EXPERIMENTAL STUDY OF MACHINABILITY FACTORS IN MACHINING OF AL6061-B_4C COMPOSITES: DOE APPROACH

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Abstract: In the present work the surface generation is studied during dry turning of Al6061- B_4C metal-matrix composites, and was investigated based on analytical approaches which include DoE analysis. Al6061 is reinforced with B_4C MMC's were produced using stir casting method. The prepared MMC's were characterized under SEM, EDAX and XRD tests. The tests were confirmed the B_4C were fairly distributed in Al6061 alloy. Poly Crystalline Diamond (PCD) brazed tool is used for machining of MMC's. Analytical approach was performed to explore the inter-relation between the process parameters, and its effect on surface roughness, cutting forces, tool tip temperature and built-up edge. The effects of machining parameters like speed, feed, depth of cut is varied to level-3 with a confidence level of 95%, and responses of machinability cutting forces were measured using lathe tool dynamometer, surface roughness using surface tester and temperature measured using heat gun. After the machining the tool tip is adhered with built up edge which is measured in INSIZE Microscope Analyzer.

Key words: Turning, machinability, DOE, metal matrix composites, MMC's, polycrystalline diamond, PCD.

1. INTRODUCTION

Composite material given different direction to explore new material, which can fulfil all needs. They can be used in varies field from automobile to aeronautical field. Composite material is used to fabricate chasse of automobile and outer most body of space shuttle which can sustain a large temperature variation due to its low temperature coefficient property. Composite consist of two main constituents i.e., matrix and reinforcement. Matrix is a monolithic material into which the reinforcement is embedded. The new material may be preferred because they are stronger, lighter and have a low coefficient of thermal expansion, good wear resistance etc., when compared to other materials, [1]. In most of the application metal matrix composites (MMC) are used due its low cost and ease of fabrication. MMC are composed of an element or an alloy matrix in which a second phase is embedded and distributed to achieve some property improvement [4]. They have outstanding benefits due to the combined metallic and non-metallic properties, there by yielding improved physical and chemical properties. Among the various types of MMC's, particulate reinforced composites are the most versatile and economic one. MMC are increasingly found in the mobile industry, these materials use a metal such as Aluminium as a matrix, and reinforce with fibres, [1].

Al6061 alloy reinforced with B_4C MMC have attracted much interest due to their increased mechanical properties and wear properties studied by Kremer et al., [2]. Machinability of Al6061 is excellent, good mechanical properties, excellent corrosion properties and weldability properties according to Vijaykumar et al., [3], S. Kennan et al., [4], studied the effect of cutting parameters and particulate properties (volume fraction and average particulate size) on the micro hardness variations of the aluminum matrix beneath the machined surface. They reported micro hardness is generally found to be higher near machined surface layer this is remarkable result of work hardening of the matrix material under the surface layer.

Al6061 alloy reinforced with boron carbide which resulted in increase in ultimate tensile strength by 17%, machinability studied have been done using PCD tools. The Material properties were tailored in MMC's by addition of hard reinforcement's studied, [5-15].

K. Palanikumar and R. Karthikeyan, [16], optimized the machinability parameters and results were analyzed using Taguchi and Response surface methods. The effect of machining parameters on the surface roughness is evaluated with the help of Taguchi method. The % volume fraction of SiC and feed is dominant parameters for surface roughness. Most of the studies on Al-MMC's machining shows

that minimizing the surface roughness is very difficult and is to be controlled et al., [17-23].
The present work focused on the influences of machining parameters on the surface roughness is evaluated. Influence of the cutting forces on surfaces is investigated. Optimum machining conditions for maximizing the metal removal rate and minimizing the surface roughness using DoE analysis methodology.

2. EXPERIMENTAL INVESTIGATION

In the present work Al6061 alloy with the composition quoted in Table 1 checked using Atomic Absorption Spectroscopy (VARIAN) and mechanical properties are detailed in Table 2 is used as matrix material, [3]. B_4C particulate of equivalent size 37µm is used as reinforcement material and mechanical properties are detailed in Table 2. Al6061 MMC's were prepared using the metal stir casting with weight percentage of 9 % B_4C shown Figure 1. While stirring to increase the wettability small quantities of Magnesium (0.2% to 0.5%) and solid hexachloroethane (C_2Cl_6) to release all the absorbed gases were added to the melt. The stirring of the melt was done with the help of a Zirconium coated steel rod to generate parabolic vortex. A spindle speed of 220rpm and stirring time 5-6 min were adopted. Casting is done for the specimen size of diameter 35mm and length of 150mm using permanent mould die. Casted material is further studied in Scanning Electron Microscopy and EDAX Figure 2(a-e).

Table 1. Chemical composition of Al6061 alloy

Elements	Mg	Si	Fe	Cu	Mn	Cr	Zn	Ti	Al
% by Weight	0.95	0.54	0.22	0.17	0.13	0.09	0.08	0.01	Bal

The experiments were planned using Taguchi's orthogonal array in the Design of Experiments (DoE), which help in deciding the number of experiments to be carried out. The machining parameters considered for the present investigation is speed, feed and depth of cut. The trails are conducted according to 3-level L_{27} orthogonal array.
The experiments were carried out in BANKA self-centered 3-Jaw lathe machine (LTM 20, 3kW, 4HP). The job length of 150mm and diameter 35mm is machined using Brazed PCD tool size of 10µm with the following geometry: rake angle - 0°, clearance angle - 7°, cutting edge angle - 85° and nose-0.8 mm. All machining tests are carried out without coolant. The selected machining parameters are given in Table 3.
The fabricated MMC's were machined using horizontal lathe machine. Experiments were done based on Taguchi's orthogonal array with input factors speed, feed and depth of cut.
Level-3 full factorial is prepared using DoE MINITAB software. Cutting forces were tabulated using three-axis piezo-electric dynamometer with a PC-based data acquisition system fabricated by National Instruments Lab, from which F_x- axial force, F_y- cutting Force and F_z- radial forces were measured. Surface Roughness of machined surface is measured using Mitutoyo Surface Roughness Tester SJ201. Tool tip Temperature is measured using Laser Temperature gun. Built up Edge, machined Surface is studied using INSIZE Digital Microscope Analyzer.

Table 2. Mechanical properties of Al6061 alloy and B_4C Particulates

Mechanical Properties	Al6061 alloy	B_4C Particulates
Density (g/cc)	2.7	2.50
Elastic Modulus (GPa)	70-80	460
Poisson's Ratio	0.33	0.17
Rockwell Hardness (Kg/mm^2)	95-97	3200
Thermal Conductivity (W/mK) at 25°C	173	90
Melting temperature (°C)	580	2445

Table 3. Machining parameters of Al6061- 9%B_4C

Factors: 3	Factor Levels: 3		Levels		
Runs: 27	Replicates: 81				
Factor	Name	Unit	I	II	III
A	Speed	m/min	29	43	65
B	Feed	mm/rev	0.111	0.222	0.333
C	Depth of cut	mm	0.50	0.75	1.00

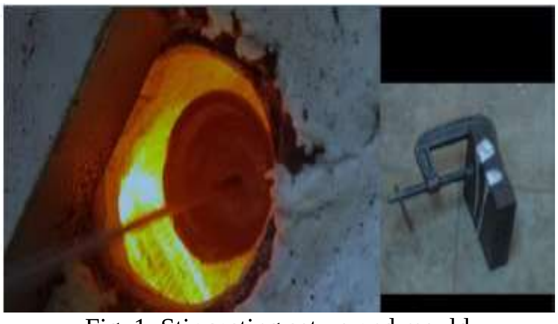


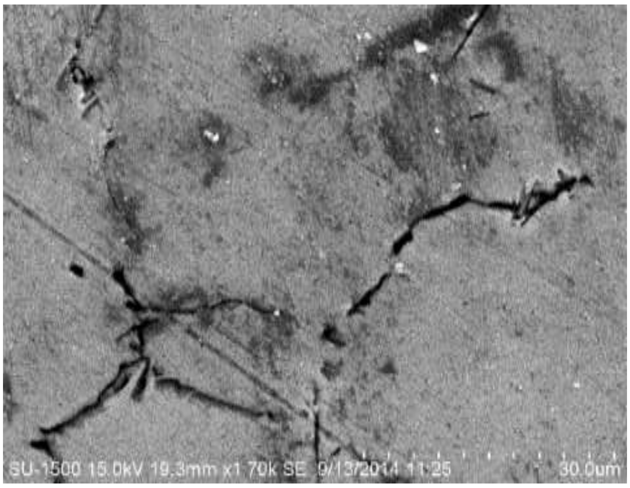
Fig. 1. Stir casting set up and mould

3. RESULTS AND DISCUSSION

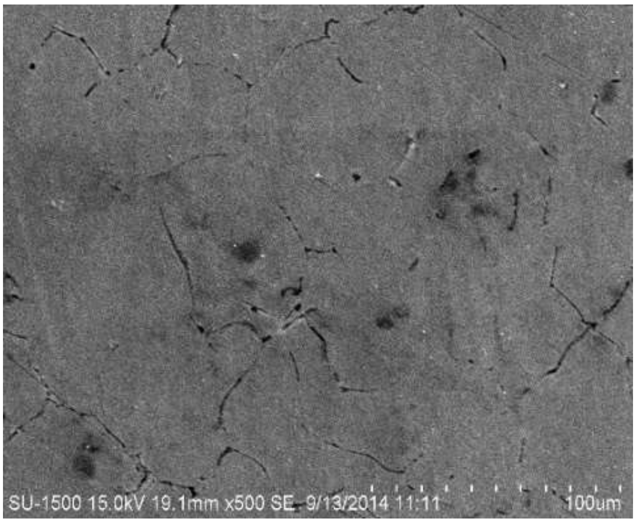
3.1 Microstructural analysis

Analysis of microstructure will gives uniform distribution of B_4C particle in Al6061. Uniform distribution will improve the mechanical and machining characteristics of composite.

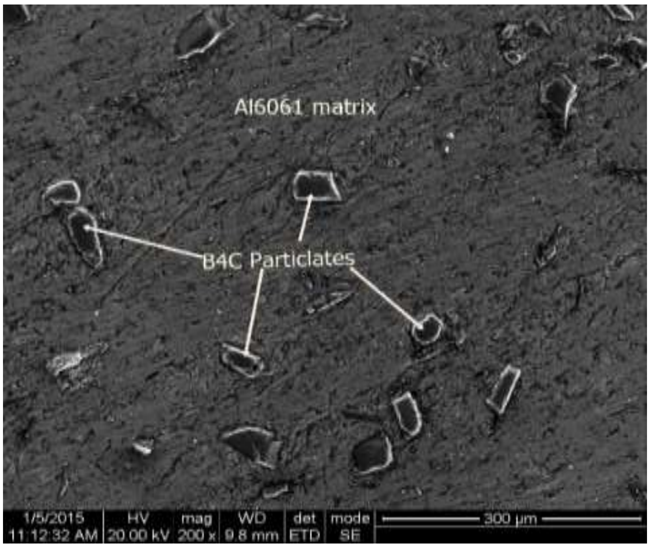
The SEM microphotograph images of Al6061 as cast and Al6061 reinforced with 9% B_4C presented in Figure 2 (a-d). EDX spectrum taken on one of the B_4C particulate present in Al6061 matrix composite prepared with metal stir casting using two stage method. It is clear that two step additions have resulted in fairly homogeneous distribution of B_4C reinforcing particulates in the Al6061 alloy. The presence of B_4C particulates was observed using EDX analysis which was carried out on one of the B_4C particle present in Al6061 matrix and reported in Figure 3.



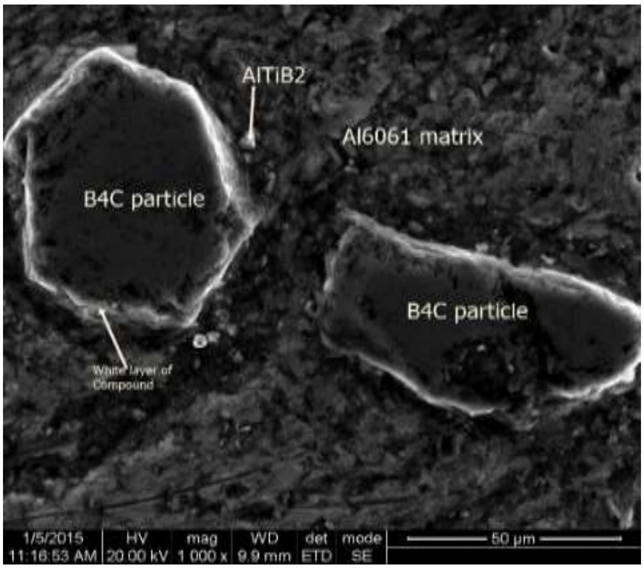
(a)



(b)



(c)



(d)

Fig. 2. The SEM micrograph of Al6061 alloy (a-b), Al6061 alloy reinforced with 9% B4C Particulates(c-d)

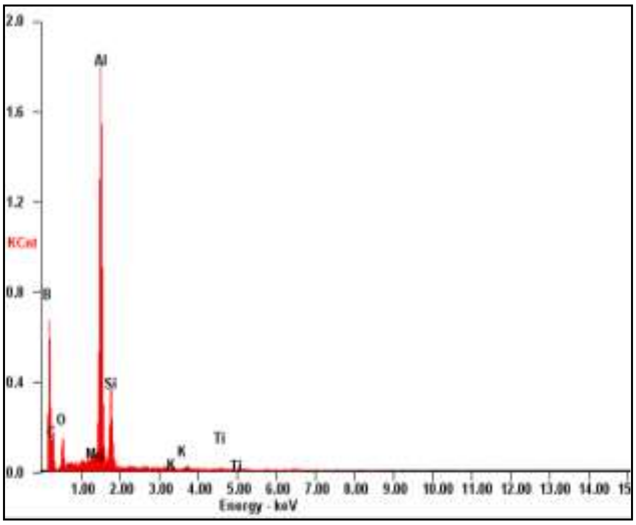


Fig. 3. The microanalysis EDAX result of Al6061+9%B4C

3.2. Machinability Studies

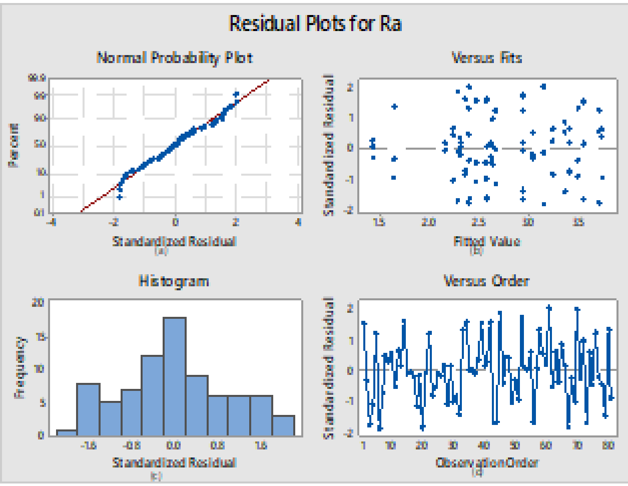
a) Influence of machinability parameters of surface roughness (R_a)

The residual plots Figure 4(a) for surface roughness give the additional information about the model developed. The real or chance effects of the residuals are analyzed using normal probability plot Normal plot is a graphical technique based on "Central limit theorem". In the plot Figure 4(b) the data are spread approximately in a straight line, which shows that our experimental results meeting normality assumption. In versus fit graph most of the points are close to center line hence the graph indicating constant variance. Histogram graph indicate the Bird eye view of result distribution. Versus order graph shows there is no trend in the experimental data hence our experiments meeting the randomization.

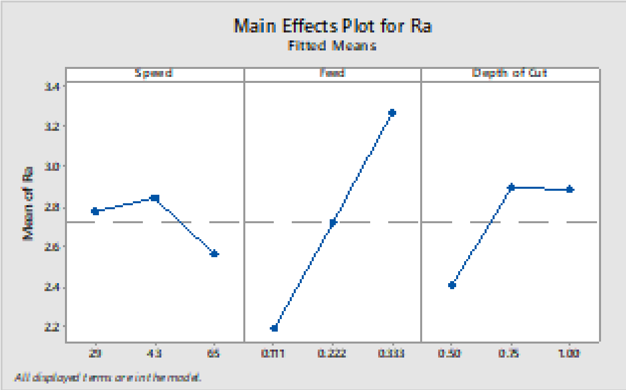
Surface roughness at 9wt % of B_4C_p is high when compared to all other weight percentage of composites. Main effect plotted in Figure 4(b) is evident that least surface roughness is to be with minimum feed (0.111mm/rev) and minimum depth of cut (0.5mm). At high speed, the area of contact between tool-work piece is fewer as a result least surface roughness is attained, which is due to high hardness of the material. Increased feed rate resulted in rough surface which is due to more amount of work piece will be in contact with tool surface. More depth of cut lead to the rough surface, with increasing depth of cut greater amount of chips with larger cross sectional area formed. DoE analysis resulted in accepting the null hypothesis for surface roughness.

b) Influence of machinability parameters of Cutting Force (Fy)

Al6061 is reinforced with 9wt% of B_4C particulates resulted in the increase in ultimate tensile strength and % of elongation is reduced from 13 to 5% published in our previous work.



(a)



(b)

Fig. 4. (a-b) The DoE Result influence of machining parameters on surface roughness

Main effect plotted in Figure 5 is evident that least cutting force is with speed 43m/min, feed 0.111mm/rev and depth of cut 0.75mm. Least speed leads to rise in cutting forces because of more tangential forces and contact between tool tip-work piece. The presence of B_4C particulate plays a vital role in cutting force analysis, as the force required to remove the B_4C particulate from the surface is sufficiently high no of particulates in unit area is raised at 9 wt. %. More feed rate lead to increase in cutting force may be attributed due to higher chip tool contact length cutting forces are more at less depth of cut because metal removal rate is low. DoE analysis provided firm evidence to reject the null hypothesis for cutting forces resulted with P=0.2% for speed, P=0.8% for feed and P=0.2% for depth of cut, hence speed, feed and depth of cut play a vital role in influencing the machinability of Al6061+9%B_4C_p.

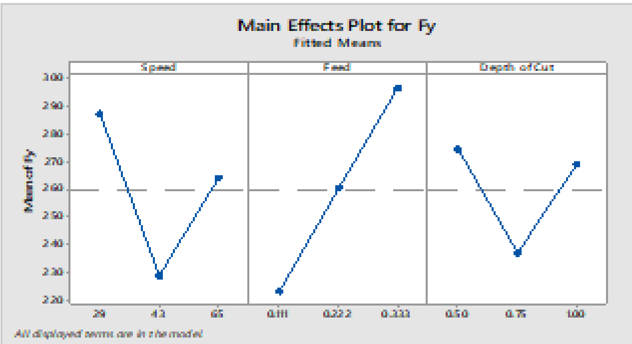


Fig. 5. The DoE Result of influence of machining parameters on Cutting Force (FY)

c) Influence of machinability parameters of Tool Tip Temperature (T)

Main effect plotted in Figure 6 indicated that least tool tip temperature is to be with the speed 43m/min, feed 0.111mm/rev and depth of cut 0.5mm. Increased speed resulted in increase in the tool tip temperature which is due to higher tangential force between tool-work pieces. Higher feed rate leads to enhance the temperature, due to the higher frictional force acting at the tool and work piece interface.

More depth of cut resulted in increasing the tool tip temperature which is due to higher metal removal rate occurring at higher depth of cut. DoE analysis ensued to reject the null hypothesis for tool tip temperature. Speed, feed and depth of cut is playing a vital role in machining of composites as we have strong evidence to reject the null hypothesis P=0.6% for speed, P=4.7% for Feed and P=2.6% for depth of cut.

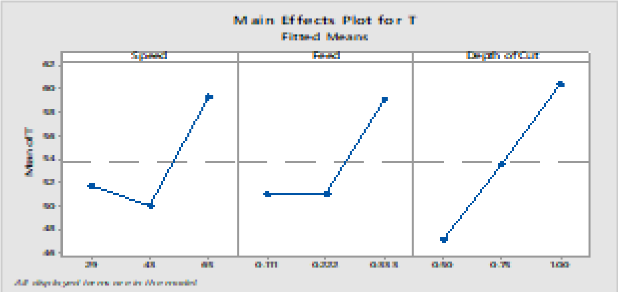


Fig. 6. The DoE Result of influence of machining parameters on Tool Tip Temp (T)

d) Influence of machinability parameters of Built up Edge

Built-up edge formed at the tool tip surface during the machining of 9wt.% MMC's is less compared to other weight percentages. Main effect plotted in Figure 7 is evident that least cutting force is to be with speed 65m/min, Feed 0.333mm/rev and depth of cut 1.0mm. High speed lead to increased metal removal rate (MRR) and cutting forces. Feed has very least impact on BUE in the machining of Al6061 reinforced with 9wt.% of B_4C_p. Speed and depth of cut is playing a vital role in machining of composites as we have strong evidence to reject the null hypothesis P=0% & 0% and all these "P-value" of variables which are less than significant level (5%).

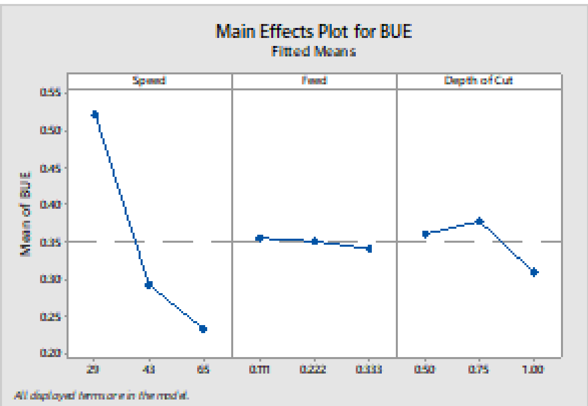
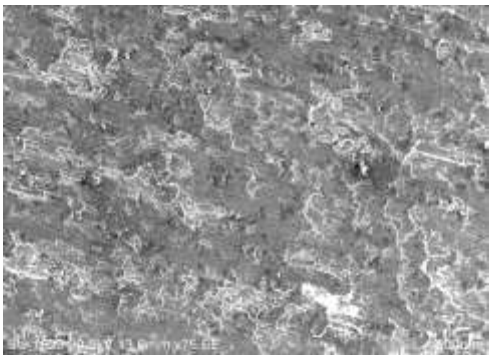


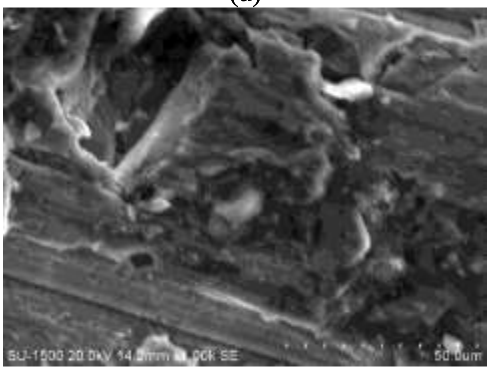
Fig. 7. DoE Result of influence of machining parameters on Built-up Edge (BUE)

3.3 Machined surface

Machined surface quality is measured using the surface roughness tester. Optimum machined surface obtained for as cast Al6061 alloy is R_a=1.2µm surface roughness of Al6061 reinforced with 9Wt% of B_4C is R_a=1.64µm, chips formed are short and dis-continuous and sharp cornered due to the presence of reinforcement. Optimum machined surface is cross sectioned, studied under SEM, surface morphology is indicated in Figure 8 which clearly reveals that B_4C particulate are holding the base metal which is the reason for increase in UTS and cutting forces and some region B_4C particulate are removed from the surface, cavities are created which are indicated in Figure 8.



(a)



(b)

Fig. 8. The SEM morphology of machined surface of MMC's

4. CONCLUSIONS

The surface roughness in the machining process has been investigated according to the orthogonal array of experiments. Based on experimental and analytical analysis, the following conclusions are made.

MMC's are successfully fabricated using Al6061 as Matrix material and 9 weight% of B_4C as reinforcement. The influence of machining parameters on Surface Roughness, Cutting Force, Tool Tip Temperature and Built-up edge is evaluated using DoE analysis method and dominant parameters are tabulated below. Dominant parameters acting on surface roughness is speed, feed and depth of cut, for Temperature and Built-up Edge is speed and depth of cut. Optimal machining conditions for minimizing the surface roughness are determined. Speed 63m/min, Feed 0.111mm/rev and Depth of Cut 0.5mm. Experiments for Proof check of the optimal machining conditions is done and found surface roughness Ra 1.64µm satisfactory in comparison with Al6061.The results reveal that minimization of surface roughness and cutting forces could be arrived prominently for MMC's turning operations.

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