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Experimental Investigation & Optimization of Machining Parameter in Milling of Aluminium 2014 -T6 Alloy under Different Lubrication Conditions

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Abstract- **This experimental investigation was conducted to determine the effects of machining parameters on surface roughness and cutting forces in slot milling of A1uminium 2014-T6 under different lubrication conditions such as dry , MQL and also an external minimum quantity lubrication system was developed. Here the experiments are designed using Taguchi orthogonal array and nine experiments each under different lubrications .Then Taguchi based grey relation analysis is used to optimize the cutting parameters to have lowest surface roughness and cutting force among different combinations of speed ,feed and depth of cut. After that the results are analyzed using analysis of variance which is used for identifying the factors significantly affecting the performance measures and developed a mathematical model using regression technique to predict performance measures (surface roughness, cutting force).And finally the results shows that MQL system has better surface finish and low cutting force than dry lubrication systems. It is true that this small reduction has enabled significant improvement in machinability indices , so we can say that MQL machining is an alternative for dry systems.**

Index Terms- Grey relation Analysis , Minimum quantity lubrication,

I. INTRODUCTION

The quality of machined components is evaluated in respect of how closely they adhere to set product finish, and reflective properties. Dimensional accuracy, tool wear and quality of surface finish are three factors that manufacturers must be able to control at the machining operations to ensure better performance and service life of engineering component. The competitive manufacturing field are facing competitive manufacturing field , manufactures are facing the challenges of higher productivity ,quality and overall economy in the field of manufacturing by machining. The above challenges in a global environment, there is an increasing demand for better surface finish and also longer life and stability of the cutting tool But high production machining with high cutting speed, feed and depth of cut generates large amount of heat and temperature at the chip-tool interface which ultimately reduces dimensional accuracy, tool life, so temperature needs to be controlled at an optimum level to achieve better surface finish and overall machining economy.

The conventional types and methods of application of cutting fluid have been found to become less effective with the increase in cutting velocity and feed. The most common way of applying cutting fluids in machining process is by flood cooling in which the machining area is flooded with an abundant amount of cutting fluid. It is important to find a way to manufacture products using more sustainable methods and processes, which could minimize the use of cutting fluids in the machining operation and provide a healthy and safe working environment. The ideal way of performing manufacturing processes in this regard is by dry machining, which will eliminate completely, any use of cutting fluids. However, cutting fluids have their own advantages and positive effects which have to be assured in dry machining. Near-dry machining, which is also referred to as MQL (Minimum Quantity Lubrication), is a more realistic approach which is an intermediary stage between flood cooling and dry machining.

The Paper has been organised as follows. Section II deals with the experimental details. Section III deals with the optimization of machining parameters. Section IV deals with Statistical analysis. In Section V conformation test. Section VI is the Conclusion part and Section VII .

II. EXPERIMENTAL DETAILS

The experiment is performed on 2014-T6 Aluminium alloy in the form of rectangular piece having 110 mm length , 100 width and 25 mm height . 2014-T6 Aluminium alloy was selected due to its emergent range applications in the field of space vehicles ,aerospace application e.t.c . The cutting tool insert for slot milling is uncoated carbide insert (Sanvik R390- 11T3 08 E - NL - H13A). The different set of slot milling experiments are performed using a HSC linear 75 , 3- axis vertical milling.

In this work , Taguchi method uses a special design of orthogonal array to design the experiment. According to the Taguchi method, a robust design and an L9 orthogonal array are employed for the experimentation. Three machining parameters are considered as controlling factors- namely cutting speed, feed/tooth, depth of cut and each has three levels – namely low, medium, and high, denoted by 1, 2 and 3 respectively. Table 1 shows the cutting parameters and their levels considered for experimentation and Figure 1&2 shows block diagram external minimum quantity lubrication setup and photographic view.

Table 1 :Cutting parameters and their levels

Parameters	Units	Level 1	Level 2	Level 3
Cutting speed(CS)	m/min	700	800	850
Feed/tooth(F_z)	mm/tooth	0.1	0.15	0.20
Depth of cut (Doc)	mm	0.6	1.2	1.8
Type of lubrications: Dry ,MQL(75ml/hr)				

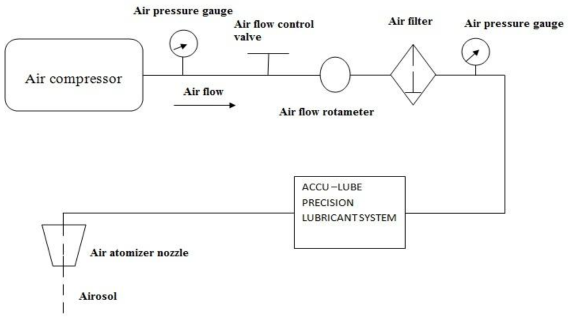

Figure 1: Block diagram of external MQL setup

Figure 2: Photo graphic view of external MQL setup

Minimal quantity lubrication (MQL) machining, also known as near-dry machining (NDM), supplies very small quantities of lubricant to the machining zone. It was developed as an alternative to flood and internal high-pressure coolant supply to reduce metal working fluids consumption. In MQL machining, the cooling media is supplied as a mixture of air and an oil in the form of an aerosol (often referred to as the mist). An aerosol is a gaseous suspension of solid or liquid particles in air. In MQL machining aerosols are oil droplets dispersed in a jet of air. An idealized picture of MQL machining is shown in Fig. 2: small oil droplets carried by the air fly directly to the tool working zone, providing the needed cooling and lubricating actions.

This lubrication system is used to deliver metered quantity aerosol mixture to tool work piece interface. With a small amount lubricant, tools last longer and parts come out cleaner. By eliminating flood coolant the impact on environment is minimized. Accu-Lube system didn't have a provision to measure the amount of coolant dispensed. The amount of air flow through the device also couldn't be measured. Hence the Accu-Lube system was fitted with a beaker to measure the oil flow and a rotameter was connected to the inlet to measure the air flow.

For three components measurement of cutting forces in X, Y and Z directions were recorded using a standard quartz dynamometer (Kistler 9257B) allowing measurements from−5 to 5 KN The Kistler dynamometer is connected to the charge amplifier and from the amplifier, it is connected to the Digital Acquisition Board (DAQ) and finally, it is connected to personal computer. The personal computer is equipped with software of Kistler Dynoware for data acquisition using cable that is provided in the Kistler dynamometer. During the milling operation, the cutting force produced will be detected by the sensors of the Kistler dynamometer and this cutting force signals will transmit to the amplifier. The amplifier will enlarge the signals and then transmitted to the DAQ board and then personal computer. With the assistance of the software of Kistler Dynoware. And the machined slot surface was measured at two different positions and the average (R_a) values are taken using Form Talysurf PGI 800 ,which has diamond stylus tip with accuracy of 2μm and resolution of 3.2 nm and the maximum transverse length 200mm and the pickup system used is phase grating laser interferometric.

In this work total 18 experiments are conducted under two different lubrication category ,and the observed response values are tabulated in Table 2.

Table 2: Observations of average surface roughness and resultant cutting force for dry and MQL conditions

Ex .no	CS	F_Z	DOC	Avg R_a (dry)	Avg R_a (MQL)	F_c (dry)	F_c (MQL)
1	700	0.1	0.6	0.66	0.68	128.3	126.6
2	700	0.15	1.2	0.86	0.87	139.6	137.6
3	700	0.20	1.8	0.75	0.73	181.4	198.9
4	800	0.1	1.2	0.61	0.62	148.5	136.9
5	800	0.15	1.8	0.85	0.76	166.1	136.7
6	800	0.20	0.6	0.86	0.85	96.00	197.7
7	850	0.1	1.8	0.59	0.62	178.3	87.41
8	850	0.15	0.6	0.89	0.74	94.21	178.7
9	850	0.20	1.2	0.86	0.78	126.3	80.21

III. OPTIMIZATION

A. Grey relational analysis(GRA)

By using multiple objective optimization(grey relation analysis) technique, used to found out the optimal set values of cutting parameters which minimize the both objective functions. In GRA higher grey relation grade is optimized level. And the general equations that are used as follows,

$$\text{Normalized value} = \frac{\text{Max } X_i^{(o)}k - \text{Mi}X_i^{(o)}k}{\text{Max } X_i^{(o)}k - \text{Min}X_i^{(o)}k} \quad (1)$$

where , Max $X_i^{(o)}k$ & Min$X_i^{(o)}k$ are the maximum and minimum value of response value and Mi$X_i^{(o)}k$ is current value of response value

$$\text{GRC } (\varphi_i(k)) = \frac{\Delta_{min} + \delta\Delta_{max}}{\Delta_{oi}(k) + \delta\Delta_{max}} \quad (2)$$

Where GRC ($\varphi_i(k)$) is Grey relation coefficient , Δ_{min} & Δ_{max} are the maximum and minimum value of change , $\Delta_{oi}(k)$ is the current value of change and δ relational coefficient and its value is 0.5.

$$GRG\ (\gamma_i) = \frac{1}{n}\sum_{k=1}^{n} \varphi_i(k) \quad (3)$$

Where GRG (γ_i) is grey relation grade and n is the number of response factor. Based on the above equations grey relation grade and response GRG for parameter levels were tabulated for both dry and MQL lubrication systems in Table 3, Table 4 ,Table 5, Table 6 .

Table 3 : GRG for Dry lubrication system

Ex.no	Normalized value		Grey coefficient		Grey grade
	R_a	F_c	R_a	F_c	
1	0.751	0.609	0.667	0.561	0.614
2	0.105	0.479	0.358	0.489	0.423
3	0.473	0	0.486	0.333	0.409
4	0.913	0.382	0.851	0.447	0.649
5	0.145	0.175	0.369	0.377	0.373
6	0.099	0.979	0.356	0.959	0.657
7	1	0.035	1	0.341	0.670
8	0	1	0.333	1	0.666
9	0.089	0.631	0.354	0.575	0.464
Total mean G.R.G = 0.5927					

Table 4:Response GRG for parameter level(Dry)

Process Parameter	GREY RELATIONAL GRADE				
	Level 1	Level 2	Level 3	G.R.G	Rank
Cutting speed	0.482	0.5596	0.6*	0.118	3
Feed/tooth	0.6443*	0.4873	0.51	0.157.2	2
Depth of cut	0.6456*	0.512	0.484	0.1616	1
Optimum levels*					

Table 5 : GRG for MQL lubrication system

Ex.no	Normalized value		Grey coefficient		Grey grade
	R_a	F_c	R_a	F_c	
1	0.741	0.608	0.658	0.560	0.690
2	0	0.515	0.333	0.507	0.420
3	0.544	0	0.523	0.333	0.428
4	0.983	0.523	0.927	0.511	0.739
5	0.415	0.010	0.460	0.335	0.397
6	0.076	0.939	0.351	0.891	0.627
7	1	0.169	1	0.375	0.687
8	0.5	1	0.5	1	0.75
9	0334	0.626	0.428	0.572	0.5
Total mean G.R.G = 0.581					

Table 6:Response GRG for parameter level(MQL)

Process Parameter	GREY RELATIONAL GRADE				
	Level 1	Level 2	Level 3	G.R.G	Rank
Cutting speed	0.5126	0.5858	**0.645***	0.1330	3
Feed/tooth	**0.7053***	0.5225	0.5163	0.189	1
Depth of cut	**0.6870***	0.553	0.5041	0.182	2
Optimum levels*					

IV. STATISTICAL ANALYSIS

A. Analysis of variance(ANOVA)

ANOVA is useful for determining influence of any given input parameter from a series of experimental result by design of experiment for machining process and it can be used to interpret experimental data.

B. Regression analysis

Regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modelling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables.

Analysis of variance & Regression equations for various lubrication systems were tabulated in Table 7 and Table 8 .

Table 7 : Analysis of variance for Dry

Source	DOF	S.S	M.S	F	%C
Cutting speed	2	0.040	0.020105	0.0100	24.3
Feed/tooth	2	0.061	0.030916	0.0154	37.37
Depth of cut	2	0.063	0.031689	0.01584	38.31
Error	2	-	-	-	-
Total fishers value = 0.04135564					

Regression equations are,

1)Surface roughness (R_a) = 0.421+0.000164 cutting speed +2.017Feed/tooth – 0.0644depth of cut

Optimized parameter levels- 3 ,1,1(cutting speed=850 ; feed =0.1 ; depth of cut = 0.6)

Predicted Surface roughness (R_a) = 0.7234 µm

2)Cutting force (F_C) = 186.1 – 0.1149 cutting speed -169.5 feed/tooth + 57.61 depth of cut

Predicted Cutting force (F_C) = 106.05 N

Table 8 : Analysis of variance for MQL

Source	DOF	S.S	M.S	F	%C
Cutting speed	2	0.026	0.013312	0.00665	17.796
Feed/tooth	2	0.069	0.034588	0.01729	46.23
Depth of cut	2	0.053	0.029004	0.01345	35.62
Error	2	-	-	-	-
Total fishers value = 0.037400399					

Regression equations are,

1)Surface roughness (R_a) = 0.797+0.000281 cutting speed +1.463Feed/tooth – 0.0442depth of cut

Optimized parameter levels - 3 ,1,1 (cutting speed=850 ; feed =0.1 ; depth of cut = 0.6)

Predicted Surface roughness (R_a) = 0.67793 µm

2)Cutting force (F_C) = 197.3 – 0.1716 cutting speed -104.3 feed/tooth + 0.0442 depth of cut

Predicted Cutting force (F_C) = 87.858 N

V. CONFORMATION TEST

Once the optimal combination of process parameters and their levels are obtained the final step was to verify the predicted results with experimental value .The predicted values were compared with actual values for both dry and MQL lubrication systems were tabulated in Table 9.

Table 9: Comparison of predicted and actual values

Cutting conditions	Predicted values		Experimental values	
	R_a (µm)	F_c (N)	R_a (µm)	F_c (N)
Dry	0.7234	106.05	0.701	106.01
MQL	0.67793	87.858	0.653	87.81

VI RESULTS AND DISCUSSIONS

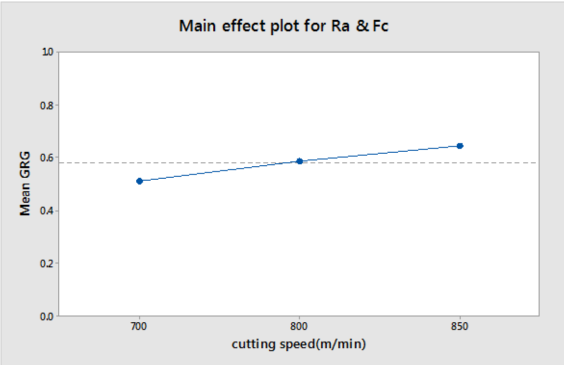

Fig.3: Cutting speed V_s Mean GRG (MQL)

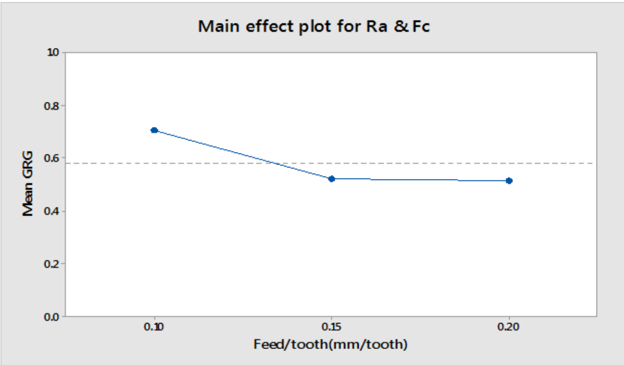

Fig.4: Feed/tooth V_s Mean GRG (MQL)

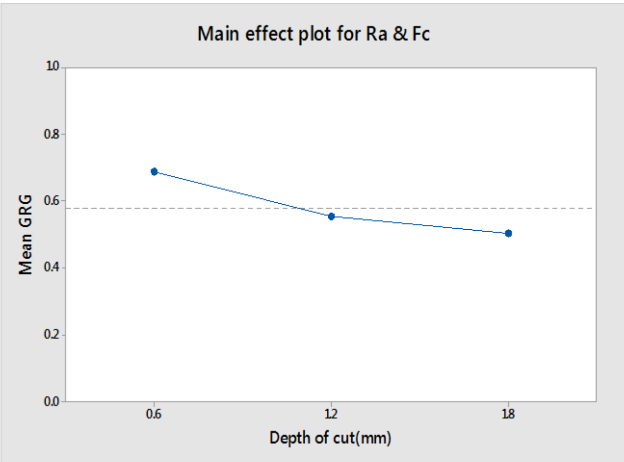

Fig.5: Depth of cut Vs Mean GRG (MQL)

Fig:3-5shows the main effect plot for both Ra & Resultant cutting force. The result shows that with increase in cutting speed, there are continuous decreases in surface roughness and cutting force (ie; high G.R.G has low Ra & cutting force). On the other hand as the feed increases both Ra &Fr

values increases up to 0.15 feed/tooth and then slightly decreases, however with increase in depth of cut there is a continuous increase in both R_a&F_c. Optimum value of surface value was obtained at cutting speed 850 m/min (level 3), feed/tooth 0.1mm/tooth (level 1) and depth of cut 0.6 mm (level1).

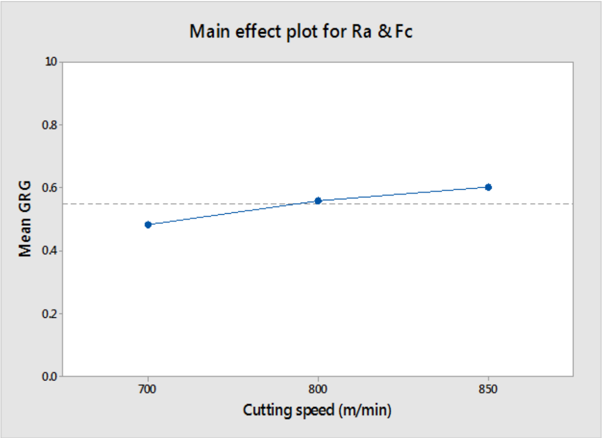

Fig.6: Cutting speed V_s Mean GRG (DRY)

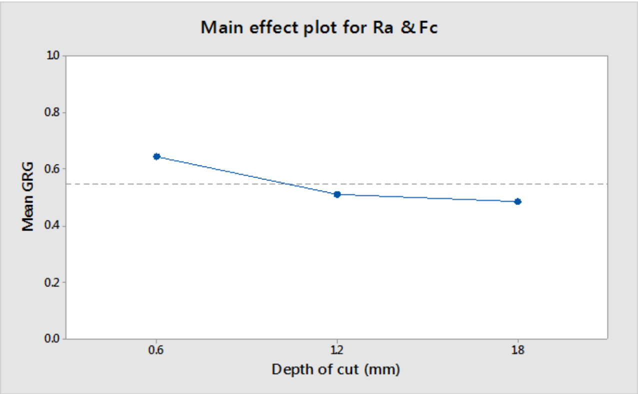

Fig.7: Depth of cut Vs Mean GRG (DRY)

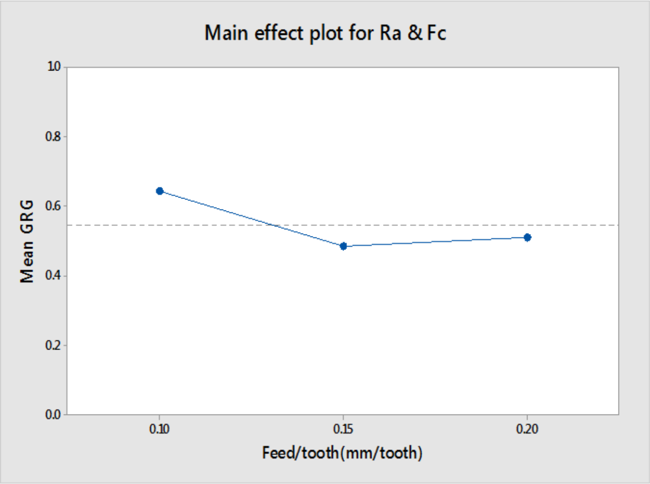

Fig.8: Feed/tooth V_s Mean GRG (DRY)

Fig 6-8 shows the main effect plot for both Ra& Resultant cutting force. The result shows that with increase in cutting speed, there are is a continuous decreases in surface roughness and cutting force (ie; high G.R.G has low Ra& cutting force). On the other hand as the feed increases both R_a&F_c values increases up to 0.15 feed/tooth and then slightly decreases, however with increase in depth of cut there is a continuous increase in both R_a&F_c. Optimum value of surface value was obtained at cutting speed 850 m/min (level 3), feed/tooth 0.1mm/tooth (level 1) and depth of cut 0.6 mm (level 1).

VII CONCLUSION

The aim this work was to take advantage of the Taguchi method to perform optimization with small number of experiment and utilization of multiple regression analysis to obtain mathematical model which are a powerful tool to predict response for any of input parameters within the experimental domain.

Through ANOVA it was conformed that feed/tooth was the major significant factor followed by cutting speed and depth of cut. Cutting speed and depth of cut played an insignificant role in affecting both surface roughness and cutting force . This was true for minimum quantity lubrication in dry lubrication system depth of cut was major significant factor.

Through Taguchi based grey relation analysis; the optimum levels of cutting speed, feed/tooth and depth of cut is obtained as 850m/min ,0.1feed/tooth ,0.6mm respectively this was true for a all conditions of lubrication systems (dry, MQL(75ml/hr).The predicted surface roughness and cutting force at optimal condition for MQL(75ml/hr) is 0.67793 µm and 87.858N which was below than dry lubrication system. So It is true that this small reduction has enabled significant improvement in machinability indices. MQL has reduced the cutting force so we can say that MQL machining is an alternative for both flood and dry systems.

From the above experiments it shows that surface roughness and cutting force value is low in minimum quantity lubrication system when compared with dry lubrication system , Also its clear that while machining aluminium or its alloys coolant is necessary to get better surface finish.

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