Drilling of Ceramic Reinforced Aluminum Matrix Composite under Minimum Quantity Lubrication using Bio Cutting Fluid

Sachin M. Agrawal, Nilesh G. Patil

***Abstract:** 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 minimum quantity lubrication (MQL) condition was carried out. Cutting speed , feed rate, flow 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 MQL condition and the surface roughness measured using Mitutoyo surface tester. Surface roughness values for MQL 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:** MQL, aluminum matrix composites.*

I. INTRODUCTION

Machining industry utilizes cutting fluids to increase the performance of the metal cutting process. However, several environmental and health issues limit their usage. Metal cutting industries use cutting fluids to reduce temperatures and forces in machining. However, the application of cutting fluids has been always debatable due to their impact on workers' health. With the increase in awareness on sustainable practices, several alternatives have like Minimum Quantity Lubrication (MQL) are replacing the conventional form of cutting fluid application. Currently a wide variety of cutting fluids are available in the market, amongst which water based emulsions are most popular. Water based emulsions have a confluence of the beneficial properties of both water and oil. However, these fluids are highly susceptible to microbial contamination and can cause various health issues to the operators. Further, the fluids are not biodegradable and need treatment before disposal. This increases the maintenance and disposal cost of the fluids.

Revised Manuscript Received on February 28, 2020.
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II. BACKGROUND

Sharma et.al. used TiO_2 based nanofluid and he concluded that There is very little difference in machining performance of conventional cutting fluid under MQL and wet machining. MQL shows the machining performance comparable to wet machining [1].

Lohar et. al. studied the performance of MQL using CBN tool during hard turning of AISI 4340, It is observed that There is 40% decrease in cutting forces during MQL also The MQL shows lower range of temperature which helps to improve tool life [2]. Patole et. al. focused on optimization of process parameters under MQL application of MQL with nano fluid is an alternative for a conventional flood system, if it can be properly applied. There is a considerable improvement in surface roughness and cutting force [3].Khan et. al. concluded that the both air pressure and surface roughness of MQL nozzle affected the lubricant droplet sizes after investigated on micromilling of Inconel 718 [4]. Niketh et. al. concluded that the MQL based machining technique can be opted for the better utilization of energy resources, as it consumes minimum quantity of energy resources in terms of cutting fluids after studied on Drilling performance of micro textured tools under MQL condition [5]. Amini et. al. studied on drilling process of AISI 1045 steel using hybrid optimization. It is concluded that combination of UV and MQL provides minimum thrust force and surface roughness compare to other conditions [6]. Chetan et. al. concluded that for the high cutting speed of 80 m/min, the use of alumina nanofluids under MQL mode reduced the main cutting force by 16%. After study Comparison between sustainable cryogenic techniques and nano-MQL cooling mode in turning of nickel-based alloy [7]. Shokrani et. al. concluded that MQL are highly effective cooling and lubricating technologies in extending the tool life up to 30 times over commonly used flood cooling [8]. Muaz et. al. investigates solid lubricant-assisted cutting fluids applied through MQL assisted milling process. It is concluded that Low viscosity fluids were best suited for MQL as a contrast to the flooded lubrication where high viscosity fluids performed better due to the formation of a stable and thick lubricating film [9]. Zaman et. al. concluded that the double jet MQL system is evident for better performance compared to the conventional single jet with respect to various process responses [10]. Lutfi Tunc et. al. Effects of minimal quantity lubrication (MQL) on surface integrity in robotic milling. It is concluded that the surface residual stresses can be decreased by well controlled MQL oil flow [11].

Rajaguru J et. al. investigated on the effect of flood and MQL coolant on the machinability after study he concluded that Machining under flood and MQL environment reduced the built-up edge occurrence and improved the tool wear performance by 11.95% and 33.08% respectively in comparison with dry cutting also lower energy consumption

In flood and MQL environment [12]. Jadhav et al. in his study found that in drilling MMC of Al-6061 series with 0% and 10% particulate reinforcement of Al2O3p, 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, wet (SAE 40 oil and cotton seed oil) conditions [15]. MQL with vegetable oil protects environmental pollution by discharging small amounts of fumes, mist, oxides as compared to mineral oil which is non biodegradable and also not operator friendly.[16]

III. EXPERIMENTAL PROCEDURE

A. Machining Parameters and their levels

Process Parameters and their Levels selected based on the literature review & preliminary experimentation which are listed in below table. The parameters which directly affecting the drilling process are cutting speed, feed, flow rate and % SiC in aluminium matrix composite . Table 1 gives the machining parameters and their levels for experiments approach is the technique for finding the relationship between various process parameters with the various machining criteria and determining the effect of these process parameters on the responses. It is seen from the published literature 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 evaluated by measurement of surface finish using Mitutoyo surface tester.

Table 1. Machining Parameters and their levels

	Speed (m/min)	Feed (mm/rev)	Flow Rate(ml/hr)	% SiC Conc.
Level (-2)	30	0.05	60	10
Level (-1)	60	0.1	90	10
Level (0)	90	0.15	120	20
Level (+1)	120	0.2	150	30
Level (+2)	150	0.25	180	30

B. Workpiece material

Aluminium-based SiC particle reinforced MMC materials have become useful engineering materials due to their properties such as low weight, heat-resistant, wear-resistant and low cost. The recurring problem with MMCs is that they are difficult to machine, due to the hardness and abrasive nature of the reinforcing particles. The particles used in the MMCs are harder than most of the cutting tool materials.

Table 2 Workpiece Properties

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 Seco 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

Figure 2 CNC Machine

E. MQL Set up

The MQL set up used in this study is imported from Israel. As shown in below figure it has two inlet pipes and one discharge tubes which are joined at mixing chamber. There are nozzles at the end of both discharge tubes. One inlet pipe is connected to the compressed air pipe while the other is dipped in the container containing undi oil. Depending on the pressure of the air, the oil from the container is sucked and delivered through the discharge tubes in the form of mist. There is a pull-push button which allows the aerosol supply when pulled out and stops the supply when pushed inwards. Cutting oil was applied on tool cutting edge in the form of fine mist (aerosol) delivered at 7 bar pressure through a nozzles at an angle of 45^0 to the tool feed direction. Drilling tests were completed for various combinations of machining parameters.

Figure 3 .Minicool MQL Setup

F. Vegetable Oil (Undi Oil)

People across India have been using the nonedible oil extracted from various commonly occurring native tree species for household uses for centuries, and Undi oil is one among the most useful trees.Undi (Calophyllum Inophyllum Linn) trees are normally planted along the highways, roads to stop soil erosion. Millions of trees exist all over Coastal India. If the seeds fallen along road side are collected, and oil is extracted at village level, by hand operated expellers, thousands of tons of oil will be available for Lighting the Lamps in rural area Undi (Calophyllum Inophyllum Linn) trees are normally planted along the highways, roads to stop soil erosion. Millions of trees exist all over Coastal India. If the seeds fallen along road side are collected, and oil is extracted at village level, by hand operated expellers, thousands of tons of oil will be available for Lighting the Lamps in rural area.

Table 4. Properties of Undi Oil

Sr. No.	Test Description	Ref. Std.ASTM 6751	Reference	Undi oil
1	Density	D1448	*gm/cc*	0.91
2	Flash point	D93	*"C*	152
3	Fire point	D93	*"C*	169
4	Viscosity	D445	*Cst*	38.12
5	Moisture	D2709	%	NA
6	Thermal conductivity	-	W/m K	164-168
7	Ph range	-	- .	6.7

In the Konkan region of Maharashtra (India), Calophyllum inophyllum occurs along the coast where local communities have a tradition of extracting oil from the seeds . The oil is still being used for painting fishing boats to prevent deterioration of wood and metal component. However, due to modernization, the traditional oil extraction business in rural areas is declining whereas the demand for its hard wood in the construction of boats and houses has been increasing. So, people have started to cut mature trees for sale instead of sustainably using the seeds for oil extraction.

The Undi oil is identified for high oil content through selection method. This is a middle aged tree with an average seed yield of 28.83 kg. It has an average seed size and shape with a seed weight of 5.53g. The oil content of the seed is 79.34 percent with the oil recovery of 72.66 ml per 100 g seed.

IV. VI. RESULT AND DISCUSSION

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

Table 5. Experimental results for MQL Condition

Std Order	Cutting Speed	Feed	Matl. Conc.	Flow Rate	MQL
	m/min	mm/rev	% SiC	ml/hr	Ra
1	60	0.1	10	90	0.521
2	120	0.1	10	90	0.754
3	60	0.2	10	90	1.033
4	120	0.2	10	90	0.767
5	60	0.1	10	150	2.037
6	120	0.1	10	150	1.294
7	60	0.2	10	150	2.308
8	120	0.2	10	150	1.611
9	60	0.1	30	90	0.067
10	120	0.1	30	90	0.084
11	60	0.2	30	90	0.086
12	120	0.2	30	90	0.118
13	60	0.1	30	150	0.121
14	120	0.1	30	150	0.078
15	60	0.2	30	150	0.075
16	120	0.2	30	150	0.14
17	30	0.15	20	120	0.535
18	150	0.15	20	120	1.574
19	90	0.05	20	120	0.416
20	90	0.25	20	120	1.017
21	90	0.15	20	60	1.143
22	90	0.15	20	180	0.957
23	90	0.15	10	120	1.999
24	90	0.15	30	120	0.677
25	90	0.15	20	120	1.395
26	90	0.15	20	120	1.204
27	90	0.15	20	120	1.588
28	90	0.15	20	120	1.264
29	90	0.15	20	120	1.184
30	90	0.15	20	120	0.841
31	90	0.15	20	120	1.973

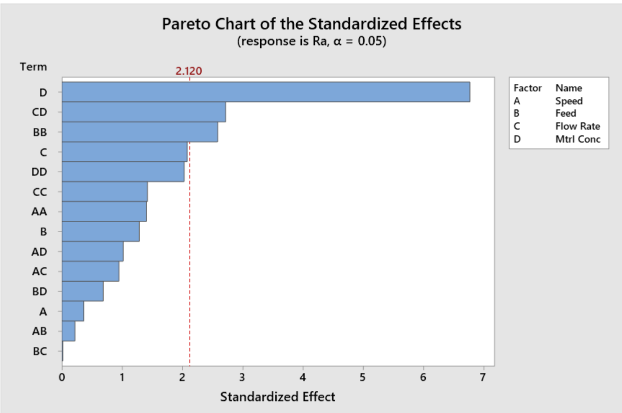


Figure 4. Pareto Chart of the standardised effects

In MQL, parameters such as D (material concentration), B (feed), and C (flow rate) shows their influence on the surface roughness in MQL drilling, which shown in Fig. 4.The presented statistical analysis of factorial effect recommended that % SiC in MMC has the most significant effect on the Ra value while the combination of flow rate and % SiC in MMC has also significant effect on *R*a value.

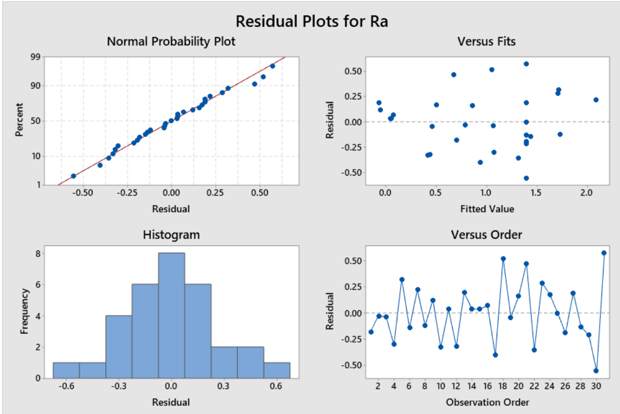


Figure 5.Residual plots for Ra

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, figure 5 showed that the regression models provided good fits

Figure 6.Main effects plot for Ra

Above figure shows that main effect plot for Ra value obtained in the MQL drilling in concern with cutting speed, feed, MQL flow rate, and SiC particle, respectively. It shows that all these parameters have influence on the surface roughness in MQL based drilling.

Table 6. Coded Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	1.399	0.135	10.36	0.000	
Speed	0.0282	0.0773	0.36	0.720	1.00
Feed	0.0993	0.0773	1.29	0.217	1.00
Flow Rate	0.1609	0.0773	2.08	0.054	1.00
Mtrl Conc	-0.6043	0.0892	-6.77	0.000	1.00
Speed*Speed	-0.1004	0.0714	-1.41	0.179	1.05
Feed*Feed	-0.1849	0.0714	-2.59	0.020	1.05
Flow Rate*Flow Rate	-0.1016	0.0714	-1.42	0.174	1.05
Mtrl Conc*Mtrl Conc	-0.290	0.143	-2.03	0.059	1.08

Speed*Feed	-0.0206	0.0947	-0.22	0.830	1.00
Speed*Flow Rate	-0.0896	0.0947	-0.95	0.358	1.00
Speed*Mtrl Conc	0.0965	0.0947	1.02	0.323	1.00
Feed*Flow Rate	0.0016	0.0947	0.02	0.987	1.00
Feed*Mtrl Conc	-0.0652	0.0947	-0.69	0.500	1.00
Flow Rate*Mtrl Conc	-0.2572	0.0947	-2.72	0.015	1.00

shows the results of ANOVA on performance characteristic. The F-Ratio in Table No. indicates the significant condition of each factor and its interactions. % SiC concentration has major percent contribution (45.86%) in optimizing the performance characteristics followed by flow rate (4.34 %), federate (1.65 %) and speed (0.13%). Further the interaction between flowrate and material concentration is most significant. From the ANOVA analysis of Ra value Tables reflected that all the four parameters were significant as their P values are less than 1.

Table 7. Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	14	11.3216	0.80869	5.64	0.001
Linear	4	7.4512	1.86281	13.00	0.000
Speed	1	0.0190	0.01904	0.13	0.720
Feed	1	0.2368	0.23681	1.65	0.217
Flow Rate	1	0.6215	0.62146	4.34	0.054
Mtrl Conc	1	6.5739	6.57394	45.86	0.000
Square	4	2.4591	0.61477	4.29	0.015
Speed*Speed	1	0.2833	0.28326	1.98	0.179
Feed*Feed	1	0.9605	0.96047	6.70	0.020
Flow Rate*Flow Rate	1	0.2896	0.28965	2.02	0.174
Mtrl Conc*Mtrl Conc	1	0.5906	0.59059	4.12	0.059
2-Way Interaction	6	1.4113	0.23522	1.64	0.200
Speed*Feed	1	0.0068	0.00681	0.05	0.830
Speed*Flow Rate	1	0.1285	0.12852	0.90	0.358
Speed*Mtrl Conc	1	0.1490	0.14900	1.04	0.323
Feed*Flow Rate	1	0.0000	0.00004	0.00	0.987
Feed*Mtrl Conc	1	0.0681	0.06812	0.48	0.500
Flow Rate*Mtrl Conc	1	1.0588	1.05884	7.39	0.015
Error	16	2.2935	0.14335		
Lack-of-Fit	10	1.5314	0.15314	1.21	0.427
Pure Error	6	0.7621	0.12702		
Total	30	13.6152			

The adequacy of the model fit, measured by the coefficient of determination (adjusted R2), was calculated as 0.684, showing that 68.41% of the variability in Ra readings is explained by the fitted model. The predicted R2 was calculated as 0.147, proving that the model is not over-fitted and has a good predictability. Figure 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

Table 8. Model Summary

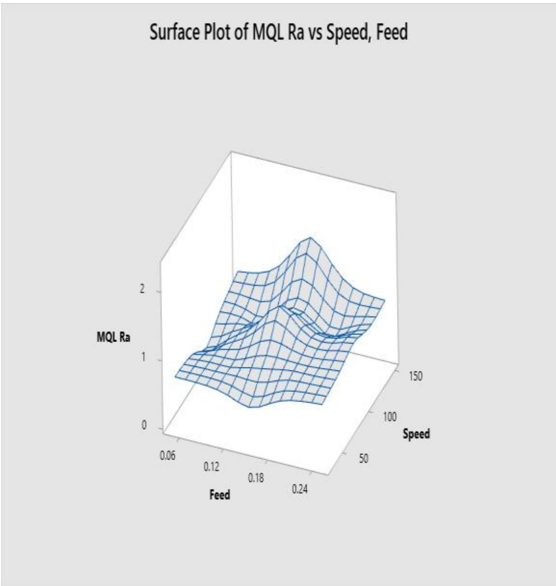
S	R-sq	R-sq(adj)	R-sq(pred)
0.378610	83.15%	68.41%	14.74%

The developed mathematical models is used for predicting the relationship between process parameters and surface roughness. The R-squared values of surface roughness model are 0.8315 indicates that the developed models can be used to predict the surface roughness during drilling of Al-SiC added MMC in MQL condition.

$$
\begin{aligned}
Ra = {} & -6.88 + 0.0286\ Speed + 27.9\ Feed + 0.0584\ Flow\ Rate \\
& + 0.1491\ Mtrl\ Conc - 0.000112\ Speed*Speed \\
& - 74.0\ Feed*Feed - 0.000113\ Flow\ Rate*Flow\ Rate \\
& - 0.00290\ Mtrl\ Conc*Mtrl\ Conc - 0.0138\ Speed*Feed \\
& - 0.000100\ Speed*Flow\ Rate + 0.000322\ Speed*Mtrl\ Conc \\
& + 0.0011\ Feed*Flow\ Rate - 0.131\ Feed*Mtrl\ Conc \\
& - 0.000857\ Flow\ Rate*Mtrl\ Conc
\end{aligned}
$$

The above regression equations are valid for the parameter range of feed range of 0.08–0.24 mm/rev, SiC weight percentage (10-30%), Flow Rate in the range of 30 to 150 mml/hr and cutting speed in the range of 50-150 m/min.

Interaction effect on responses (3D plots) Three-dimensional (3D) response surface plots were drawn to study the effect of the input machining parameters on Ra . These plots can supplementarily provide further assessment of the relationship between the process parameters and replication. 3D surface plots are drawn as two of the factors were maintained constant at their middle level, while the other two are varied. The effect of cutting speed and the lubrication condition is presented in Figure 7



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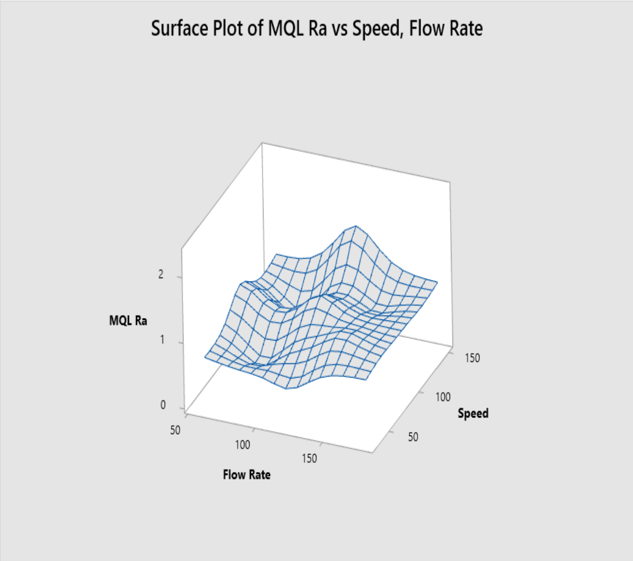

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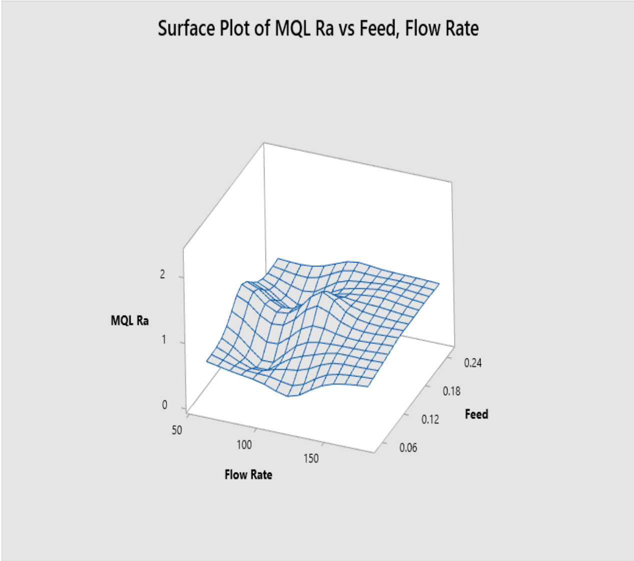

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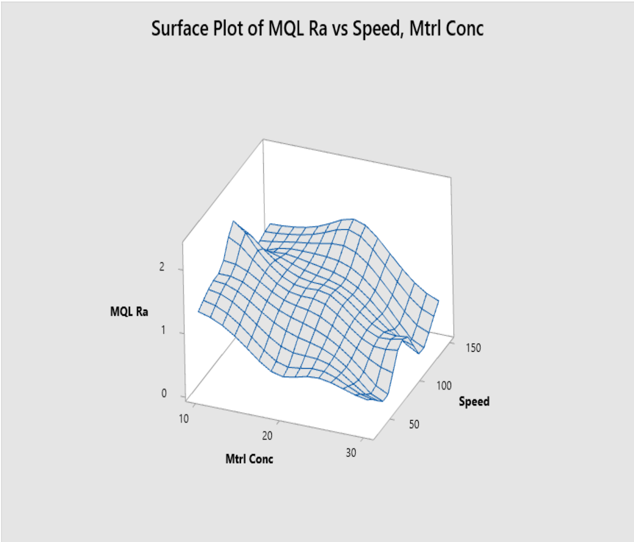

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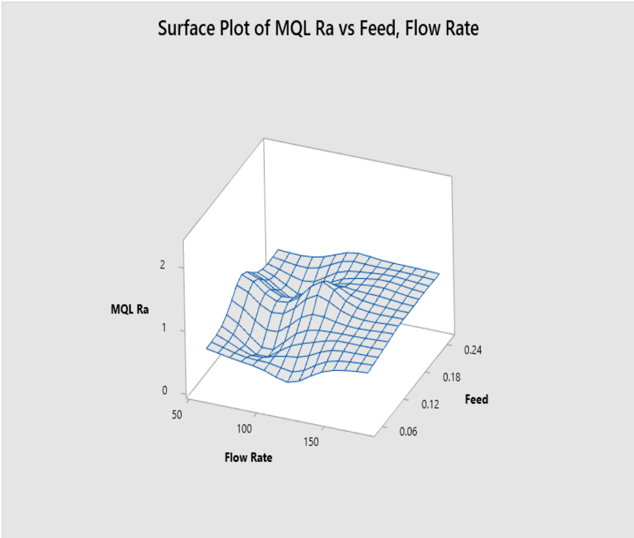

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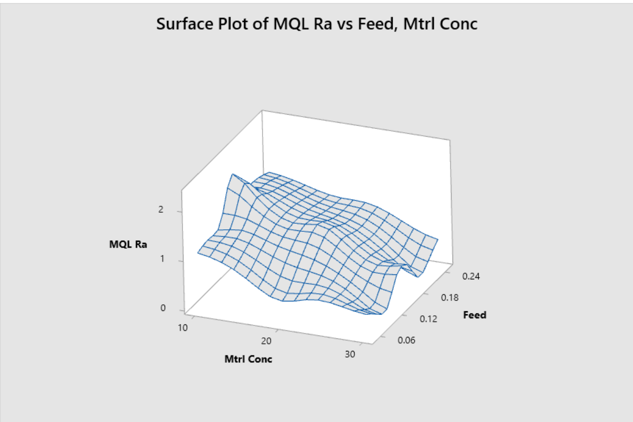

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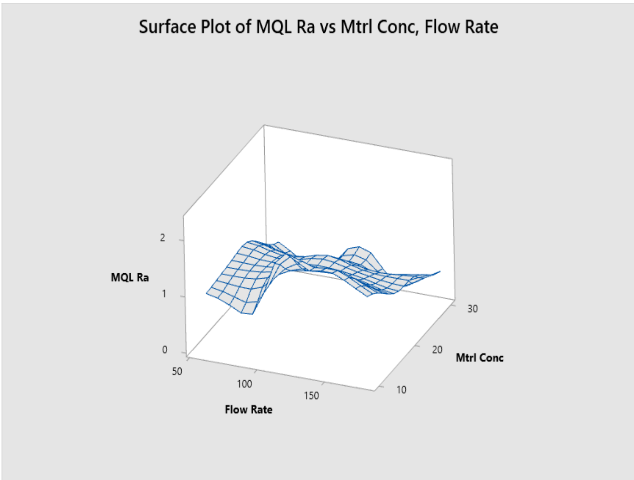

Figure 7.Surface plot of Ra value vs Speed, Feed, Flow rate & % SiC

The Fig. 7 shows the surface plots obtained for surface roughness observed in MQL based drilling. The surface plots were mapped with obtained Ra value which correlated to parameters interaction. The seven different interaction such as AB (Cutting speed*feed), AC (Cutting speed*flow rate), AD (Cutting speed*material concentration), BC (feed*flow rate), BD (feed*material concentration), CD (flow rate* material concentration) are used in the surface plots.

Surface roughness plays an important role in many areas and one of the factors of great importance in evaluation of machining accuracy. Machining parameters such as cutting speed, feed rate, flow rate, % SiC concentration have significant influence on the surface roughness for a given machining setup. The variation of surface roughness with respect to the machining parameters indicates that the surface roughness fluctuated for various cutting speed, feed rate, and flow rate, % SiC concentration . The surface roughness is better at low cutting speed & low feed rate.

V. CONCLUSION

Application of MQL machining is much more acceptable from an environmental viewpoint as the machining used non vegetable oil that does not pollute the environment. The amount of oil used in MQL is many times less than the flooding condition.

% SiC is most significant factor affecting surface roughness of aluminium metal matrix composite as % SiC increased from 10 to 30 Ra value shows decreasing trend from 0.086 µm to 1.6 µm. Also increasing flow rate increased Ra value from 0.1 µm to 2.3 µm.

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