Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 97 (2014) 677 – 686

Procedia Engineering

www.elsevier.com/locate/procedia

12th GLOBAL CONGRESS ON MANUFACTURING AND MANAGEMENT, GCMM 2014

Study of Cutting force and Surface Roughness in machining of Al alloy Hybrid Composite and Optimized using Response Surface Methodology

K. Venkatesan[1*], R. Ramanujam[1], J.Joel[1], P.Jeyapandiarajan[1], M.Vignesh[1],Darsh Jiten Tolia[1], R.Venkata Krishna[1]

[1]School of Mechanical and Building Sciences,VIT University ,Vellore 632014, India

Abstract

Metal matrix composites, in particular, Aluminium Hybrid Composites are gaining increasing attention for applications in air and land because of their superior strength to weight ratio, density and high temperature resistance. This paper presents the results of experimental investigation on machinability properties of Silicon Carbide and Boron Carbide reinforced Aluminium 356 hybrid metal matrix composite. The composites were prepared by varying weight fraction of SiC (5%, 10%, 15%) and keeping the Boron Carbide weight fraction (5%) is constant using modified stir casting technique. Four layer coated carbide insert (TiN. Al_2O_3, TICN, TiN) designated as CNMG 120408 FR was used to machine the fabricated composites. Face centered central composite experimental design coupled with Response Surface Methodology (RSM) was used for modeling that the process output characteristics that influence by weight fraction, speed, feed rate, cutting depth. The experimental results imply that surface Roughness criteria are found to increase with increase of feed. At 0.206.mm/rev feed, the Surface Roughness deteriorated rapidly. Roughness decreases at higher cutting speed during machining. With the help of Mintab software, RSM showed an accuracy of 95%. Moreover, a good agreement was observed between the experimental and the predicted values of surface roughness and cutting force. Optimal cutting condition which leading to the minimum surface roughness and cutting force were highlighted.

© 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).
Selection and peer-review under responsibility of the Organizing Committee of GCMM 2014

Keywords:AL-A356, SiC& Boron Carbide, Machinability, Feed rate, Desirability -based response surface methodology

* Corresponding author. Tel.: +919443810370.
E-mail address: venkatesan.kannan@vit.ac.in

1877-7058 © 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).
Selection and peer-review under responsibility of the Organizing Committee of GCMM 2014
doi:10.1016/j.proeng.2014.12.297

1. Introduction

Aluminium and its alloys have continued to maintain their mark as the matrix material most in demand for the development of Metal Matrix Composites (MMCs). This is primarily due to the broad spectrum of unique properties it offers at relatively low processing cost. In this, Al/Si base alloys are commonly used due to its attractive properties such as high strength to weight ratio, good thermal conductivity, corrosion resistance, good workability and excellent castability. The family of this Al/Si alloy is widely used in applications such as brakes, pistons, cylinder liners and motor casing [1-3]. However, the one of the major drawbacks of this alloys are have poor tribological characteristics which hinders the usage of this alloy. The desired properties of this alloy can be improved by addition of various carbides, oxides, borides and nitrides in particulate, fibers and whiskers. The functionality of this alloy can be bordered and so find its important application in air and land field. So, there is an increasing demand in producing the discontinuously reinforced Aluminium MMCs for air and land applications. The multifunctional nature of Al matrix composites has resulted in its numerous applications in aerospace technology, electronic heat sinks, solar panel substrates and antenna reflectors, automotive drive shaft fins, and explosion engine components, among others [5-8]. On the view of excellent thermo-physical properties, the chemical instability between the matrix and reinforcement is still gives a greater challenge during fabrication. It is revealed that difficult to fabricate the Al-MMCs because of poor wettability between the reinforcement and matrix (particularly B_4C). Therefore, most of research is dedicated to produce Al-MMCs with low cost. On the account, it is found that stir casting is a successful method of producing the composites in terms of economical way.

The use of particulate Al-MMCs in industrial application is limited due to difficult associated in machine. It was reported that the main concern while machining is abrasive action of ceramic particles which lead to high tool wear. From the published literature, it is reported that polycrystalline diamond tools (PCD) provided a useful tool life and does not have a chemical tendency while machining on these materials. However, research on less expensive cutting tools like cemented carbide and ceramics were also carried out to machine this material due to the relatively high cost associated with PCD tools. In this, carbide tool produces acceptable tool life while machining at low cutting speed (<60 m/min) and high feed rate while ceramic tools and HSS tools were found to be unsatisfactory in terms tool life. [9]. However, a limited number of studies are reported on the particulate MMCs using coated carbide cutting tools with respect of surface roughness and cutting forcer based on orthogonal arrays under varying cutting conditions [10-12].Moreover, the considerable quantity of research has been done on mechanical properties and machining characteristics of MMCs reinforced with different single reinforcements (SiC, Al_2O_3, B_4C graphite, TiB_2, etc.,). However, limited information is available on the machining of hybrid metal matrix composites with more than one reinforcement materials [13-16].However, various alloys of aluminium have been used as matrix materials and SiC has been used as reinforcements [17-22], Al 356/SiC/B_4C composites have not been studied in detail so far.

In the present study, an attempt has been made to fabricate Al 356/SiC/B_4C composites metal matrix composites reinforced with two different ceramics particles. Therefore, in first part of research work, three types of PMMC i.e A1356/5wt% SiC/ 5 wt% B_4C (particle size10-20 µm), A1356/10wt% SiC/ 5 wt% B4C(particle size10-20 µm), and A1356/15wt% SiC/ 5 wt% B_4C(particle size 10-20 µm) in the shape of cylindrical rods of 30 mm and length 300 mm have been casted by modified stir casting process. Medium dutylathe have been used for machining. Tungsten carbide inserts have been used for machining the PMMCs. Design of experimentation technique viz Response Surface Methodology has been used for studying the influence of process parameters (cutting speed, feed and depth of cut) on the responses. Developed Regression model has been validated.

2. Experimental Methods

2.1. Stir Casting-Fabrication procedure

The hybrid metal matrix composite comprises Al-356 aluminum alloy as matrix and SiC and B4C as reinforcements. Samples with different volume fraction of SiC (5, 10 and 15 wt.%) and B_4C (5%) has been prepared to study the effect of addition of B_4C on the properties of the hybrid composite, particularly its machinability. Al-MMC samples were prepared by stir casting route. Figure 1 shows the stir casting setup used in the present study

[23-24]. The fabrication procedure followed in this study is as follows: Al356 ingot is cleaned using acetone and it is melted in electric arc furnace. Once the base melt is melted around 700˚C, coverall powder is added to removes the slurry on the base metal ingot. The SiC range form 10-20 µm, and B_4C range from 30 to 70 µm are preheated to a temperature of 650˚C and then continuously added to the melt. The magnesium is added to improve the wettability between reinforcement and matrix. The melt was stirred with help of a mechanical stirrer for about 15 min at 350 rpm. Argon gas was supplied into the melt during the operation to provide an inert atmosphere. After stirring the molten mixture, it was poured down into the preheated permanent mould. The cylindrical samples of dimension 30mm X 300mm were obtained using this method. Table 1 gives the chemical composition of the matrix material.

Table 1 Chemical composition of Al356 alloy

Elements	Cu	Si	Mg	Mn	Fe	Ti	Ni	Zn	Pb	Tn	Al
% by weight	0.09	7.19	0.44	0.23	0.23	0.04	0.006	0.02	0.009	<0.001	Balance

2.2. Experimental method

The machining experiments were carried out according to the central composite rotatable second-order design based on Response Surface Methodology (RSM) of experimental design on a high speed lathe of spindle power 7.5 kW. Figure 3 shows the experimental setup used for the current study. Volume fraction of SiC, cutting speed, feed rate and depth of cut were considered as control factors and each varied for three levels. The machining parameters and their levels are given in Table 2. Three levels of each parameter were determined and arranged according to the L_{31}central composite designs (CCD) as shown in Table 3. Eighty one cases should be examined if three levels of four parameters were fully arranged; however, only 31 cases were examined using the second-order design based on Response Surface Methodology (RSM) of experimental design. The cutting tool selected for machining Al/SiC/B_4C MMCs was coated carbide inserts. The inserts used were of ISO coding CNMG 120408 and tool holder of ISO coding PCLNR 2525M12. Surface roughness measures Ra and cutting force were considered as performance characteristics. The surface roughness was measured using Mahr surf test (Make-Japan –Model GD120) measuring instrument with the cut-off 5.6 mm. Three surface roughness measurements were made and an average of these values was taken for the analysis. Cutting force was measured using 9121 type Kistler dynamometer with digital indicator connected to a data acquisition system.

Fig.1 Fabrication of hybrid MMCs

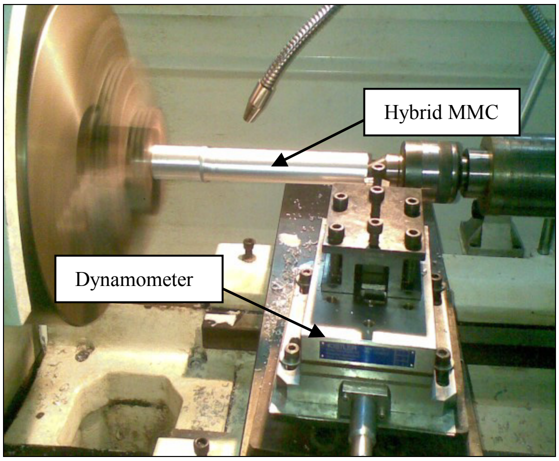

Fig.2 Experimental setup

2.3. Cutting tool material

The cutting tool selected for machining of prepared composites was CVD ($TiN/TiCN/Al_2O_3/TiN$)coated carbide tungsten inserts (grade TN8135). The ISO coding for the insert is CNMG 120408-FR.The grade TN8135, MTCVD coated with a supporting thick layer TiN, TiCN, Al_2O_3 and TiN (outermost) coating gives excellent wear and heat resistant properties. The cemented carbide substrates belonged to the ISO application range of P15–P30.Table 2 shows the tool nomenclatures of cutting insert used in the present study.

Table 2.Nomenclature of Cutting inserts

Rake angle (γ)	Clearance angle (α)	Inclination angle (η)	Approach angle (φ)	Point angle (β)	Nose radius r (mm)
-6˚	0˚	-6˚	95˚	80˚	0.8

2.4. RSM-Design of experiments

In order to investigate the influence of machining parameters on the surface roughness (Ra) and cutting force (Fz)four principal machining parameters such as the volume fraction of SiC, cutting speed (v),feed rate (f), and depth of cut (d) were taken. In this study, these machining parameters were chosen as the independent input variables. The desired response was the surface roughness (Ra) and cutting force (Fz) which is assumed to be affected by the above four principal machining parameters. The response surface methodology was employed for modeling and analyzing the machining parameters in the turning process so as to obtain the machinability performances of Ra and Fz. The sequential approach of RSM [25-26]can be used in the following order are, 1) to determine the factor levels that will simultaneously satisfy a set of desired specifications, 2) to determine the optimum combination of factors that yields a desired response and describes the response near the optimum, 3) to determine how a specific response is affected by changes in the level of the factors over the specified levels of interest,4) to achieve quantitative understanding of the system behavior over the region tested, 5) to predict product properties throughout the region, even for a factor combinations not actually run, 6) to find the conditions necessary for process stability. In the RSM, the quantitative form of relationship between the desired response and independent input variables is represented as follows:

$$Y=\varphi(x_1,x_2\ldots\ldots.)+e_u\text{---------}(1)$$

Where Y is the desired response and φ is the response function (or response surface). In the procedure of analysis, the approximation of Y was proposed using the fitted second-order polynomial regression model, which is called the quadratic model. The quadratic model of Y can be written as follows:

$$Y = a_0+\sum_{i=1}^{k} biX\ i+e_u\text{--------------}(2)$$

where, a_o is constant, b_i, b_{ij}, and a_{ij} represent the coefficients of linear, quadratic, and cross product terms, respectively. x_i reveals the coded variables that correspond to the studied machining parameters. The design was generated and analyzed using MINITAB statistical package.

Table 3: Cutting parameter and their levels

Parameter and symbol	Unit	Level 1	Level 2	Level 3
Cutting speed (v)	m/min	80	100	120
Feed rate (f)	mm/rev	0.103	0.206	0.294
Depth of cut (d)	Mm	0.3	0.6	0.9
% reinforcement of SiC (n)	%	5	10	15

3. Results and Discussion

The experiments were performed according CCD L_{31}experimental design and the results are tabulated in the Table 4. The cutting forces and surface roughness were measured for all the experiments. The effects of the input parameters on the responses were analyzed using the MINITAB® statistical software. A quadratic model was developed for the response based on the experimental plans. Further, the test for significance of the regression model, for significance on individual model coefficients and the test for lack-of-fit were performed in order to verify the goodness of the fit obtained from the quadratic model. The analysis of variance (ANOVA) is usually performed to summarize the above tests.

3.1Analysis of S/N ratio and ANOVA for cutting force and surface temperature

As mentioned previously, the model is tested for its significance by its regression equation, model individual model coefficients and lack of fit. An analysis of variance (ANOVA) table is usually performed to summarize the test significance. From Table 5, it is observed that square terms for response Fz in Eq. (3) and linear terms for response Ra in Eq. (4) are significant since the p-value belongs to these terms are less than 0.05. Tables 6 shows the AVOVA table for response surface quadratic model for Fz and Ra. The values of 'p' are less than 0.05 in Table 6 indicates that the particular terms in the model are considered to be statistically significant. The other terms in the model does not have significant effect on the responses. The term R^2 (determination coefficients) is defined as the ratio of the explained variation in the model to the total variation and also it measure the degree of fit. When this R^2 reaches to unity, it indicated the model fit exactly with the actual data. The obtained R^2 values for Fz and Ra are 0.76 and 0.86. This indicates the responses surface quadratic equations have a good correlation between the predicted and experimental values. Also from the Table 6, the tabulated value of lack of fit for Ra is smaller than the calculated value of F-ratio $F = 2.54 < 3.13$ ($F_{0.05,10,5} = 3.13$). This indicates the model is adequate and significant. But, the test of lack-of fit is insignificant.

Table 4 Design layout and experimental results for cutting force and surface roughness components

Sl. No.	Cutting speed m/min (v)	Feed rate mm/rev (f)	Depth of cut mm (d)	%Reinforcement (n)	Fz kN	Ra µm	Sl. No.	Cutting speed m/min (v)	Feed rate mm/rev (f)	Depth of cut mm (d)	%Reinforcement (n)	Fz kN	Ra µm
1	120	0.103	0.3	5	21.97	1.118	17	80	0.296	0.3	15	93.75	1.831
2	120	0.296	0.9	5	68.4	1.932	18	120	0.103	0.9	5	69.14	1.599
3	80	0.296	0.9	5	58.3	1.363	19	80	0.103	0.9	15	20.21	1.908
4	120	0.103	0.3	15	51.86	2.672	20	80	0.103	0.3	5	59.47	1.754
5	100	0.206	0.6	10	102.8	2.31	21	100	0.103	0.6	10	69.14	1.593
6	80	0.296	0.3	5	42.77	2.079	22	120	0.206	0.6	10	83.79	1.144
7	80	0.296	0.9	15	53.03	1.98	23	100	0.296	0.6	10	101.4	2.62
8	100	0.206	0.6	10	56.54	1.657	24	100	0.206	0.9	10	100.2	1.966
9	80	0.103	0.9	5	45.12	1.42	25	100	0.206	0.6	10	48.05	2.04
10	120	0.296	0.3	15	74.71	2.456	26	100	0.206	0.6	10	76.76	1.092
11	120	0.103	0.9	15	48.34	1.441	27	100	0.206	0.6	15	88.48	1.448
12	80	0.103	0.3	15	47.46	2.69	28	80	0.206	0.6	10	180.8	1.389
13	100	0.206	0.6	10	95.21	1.934	29	100	0.206	0.6	5	165.5	1.134
14	100	0.206	0.6	10	77.34	1.658	30	100	0.206	0.3	10	160.8	2.192
15	120	0.296	0.3	5	80.27	1.842	31	100	0.206	0.6	10	101.4	2.62
16	120	0.296	0.9	15	69.14	1.824							

Because F = 2.54 < 3.13 (F0.05,10,5 = 3.13) so null hypothesis cannot be rejected which means that model is adequate. It is also observed that good correlation between the predicated and the experimental values due to high R^2 value (0.85). The quadratic models of response are presented as follows (see Table 6):

$$cuttingForce(Fz) = 102.228 - 1.858 * v + 11.614 * f - 5.599 * d - 3.583 * n + 2.786 * v * v - 43.654 * f * f + 0.991 * d * d - 2.529 * n * n + 1.208 * v * d - 0.283 * v * n - 2.999 * f * d + 3.999 * f * n - 7.096 * d * n ------(3)$$

$$Surfaceroughness(Ra) = 1.8201 - 0.0829 * v + 0.3136 * f - 0.0244 * d - 0.2067 * n + 0.010309 * v * v - 0.2869 * f * f + 0.04939 * d * d + 0.14739 * n * n - 0.0359 * v * f - 0.0542 * v * d + 0.00181 * v * n - 0.0539 * f * d + 0.00006 * f * n - 0.0649 * d * n ----------------------------------(4)$$

Fig 3 shows the residual plots for cutting force (Fz) and surface roughness (Ra). The Figs 3a&3b includes the normal probability plots of the residuals, the plots of the residuals vs. the predicted response for cutting force (Fz) and surface roughness (Ra). From the plots, it observed that the residuals are fall on straight line which implies that the errors are distributed normally. This is attributed that the proposed models are adequate. And it does not suspect that it violate the functional relationship between the predictor and response or variance assumption among the responses.

Table 5: Regression coefficients for Ra and Fz

Term	Cutting force (Fz)		Surface Roughness (Ra)	
	Coef	P	Coef	P
Constant	102.228	0.000	1.82089	0.000
v	-1.858	0.844	-0.0829	0.301
f	11.614	0.229	0.31367	0.001
d	-5.599	0.554	-0.0244	0.756
%	-3.583	0.704	-0.2067	0.017
V*V	2.786	0.911	0.01039	0.96
f*f	-43.654	0.095	-0.2896	0.176
d*d	0.991	0.968	0.04939	0.812
n*n	-2.519	0.919	0.14739	0.481
V*f	1.208	0.904	-0.0359	0.668
V*d	5.812	0.563	-0.0542	0.519
V*n	-0.283	0.977	0.00181	0.983
f*d	-2.999	0.764	-0.0539	0.521
f*n	3.999	0.690	0.00006	0.999
d*n	-7.096	0.481	-0.0694	0.411

Table 6 Analysis of Variance

Surface Roughness (Ra)						Cutting force (Fz)					
Source	DF	Sum of Squares	Mean Square	F	P	Source	DF	Sum of Squares	Mean Square	F	P
Regression	14	3.1172	0.22266	2.07	0.088	Regression	14	18606.4	1329.03	0.86	0.607
Linear	4	2.6742	0.66855	6.21	0.004	Linear	4	3793	821.39	0.53	0.714
Square	4	0.2516	0.0629	0.58	0.679	Square	4	13042.5	3260.64	2.11	0.013
Interaction	6	0.1914	0.0319	0.3	0.929	Interaction	6	1770.8	295.14	0.19	0.975
Residual Error	15	1.6159	0.10773			Residual Error	15	23143.2	1542.88		
Lack-of-Fit	10	1.3501	0.13501	2.54	0.158	Lack-of-Fit	10	20893.7	2089.37	3.03	0.520
Pure Error	5	0.2659	0.05317			Pure Error	5	2249.4	449.89		
Total	29	4.7331				Total	29	41749.5			

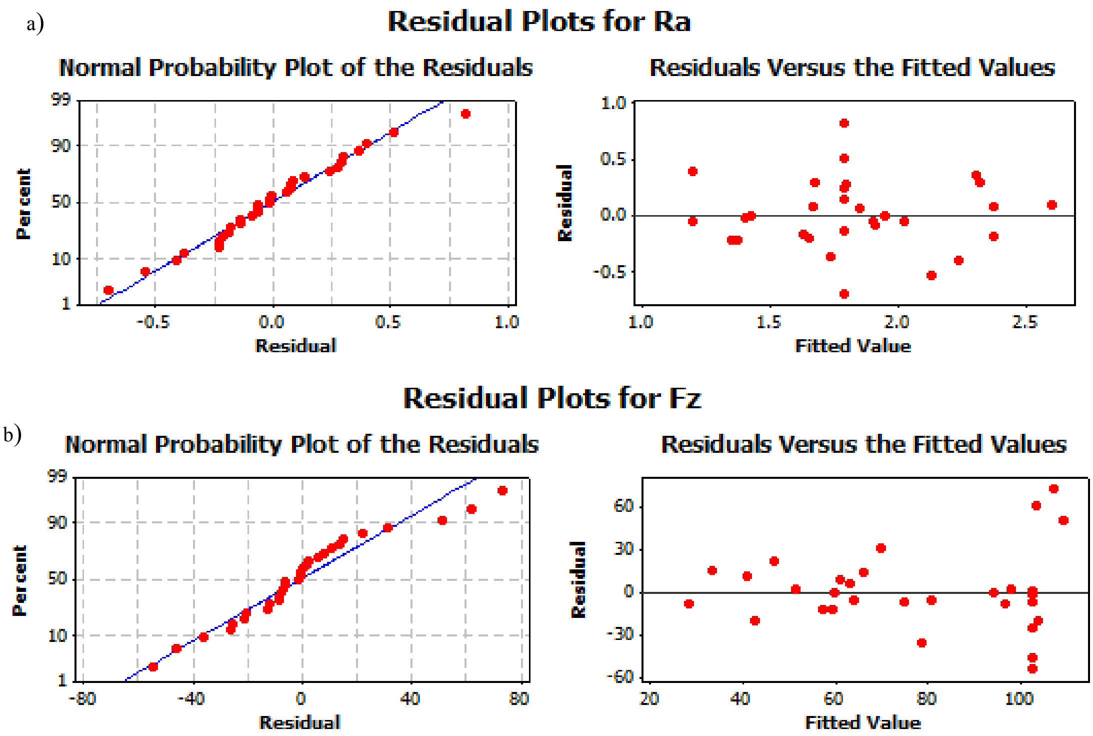

Fig. 3.Residual Plots of Factor effectsa) Surface roughness (Ra) b) Cutting Force (Fz)

Figure 4 shows the 3D surface graphs for cutting forces (Fz) and Surface roughness (Ra). It is observed for the ANOVA table 6, the % reinforcement has significant effect on the responses and all surface graphs were plotted based on the % reinforcement. Form the all the 3D surface graphs, it is observed the curvilinear profile in according to the quadratic model that fitted with responses. It is clear from the Fig 4 that the lower cutting force is obtained at cutting speed levels at medium, feed rate at low and depth of cut is medium. Similarly observation was made for the surface roughness criteria (Ra).The optimum process that yields minimum cutting force is 90 m/min (cutting speed), 0.103 (feed rate) mm/rev, 0.6 mm (depth of cut) and % 5 reinforcement of SiC. Similarly, for surface criteria (Ra), the optimum process that yields minimum value is 120 m/min (cutting speed), 0.103 (feed rate) mm/rev, 0.6 mm (depth of cut) and % 5 reinforcement of SiC Moreover, effect of cutting speed, feed rate and depth of cut is increased when the % reinforcement of SiC is greater than 12.5%.From the 3D surface plot, it observed that the combination of 12.5% with %5B_4C yields the minimum cutting force and surface roughness. For this optimized cutting condition the cutting force and surface roughness values are 56 N and 1.6 µmat 120 m/min, 0.103 mm/rev and 0.6 mm.

The influence of process parameter on the cutting force (Fz) and surface roughness (Ra) were investigated by plotting the main effect plots. Fig 5 shows the main effect plots for the responses. From the Fig 5a, it is observed the weight percentage of SiCp(A), cutting speed (B), feed rate (C) and depth of cut (D) are the most variable factor for cutting force. But for surface roughness the weight percentage of SiCp(A) and feed rate (C) are the most variable factor. These graphs indicates that the weight percentage of silicon carbide particles, feed rate, depth of cut and cutting speed increases the cutting force also increases. All the terms have an important and decreasing effect on the cutting force is observed at 12.5% of SiC. It is also observed that in Fig 5b, the cutting speed has an important factor and increasing of surface roughness is observed at 100 m/min. The weight percentage of SiCp, depth of cut and feed rate are the significant factors on surface roughness criteria. The increase in weight of SiC particles and depth of cut increases the both cutting force and surface roughness. Both cutting force and surface roughness appears to be decreased at 12.5% of SiC form the main effect plots.

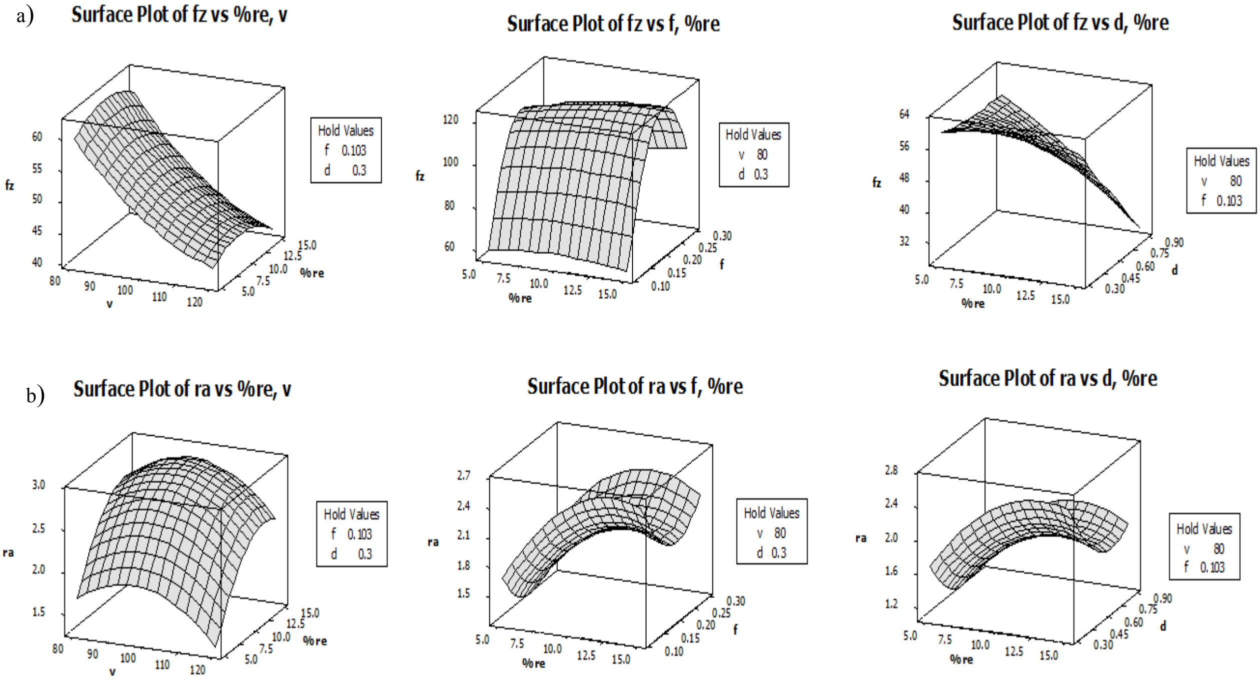

Fig. 4.Surface Plot of a) Cutting Force (Fz) and b) Surface Roughness (Ra)

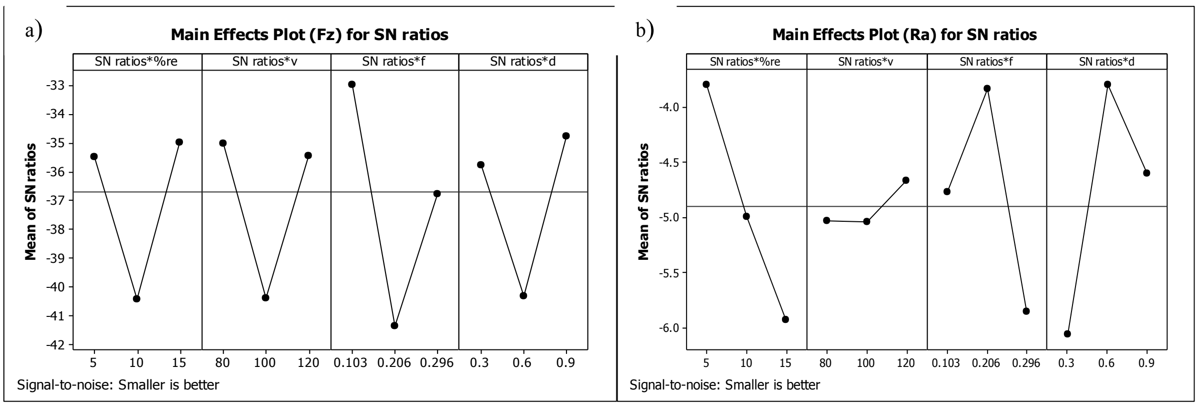

Fig.5. Plot of Factor effects

3.2Confirmation test

The error differences between predicted and experiment responses are shown in Fig. 9. From the results, it observed the predicted value of cutting force (Fz) and surface roughness (Ra) has a goodness of fit with quadratic model with a 95% confident interval.

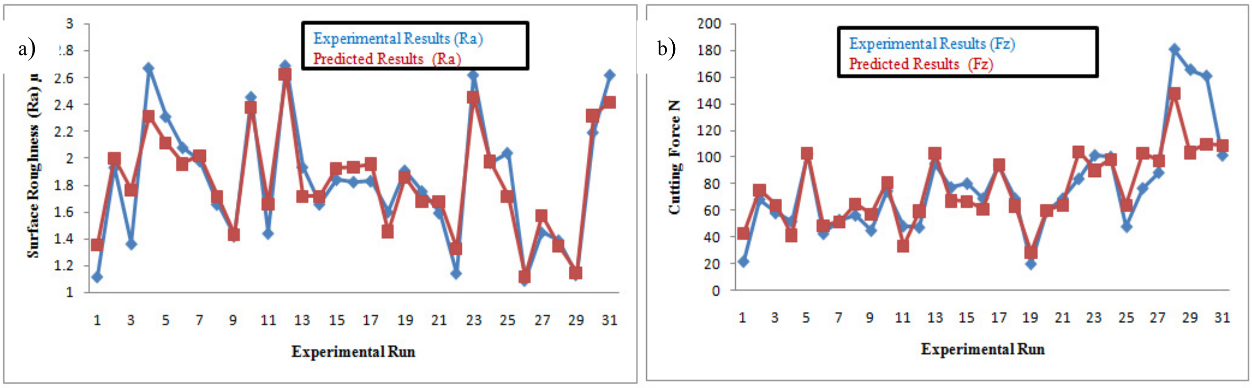

Fig. 9.Plots between predicted and experimental values a) Cutting Force (Fz) and Surface Roughness (Ra)

4. Conclusion

This paper discusses about CCD and ANOVA which was adopted for finding the optimal process parameter for the performance measures of cutting force (Fz) and surface roughness. The following conclusions were drawn from the present research:

1. Face central composite design is adopted for experimentation as it serves the beneficial of reducing the number of experiments required and also serves benefits of the middle effect of parameters on the responses.
2. A functional relationship between the regressor-responses was established using response surface methodology.
3. The results of ANOVA and conducting confirmation experiments proved that the predicted value of cutting force (Fz) and surface roughness (Ra) has a goodness of fit with quadratic model with a 95% confident interval.
4. The depth of cut and feed rate are the major influencing factors to affect the performance measures surface roughness and cutting force. Also, it is evident that higher percentages of reinforcement leading to poor surface finish and consumes higher cutting energy.
5. From the 3D surface plot, it observed that the combination of 12.5% with %5B_4C yields the minimum cutting force and surface roughness. For this optimized cutting condition the cutting force and surface roughness values are 56 N and 1.6 µmat 120 m/min, 0.103 mm/rev and 0.6 mm.
6. The increase in weight of SiC particles and depth of cut increases the both cutting force and surface roughness. Both cutting force and surface roughness appears to be decreased at 12.5% of SiC form the main effect plots.

References

[1] T.W. Clyne, Metal matrix composites: matrices and processing, encyclopedia of materials science and technology composites: MMC, CMC, PMC, In: Mortenson A (Ed) Elsevier, 2001, pp. 1–14 (chapter3.7.12)
[2] Hemanth Joel, Quartz (SiO2P) reinforced chilled metal matrix composite (CMMC) for automobile applications, Mater. Des. 30 (2009) 323–329
[3] C.S. Ramesh, R. Keshavamurthy, B.H. Channabasappa, Abrar Ahmed, Microstructure and mechanical properties of Ni–P coated Si3N4 reinforced Al6061 composites, Mater. Sci. Eng. A 502(2009) 99–106
[4] H.R. Lashgari, A.R Sufizadeh, M. Emamy, The effect of strontium on the microstructure and wear properties of A356–10%B4C cast composites, Mater. Des. 31(2010) 2187–2189
[5] I. Kerti, F. Toptan, Microstructural variations in cast B4C-reinforced aluminium matrix composites (AMCs), Mater. Lett. 62(2008) 1215–1218.

[6] F. Toptan, A. Kilicarslan, M. Cigdem, I. Kerti, Processing and microstructural characterization of AA1070 and AA 6063 matrix B4CP reinforced composites, Mater. Des. 319 (2010):587–591
[7] Y.C. Feng, L. Geng, P.Q. Zheng, Z. Z. Zheng, G.S. Wang, Fabrication and characteristic of Al-based hybrid composite reinforced with tungsten oxide particle and aluminum borate whisker by squeeze casting, Mater. Des. 29 (2008) 2023–2026
[8] R.M. Mohanty, K. Balasubramanian, S.K. Seshadri, Boron carbide-reinforced alumnium 1100 matrix composites: fabrication and properties, Mater. Sci.Eng. A 498(2008) 42–52
[9]Muthukrishnan, N., Murugan, M., Prahladarao, K.: Machinability issues in turning of Al-SiC (10p) Metal matrix composites,International Journal of AdvancedManufacturing Technology, 39 (2008), 211-218.
[10]Sahin Y., Sur G.: The effect of Al2O3, TiNand TiC, N-based CVD coatings on tool wearin machining metal matrix composites,Surface Coating Technology, 179 (2004),349–355.
[11] Ashok Kumar Sahoo , Swastik Pradhan, Modeling and optimization of Al/SiCp MMC machining usingTaguchi approach,Measurement 46 (2013) 3064–3072.
[12] A.K. Sahoo, S. Pradhana, A.K. Rout,Development and machinability assessment in turningAl/SiCp-metal matrix composite with multilayer coatedcarbide insert using Taguchi and statistical techniques, Archives of civil and mechanical Engineering, 13(2013),27-
[13] S. Basavarajappaa, G. Chandramohana, M. Prabub, K. Mukundb, M. Ashwin, Drilling of hybrid metal matrix composites—Workpiece surface integrity, I. J. Mac. Tools Manuf. 47 (2007) 92–96
[14] A. Riaz Ahamed, Paravasu Asokan, Sivanandam Aravindan, M. K. Prakash, A. Riaz , Drilling of hybrid Al-5%SiCp-5%B4Cp metal matrix composites, I. J. Mac. Tools Manuf. (2010) 49:871–877
[15] L. Krishnamurthy, B.K. Sridhara, D. Abdul Budan, Comparative study on the machinability aspects of aluminum silicon carbide and aluminum-graphite-silicon carbide hybrid composites, Int. J. Mach. Machin. Mater. 10 (2011) 137 – 152.
[16] T. Sasimurugan, K. Palanikumar, Analysis of the Machining Characteristics on Surface Roughness of a Hybrid Aluminium Metal Matrix Composite (Al6061-SiC-Al2O3), J. Min. Mater. Character. Eng. 10 (2011) 13 1213-1224
[17] H.Sevik, S. Can kurnaz, Properties of alumina particulate reinforced aluminium alloy produced by pressure die casting, Mater. Des. 279(2006):676–683
[18] K. M. Shorowordi, T. Laoui, A.S. M. A Haseeb, J.P. Celis, L. Froyen, Microstructure and interface characteristics of B4C, SiC, and Al2O3 reinforced Al matrix composites: a comparative study, J. Mater. Process Technol.142 (2003) 738–743.
[19] M. Kok, Production and mechanical properties of Al2O3 particle-reinforced 2024 aluminium alloy composites, J. Mater. Process Technol. 161(2005) 381–387
[20] J. Abenojar, F. Velasco, M.A Martinez, Optimization of processing parameters for the Al + 10%B4C system obtained by mechanical alloying, J. Mater. Process Technol.184 (2007) 441–446
[21] Y. C. Feng, L. Geng, G.H. Fan, A.B. Li, Z. Z. Zheng, The properties and microstructure of hybrid composites reinforced with WO3 particles and Al18B4O33 whiskers by squeeze casting, Mater. Des. 30 (2009):3632–363.
[22] E. Mohammad Sharifi, F. Karimzadeh, M.H. Enayati, Fabrication and evaluation of mechanical and tribological properties of boron carbide reinforced aluminum matrix nanocomposites, Mater. Des. 32 (2011) 3263– 3271
[23] J. Hashim, L. Looney, M.S.J Hashmi, Metal matrix composites: production by the stir casting method, J. Mater. Process Technol. 92–93 (1999) 1–7
[24] H.Sevik, S. Can kurnaz, Properties of alumina particulate reinforced aluminium alloy produced by pressure die casting, Mater. Des. 279(2006):676–683
[25]J.S. Kwak, Application of Taguchi and response surfacemethodologies for geometric error in surface grinding process,International journal of machine tools and manufacture, 45 (3), 2005, 327-334.
[26] K. Palani Kumar, Modelling and analysis for surface roughness inmachining glass fiber reinforced plastics using response surface methodology, Materials and Design, 28 (1) 2007 2611-2618.