Analysis on Machinability of Aluminium Metal Matrix Composites Reinforced With B4c And Graphite Particles Under Specified Machining Conditions – A Critical Study on the Effect Of Surface Roughness And Swarf Formation

Engineering

KEYWORDS : Boron carbide , Graphite, Metal Matrix Composite (MMCs), surface roughness, swarf formation, Cubic Boron Carbide,

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ABSTRACT

Aim of this work is to do a viable machinability study by experimental investigations on surface roughness and swarf formation in turning of AA6061 aluminium alloy (100%), AA6061-B4C (90% and 10%) and AA6061-B4C-Gr (87%-10% and 3%) hybrid composites. Experiments were conducted with different cutting conditions using Carbide , CBN (Cubic Boron Nitride) and PCD (Poly Crystalline Diamond) tools. Surface roughness are more for carbide tools in comparison with PCD tools which are minimum. PCD tools perform better than CBN and carbide tools. This is due to the daubing effect and dismissal of softer and amorphous Graphite particles on the surface of the composite specimen, which produces pits on the machined and hence reduces the surface finish level. On the other hand graphite particulated composite produces discontinuous chips that led to the smooth machining. PCD tools are better than carbide and coated carbide tools in the reduction of surface roughness. Machining parameters like cutting speed, feed rate and spindle speed and cutting tool also influencing the surface finish level. Influence of these parameters in turning of AA6061 aluminium alloy, AA6061-B4C and AA6061-B4C-Gr hybrid composites are discussed with the experiment results here.

INTRODUCTION

Metal Matrix Composites are increasingly used in Aerospace, automotive industries, heat sinks, infrastructures development and construction industries, energy production and power distribution lines, pressure vessels etc. because of their advantages over conventional alloys like high specific strength, improved surface finish etc. Inspite of these positives in MMCs and even near net shape formed castings, we need to address on machinability yet. Although these composites have excellent performance characteristics, their poor machining efficiencies lead to severe cutting tool wear and difficulty in obtaining fine surface quality. Same was explained in review by Basavarajappa et al.,[1]. Pramanik et al.,[2] , Basavarajappa [3] and Chou and Liu [4] were reported that the main concern when machining of particulate metal matrix composite is extreme tool wear, poor surface finish and uncomfortable chip formation. The cutting parameters influence the machining characteristics of MMCs. Higher cutting speeds are not advantageous in all cases except when PCD tools are used.[5,6]. Gaitonde et al.,[7] identified that medium cutting speed ranges from 200 to 450 m/min.are recommended for carbide and coated carbide tools for better surface finish and reduced tool wear. Higher cutting speeds are not beneficial in all cases except when PCD and CBN tools are used [7,8]. Davim [9] identified that the medium cutting speed ranges from 200 to 450 m/min. are recommended for carbide and coated carbide tools for better surface finish and reduced tool wear. Kannan and Kishawy [10] studied the tool wear, surface finish and swarf formation under both dry and wet machining condition of A356 / 20% of SiCp at particle size of 12 microns and Al7075/10% of alumina of particle size of 15 microns. Sahin et al.,[11] reported that while turning Al_2O_3 particle reinforced composites the surface roughness increases with increase in particle volume fraction. Reduction in machining forces, surface roughness and chip formation /thickness after increasing the graphite content to 6% in aluminium / graphite composites have been reported by Gibson et al., [12]. CJ Rao et al.,[13] said it is the feed rate which has significant influence both on cutting force as well as surface roughness. The machinability during turning of Al/Si/Gr composites was studied by Brown and Surappa [14] and they were under the opinion that the reduction in machining forces with graphite reinforcement content is due to decrease in shear flow stress rather than to lower chip-rake-face friction. Basavarajappa et al., [15] studied the influence of various parameters on surface finish and subsurface deformation in drilling of Al/SiCp and Al/SiCp-Gr composites and they reported that the surface roughness of hybrid composite Al2211/15SiCp-3Gr is high when compared to Al2219/15SiCp. The reinforcing particles both SiCp and Graphite act as chip breakers in turning of Metal Matrix Composites [16]. This paper describes an experimental machinability study of MMCs. Aim of this research work is to arrive at an optimum cutting conditions for achieving better machinability aspects like surface finish and comfortable swarf formation from AA6061-B_4C-Gr and AA6061-B_4C hybrid composites hence we gain mileage in utilizing the fullest benefit.

MATERIALS AND EXPERIMENTAL PROCEDURE:

Material: Aluminium is the most abundant metallic element which is easily and most economically available on the earth. Aluminium matrix that is presently chosen for the present investigation being AA6061 alloy system which is designated by American Aluminum Association. Chemical composition of aluminium alloy AA6061 matrix is presented in table 1. The B_4C particle which is used to fabricate the composite being 20 – 50 microns size and that of Graphite particles is 20 microns. The composites namely AA6061-B_4C and AA6061-B_4C-Gr are fabricated using Stir casting technique.

TABLE 1: CHEMICAL COMPOSITION (WT %) OF AA6061 MATRIX

Si	Fe	Cu	Mn	Mg	Ti	Ni	Al
0.64	0.14	0.26	0.30	0.90	0.025	0.001	Balance

B.Experimental setup: Turning operations were conducted on composite specimen to measure the surface finish and to observe the swarf formation pattern. Specimens were fabricated which are AA6061 matrix, AA6061-B_4C (AA6061 – 90% and B_4C-10%) and AA6061-B_4C-Gr (AA6061 – 87% , B_4C-10% and Gr-3%) composites. Samples are having a size of Dia. 20 x 200 mm long. The tooling system and cutting parameters adopted being shown in Table 2. Machining tests were performed for 40 mm length of continuous turning under dry cutting conditions on a conventional lathe. The cutting forces were observed during cutting were measured using "Lathe tool force measuring system dynamometer" separately. Surface finish are checked by a " Surtest SJ210 – MITUTOYO" surface finish tester at 4 locations around the turned specimen surface and the average surface roughness value in terms of Ra had been taken for the analysis purpose.

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TABLE 2 : TOOLING SYSTEM AND CUTTING PARARMETERS EMPLOYED

Cutting Tool type	Cutting speed in m/min	Feed in mm/rev	Depth of cut in mm	Recommended Spindle speed in RPM	Machine Tool type
Carbide	40	0.05	0.2	640	Belt driven conventional lathe
	60	0.8	0.4	960	Gear driven conventional lathe
	80	1.0	0.6	1300	CNC lathe
Cubic Boron Nitride (CBN)	120	0.05	0.2	1920	Belt driven conventional lathe
	140	0.8	0.4	2240	Gear driven conventional lathe
	160	1.0	0.6	2560	CNC lathe
Poly Crystalline Diamond (PCD)	200	0.05	0.2	3200	Belt driven conventional lathe
	240	0.8	0.4	3840	Gear driven conventional lathe
	280	1.0	0.6	4460	CNC lathe

RESULTS AND DISCUSSIONS

Effect on turning (machining parameters) on surface finish and chip formation were analysed and discussed in the following sections for AA6061 matrix sample , AA6061-B_4C and AA6061-B_4C-Gr composites samples.

Effect of surface finish values (Ra) at fixed feed rate and depth of cut parameters :

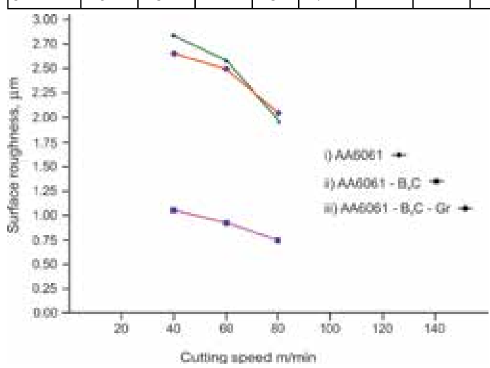
The turning operation was done on 3 different material samples like AA6061 matrix , AA6061-B_4C and AA6061-B_4C-Gr composites for a length of 40 mm cut. Turning done using 3 different cutting speeds viz. 40 m/min , 60 m/min and 80 m/min using carbide tool in conventional lathe of belt driven where we need spindle speed in the range of 600 to 1400 rpm to work on these cutting speed as per calculation. Then turning done in other conventional lathe of gear driven where we need spindle speed in the range of 1800 to 2600 rpm using CBN cutting tool applying 120 m/min, 140 m/min and 160 m/min cutting speed. Then turning done in a CNC lathe using PCD tool applying 200 m/min, 240 m/min and 280 m/min cutting speed. Since for these higher cutting speed, proportionate spindle speed will be in the range of 3200, 3800 and 4500 rpm hence CNC lathe had been chosen for these trials. Surface roughness was measured using **" Surtest SJ210 – MITUTOYO"** surface finish tester. One such testing is shown in fig.1

Fig.1 : Surface roughness inspection on turned sample

Figure 2 depicts different values of surface roughness obtained during turning operation under pre determined machining parameters of 0.08 mm/rev. feed rate and 0.2 mm depth of cut with Carbide, CBN (Cubic Boron Nitride) and PCD (Poly Crystalline Diamond) tools. It was observed that the surface roughness values of Ra is high at lower cutting speeds and low at higher cutting speeds. Same is represented in the Table 3. This is due to the burnishing effect produced by the rubbing action of micro particles of B_4C reinforcements trapped between the tool flank face and the surface of the work sample. Similar effect was observed by many other researchers [5,10,17]. At lower cutting speed surface roughness Ra is higher. This may be attributed by the fact that the inability of the cutting tool to cut these particles. Therefore a higher cutting speed is required to achieve better surface finish [11]. Whereas in case of AA6061-B_4C-Gr composite, surface roughness values are less for CBN tools when compared with carbide tools and are very minimum in the case of PCD tools.

TABLE 3: SURFACE ROUGHNESS VALUES FOR VARYING CUTTING SPEED

Surface roughness value ' Ra' in µm									
Sample #	Carbide tool			CBN tool			PCD tool		
	40 m/min.	60 m/min.	80 m/min.	120 m/min.	140 m/min.	160 m/min.	200 m/min.	240 m/min.	280 m/min.
1	2.8	2.6	1.9	2.6	2.1	1.8	2.3	1.9	1.6
2	1.1	0.9	0.75	1.0	0.8	0.6	0.75	0.6	0.5
3	2.6	2.5	2.1	2.5	1.9	1.7	2.2	2.0	1.8



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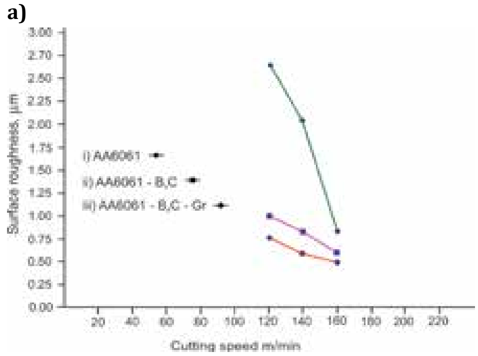

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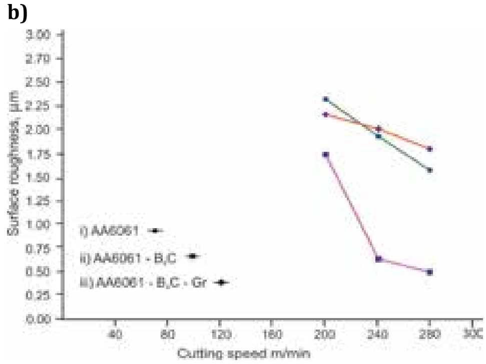

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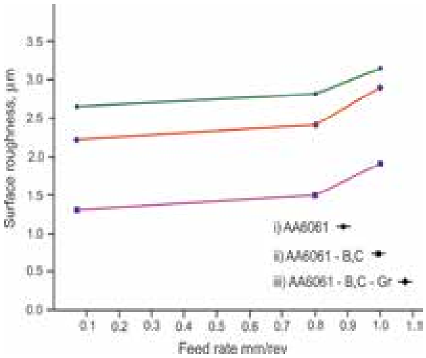
Fig.2 : Different values of surface finish (Ra) for varying cutting speed and at fixed feed rate of 0.08 mm/rev. and at 0.2 mm depth of cut for a) Carbide tool , b) CBN tool and c) PCD tool.

Effect of surface finish values (Ra) at fixed cutting speed and depth of cut parameters :

Figure 3 depicts the influence of different feed rate viz. 0.05, 0.8, 1.0 mm/rev. on surface finish value (Ra) with the fixed cutting speed of 80 m/min. in a belt driven conventional lathe employing carbide tool, 160 m/min cutting speed in a conventional gear driven lathe employing CBN tool and 280 m/min cutting speed in a CNC lathe employing PCD tool. Depth of cut of 0.2 mm was given for turning a length of 40 mm in AA6061 matrix , AA6061-B_4C and AA6061-B_4C-Gr composite samples individually. The measured values of surface finish (Ra) for different machining parameters of feed rate show that Ra value increases with the increase of feed rate. Same is represented in the Table 4. This is due to the fact that the temperature at cutting zone is increasing steadily when feed rate increases and cause disturbance in bonding effect between B_4C particles and Aluminium alloy matrix. [11]. In the case of AA6061-B_4C-Gr, due to the presence of graphite particles, being softer in nature that causes debonding effect between the graphite particles and Aluminium alloy matrix. Hence the surface finish values (Ra) increasing proportional to the increase in feed rate. Of course this Ra values are varying with respect to the type of 3 different tools used in this trial for turning. Values are used in plotting the curve as shown in figure 3. The experiments reveal that feed rate influences surface finish on non favourable direction which is in agreement with other researchers [11,18]

TABLE 4: SURFACE ROUGHNESS VALUES FOR VARYING FEED RATE

Surface roughness value ' Ra' in µm									
Sample #	Carbide tool			CBN tool			PCD tool		
	0.05 mm/ rev.	0.8 mm/ rev.	1.0 mm/ rev.	0.05 mm/ rev.	0.8 mm/ rev.	1.0 mm/ rev.	0.05 mm/ rev.	0.8 mm/ rev.	1.0 mm/ rev.
1	2.6	2.8	3.2	2.5	2.8	3.0	2.2	2.4	2.9
2	1.3	1.5	1.9	1.1	1.4	1.6	0.8	1.0	1.2
3	2.2	2.4	2.9	2.0	2.2	2.6	1.9	2.3	2.4



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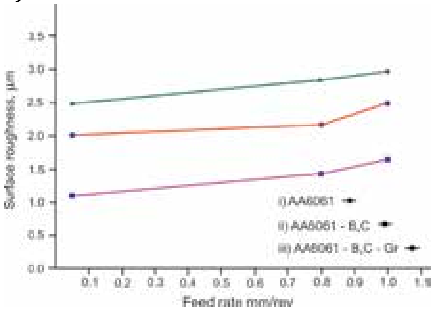

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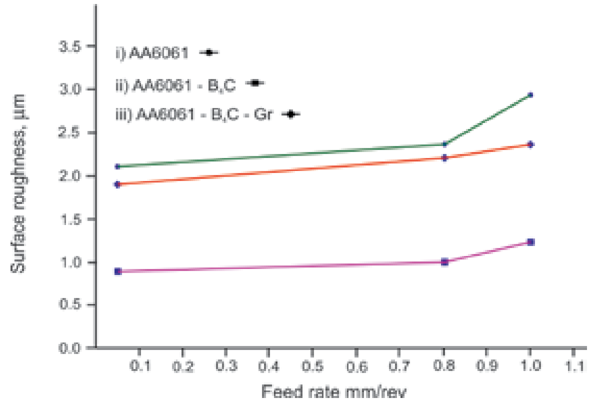

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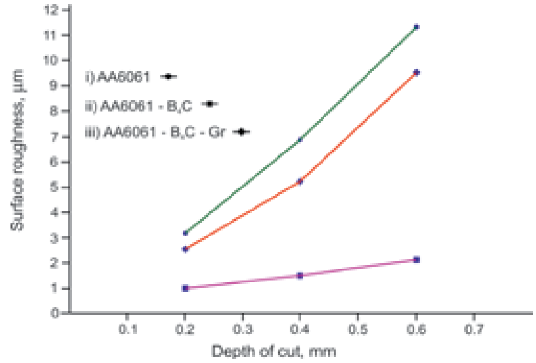
Fig.3 : Different values of surface finish (Ra) for varying feed rate and at fixed cutting speed of a)80, b)160 and c)280 m/min for a) Carbide tool , b) CBN tool and c) PCD tool respectively. Fixed depth of cut being 0.2 mm on tool point.

Effect of surface finish values (Ra) at fixed cutting speed and feed rate parameters :

Figure 4 depicts influence of the machining parameter , "depth of cut" viz. 0.2mm, 0.4mm and 0.8mm on the surface finish (Ra value) with the fixed cutting parameters say 80 m/min cutting speed in a belt driven conventional lathe employing carbide tool, 160 m/min cutting speed in a conventional gear driven lathe employing CBN tool and 280 m/min cutting speed in a CNC lathe employing PCD tool. 0.08 mm/rev. feed was used for a turning length of 40mm in AA6061 matrix , AA6061-B_4C and AA6061-B_4C-Gr composite samples. The measured values of Ra at different machining parameter (depth of cut) show that the surface roughness increases with the increase of depth of cut. Same is represented in the Table 5. This is due to the fact that the cutting forces and surface deformation increases which leads to the increase in surface roughness (Ra value). In the case of AA6061-B_4C-Gr composite, due to the presence of graphite particles, the disturbance in bonding between the Gr particles and Aluminium alloy matrix is severe which causes the surface roughness values to increase proportionately according to the increase in depth of cut applied while machining. Moresoever the Ra values are varying with respect to type of cutting tools used in turning the same intensity as shown in the figure 4

TABLE 5 : SURFACE ROUGHNESS VALUES FOR VARYING DEPTH OF CUT

Surface roughness value ' Ra' in µm									
Sample #	Carbide tool			CBN tool			PCD tool		
	0.2 mm	0.4 mm	0.6 mm	0.2 mm	0.4 mm	0.6 mm	0.2 mm	0.4 mm	0.6 mm
1	3.2	6.9	11.3	2.8	5.1	9.6	1.4	2.1	3.4
2	1.0	1.6	2.1	0.9	1.2	1.8	0.7	1.5	1.6
3	2.6	5.3	9.6	2.1	3.9	6.5	1.1	1.6	2.4



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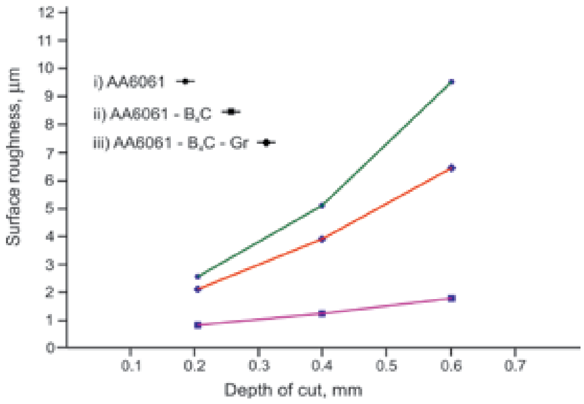

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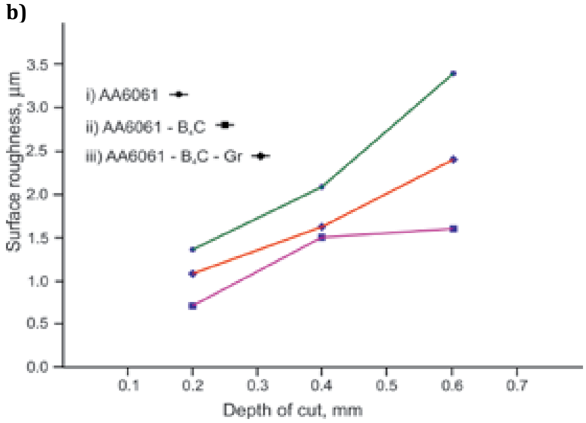

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Fig.4 : Different values of surface finish (Ra) for varying depth of cut and at fixed cutting speed of a) 80, b) 160 and c) 280 m/min for a) Carbide tool , b) CBN tool and c) PCD tool respectively. Fixed feed rate being 0.08 mm/rev.

Effect of Graphite on surface finish:
The surface roughness values (Ra) of AA6061-B$_4$C composite are less than that of AA6061-B$_4$C-Gr composite under all machining conditions. This is due to the reduced honing effect because of presence of graphite film that reduces coefficient of friction between the tool flank face and the work piece. It allows cutting tool to slide easily over the work piece surface. Due to the smearing and removal of graphite particles from the work piece surface creates voids which leads to higher surface roughness values.

Swarf formation study:
The machining (turning operation) of B$_4$C particles reinforced aluminium composites resulting different types of swarf formation. When the tool edge meets only matrix material then the chips formed are long continuous due to plastic deformation. When the tool edge faces the reinforced particles (B$_4$C) swarf breaking occurs and shorter discontinuous chips are produced.

Fig.5: Swarf Layout with different material and respective cutting tools in turning

Figure 5 shows the shape of the swarf formed during dry cutting (turning) of AA6061, AA6061-B$_4$C and AA6061-B$_4$C-Gr composite samples using 3 different tooling viz. Carbide , CBN and PCD tools. For this experiment the cutting parameters used are 160 m/ min. cutting speed, 0.1 mm/rev. feed rate and 0.2 mm depth of cut.

Figure 5a shows the type of swarf produced which are of long continuous, saw tooth shape with long radius of curvature ie AA6061 with carbide tool.

Figure 5b shows the swarf produced which are semi discontinuous, semi circular and spiral. ie AA6061-B$_4$C with CBN tool.

Figure 5c depicts the swarf formed are of discontinuous during turning of AA6061-B$_4$C-Gr composite using PCD tool. Swarf are shorter in graphitic composite and frequently cracks are formed on the outer surface of chips. Graphite being soft and having less density, graphite particles act as chip breakers and helps to produce serrated chips of small length and hence enables easy machinability.

CONCLUSIONS
Incorporation of hard B$_4$C particles in AA6061-B$_4$C composite generates lower surface roughness values (Ra) due to the burnishing effect produced by rubbing micro B$_4$C particles trapped between the flank face of the tool and work piece.

Surface roughness still lowers when cutting speed increases upto 120 m/min. and feed rate reduces upto 0.05 mm/rev.

Surface roughness of AA6061-B$_4$C composite is lower when machined by CBN tool compared with carbide tool and still lower when machined with PCD tools.

Incorporation of soft graphite particles in AA6061-B$_4$C composite generates higher surface roughness values (Ra) due to the severe disturbance in bonding between Gr.particles and aluminium matrix. Ra value still increases for higher feed rate and depth of cut.

Swarf formation in case of machining of AA6061 is almost continuous and having large radius and in case of machining of AA6061-B$_4$C-Gr composite is shorter of discontinuous nature with serrated edge that enables easy machining.

In conclusion, this investigation prove that by choosing the right cutting speed,feed rate, depth of cut and with appropriate cutting tool we can produce surface roughness Ra=1.3 µm (3 triangles, grinding finish) with basic AA6061 alloy, Ra = 0.5 µm (4 triangles, lapping finish) with AA6061-B$_4$C composite and Ra = 1.1 µm (3 triangles, grinding finish) with AA6061-B$_4$C-Gr composite in turning operation itself which is cheaper. Moreover the benefit of machinability , wear resistance both are obtained simultaneously from this hybrid composite.

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