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Fabrication and Optimization of Machining Parameters on Al 2024-Gr-B_4C Hybrid MMCS during Machining Process

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Abstract

In this experimental work, hybrid metal matrix composites by using Al2024 as a matrix and was reinforced with two types of materials in which one is fixed amount of Gr (3%) and the other is varying amount of B_4C (0,6 &12%). The composites were fabricated by using powder metallurgy technique. The effect of cutting speed, feed depth of cut and % of composition on material removal rate (MRR) was investigated during turning operation on the fabricated Al/B_4C/Gr hybrid MMCs. MRR was calculated for the set of combinations such as cutting speeds (315, 400 and 500 RPM), feed rates (0.05, 0.10, 0.15 mm/rev) and depth of cut (0.1, 0.2, 0.3 mm), which were obtained from Taguchi optimization technique. Taguchi L27 orthogonal array was used for the experiment plan. Micro structural and FESEM analysis shows the presence and uniform distribution of reinforcement particles in aluminium matrix. ANOVA results show the percentage contribution of every parameter during the machining operation. These results revealed that The effect of machining process of Al-Gr-B_4C was cutting Speed (29.45%) followed by depth of cut (29.36%), feed rate (21.82%) and lastly % of composition (9.52%).

Keywords: Powder metallurgy, Speed, Feed, Depth of cut, Material removal rate, Taguchi, Anova, Microstructure, FESEM.

INTRODUCTION

The use and application of composites in every sector is goes on increasing due to their enhanced properties. The addition of reinforcing particles to the base material leads to the promising materials with better properties; hence these are used in many areas like Aerospace, Naval and Automobile etc. These properties vary with the method of fabrication and the type of matrix and reinforcing material. The mechanical, chemical and thermal properties are also being changed by the addition of different reinforcing materials. There is a limit for the enhancement of properties by the use of single reinforcements. Hence better properties can be achieved by adding more number of reinforcements to the base material and these are called as hybrid composites. Aluminum-matrix composites are consisting of a family of different materials for the improvement in density, hardness, stiffness, toughness, thermal and electrical properties. Now a days, most of the researchers are using Al2024, Al6067, Al 7075 as matrix elements, these are reinforced with various metal and non metals like Sic, B_4C, Al_2O_3, Tic, Zr and Gr. In this work, Al2024-Gr-B_4C hybrid composites were fabricated by using Al 2024 as matrix and two types of reinforcements (B_4C and Gr) were added to the matrix alloy. The fabricated composites can be used in aerospace and automobile applications. Al2024 alloy is having highest hardness [1] among all the other Al alloys, hence it can be chosen for the fabrication composites. Boron carbide is the third hardest material and can be used as the better choice for the selection of reinforcement. Graphite particulates are also be used as a reinforcement, as their addition improves the machinability and wear resistance [2] of Al–SiC composites. The method of fabrication affects the properties of the final composite. The powder metallurgy technique is the simplest method for the fabrication of composites. Aluminium hybrid composites [2, 3, 7-12, 18] fabricated by many of the researchers by using Gr as additional reinforcement. SanjayYadav and Sanjay Kajal [11] conducted a test on optimization of different machining Parameters of En 354 alloy steel In CNC turning operation Using Taguchi Method .The experimental results show that the Taguchi parameter design is an effective way of determining the optimal cutting parameters for achieving low surface roughness. Soorya prakash Kumarasamy et al [12] investigated the mechanical and machinability behaviour of Al/Flyash cenosphere/Gr hybrid composites processed through compo-casting, based on the ANOVA results the cutting speed and % composition are the major parameters which effects the surface roughness. Vikasa et al [13] examined the effect and optimization of machine process Parameters on MRR for EN19 & EN41 materials using Taguchi, the optimal process parameters for maximum MRR for EN19 were current 24 amps, voltage 40 V, pulse ontime 400 μs and pulse off time 2300 μs whereas the same for EN41 are 24 amps, 40V, 400 μs and 2100 μs respectively. Hemant Jaina et al [14] explained about the Optimisation and evaluation of machining parameters for turning operation of Inconel-625, the experimental results demonstrate that the insert spindle speed and feed rate are the main parameters among the three controllable factors (spindle speed, feed rate and depth of cut) that influence the material removal rate in turning smart alloy Inconel-25. Sayak Mukherjeea et al [15] found the optimization of material removal rate during turning of SAE 1020 Material in CNC lathe using Taguchi technique, the analysis shows that depth of cut had the most significant effect on MRR followed by feed. With an increase in depth of cut MRR increased in the studied range. Optimum cutting parameter combination was found out for maximum MRR and this study may be useful in computer aided process plan, Asheet Kumar et al [16] reported optimization of turning parameters by using Taguchi Method. For optimum surface finish, based on ANOVA analysis feed rate is the most significant parameter followed by depth of cut and RPM to affect the surface roughness. Senthil Kumar MP and Rajendran [18] were examined the optimization of CNC turning parameters on Aluminum 7015 hybrid metal matrix composite by using Taguchi robust design. It was found that the feed rate is the most significant parameter, cutting speed is the next significant parameter and the depth of cut is the third significant parameter on MRR. W.H. Yang and Y.S. Tarng [19] were conducted tests on design optimization of cutting parameters for turning operations based on the Taguchi method. Taguchi method provides a systematic and efficient methodology for the design optimization of the cutting parameters with far less effect than would be required for most optimization techniques. It has been shown that tool life and surface roughness can be improved significantly for turning operations. Krishankant et al [20] reported the application of Taguchi method for optimizing turning process by the effects of machining parameters. MRR is increasing with increase of feed rate. A Saravanakumar et al [21] investigated the optimization of machining parameters using Taguchi method for surface roughness. From the main effects plot for S/N ratio, it is clear that 6 wt % of alumina shows better surface finish compared to other alumina compositions, from the response table for S/N ratio, it is confirmed that feed rate is the most influencing factor followed by wt % of alumina and spindle speed in reducing surface roughness during machining of Al/Al2O3/Gr composite.

EXPERIMENTAL PROCEDURE

Materials

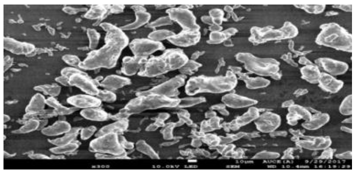
Powder metallurgy technique was used for the fabrication of Aluminium metal matrix hybrid composites (AMMHCS). Al 2024 of an average grain size 50µm was used as matrix and was received from Parshwamani metals, Mumbai; the elemental composition of this matrix was shown in Table 1. In the present work, two reinforcing elements of an average grain size 100 µm were used for the fabrication of these composites; in which B_4C received from Parshwamani metals Mumbai and graphite powder was received from Amazon India. The density and size of the used powders were shown in Table 2. The required quantity of composite powders are weighed in a simple balance of accuracy 0.001g and are taken in a Tungsten carbide bowl of planetary ball mill for proper mixing. The SEM images of received powders were shown in Figure.1

Table 1. Elemental composition of Al 2024

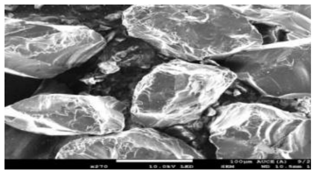
Component	% Of Weight
Aluminium	90.7-94.73.
Copper	8-4.9
Chromium	Max 0.1
Ferrous	Max 0.5
Magnesium	1.2-1.8
Manganese	0.3-0.9
Silicon	Max 0.5
Titanium	Max 0.15
Zinc	Max 0.25
Other total	Max 0.3

Table 2. Particle size and density of various elements

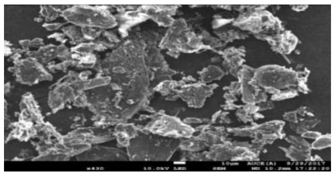
Material	Average Size	Density(g/cc)
Al 2024	50 µm	2.71
B_4C	100 µm	2.52
Gr	100 µm	2.09



(a)



(b)



(c)

Figure 1. FESEM images of received (a) Al 2024 (b) B_4C (c) Graphte

Blending of Powder

The final results of the composites were influenced by ball milling Parameters like milling time, milling speed; milling environment during the process of mechanical alloying [8]. A Retsch100 Ball Mill, Germany make was used for mechanical milling and alloying. Tungsten carbide balls of 10 mm diameter are added to these powders with Ball to Powder ratio of 10:1[22], Various weight based powdered compositions are milled in a RESTECH 100 planetary ball mill (Figure.2) for about 30 minutes for uniform mixing of the powders. different hybrid compositions Al-3%Gr-3%B_4C, Al-3%Gr-6 %B_4C , Al-3%Gr-12%B_4C were weighed in a balance and were blended in ball milling machine. FESEM machine as shown in Figure.2 was conducted on mixed powders to know the presence of reinforced particles in each blend was shown in Fig.4

Figure 2. Restech 100 ball milling

Figure 3. FESEM used for

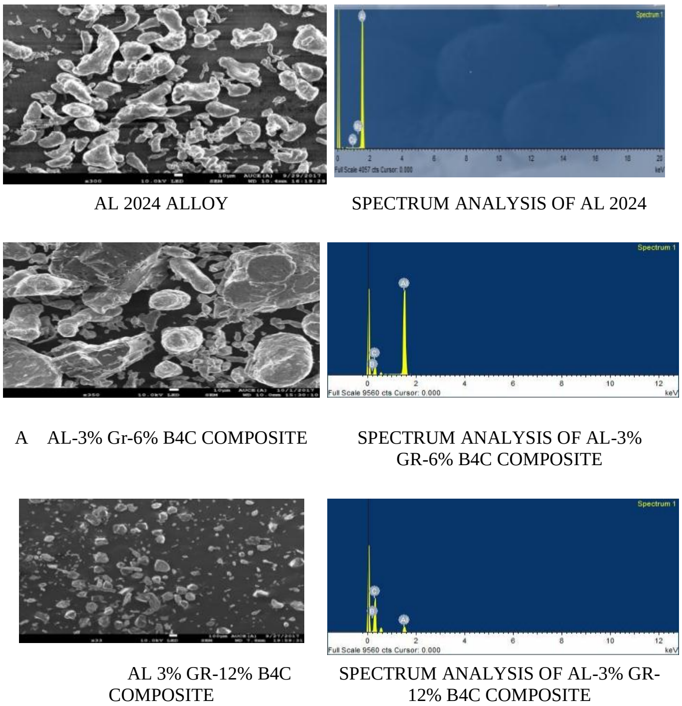


Figure 4. FESEM micrographs of produced powder mixtures

Preparation of Pellets

To carry out the study, twelve types of pellets, each of five in number were consolidated for different analysis. A die with punch are made up of hardened steel Figure.5 was used for compaction of the blended and mixed powders by using hydraulic compressive testing machine Figure.6 at a pressure of 400 Mpa [22,23] , after compaction the green pellets of 20 mm diameter and 25mm length were obtained at room temperature. After compression of each pellet, same pressure was maintained for about 10 seconds then the pellets were ejected out from the die. The Pellets of 20mm diameter and approximately 25mm height were obtained by compacting powders in die-punch. For each run, the die was filled with approximately same quantity of well-mixed powders, Silicon spray was sprayed into the die before the powder was put in the dye so as to provide proper lubrication between the die walls and the powder. Then the punch was placed over the filled powder and gradual pressure was applied over the powder.

Figure 5. Hardened steel die and plunger for compression

Figure 6. Compact testing machine

Sintering

The green pellets obtained after compression were converted into specimens by using sintering process. The sintering process was carried out in a muffle furnace (Figure.7). The sintering involves heating the samples in controlled atmosphere in an inert atmosphere (organ gas) to prevent oxides during the process; the pellets were heated up to the bonding temperature and cooled in the furnace itself. Muffle furnace was used for sintering process following the sintering cycle at the rate of increase of temperature 10^0 C per minute and heated up to the temperature 600^0C for about 3hours, and the samples were allowed to cool in the furnace itself to reach room temperature. This sintering process improves the grain growth and good grain bonding in between the neighbour particles. The obtained specimens after sintering were shown in Figure.8.

Figure 7. Muffle furnace for sintering

Figure 8. Specimens after sintering

TAGUCHI OPTIMIZATION

Experimental setup

The machining process was carried out on lathe machine Figure.9 by using HCS as cutting tool. The plan of combinations for experimental setup was obtained from Taguchi optimization technique, the Plan of experiments was obtained from Minitab 17 software. The turning operation was performed by considering process parameters like % of composition, Speed, Feed and depth of cut. MRR was measured at three different % of compositions (0%, 6%, 12%), cutting speeds (315, 400 and 500 RPM), feed rates (0.05, 0.1, 0.2 mm/rev) and depth of cuts (0.1, 0.2, 0.3 mm). All the parameters and their levels were shown in Table.3.

Table 3. Turning Parameters and Their Levels

S.No	Reinforcement (%)	Cutting Speed (N)	Feed(mm/Rev)	Depth of cut(mm)
1	0	315	0.05	0.1
2	6	400	0.1	0.2
3	12	500	0.2	0.3

Figure 9. Lathe for turning

Figure 10. Specimens after turning

EXPERIMENTAL PROCEDURE

The fabricated Al/B_4C/Gr Metal Matrix hybrid Composite specimens by using powder metallurgy technique are used as work-piece materials. For effective machining, it is essential to select proper machining parameters for Al/B_4C/Gr composites. All the Experiments were conducted based on Taguchi's method and as per L27orthogonal array with considering four controllable factors (i.e. parameters). Each factor has three levels. The levels of parameters will be deciding through the detailed study of literature and based on the preliminary experimentation. The values taken in each factor are termed as levels. The factors and the levels in these factors are chosen were given in the Table.3. All the experiments were conducted by considering 4 factors each of three levels and their combinations were shown in Table.4. The removed material during turning operation was collected and was weighed in a sensitive balance. The time for the removal of material has been taken during the turning operation. The samples obtained after the machining were shown in Fig.10.

Data Analysis

All the experiments were conducted as per the combinations given by Taguchi orthogonal array by using MINITAB 17 software. The combinations for conducting the experiments were taken from table. 4 then the material removal rate was calculated and tabulated in table.4. The S/N ratio was obtained from the Minitab software based on Equation given below. The experimental results are then transformed into signal to noise ratio. Taguchi recommends the use of S/N ratio to measure the quality characteristics deviating from the desired values. The material removal rate, (MRR) in mm^3/sec has been calculated from following relation:

$$MRR = \frac{Total\ material\ removed}{Time\ Taken}$$

MRR is calculated for both set of experiment. Considering one set correct S/N ratio is calculated from MINITAB 17 software.

Taguchi method

The powerful and simple statistical data technique to study the multiple variables is Taguchi. By using Taguchi emphasizes a mean performance characteristic value hence the product quantity can be improved. The number of experiments carried out is more when the number of process parameters increased. To overcome this problem, small number of experiments can be achieved to study the entire process by Taguchi method. The obtained results are converted into S/N ratios, which is a measure of quality characteristics based on larger the better, normal the better and smaller the better. The Taguchi optimization can be performed based on the process in which S/N ratios may be larger is better, Normal is better and

Smaller is better. For the machining process, all the experiments were done by choosing S/N ratios with Larger are better. This can be governed by the following equation.

$$SN_S = -10 \log 1/n \left(\sum_{i=1}^{n} 1/y_i^2\right)$$

Table 4. Taguchi's L27 Orthogonal Array

Run No	Reinforcement % of B_4C	Cutting speed (RPM)	Feed(mm/rev)	Depth of cut(mm)	MMR in mm^3/Min	S/N Ratio
1	0	315	0.05	0.1	76.92	37.7208
2	0	315	0.1	0.2	134.68	42.5861
3	0	315	0.15	0.3	139.92	42.9176
4	0	400	0.05	0.2	124.34	41.8922
5	0	400	0.1	0.3	152.00	43.6369
6	0	400	0.15	0.1	112.32	41.0091
7	0	500	0.05	0.3	125.00	41.9382

Run No	Reinforcement % of B_4C	Cutting speed (RPM)	Feed(mm/rev)	Depth of cut(mm)	MMR in mm^3/Min	S/N Ratio
8	0	500	0.1	0.1	119.45	41.5437
9	0	500	0.15	0.2	155.23	43.8195
10	6	315	0.05	0.2	87.85	38.8748
11	6	315	0.1	0.3	145.57	43.2614
12	6	315	0.15	0.1	127.00	42.0761
13	6	400	0.05	0.3	132.00	42.4115
14	6	400	0.1	0.1	159.00	44.0279
15	6	400	0.15	0.2	131.79	42.3976
16	6	500	0.05	0.1	155.00	43.8066
17	6	500	0.1	0.2	145.00	43.2274
18	6	500	0.15	0.3	169.00	44.5577
19	12	315	0.05	0.3	96.35	39.6770
20	12	315	0.1	0.1	127.43	42.1054
21	12	315	0.15	0.2	137.89	42.7907
22	12	400	0.05	0.1	148.00	43.4052
23	12	400	0.1	0.2	177.00	44.9595
24	12	400	0.15	0.3	135.00	42.6067
25	12	500	0.05	0.2	151.00	43.5795
26	12	500	0.1	0.3	167.00	44.4543
27	12	500	0.15	0.1	162.00	44.1903

Larger is better

Table 5. Response Table for Signal to Noise Ratios

Level	% of reinforcement	Speed(RPM)	Feed	Depth of cut
1	41.9	41.33	41.48	41.28
2	42.74	42.93	43.31	43.14
3	43.09	43.46	42.93	43.30
Delta	1.19	2.12	1.83	2.02
Rank	4	1	3	2

Table 6. Factor Information

Factor	Type	Levels	Values
A	Fixed	3	0,6,12
B	Fixed	3	315,400,500
C	Fixed	3	0.05,0.10,0.15
D	Fixed	3	0.1,0.2,0.3

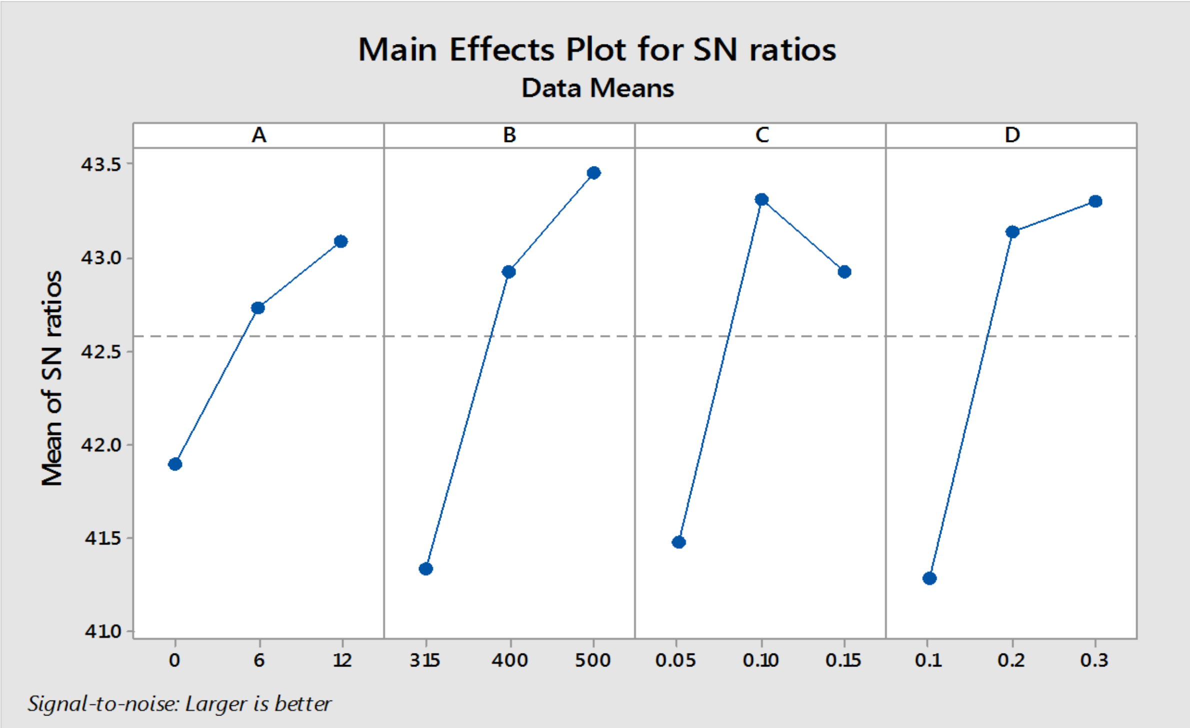


Figure 11. Main effects plot for S/N ratios data means

ANOVA analysis:

Method

Factor coding (-1, 0, +1)

Box-Cox transformation λ = 0.

Table 7. Analysis of Variance for Transformed Response

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% of P
% of Reinforcement	2	2.889	1.4445	8.72	0.002	9.52
Speed	2	8.932	4.4661	26.96	0.000	29.45
Feed	2	6.619	3.3094	19.98	0.000	21.82
Depth of cut	2	8.905	4.4526	26.88	0.000	29.36
ERROR	18	2.982	0.1656			9.83
TOTAL	26	30.327				

Table 8. Model Summary for Transformed Response

S	R-Sq	R-sq(adj)	R-sq(pred)
0.04879	90.56%	86.37%	78.77%

Regression Equation

MRR = 11.6483 - 0.443 A0 + 0.105 A6 + 0.338 A12 - 0.786 B315 +0.212 B400+ 0.574 B500- 0.683 C0.05 + 0.473 C0.10 + 0.210 C0.15 - 0.809 D0.1 + 0.346 D0.2 + 0.463 D0.3

MICRO STRUCTURAL AND FESEM ANALYSIS

Micro Structural and FESEM Analysis

Microscope was used for microstructure examinations. Aluminium, boron carbide and graphite were detected in the analysis. The fabricated Metallographic specimens of sintered preforms were prepared using standard hand polishing using 240, 600, 800 and 1000-grit silicon carbide papers. The specimens were then finish-polished using lm diamond paste suspended in distilled water to obtain mirror-like surface finish. To expose the micro structural features, the polished specimens were etched with Keller etching solution. The etch–polish–etch procedures were used to attain good microstructure. The obtained images the graphite and B4C particles are uniformly distributed throughout the Al 2024 matrix phase. The absence of cracks can also be observed from the micrographs. Figure.11 shows the distribution of Boron carbide (B4C), graphite (Gr) particles in aluminium (Al).

FESEM examination was also been conducted on the collected material obtained after the turning operation. The examination shows the Reinforced particles such as B4C and Gr are being in the collected material. The FESEM examination on the specimen after the turning process was conducted and was shown in Figure.11.

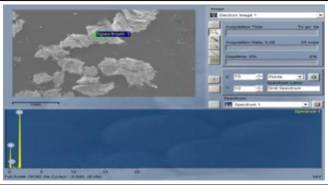
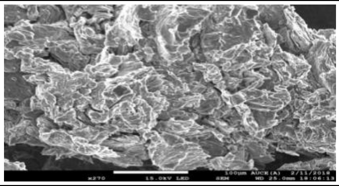
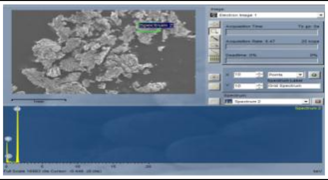
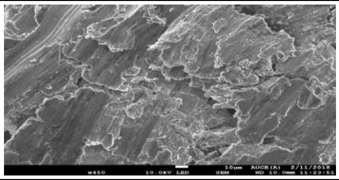
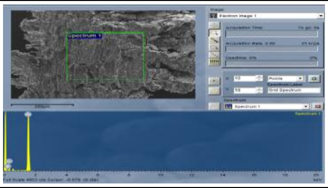
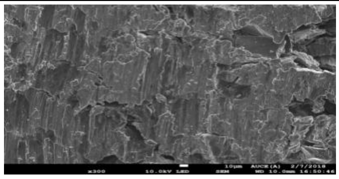
S. No	Material	Microstructure Of The Fabricated Specimens	Fesem Alalysis Of Machined Particles	FESEM analysis of the specimen after Machining
1	Al2024 Alloy			
2	Al 2024-3% Gr-6%B4c			
3	Al 2024-3% Gr-12 %B4c			

Figure 12. Optical micrographs and FESEM analysis of the produced composite

RESULTS AND DISCUSSION

Minitab 17 software was used for the optimization of process parameters. Taguchi optimization technique was applied to the results of 27 experiments which were conducted as per L27 orthogonal array to get optimal values for response variables. In next stage, ANOVA was applied to identify the parameters which affect the machinability of Al-Gr-B_4C mm composites. The conduced experimental results as per L27 with S/N ratio are furnished in table.4 The effect of machining process of Al-Gr-B_4C was cutting Speed(29.45%) followed by depth of cut(29.36%), feed rate (21.82%) and lastly % of composition (9.52%).

CONCLUSIONS

- Al-Gr-B_4C hybrid metal matrix composites were successfully fabricated by using Powder metallurgy technique
- The microscopic examination shows the presence of reinforced particles in alloy and their uniform distribution of particles throughout the alloy.
- FESEM examination also shows the presence of the particles in alloy before the fabrication of composites and also the nature of machined surface after machining process.
- Taguchi experimental plan along with Anova analysis was applied successfully by using MINITAB17 software.
- The effect of machining process of Al-Gr-B_4C was cutting Speed(29.45%) followed by depth of cut(29.36%), feed rate (21.82%) and lastly % of composition (9.52%).

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