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Optimization of process parameters on Over-Cut in drilling of Al-B_4C MMC

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ABSTRACT: *This paper presents an experimental investigation on Over-Cut in Drilling of aluminum hybrid metal matrix composite (Al-15%B_4C). The parameters used for drilling here was Depth of Cut, Spindle Speed, and Drill Diameter. Taguchi's L27 orthogonal array experimentation was used to optimize the parameters of Al-B_4C MMC. ANOVA method was used for finding significant parameter. Taguchi's technique was found using Minitab software. The experiments are conducted on vertical milling machine using High Speed Steel drills of 6 mm, 9 mm and 12 mm diameter under dry drilling conditions. A Taguchi analysis is carried out. The effect of drilling parameters on Over-Cut is studied and presented.*

Keywords: *Drilling, Metal Matrix Composites, Taguchi, Over-Cut*

I. INTRODUCTION

Amongst different classes of composites the Metal Matrix Composites (MMCs) have always been the forerunners. From being just a topic of scientific and intellectual interest, Metal Matrix Composites (MMCs) have been transformed into a material of broad commercial and technological significance, in past two decades. A unique balance of mechanical and physical properties is always offered by MMCs. In recent decades, Aluminium based MMCs have received quite high attention as engineering materials, as, majority of the Al based MMCs have possessed the advantages of wear resistance, high strength and hardness.

II. LITERATURE REVIEW

Suresh et al. (2012) [1] have used response surface methodology on AISI 4340 high strength low alloy steel to optimize surface roughness, machining force and tool wear. They concluded that, for minimizing the machining force, the combination of low feed rate, low depth of cut and low machining time with high cutting speed is beneficial. **Davim et al. (2001) [2]** found that when machining the PMMCs, the predominant wear mechanism is abrasive and the feed force increases with the flank wear of the drills. **Basavarajappa et al. (2007) [3]** have used response surface methodology on Al2219/15%SiCp to optimize effect of machining parameters on material, Surface finish and morphology. They concluded that with the increase in feed rate, Surface roughness increases and with the increase in cutting speed, Surface roughness decreases. **Palanikumar (2011) [4]** has used Taguchi's method on Glass fibre-reinforced polymer (GFRP) composite materials to optimize thrust force, work piece surface roughness. **Aouici et al. (2012) [5]** have used statistical analysis of variance (ANOVA) and response surface methodology (RSM) on AISI D3 cold work Steel to optimize surface roughness and cutting force. They concluded that cutting force is mostly affected by feed rate followed by depth of cut. **Ramesh et al. (2012) [6]** used Response surface methodology on titanium alloy to optimize the surface roughness. They concluded that the most influencing parameter was identified as the feed. **Suresh R et al. (2012) [7]** have used Taguchi technique on AISI 4340 steel to optimize Cutting force and thrust force. They concluded that for minimizing the machining force, the combination of low feed rate, low depth of cut with high cutting speed is beneficial. Machining force initially increases with increase in feed rate and depth of cut and decreases with increase in cutting speed.**Hessainia et al. (2013) [8]** have used Response surface methodology on 42CrMo4 hardened steel to optimize surface roughness. They concluded that the feed rate is the dominant factor affecting the surface roughness, whereas vibrations on both directions have a low effect on it. **Gopalakannan et al. (2013) [9]** have used Response surface methodology on Al–SiCnano-composites material to optimize Surface roughness and feed rate. **Sahoo et al. (2013) [10]** have used Taguchi's L9 orthogonal array on Al/SiCp MMC to optimise Feed rate. They concluded that Cutting speed is found to be the most significant parameter for flank wear followed by feed. Depth of cut has the insignificant effect on flank wear. **Taskesen et al. (2013) [11]** have used Grey relational analysis on B4C reinforced Al-alloy to optimise thrust force, torque and surface roughness. They conclude that Flank wear of the cutting tool was found to be mostly dependent upon particle mass fraction, followed by feed rate, drill hardness and spindle speed, respectively. **Karabulut (2015) [12]** have used Taguchi method and neural network on AA7039/Al2O3 metal matrix composites material to optimise surface roughness and cutting force. ANOVA technique is also used. They concluded that the analysis results showed that material structure was the most effective factor on surface roughness and feed rate was the dominant factor affecting cutting force. ANOVA results show that the most effective control factor for surface roughness, with a percentage contribution of 85.24%, was the type of material. The feed rate and cutting speed affect the surface roughness by 7.12% and 5.05% respectively. The depth of cut has the least effect on surface roughness.**Suresh et al. (2012) [13]** have used response surface methodology on AISI 4340 high strength low alloy steel to optimize surface roughness, machining force and tool wear.They concluded that, for minimizing the machining force, the combination of low feed rate, low depth of cut and low machining time with high cutting speed is beneficial. **Gallab et al. (1998) [14]** have used Dry turning test on Al:SiC particulate metal-matrix composites to optimise Rake angles. They concluded that for the roughing operations, Polycrystalline tools with zero rake angle and large tool nose radii are recommended. The main tool wear mechanism is abrasion and micro-cutting of tool material grains, manifested as grooves on the tool face parallel to the chip flow direction.**Hayajneh et al. (2009) [15]** have used Artificial neural network modeling on aluminum / alumina / graphite hybrid composites to optimise Cutting speed ,Cutting feed ,volume fraction of the reinforced particles and thrust force. They concluded that ANN is an excellent analytical tool, if it is well trained, can be used for other machining processes. The models for the thrust force and cutting torque were identified by using the alumina (Al2O3) particles contents, graphite (Gr) particles contents, cutting feeds (F) and spindle speeds (N) as input data and thrust force and cutting torque as the output data.**Rajmohan et al. (2012) [16]** used Taguchi's method on hybrid mmc to optimise Surface finish, thrust force, tool wear, and burr height in the drilling of composites. They concluded that, the factors which affect the drilling process are feed rate and the type of drill. The tested parameters, the feed rate shows strongest correlation to the thrust force, surface roughness, tool wear and burr height (exit). **Rajmohan et al. (2013) [17]** used Microstructure and mechanical characterization on hybrid aluminium matrix composites to optimise strength and hardness. They concluded that the better strength and hardness are achieved with Al/10SiC−3mica composites. The increase in mass fraction of mica improves the wear loss of the composites. Mica reinforced composites exhibits less wear loss and higher density compared with the ceramic reinforced composites.**Taskesen et al. (2013) [18]** have used grey relational analysis on boron carbide reinforced metal matrix composites to optimise Feed rate and spindle speed. They concluded that the weight fraction of the B4C resulted in a considerable increase in the thrust force. Average surface roughness of drilled hole decreased with increasing particle content for carbide tools and increased for HSS tools. TiAlN coated carbide drills showed the best performance with regard to the surface roughness.**Davim (2003) [19]** have used Taguchi's method on MMC to optimise Correlation between cutting velocity, feed rate and cutting time. Feed rate is the cutting parameter which has greater influence on surface roughness and specific cutting pressure followed by cutting velocity and cutting time. To analyze interaction in the holes surface roughness, the interaction cutting velocity/feed is the most important. **Kumar et al. (2012) [20]** have used Optimization of drilling parameters on Al6061–SiC composites to optimise Hardness, Ultimate tensile strength and feed rate. They concluded that the experimental results showed that the density of the composites increase with increased SiC content. The wear resistance of the composites is higher than that of base alloy. Hardness of the composites was found to increase with increased filler content. The ultimate tensile strength properties of the composites are found to be higher than that of base matrix.**Barnes et al. (2000) [21]** have used Taguchi's method and ANOVA on Aluminum/SiC Metal Matrix Composite to optimiseDrill wear, Hole diameter and Surface roughness. They concluded that in the drilling performance, the application of through toolcoolant (even at low pressure) produced a significant improvement. In agreement with otherwork, the wear observed at some locations increased when usingconventional cooling relative to dry drilling.**Horvath et al. (2011) [22]** have used Response surface method (RSM) on Aluminum alloys to optimise Surface roughness, Feed rate Surface height and standard deviation. They concluded that the cutting speed and feed have the largest influence on surface roughness. Also the interactions of these factors also significantly affect surface roughness. The harder hyper-eutectic alloy has better finish turning and lower roughness values.**(Rana (2014) [27], Rana (2014)[28])**have alsoreviewed thepapers on Taguchi optimization which, shows that Taguchi can be applied to find whether the factors are significant or not on the optimized results.**(Rana (2015) [27], Lata (2015) [28])**haveapplied RSM on the welding techniques to improve the weld abilities.

III. EXPERIMENTAL SETUP

A number of experiments were conducted to study the effects of various parameters of drilling Al-B_4C MMC. These studies were undertaken to investigate the effects of D.O.C., Speed and Drill Diameter for drilling Al-B_4C MMC.

The selected workpiece material for the research work was Al 6061 (composition shown in Table 1) as the matrix and containing 15% wt. of B_4C particulate of 220 µm. Al-B_4C MMC was selected due to its emergent range of applications in the field of manufacturing. The Drilled pieces are shown in Figure 2 (a) & (b). The test conditions are depicted in Table II.

Table 1. Chemical composition of Al 6061

Element	Weight percentage
Cromium (Cr)	0.15
Copper (Cu)	0.40
Iron (Fe)	0.7
Magnesium (Mg)	0.80
Manganese (Mn)	0.15
Silicon (Si)	7.00
Titanium (Ti)	0.20
Zinc (Zn)	0.25
Aluminium (Al)	90.35

(a) (b)

Figure 2: Photographic View of Al-B_4C_p Drilled pieces

Table II: Different Variables Used In The Experiment And Their Level

Variable	CODE	LEVELS		
		1	2	3
D.O.C.	A	5	10	15
SPEED	B	660	1110	1320
DRILL DIA	C	6	9	12

IV. TAGUCHI OPTIMIZATION

One of the powerful and most important statistical technique is Design of Experiment (DOE), which is used to study the effect of multiple variables simultaneously. DOE involves a series of steps which must follow a certain sequence for the experiment to yield an improved understanding of process performance **(Taguchi (1990) [23])**.Analysis of the responses uses a signal to noise (S/N) ratio to determine the best process parameters. This method improves the design of machining processes. In the present work, experiments were performed by Taguchi method using orthogonal arrays **(Ross (1996) [24])**. This method yields the rank of various parameters with the level of significance of influence of a factor or the interaction of factors on a particular output response.

In present work Over-Cut (OC) is being measured by conducting total 27 numbers of experiments (shown in Table III). Digital Vernier Caliper was used for the measurement of Over-Cut. Over-Cut is the measure of cut produced exceeding the diameter of the tool. The hole created while drilling process is generally slightly larger than the original diameter of the Drill Diameter. Over-Cut is calculated as half the difference of the diameter of the hole produced to the tool diameter as shown in the equations below:

$$\text{Over-Cut} = \frac{D_i - D_o}{2} \qquad \ldots (1)$$

Where D_i is the diameter of the hole and D_o is the outer diameter of the Drill.

Table III: Response parameters (Over-Cut) along with its S/N Ratio

DOC	SPEED	DRILL DIA	Over-Cut		S/N Ratio (db)
			R_1	R_2	
5	660	6	0.1	0.12	19.1364
5	1110	6	0.08	0.24	14.9485
5	1320	6	0.22	0.3	11.59894
10	660	6	0.13	0.58	7.528864
10	1110	6	0.13	0.23	14.57175
10	1320	6	0.18	0.38	10.53548
15	660	6	0.12	0.62	7.002748
15	1110	6	0.16	0.24	13.80907
15	1320	6	0.16	0.22	14.31798
5	660	9	0.08	0.09	21.39662
5	1110	9	0.09	0.12	19.48847
5	1320	9	0.22	0.9	3.673403
10	660	9	0.19	0.28	12.42225
10	1110	9	0.24	0.13	14.28874
10	1320	9	0.06	0.18	17.44727
15	660	9	0.07	0.02	25.76754
15	1110	9	0.05	0.18	17.58205
15	1320	9	0.02	0.15	19.41195
5	660	12	0.54	0.56	5.191311
5	1110	12	0.71	0.69	3.097153
5	1320	12	0.78	0.6	3.149752
10	660	12	0.66	0.54	4.393761
10	1110	12	0.88	0.75	1.749311
10	1320	12	0.63	0.49	4.968906
15	660	12	0.48	0.32	7.788467
15	1110	12	0.54	0.95	2.239893
15	1320	12	0.72	0.56	3.809067

V. RESULTS AND DISCUSSIONS

After the conduction of all the 27 experiments, the following results were obtained for Over-Cut. Results include the Response Table according to Taguchi method and Graphs for S/N ratio and Mean values along with Contour Plot, 3D Scatter Plots and Surface Plots. The S/N ratio and the mean values were calculated by putting the values of Over-Cut in Minitab software.

Table IV: Response Table for Signal to Noise Ratios (Smaller is better)

LEVEL	D.O.C.	SPEED	DRILL DIAMETER
1	11.519	8.732	12.491
2	14.101	9.242	7.439
3	3.743	11.389	9.433
DELTA	10.357	2.657	5.052
RANK	1	3	2

Table V: Response Table for Means

LEVEL	D.O.C.	SPEED	DRILL DIAMETER
1	0.2339	0.3578	0.3056
2	0.1706	0.3700	0.3722
3	0.6333	0.3100	0.3600
DELTA	0.4628	0.0600	0.0667
RANK	1	3	2

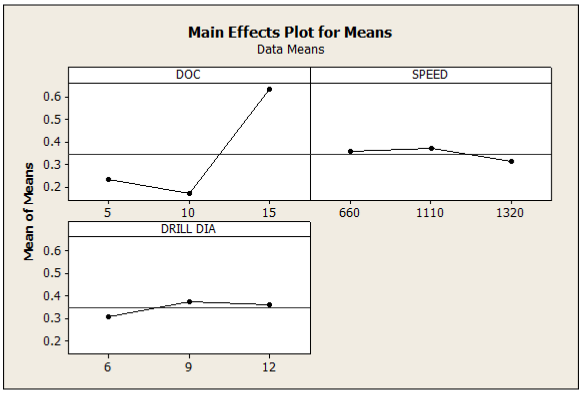


Figure 3: Effect of Mean on D.O.C., SPEED & Drill Diameter

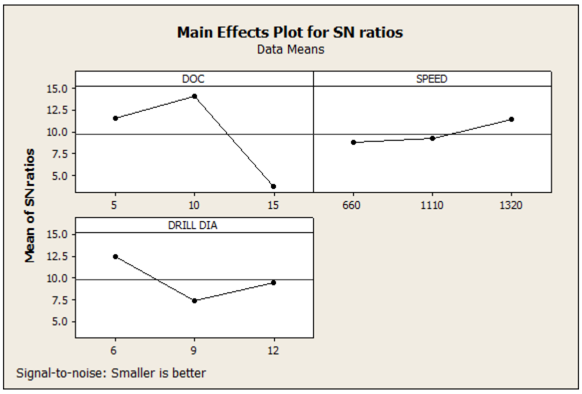
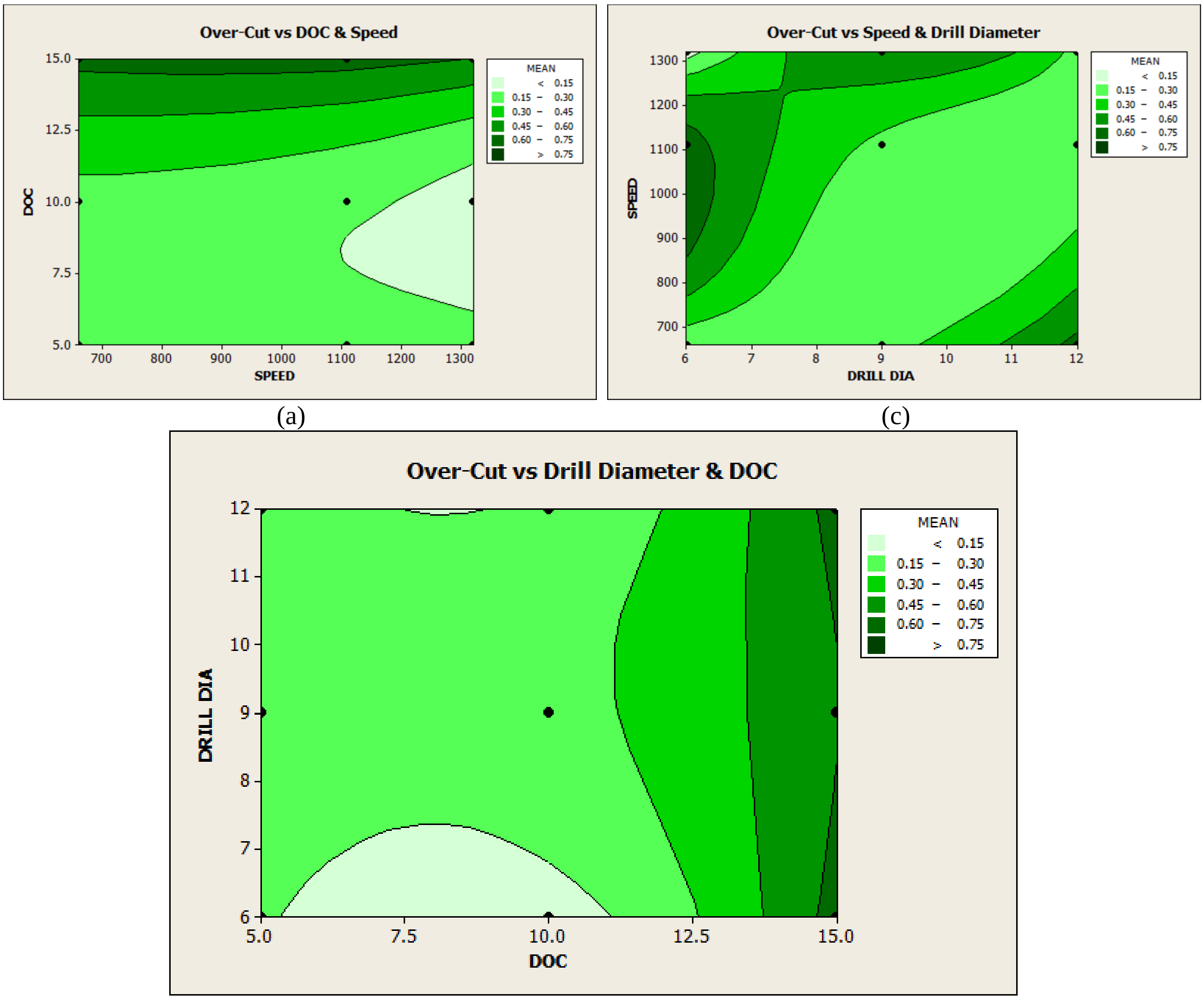


Figure 4: Effect of S/N Ratio on D.O.C., SPEED & Drill Diameter

Figure 3 & 4 depicts that, with the increase in the Depth of Cut Over-Cut decreases upto a level of 10 mm and then again starts increasing after 10mm, it also shows that with the increase in the speed of the drill there is a decrease in the Over-Cut but with a slight increase in between. The Figure 3& 4 also shows that drill diameter also affects the Over-Cut. All these ranges are also shown in the Figure 6,7,8, & 9.



(a) (c)

(b)

Figure 5: Contour Plots of Over Cut vs various Process Parameters

Figure 5 (a), (b) & (c) are the contour plot of Over-Cut vs Speed, D.O.C. and Drill Diameter respectively, and shows the range where one can achieve the minimum Over-Cut by selecting the shown range of parameters.

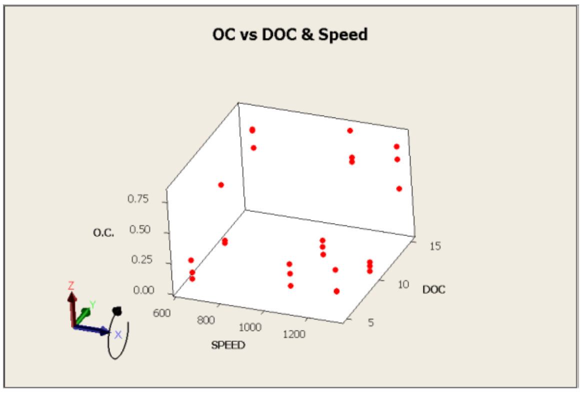


Figure 6:3D Scatter Plot of Over-Cut vs D.O.C. & Speed

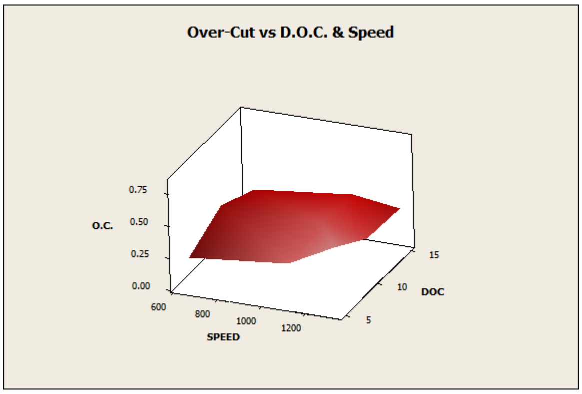


Figure 7: Surface Plot of Over-Cut vs D.O.C. & Speed

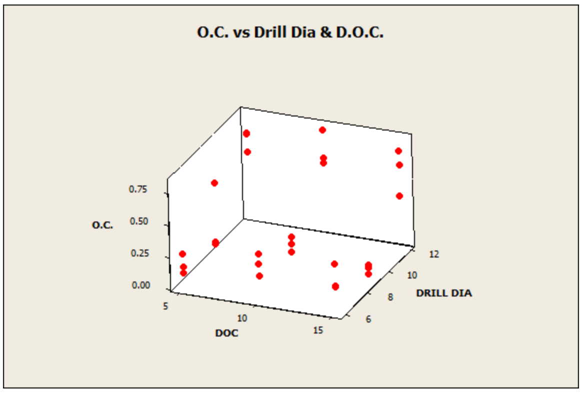


Figure 8:3D Scatter Plot of Over-Cut vs Drill Diameter & D.O.C.

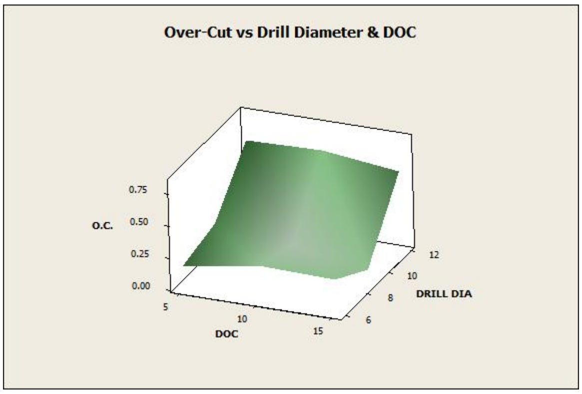


Figure 9: Surface Plot of Over-Cut vs Drill Diameter & D.O.C.

VI. CONCLUSION

The experiments were conducted on a vertical milling machine for the machining of Al/B_4Cp. The tool used for the drilling operation is a High Speed Steel. The response Over-Cut was studied. It was found that Speed, D.O.C. & Drill Diameter significantly affect the Over-Cut. Over-Cut is linearly proportional to the effect of Speed, D.O.C. & Drill Diameter. The lower value of Over-Cut is achieved with Speed = 1320 RPM, D.O.C. = 10 mm & Drill Diameter = 12 mm within the experimental domain. The research findings of the present study is based on Taguchi optimization, and can be used effectively in drilling of Al-B_4Cp, in order to obtain best drill hole.

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