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Performance Evaluation of PCD Insert 1600 Grade on Turning of Al 6061 Reinforced with 7.5% ZrB_2 Metal Matrix Composite

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Abstract. Aluminum matrix composite is the innovation of high performance material technology and it has superior interfacial integrity and thermodynamic stability between the matrix and reinforcement. Making the engineering components from this composite material require subsequent machining operations. This paper presents the detailed experimental investigation of the machining behaviour in turning of Al 6061-7.5% ZrB_2 Metal Matrix Composite (MMC) by using Poly Crystalline Diamond (PCD) insert of 1600 grade. The effect of ZrB_2 reinforcement particles on machinability behaviour need to be studied. It is concluded that the feed rate has great influence on surface roughness and depth of cut has great influence on cutting force. The confirmation experiment indicates that there is a good agreement between the estimated value and experimental Value. Tool wear study also carried out for time duration of 15 minutes.

1 Introduction

Metal matrix composites have attracted the attention of many researchers for its superior hardness, wear resistant, formability, corrosion resistance and elevated strength with minimal weight. Machinability issues of ex-situ metal matrix composites are highly focused in literatures [1-3]. Coarse, uninformed distribution and agglomeration of reinforcements present in the matrix are obstacles for machinability behavior of metal matrix composites[4]. In-situ composites have overcome these problems because of the formation of reinforcements by exothermal chemical reaction. The 6061 aluminum alloy has been used in automotive industry for the fabrication of parts which includes wheel, panels and vehicle structure [5] ZrB_2 is known to have many superior properties such as high melting temperature, hardness, corrosion resistance, oxidation resistance and electrical conductivity, being used for aircraft / rocket components working at special high temperature, cutting tools and cathode material for aluminum refinement furnace [6]. Production of in-situ metal matrix composite by flux assisted synthesis was widely reported in the literatures [7- 8,10].

Anandakrishnan and Mahamani [9, 15] investigated machinability of the in-situ Al6061-TiB2 composites. They reported the effect of speed, feed and depth of cut on flank wear, cutting force and surface roughness. It was observed that presence of small and fine TiB_2 particles have offered significant influence on machinability.

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Table 1. Chemical composition of Al-6061

Component	Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr	Al
Wt (%)	0.08	0.65	0.34	0.16	0.12	0.15	0.18	0.09	Balance

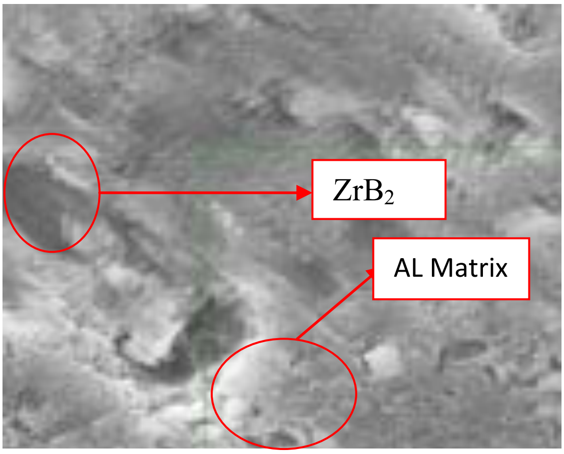

Figure 1. Microstructure of the workpiece (Al6061 – 7.5% ZrB_2)

In this direction an attempt has been made to investigate the turning parameters in machining of Al 6061 -7.5 % ZrB_2 metal matrix composite using PCD 1600 grade insert. Table -1 shows the Chemical composition of Al6061 .Figure- 1 shows the Microstructure of work piece

2 Experimental Procedure

Commercially fabricated cylindrical bars having 7.5 % of Z_rB_2 particles on matrix of Al 6061, using stir casting method of diameter 100 mm and 350 mm long are turned on self centered three jaw chuck, medium duty lathe of spindle power 2 kw. Fig -2 shows the experimental setup with tool dynamometer integral with it. Parameters such as surface roughness of machined component were measured by Mitutoyo surftest (Make-Japan –Model SJ-301) measuring instrument with the cutoff length 2.5 mm. Cutting force was measured by using Unitech lathe tool dynamometer with digital indicator. The cutting tool selected for machining Al-6061/ZrB_2 metal matrix composites was Poly Crystalline Diamond (PCD) insert of 1600 grade. The PCD inserts used were of ISO coding CNMA 120408 and tool holder of ISO coding PCLNR 2020M12.

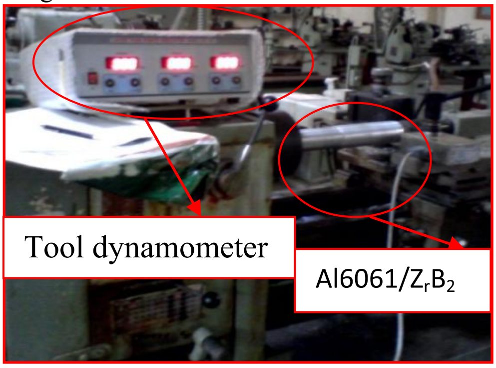

Figure 2. Experimental set up

Table 2. Machining parameter and their levels

Symbol	Machining parameter	Unit	Level 1	Level 2	Level 3
A	Cutting Speed	m/min	40	80	120
B	Feed	mm/rev	0.1	0.2	0.3
C	Depth of cut	mm	0.5	1.0	1.5

3 Results and Discussions

3.1 Surface Roughnss

Surface roughness is an important index of the machinability because the performance and service life of the machined component are often affected by the surface roughness. At high cutting speed, the machining condition follows the adiabatic system. With in the short interval of time the material passed away. As spindle speed increases, the strain rate will also increase, the matrix which difficult to deform, so that the particle will be crushed. Hence pits and cracks are reduced. As spindle speed decreases, the strain rate will also decrease, the matrix will be easy to deform so that particle will be pulled out [11, 12]. Hence pits and cracks formation on the machined surface is increased. Increase in feed rate also increased the chatter and produced incomplete machining at a faster transverse, which leads to higher surface roughness. Increasing in depth of cut, increased the deposition of build- up edge (BUE) over the machined surface. From fig 3and 4, it is understood that, cutting speed increases surface roughness decreases, at depth of cut 0.5 mm, and feed rate 0.3 mm/rev, surface roughness found to be 1.83 microns at cutting speed of 120 m/min. At the same feed and cutting speed at 1.5 mm depth of cut surface roughness found to be approximately two times greater than at depth of cut. It is clearly evident that depth of cut also having influence on the surface roughness [11] similar trend exists in the other depth of cut 1.5 mm.

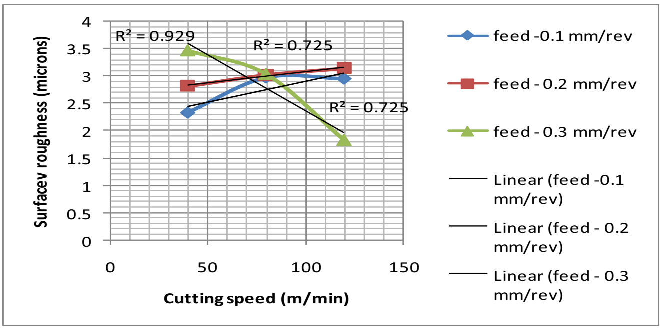

Figure 3. Cutting Speed versus Surface roughness Ra (Depth of cut 0.5 mm)

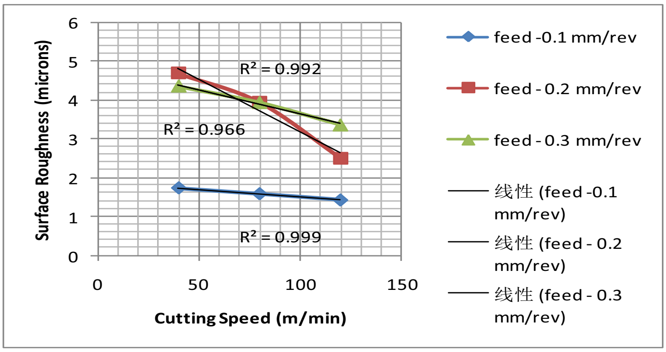

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Figure 4. Cutting Speed versus Surface roughness Ra (Depth of cut 1.5 mm)

3.2 Cutting Force

Figure 5 and 6 show the trend line for cutting speed versus main cutting force in Newton for depth of cut 0.5 mm and 1.5 mm. Cutting forces exerted by the cutting tool on the work piece during machining action to be identified in order to control the tool wear and occurrence of vibration, thus to improve tool-life [11].The increase in cutting speed will minimize the tool –chip contact length, which reduces the cutting force. Increasing the feed rate increases the cutting force drastically. When machining the work piece with 0.5 mm depth of cut at 0.3 mm/rev feed rate shows the cutting force increases with the increase in cutting speed up to 80 m/min after that it decreases with the increase in cutting speed. This is the fact that at higher cutting speed with more feed rate which softens the matrix metal and pulling the reinforcement particle from the matrix very easy which results in decreasing the cutting force [12, 14]

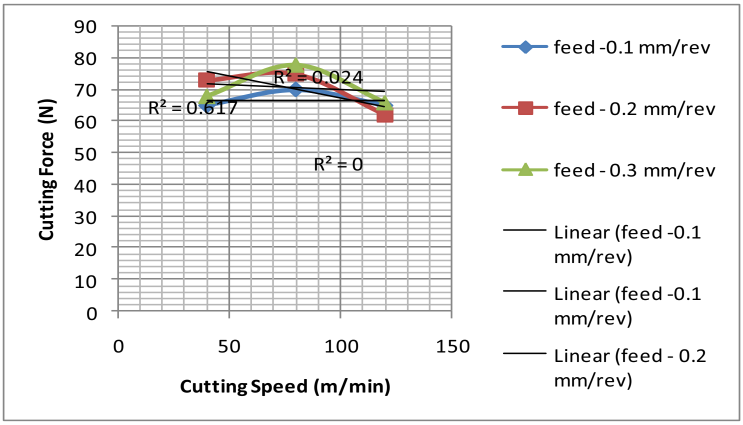


Figure 5. Cutting Speed versus Cutting force (Depth of cut 0.5 mm)

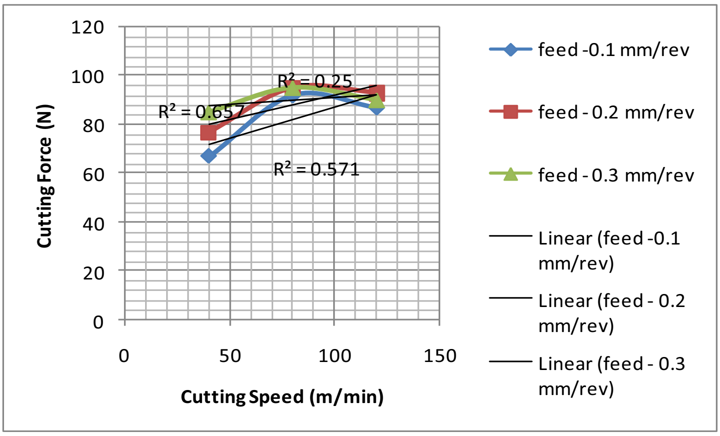


Figure 6. Cutting Speed versus Cutting force (Depth of cut 1.5 mm)

3.3 Analysis of Variance

Analysis of Variance (ANOVA) is a method of apportioning variability of an output to various inputs. Table 3 and 4 show the results of ANOVA analysis for surface roughness and cutting force respectively. This analysis was carried out at a 95% confidence level. The last column of the tables shows the percentage of contribution of each factor on the total variation of the output. This was carried out to identify the factors which most influence the machinability.

Table 3. Analysis of variance for Surface roughness

Source	DF	Seq SS	Adj SS	Adj MS	F_{test}	F_{table} at 95%	% cont.
A	2	1.1293	1.1293	0.5647	1.38	4.459	6.75
B	2	5.2221	5.2221	2.611	6.36	4.459	31.50
C	2	1.0456	1.0456	0.5228	1.27	4.459	6.56
A*B	4	2.0799	2.0799	0.52	1.27	3.8378	12.60
A*C	4	0.6793	0.6793	0.1698	0.41	3.8378	4.21
B*C	4	3.0653	3.0653	0.7663	1.87	3.8378	18.40
Error	8	3.2842	3.2842	0.4105			19.88
Total	26	16.5057					100.00

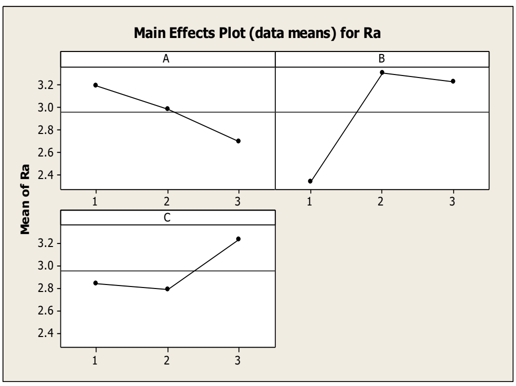


Figure 7. main effects plot for surface roughness

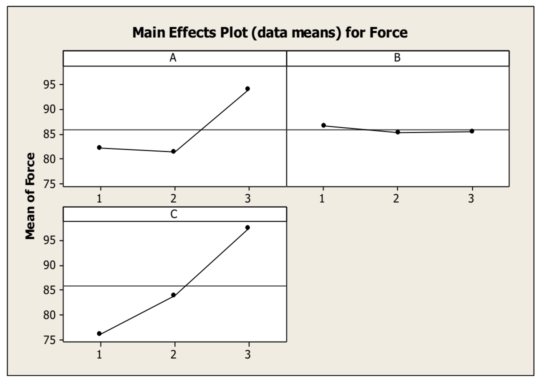


Figure 8. main effects plot for Cutting force

From .Table 3, it is clear that the surface roughness is mainly influenced by feed rate 31.50% , cutting speed has 6.75%, Interaction effect of cutting speed and feed has also influencing the surface finish by 12.60%. Feed and depth of cut also having some effect on the surface finish (18.40%). From fig -7, it is clearly understood that, to get good surface finish, the optimum parameters are $A_3B_1C_1$

Table 4. Analysis of Variance for Cutting force

Source	DF	Seq SS	Adj SS	Adj MS	F_{test}	F_{table} at 95%	% cont.
A	2	907.19	907.19	453.59	10.22	4.459	16.35
B	2	9.85	9.85	4.93	0.11	4.459	0.18
C	2	2098.07	2098.07	1049.04	23.64	4.459	37.80
A*B	4	1479.7	1479.7	369.93	8.34	3.8378	26.66
A*C	4	62.81	62.81	15.7	0.35	3.8378	1.13
B*C	4	637.48	637.48	159.37	3.59	3.8378	11.49
Error	8	354.96	354.96	44.37			6.40
Total	26	5550.07					100.00

From .Table 4, it is clear that the cutting force is mainly influenced by depth of cut, its contribution is 37.80%, followed by interaction effect of cutting speed and feed which is having 26.66% and cutting speed having 16.35%, other factors also having less influence on cutting force. From fig – 8, it is understood that, to reduce the cutting force, best machining parameters are $A_2B_3C_1$.

3.4 Confirmation Experiment

Once the optimal level of machining parameters is selected the final step is to predict and verify the improvement of the performance characteristics using the optimal level of the machining parameters. Table 5 shows the results of the confirmation experiment

$$Percentage\,of\,error = \left(\frac{\exp erimental\,value - prediction\,value}{\exp erimental\,value} \right) X100 \tag{1}$$

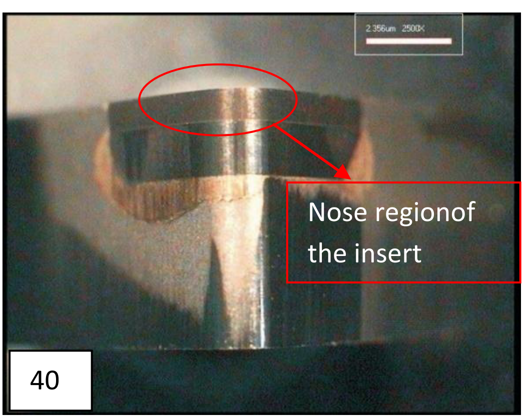
Table 5. Results of confirmation experiment

	Optimal machining parameters		
	Prediction	Experiment	% of error
Setting level	$A_1B_1C_1$	$A_1B_1C_1$	
Suraface roughness (Ra) in µm	2.18	2.54	14.17
Cutting Force in (N)	59	72	18.05

Using the optimal machining parameters, Surface roughness Ra is found as 2.54 µm in experimentation and 2.18 µm in prediction, similarly the Cutting force is found as 72 N in experimentation and 59 N in prediction. It is clearly shown that machining performance of Al6061 /ZrB_2 are greatly improved through this study. From this analysis, it is found that the percentage of error for surface roughness is found (using the equation -1) to be 14.17 %, where as the percentage of error for cutting force is found to be 18.05 %.

3.5 Tool Wear

By setting the optimum parameters $A_1B_1C_1$ as a constant parameter and tool wear study was carried out for time duration of 15 minutes and the tool flank wear study was carried out. Tool flank wear was caused by abrasive nature of the hard particles present in the work piece. At low cutting speed worn flank encourages the adhesion of work piece material on the tool insert and formed Built-Up-Edge [1-2,9,12]. Fig-9 shows the Scanning Electron Microscope (SEM) image of fresh insert. Fig- 10 shows SEM image of PCD 1600 grade insert after machining the work piece for 30 minute duration. It is proved that hard ZrB2 particles which have higher hardness than diamond abrading the cutting tool [1, 9]. It is observed that the tool life of PCD 1600 grade is performing well in the chosen cutting condition



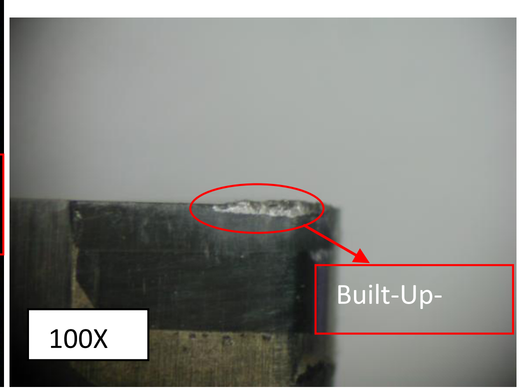


Figure 9. SEM image of fresh PCD 1600 grade Fig-10 SEM image of insert after 15 minute duration

4 Conclusion

a. The use of orthogonal array to optimize the Al-6061/7.5 % ZrB2 Metal Matrix Composites machining process has been reported in this paper.

b. Good surface finish is obtained at higher cutting speeds. Surface roughness obtained at feed rate 0.3 mm/rev at depth of cut 1.5 is nearly doubled the value of surface roughness obtained at depth of cut 0.5 mm.
c. Feed rate has strong influence on the surface finish. Depth of cut having less influence on surface roughness.
d. Percentage of error in predicted and experimental value was found to be lesser than 20 %.
e. Main cause of the tool wear is caused by abrasion of hard particles. At lower cutting speed formation of BUE is observed on the flank face of the insert.

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