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Drilling of Ceramic Reinforced Aluminum Matrix Composite under Dry Condition

Sachin M. Agrawal, Nilesh G. Patil

In this study an experimental investigation of effects of cutting parameters on surface roughness during drilling of silicon carbide particulate reinforced aluminium matrix composite material under dry condition was carried out. Cutting speed , feed rate and % SiC in aluminium matrix composites were chosen as cutting parameters. The experimental design adopted for this investigation was the central composite design of response surface methodology. Thirty one readings were taken on VMC machine for dry condition and the surface roughness measured using Mitutoyo surface tester. Surface roughness values for dry condition were lower with 30% SiC reinforced aluminium matrix composites when compared to 10 % and 20 % SiC reinforced aluminium matrix composites . As cutting speed increased Ra & Rz value also increased .% SiC was found most significant factor while drilling aluminium matrix composites.

Keywords: Dry Machining, aluminum metal matrix composites, PVD coated carbide drill

I. INTRODUCTION

In the industries, several techniques used to reduce the manufacturing costs and to protect the environment. In machining , the used of metal working fluid could play an important role in different parameter such as tool life, cutting temperature, surface finish . The use of cutting fluids is between 7 to 17% of manufacturing costs parts . In this point of view dry machining could help to reduce the cost of cutting fluid and to protect the environment. The problem of using the metal working fluid instead of decreasing the cutting zone temperature is the aerosol generation during the machining process .[1-3]

II. BACKGROUND

Suresh kannan I et.al. studied wetting behavior of a new polymer composite coating towards dry machining of aluminum alloy and it is concluded that its new soft composite coating exhibited good capabilities in machining AA2024 alloy under dry environment but within an identified regime[1].

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***** Correspondence Author
Sachin M. Agrawal*, Department of Mechanical Marathwada Institute of Technology, Aurangabad, India. E-mail:sachinmagrawal@gmail.com
Nilesh G. Patil, Department of Mechanical Marathwada Institute of Technology, Aurangabad, India. E-mail:ngpatil2007@gmail.com

Haruyo Fukui et. al. examined the impact of tribological properties of DLC coatings on cutting performance Under dry conditions, the machined surface roughness decreased to about one half for AlMg2.5 and AlCu4.5Si12 alloys by using DLC coating [2]. Tatsuya sugihara et. al. developed new tool for dry machining they concluded that Micro dimples on the rake face of a cutting tool effectively suppress the chip adhesion in dry machining of aluminum alloys[3]. H. Hanyu et. al. investigate cutting performance of the tools with finely crystallized smooth surface diamond coating in dry cutting condition. In the case of drilling of aluminum metal matrix compiosie, excellent anti sticking property of smooth surface diamond coating lead to much longer durability of drills than those with regular rough surface diamond coating in both the dry cutting conditions [4]. A. Devillez et. al. studied effect of dry machining on surface integrity. He found that in dry environment, when cutting speed was increased the max tensile stress was decreased. At high speed, the heat produced during chip formation is nearly evacuated by the chip also in dry conditions for the used of coated tool , the cutting speed of 60 m/min may be considered as optimal[5].
Sagar dhage et. al. found that the tribological conditions in dry machining shows the better result as compare to flood conditions [6]. Andrej Czan et. al. found that for dry condition of hard-to-machine materials, the temperature is very important parameter for optimization of cutting conditions for nickel alloy Inconel 718 [7]. Jagdeep Sharma et. al. concluded that use of cutting fluid at minute amounts can potentially improve the surface integrity. Surface finishes also improved mainly due to reduction of cutting temperatures and damage at the tool-tip by the application of near dry machining[8]. M. Shiva Surya et. al. concluded that for dry machining the cutting speed has more influence also most influential parameter resulted is feed rate and depth of cut [9]. J.M. Dasch et. al. resulted that dry machining was significantly improved by incorporating small amounts of FMEs in the alloy composition [10]. Binxun Li et. al. conclude that Based on the correlation of chip color and temperature, the maximum cutting temperature during dry milling of hardened AISI H13 steel can be semi-qualitatively evaluated with an acceptable discrepancy [11]. B.C. Schramm et. al. concluded that mechanical properties and the dry machining characteristics show that chromium-based cutting tools might have sufficient potential to become a machining alternative to the state-of-the-art TiAlN coating [12]. Jadhav et al. in his study found that in drilling MMC of Al-6061 series with 0% and 10% particulate reinforcement of Al_2O_{3p}, various input parameters influences the responses. The input parameter viz. material, point angle,

spindle speed and feed rate significantly affect the output parameters like surface roughness, force/torque and cylindricity of the drilled hole [13]. Jadhav et al. review on the effect of various parameters on drilling of MMC was presented, the review of the literature indicates that the research progress with the drilling of Al based MMC was scarce [14]. Agrawal et al. carried out study on M2 high speed steel under different lubricating conditions.
Speed and load have been varied in a wide range to study their combined effect on the wear behavior of this material under dry and wet conditions [15]. Agrawal et al. found that as the Cutting Speed increases the surface roughness decreases due to higher cutting temperature made the material ahead of tool softer and plastic also as cutting feed increases surface roughness also increases under dry conditions [16]

III. EXPERIMENTAL PROCEDURE

A. Machining Parameters and their levels

Cutting parameters and their levels selected based on the literature survey & pilot experimentation which are listed in table. The parameters which directly affecting the drilling operation are cutting speed, feed and % SiC in aluminium matrix composite . Table 1 gives the cutting parameters and their levels for experiments approach is the technique for investigating the relationship between different cutting parameters with the different machining criteria and finding the effect of these cutting parameters on the responses. It is seen from the literature review that the machinability of drilling operation can be evaluated in terms of surface roughness hence surface roughness selected as a response variables to assess the machining performance in drilling of aluminium matrix composite .The performance can be studied by the measurement of surface roughness using Mitutoyo surface tester.

Table 1. Machining Parameters and their levels

	Speed (m/min)	**Feed (mm/rev)**	**% SiC Conc.**
Level (-2)	30	0.05	10
Level (-1)	60	0.1	10
Level (0)	90	0.15	20
Level (+1)	120	0.2	30
Level (+2)	150	0.25	30

B. Workpiece material

Aluminium-based SiC particle reinforced metal matrix composite materials have become useful engineering materials because of their properties such as low weight and low cost. The repetative problem with metal matrix composite is that they are difficult to machine, due to the hardness and abrasive nature of the their reinforcing particles. The particles used in the MMCs are harder than many of the cutting tool materials.[16-17]

Table 2. Properties of workpiece material

Properties	**$Al/SiC_p/10\%$**	**$Al/SiC_p/20\%$**	**$Al/SiC_p/30\%$**
Density, kg/m^3	2,710	2,765	2,798
Thermal conductivity, W/m-K	156	150	144.5
Specific heat, J/kg-K	879	837	795
Melting point, K	828	828	828
Thermal coefficient of expansion, K^{-1}	20.7	17.46	14.58
Heat of fusion, J/kg	389×10^3	389×10^3	389×10^3

C. Cutting Tool Material

Seco PVD coated carbide drill (Drill bit SD1105A-0680-043-08R1) used in this study for drilling operation. Seco Universal solid carbide drills bring versatility and reduced costs to low and medium batch production. The line features a multipurpose, 4-facet point geometry that provides excellent centering capability, maintains an IT8/9 hole tolerance and is easy to regrind. Seco Universal drills also feature a polished AlCrN coating that offers high abrasion resistance, toughness and good chip evacuation. The drills feature advanced coating technology and have a universal geometry suitable for most applications across all industry segments that focus on hole quality.

Figure 1: PVD coated carbide drill

D. CNC Machine *MQL Set up*

Table 3. CNC Machine Specification

Specification	**Unit**	**BMV 60+TC24**
Table size	Mm	1250 x 600
Table longitudinal travel (X - Axis)	mm	1050
Table size	Mm	1250 x 600
Spindle taper	-	BT-40
Cutting speed - Std.	Rpm	6000
Fanuc / Mitsubishi, Cont./30 min. rating	kW	7.5/11
Siemens, cont./ S6-40% rating	kW	9/13.5

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Figure 2: Drilling of Aluminum metal matrix composites

IV. RESULT AND DISCUSSION

The experiment results observed from the surface roughness Measuring Device are tabulated in Table 4. The Minitab statistical software is used to analyze the data.

Table 4. Experimental results for MQL Condition

Std Order	Cutting Speed	Feed	Matl. Conc.	MQL	MQL
	m/min	mm/rev	% SiC	Ra	Rz
1	60	0.1	10	2.795	26.253
2	120	0.1	10	0.691	8.607
3	60	0.2	10	1.218	9.599
4	120	0.2	10	0.976	7.309
5	60	0.1	10	1.847	11.698
6	120	0.1	10	1.457	10.573
7	60	0.2	10	2.095	11.588
8	120	0.2	10	2.788	15.653
9	60	0.1	30	0.096	1.088
10	120	0.1	30	0.107	1.029
11	60	0.2	30	0.108	1.312
12	120	0.2	30	0.166	1.864
13	60	0.1	30	0.15	1.533
14	120	0.1	30	0.148	1.296
15	60	0.2	30	0.116	1.157
16	120	0.2	30	0.255	2.134
17	30	0.15	20	1.806	12.843
18	150	0.15	20	1.147	6.751
19	90	0.05	20	0.84	4.974
20	90	0.25	20	0.373	2.984
21	90	0.15	20	0.708	4.568
22	90	0.15	20	0.652	3.783
23	90	0.15	10	2.485	15.191
24	90	0.15	30	0.545	4.036
25	90	0.15	20	0.539	5.024
26	90	0.15	20	0.614	3.585
27	90	0.15	20	0.454	3.78
28	90	0.15	20	0.778	4.664
29	90	0.15	20	0.355	2.76
30	90	0.15	20	0.309	2.959
31	90	0.15	20	0.626	3.66

Table 5. Coded Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.629	0.154	4.10	0.001	
Cutting Speed	-0.1315	0.0961	-1.37	0.186	1.00
Feed	-0.0210	0.0961	-0.22	0.829	1.00
SiC %	-0.814	0.111	-7.34	0.000	1.00
Cutting Speed*Cutting Speed	0.1727	0.0882	1.96	0.064	1.03
Feed*Feed	-0.0448	0.0882	-0.51	0.617	1.03
SiC %*SiC %	0.260	0.175	1.48	0.153	1.04
Cutting Speed*Feed	0.196	0.118	1.66	0.111	1.00
Cutting Speed*SiC %	0.141	0.118	1.19	0.246	1.00
Feed*SiC %	-0.009	0.118	-0.08	0.940	1.00

From the ANOVA analysis of Ra value Table 5 reflected that all the three parameters were significant as their P values are less than 1. Table 7. shows the results of ANOVA on performance characteristic. The F-Ratio in Table 7 shows the significant condition of each factor and its interactions. % SiC concentration has major percent contribution (53.88%) in optimizing the performance characteristics followed by cutting speed (3.84 %) .

The adequacy of the model fit, measured by the coefficient of determination (adjusted R2), was calculated as 0.66, showing that 66.03 % of the variability in Ra readings is explained by the fitted model. The predicted R2 was calculated as 0.39, proving that the model is not over-fitted and has a good predictability.

Table 6. Model Summery

S	R-sq	R-sq(adj)	R-sq(pred)
0.470781	76.22%	66.03%	39.44%

Table 7. Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	14.9201	1.6578	7.48	0.000
Linear	3	12.3667	4.1222	18.60	0.000
Cutting Speed	1	0.4148	0.4148	1.87	0.186
Feed	1	0.0105	0.0105	0.05	0.829
SiC %	1	11.9414	11.9414	53.88	0.000
Square	3	1.6225	0.5408	2.44	0.093
Cutting Speed*Cutting Speed	1	0.8506	0.8506	3.84	0.064
Feed*Feed	1	0.0572	0.0572	0.26	0.617
SiC %*SiC %	1	0.4874	0.4874	2.20	0.153
2-Way Interaction	3	0.9309	0.3103	1.40	0.271
Cutting Speed*Feed	1	0.6135	0.6135	2.77	0.111
Cutting Speed*SiC %	1	0.3161	0.3161	1.43	0.246

Feed*SiC %	1	0.0013	0.0013	0.01	0.940
Error	21	4.6543	0.2216		
Lack-of-Fit	5	1.6772	0.3354	1.80	0.169
Pure Error	16	2.9771	0.1861		
Total	30	19.5744			

Regression Equation in Uncoded Units

The developed mathematical models is used for predicting the relationship between process parameters and surface roughness.

DRY Ra = 7.46 - 0.0679 Cutting Speed - 6.4 Feed
- 0.2248 SiC %
+ 0.000192 Cutting Speed*Cutting Speed
- 17.9 Feed*Feed + 0.00260 SiC %*SiC %
+ 0.1305 Cutting Speed*Feed
+ 0.000469 Cutting Speed*SiC %
- 0.018 Feed*SiC %

The R-squared values of surface roughness model 0.7622 indicates that the developed models can be used to predict the surface roughness during drilling of Al-SiC added MMC in dry condition. The above regression equation valid for the parameter range of feed range of 0.05–0.25 mm/rev, SiC weight percentage (10-30%), and cutting speed in the range of 50-150 m/min.

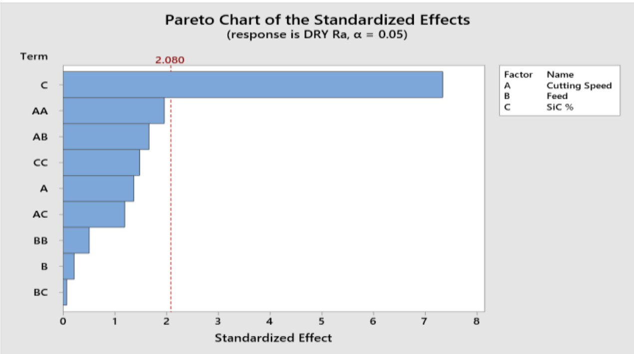

Figure 3. Pareto Chart of the standardised effects

Statistical analysis of factorial effect shown that % SiC in Figure 3 shows that SiC particle weight percentage has dominant effect of the on the surface roughness in drilling. Besides, it displays the interaction among the cutting speed is second most affecting parameter that affect the surface roughness. The other parameters and their influence mainly AB (cutting speed and feed) , CC (SiC % with SiC %), A (cutting speed), B (feed rate) do not show much more influence.

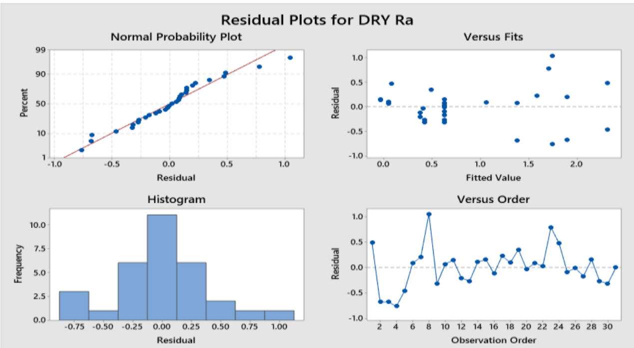

Figure 4.Residual plots for Ra

Figure 4 shows a scatter plot for the predicted Ra versus the measured Ra. It is clear from the figure that the relation between them is almost linear

The regression models were developed at 95% confidence interval for resultant surface roughness. The normal probability plots and the random distribution of residuals about the horizontal axis, above figure showed that the regression models provided good fits. [18]

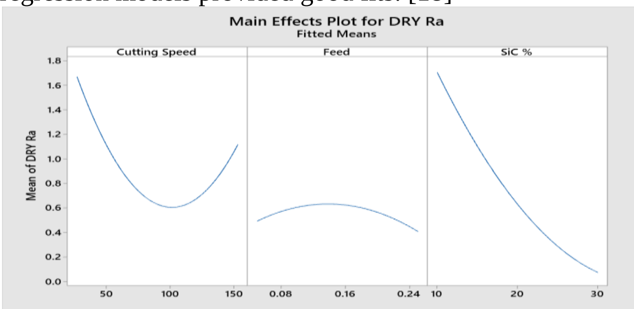

Figure 5. Main effects plot for Ra value

The impacts of cutting variables on the surface roughness are analysed with the help of the main effect plots. Figure 5 shows that main effect plot for surface roughness obtained in the dry drilling in concern with cutting speed, feed, and SiC particle, respectively. It shows that all these parameters have influence on the surface roughness during dry drilling. The cutting speed shows inverse bell type plot against surface roughness. The increase in cutting speed from 60 to 100 m/min which decreases the surface roughness from 1.7 µm to 0.6 µm. Further, increased cutting speed shows higher surface roughness to 1.1 µm. In reverse, influence of feed shows positive bell shape plot. In addition, SiC particle also shows more significant impact on the surface roughness, it shows linear behaviour in the plot with inverse proportionality.

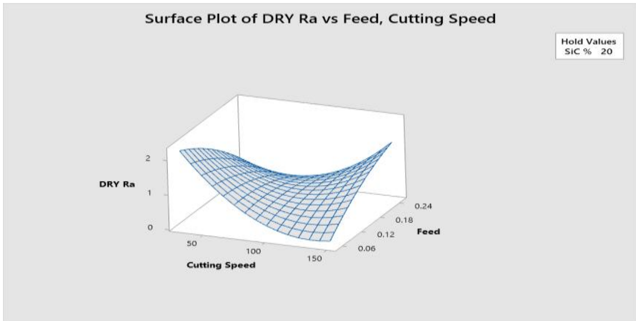

Figure 6. Surface plot of Ra vs feed, cutting speed

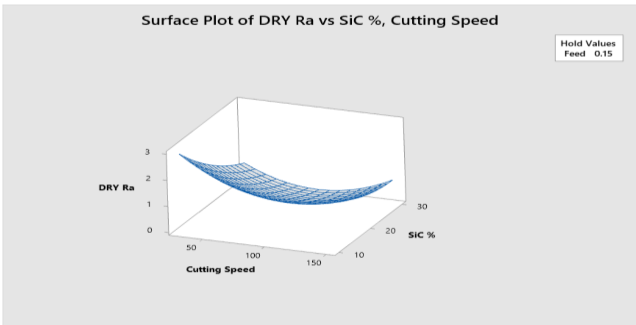

Figure 7 . Surface plot of Ra vs SiC % , cutting speed

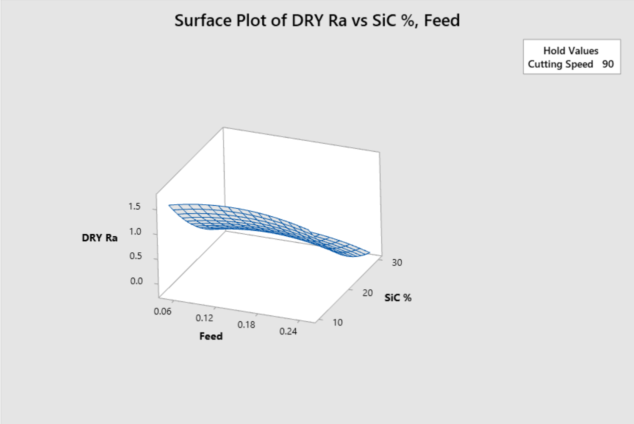

Figure 8 . Surface plot of Ra vs SiC % , feed rate

Interaction effect on responses (3D plots) Three-dimensional (3D) response surface plots were drawn to study the effect of the input cutting parameters on Ra . These plots can supplementarily provide further assessment of the relationship between the process parameters and replication.[19-20] 3D surface plots are drawn as two of the factors were maintained constant at their middle level, while the other two are varied.

V. CONCLUSION

Study shows the individual factor effects are found to be significant factors and concluded that the effect of SiC % is more followed by cutting speed and feed rate. The interaction between Surface roughness with cutting speed (m/min), feed rate (mm/rev), SiC % are also found to be significant. Feed rate is having least significant effect on Ra value during machining of aluminum metal matrix. Surface roughness decreases from 3 µm to 0.1 µm as cutting speed increase from 50 m/min to 150 m/min while as feed increases from 0.05 mm to 0.25 mm surface roughness also increase from 0.6 µm to 2.7 µm. Ra value shows the inverse relationship with SiC %

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AUTHORS PROFILE

Sachin M. Agrawal, Research Scholar at Marathwada Institute of Technology, Aurangabad

Dr. Nilesh G. Patil, Research Guide, Professor **&** Principal at Marathwada Institute of Technology, Aurangabad