoro borate (KBF4), graphite and Potassium Hexa fluoro titanate (K2TiF6). Turning is carried out on a lathe machine that provides the power to turn the work piece at a given rotational speed and to feed the cutting tool at a specified rate and depth of cut therefore, three cutting parameters, i.e. cutting speed, feed rate, and depth of cut, need to be determined in a turning operation.MRR and CF are important parameters to evaluate cutting performance. The influence of cutting speed, feed rate depth of cut and percentage reinforcement is examined. The model for the MRR and CF, is obtained using DOE in MINITAB16. The main objective of this paper is to carry out the experiments by selecting different variables and their levels, applying TAGUCHI and ANOVA, and then analyzing the results obtained. The results obtained conclude that TAGUCHI and ANOVA is reliable methods and it can be readily applied to different metal cutting processes with greater confidence. The mechanical properties in terms of hardness and impact test were carried out. It was observed that the hardness and impact strength of Al-7075-5% TiB2 & TiC in-situ composite was improved by the Al-7075 alloy respectively.

Key Words:

Optimization; turning; Taguchi; Anova; MRR; Cutting force.

1. INTRODUCTION:

Metal Matrix composites (MMCs) are the combination of two or more distinct phases that has improved properties than the monolithic alloy. The application of MMC's greatly increasing due to their high strength and toughness at elevated temperatures coupled with low-density. Turning is also commonly used as a secondary process to add or refine features on parts that were manufactured using a different process. Due to the high tolerances and surface finishes that turning can offer, it is ideal for adding precision rotational features to a part whose basic shape has already been formed.

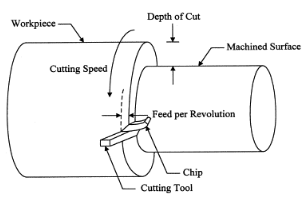

Fig.1. Turning Operation in Lathe Machine

Taguchi method is used for find a specific range and combinations of turning parameters like cutting speed, feed rate and depth of cut to achieve optimal values of response variables like Cutting force, material removal rate in turning of aluminium hybrid material material. ANOVA is used to investigate the process parameters which significantly affect the performance characteristics.Aluminum-7075 have the chemical composition of different materials with percentages are indicated in below table: 1

Table-1: Chemical composition of Al-7075 alloy

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Al-7075	Al	Cu	Mg	Si	Cr	Fe	Mn	Zn
Mtrl.%	89.20	1.76	2.55	0.10	0.19	0.25	0.09	5.81

2. EXPERIMENTAL SETUP:

2.1: Fabrication of Al7075-TiC-TiB_2

Fabrication of Al7075-2.5wt% of TiC & TiB_2 was carried out in a batch of 3 kg of Al and 2.5 wt% TiC & TiB_2. the reinforcement was carried out by 240.72 grams of K2TiF6 (Potassium hexa fluoro titanate) and 15.6 grams of graphite powder was used for the formation of TiC, and 240.72 grams of K2TiF6 (Potassium hexa fluoro titanate) and 240.72 grams of KBF_4 was used for the formation of TiB_2 . Al7075 was melted in crucible and premixed K2TiF6, KBF4 and graphite powder of measured quantity were added to the molten aluminium. Stir casting process starts with placing empty crucible in the muffle. At first heater temperature is set to 500°C and then it is gradually increased up to 900°C. The molten material was held for 30 minutes and the melt was stirred at regular intervals during this exothermal reaction will take place between the molten aluminium and halide salt K2TiF6. The reaction between the salt (K2TiF6) and molten aluminium releases Ti, the solute Ti reacts with C to produce TiC particles, and the KBF4 reacts with Al release B2 this combines with Ti forms TiB2 happens by holding the melt for 30 minutes. After 30 minutes the slag is removed from the molten mix and the molten mix is poured into the cast iron mould, shown in fig. Similarly Al7075-5 wt%TiC-TiB2 was fabricated by using proper ratios of K2TiF6, KBF4 and C.

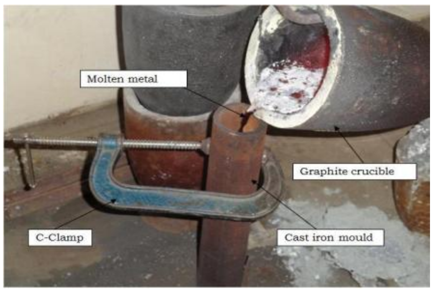

Fig:2 Casting Process

The work piece rotates in the lathe, with a certain spindle speed (N), at a certain number of revolutions per minute. The power measurements are made with the help of a wattmeter.

2.2: TURNING OPERATION

Turning operation is carried out in a Lathe Machine manually under an operator’s supervision. There are two types of motion in a turning operation. One is the cutting motion which is the circular motion of the work and the other is the feed motion which is the linear motion given to the tool. The three machining parameters i.e., Spindle speed, Feed rate and Depth of cut are used for material removal rate.

3. EXPERIMENTAL INVESTIGATION

There are various responses considered during turning of Al-Tic/TIB2 MMCs, all these responses were optimized by using Taguchi method. Taguchi method is best technique to select the best parameter combination for to get best minimized and maximized response value. Taguchi method is applied separately for each individual response output. The response output considered for the Taguchi optimization study are Cutting force (CF) and material removal rate (MRR). The process parameters with three levels of cutting speed, feed and depth of cut were used for the optimization study and a list of process parameters were displayed in below.

Table -2: process parameters and their levels

Process parameters				
Level	Speed (rpm)	Feed Rate (mm/rev)	Depth Of Cut(mm)	%Reinforcement
1	315	0.13	0.25	0
2	500	0.34	0.5	2.5
3	775	0.55	0.75	5

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3.1: EXPERIMENTAL DESING

Experiments are conducted based on planned design, the Three spindle speeds (N) 315 rpm, 500 rpm, and 775 rpm. Three feed rates (f) 0.13 mm/rev, 0.34 mm/rev, and 0.55 mm/rev. Three depth of cuts (d) 0.25mm,0.5mm, and 0.75mm.three different percentage reinforcements 0%,2.5% and 5% were selected. Details of experimental design, control factors and their levels, results for MRR and Cutting forces are shown in table 4.4. these tables show that the experimental plan had three levels and four parameters.

TABLE-3: Signal To Noise Ratio For Mrr and Cf

EXP	Speed(rpm)	Feed (mm/rev)	Doc (mm)	%R	MRR (mm³/min)	S/N ratio	CF (N)	S/N ratio
1	315	0.13	0.25	0	956	59.9	37.4	31.45
2	315	0.13	0.5	2.5	1897	65.5	38.7	31.75
3	315	0.13	0.75	5	2822	68.8	41.8	32.42
4	315	0.34	0.25	0	2460	67.9	34.9	30.85
5	315	0.34	0.5	2.5	4794	73.5	36.9	31.34
6	315	0.34	0.75	5	7002	76.8	45.2	33.10
7	315	0.55	0.25	0	3911	71.7	41.8	32.42
8	315	0.55	0.5	2.5	7483	77.3	39.7	31.97
9	315	0.55	0.75	5	10715	80.6	50.0	33.97
10	500	0.13	0.25	2.5	1365	62.8	31.4	29.93
11	500	0.13	0.5	5	2552	68.2	30.8	29.77
12	500	0.13	0.75	0	4249	72.3	29.1	29.27
13	500	0.34	0.25	2.5	3504	70.8	29.3	29.33
14	500	0.34	0.5	5	6408	76.2	34.0	30.62
15	500	0.34	0.75	0	10514	80.3	30.3	29.62
16	500	0.55	0.25	2.5	5561	74.6	29.7	29.45
17	500	0.55	0.5	5	9934	80.0	37.1	31.38
18	500	0.55	0.75	0	16036	84.2	32.4	30.21
19	775	0.13	0.25	5	1760	65.0	28.8	29.18
20	775	0.13	0.5	0	3718	71.2	22.4	27.00
21	775	0.13	0.75	2.5	5519	74.7	26.9	28.59
22	775	0.34	0.25	5	4501	73.0	25.7	28.19
23	775	0.34	0.5	0	9312	79.3	21.0	26.44
24	775	0.34	0.75	2.5	13503	82.7	29.1	29.27
25	775	0.55	0.25	5	7113	76.8	22.8	27.15
26	775	0.55	0.5	0	14394	83.1	23.5	27.42
27	775	0.55	0.75	2.5	20337	86.5	37.3	31.43

3.2: TAGUCHI DESIGN:

A standard Taguchi experimental plan with notation L27 was chosen. The rows in the L27 orthogonal array used in the experiment denotes each trial and the columns contained the factors to be studied. The first column consisted of spindle speed, the second contained feed, and the third column contained depth of cut consecutive column consisted of the Percentage of reinforcement. In the Taguchi method, the experimental results are transformed into a signal-to-noise (S/N) ratio. This method recommends the use of S/N ratio to measure the quality characteristics deviating from the desired values. To obtain optimal testing parameters, the-higher-is-better quality characteristic for machining the metal was taken due to measurement of the MRR. The S/N ratio for each level of testing parameters was computed based on the S/N analysis. With S/N ratio analysis, the optimal combination of the testing parameters could be determined.The signal-to-noise ratio for the bigger-the-better is

$$\frac{S}{N} = -10\log_{10}\left[\frac{1}{n}\sum\frac{1}{y^2}\right]$$

Where 'y' is the observed data and 'n' is the number of observations.

TABLE-4: Response Table For Signal To Noise Ratios Larger is better

Level	Speed (rpm)	Feed (mm/rev)	Doc (mm)	%R
1	71.38	67.64	69.20	74.48
2	74.43	75.65	74.98	74.31
3	76.95	79.47	78.58	73.97
Delta	5.57	11.83	9.38	0.51
Rank	3	1	2	4

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It could be seen in Table: 4 that the strongest influence was exerted by Feed rate, followed by Depth of cut, spindle speed, and lastly percentage reinforcement. Since the first level of the Material removal rate was about 67.64 mm/rev while the third level of the Material removal rate was about 79.47mm/rev the difference being the most highest of 11.83 mm/rev. It is followed by the Depth of cut which is 9.38mm which is significant level again. Which is followed by the spindle speed with 5.57rpm and The reinforcement showed the least effect on the Material removal rate which is 0.51.

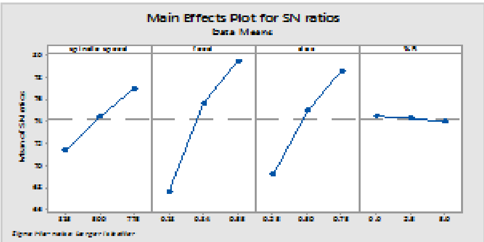

CHART-1: Effects of Means For S/N Ratio

TABLE-5: Response Table for Means

EXP	Speed (rpm)	Feed (mm/rev)	Doc (mm)	%R
1	4672	2760	3460	7284
2	6681	6889	6722	7107
3	8907	10610	10078	5868
Delta	4235	7850	6618	1416
Rank	3	1	2	4

CHART-2: Effects of Means of Means

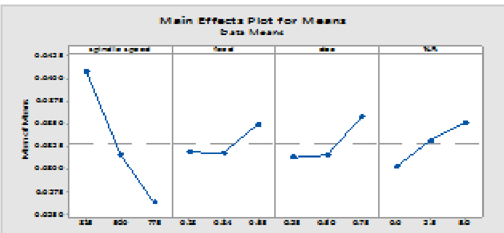

CHART -2 shows the main effect plots for Material removal rate of the metal for S/N ratios. Optimal testing conditions of these control factors could be very easily determined from the response graph. The best Material removal rate value was at the higher S/N value in the response graph.

For main control factors indicates the optimum condition for the tested samples (A3, B3, C3, D1). Thus, it could be concluded that the maximum Material removal rate of metal is achieved and their optimal setting of control factors for tested samples are shown in Table-3. To obtain optimal testing parameters, the-lower-is-better quality characteristic for machining the metals was taken due to measurement of the Cutting force. The Signal-To-Noise ratio for the Smaller-The-Better is

$$\frac{S}{N} = -10\log_{10}\left[\frac{\sum y^2}{n}\right]$$

Where 'y' is the observed data and 'n' is the number of observations.

TABLE-6: Response Table for Cutting force Smaller is better

Level	Speed (rpm)	Feed (mm/rev)	Doc (mm)	%R
1	32.13	29.9	29.76	28.0
2	29.9	29.84	29.72	30.33
3	28.27	30.59	30.8	29.74
Delta	3.86	0.75	1.08	2.33
Rank	1	4	3	2

It could be seen in Table:6 that the strongest influence was exerted by spindle speed followed by percentage reinforcement, Depth of cut and lastly feed rate. Since the first level of the Cutting force was about 27.86 rpm while the third level of the Cutting force was about 31.7 rpm the difference being the most highest of 3.85 rpm. It is followed by the percentage reinforcement with 1.23, which is significant level again. Which is followed by the Depth of cut, about 1.14 and The feed rate showed the least effect on the Cutting force was 0.74.

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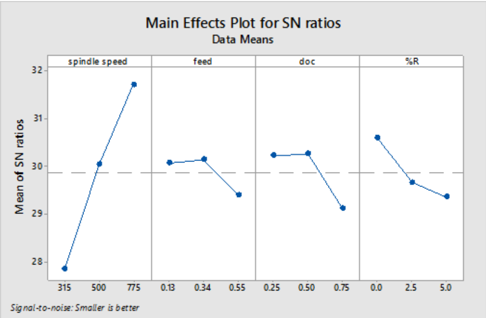

CHART-3: Effects of Means For S/N Ratio

TABLE-7:Response Table for Means

Level	Speed (rpm)	Feed (mm/rev)	Doc (mm)	%R
1	4071	3192	3135	3031
2	3157	3181	3159	3322
3	2638	3493	3579	3513
Delta	1433	312.9	448	482
Rank	1	4	3	2

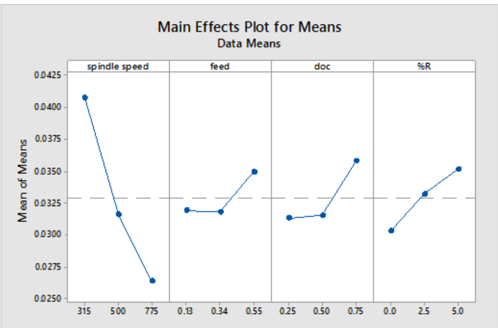

CHART-4: Effects of Means of Means

3.3: ANALYSIS OF VARIANCE (ANOVA)

Analysis of variance is a mathematical technique which is based on the least square approach. The purpose of ANOVA is to investigate the process parameters which significantly affect the performance characteristics. As per this technique, if the calculated value of the F ratio of the developed model does not exceed the standard tabulated value of F ratio for a desired level of confidence, then the model is considered to be adequate within the confidence limit.

The variance ratio, denoted by F in ANOVA tables, is the ratio of the mean square due to a factor and the error mean square. In robust design, F ratio can be used for qualitative understanding of the relative factor effects. A high value of F means that the effect of that factor is large compared to the error variance. So, the larger the value of F, the more important is that factor in influencing the process response.

Table-8: Results Of Anova For Mrr

SOURCE	DOF	SQUARES SUM	MEAN OF SQUARE	F RATIO	% OF CONTRIBUTION
SPEED	2	80786479	40393240	11.2750	12.81050
FEED	2	2.78E+08	1.39E+08	38.7328	44.00752
D.O.C	2	1.97E+08	98556707	27.5103	31.25673
% R	2	10718222	5359111	1.49590	1.699613
ERROR	18	64485526	3582529		10.2256
TOTAL	26	6.31E+08			

Table-9: ANOVA For The Response Mrr

Source	DF	Adj SS	Adj MS	F-Value
Speed	2	80786493	40393246	11.27
Feed	2	277522636	138761318	38.73
Doc	2	197113163	98556581	27.51
%R	2	10718222	5359111	1.50
Error	18	64486412	3582578	
Total	26	630626925		

The results of the ANOVA of Material removal rate in turning of work piece are shown in Table 6. In addition to degree of freedom, mean of squares (MS), sum of squares (SS) and F-ratio associated with each factor level were presented. This analysis was performed for a confidence level of 90%. The F value for each design parameters was calculated. The calculated value of the F showed a high influence of the feed rate (f) on the Material removal rate since F-calculation was equal to 38.73, but the depth of cut (d), Spindle speed (N) and percentage reinforcement (%R) had also significant effects on the surface roughness since F-test was equal to 27.51mm,11.27rpm and 1.50 respectively.

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Table-10: Analysis Of Variance For Cutting Force

Source	DF	SUM OF SQUARES	MEAN OF SQUARE	F-Value
Speed	2	947.3	474.5	56.48
feed	2	56.32	28.28	3.36
Doc	2	114.5	57.2	6.31
%R	2	106.9	53.93	6.81
Error	18	151.3	8.35	
Total	26	3043		

Table-11: Anova For The Response Cutting Force

SOURCE	DOF	SUM OF SQUARES	MEAN OF SQUARE	F RATIO	% OF CONTRIBUTION
SPEED	2	947.3	474.5	56.563245	68.91088
FEED	2	56.3	28.2	3.3639618	4.101862
D.O.C	2	114.5	57.2	6.321599	8.317934
% R	2	106.9	52.9	6.8156324	7.700982
Error	18	151.3	8.38		10.97417
TOTAL	26	3043			

The response values for MRR in ANOVA gives percentage contribution of each parameter shown in Table: 5.5.1. The feed contribution is highest which is 44%, followed by depth of cut is 31.2%, and spindle speed is 12.8% and lastly percentage reinforcement which is 1.69% and the error occurred in this is 10%.

3.4: STATISTICAL ANALYSIS:

The mathematical relationships between responses and machining parameters were established using multiple regression analysis. In the present study, the correlation between the process parameters cutting velocity, feed rate, depth of cut, MRR and CF are established. The multiple linear regression models were obtained using MINITAB 16.

Regression equation for MRR

MRR =10346 + 9.12 spindle speed + 18690 feed + 13236 doc - 283 %R

Regression equation for CF

CF = 0.03957 - 0.000030 spindle speed + 0.00717 feed + 0.00896 doc + 0.000963 %R

Table-12:Optimum sequence for MRR in Al 7075TiB_2&TiC

Speed (rpm)	Feed (mm/rev)	D.O.C (mm)	% of TiB_2&TiC	MRR mm^3/min
315	0.55	0.75	5.0	10715

Table-13:Optimum sequence for CF in Al 7075TiB_2&TiC

Speed (rpm)	Feed (mm/rev)	D.O.C (mm)	% of SiC	CF (N)
775	0.13	0.25	0	22.4

3.5: ROCKWEEL HARDNESS TEST:

The minor load is applied first and a SET position is established on the dial gauge or displacement sensor of the Rockwell tester. Then the major load is applied. Without moving the piece being tested, the major load is removed and, with the minor load still applied, the Rockwell hardness number is automatically indicated on the dial gauge or digital display. High Rockwell hardness numbers represent hard material sand low numbers soft materials.

Table-14: Rockwell Hardness Test

Sl.No	Composites	Load(Kgf)	Hardness(Hrb)
1	AL-7075(0% of Tic & TiB2)	100	74
2	AL-7075(2.5% of Tic & TiB2)	100	76
3	AL-7075(5% of Tic & TiB2)	100	83

A significant improvement is observed in the hardness of the composite with increasing percentage reinforcement of material and a decrease in the ductility.

4. CONCLUSION:

In Current work we will investigated and optimized Cutting parameters speed, feed and Depth Of Cut (DOC) for different proportions of Al-7075 with

(0 wt%,2.5 wt%,5 wt%) of TiC-TiB2. From the Taguchi optimization study it was observed that the best parameter combination for to get higher MRR for turning is A-3 (775rpm), B-3 (0.55mm/rev), C-3 (0.75mm) and D-1(0 wt%) i.e., higher cutting speed, higher feed, higher depth of cut and lower percentage reinforcement, and the best parameter combination for to get lower cutting force is A-3 (775rpm), B-1 (0.13mm/rev), C-1 (0.25) and D-1 (0 wt%) i.e., lower cutting speed, higher feed, higher depth of cut and higher percentage reinforcement. From The Analysis of variance (ANOVA) for material removal rate the strongest influence was exerted by Feed rate (44 mm/rev), followed by Depth of cut (31.2 mm), spindle speed (12.8 rpm), and lastly percentage reinforce ent (1.69), and for cutting force the strongest influence was exerted by spindle speed (68.9 rpm), followed by Depth of cut (8.31 mm), percentage reinforcement (7.7 wt%) and lastly Feed rate (4.10 mm/rev). Hence in the future we can use this Hybrid composite Al7075-TiC-TiB2 to improve machining parameters, Strength and hardness in the automobile industry.

NOMENCLATURE:

s= Spindle speed, rpm
f= Feed, mm/rev
d= Depth of cut, mm
D_{avg}= Average diameter, mm
D_i= Initial diameter, mm
D_f= Final diameter, mm
MRR= Metal removal rate, mm^3/min
CF= Cutting force, N
S/N or SN ratio= Signal to Noise ratio

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