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To Study The Influence of Machining Conditions and Surface Roughness on The Chip Geometry

Jval Sheth[1], Maneesh Gunjal[2], Apurv Choubey[3], Vijaykumar S. Jatti[4]
[1]M.Tech Student, Symbiosis Institute of Technology (SIT), Symbiosis International University (SIU), Lavale, Pune-412 115, Maharashtra State, India
sheth.jval@sitpune.edu.in
[2]Assistant Professor, Symbiosis Institute of Technology (SIT), Symbiosis International University (SIU), Lavale, Pune-412 115, Maharashtra State, India
maneesh.gunjal@sitpune.edu.in
[3]Assistant Professor, Symbiosis Institute of Technology (SIT), Symbiosis International University (SIU), Lavale, Pune-412 115, Maharashtra State, India
apurv.choubey@sitpune.edu.in
[4]Assistant Professor, Symbiosis Institute of Technology (SIT), Symbiosis International University (SIU), Lavale, Pune-412 115, Maharashtra State, India
vijaykumar.jatti@sitpune.edu.in
*Tel: +91-20-39116300; Fax: +91-20-39*116460

Abstract

Aluminium metal matrix composites are considered to be one of the most difficult to machine materials, because of the presence of reinforcements which are much harder than the parent matrix. The machining of these materials has become a very important subject for research. The review of literature on machining and mechanism of chip formation reveals that these aspects have been given relatively little attention during the machining study. This study focuses on the chip formation during the turning of aluminium metal matrix composites and to study the influence of machining conditions and surface roughness on the chip geometry. Coated tungsten carbide inserted cutting tool was used in the present study. Based on the experimental results on chip formation mechanism in machining of Al/SiC composites following conclusions can be drawn. At lower spindle speed (1500 rpm) continuous, spring type and c-type curl chips are formed, whereas at higher spindle speed (2500 rpm) generally, thin segmented, larger c- type thin chip, and tabular helix type chips are formed. At lower spindle speeds and high feed rates the chips formed were found to be unfavorable as the surface roughness values were found to be larger.

Keyword: Metal matrix composites, machining, surface roughness, chip formation.

Introduction

Nowadays, researcher all over the globe are focusing mainly variety of innovative composite materials which are quickly replacing conventional materials for different applications like automotive, aerospace, defence, sports, electrical appliance and other industries. Metal matrix composites (MMCs), as the name implies, have a metal matrix. The properties of MMCs are influenced by their matrix, reinforcement, and interface properties. Matrix materials are usually lightweight materials, and especially ceramic reinforcements are added to get high specific strength. Metals are mainly reinforced to increase or decrease their properties to suit the needs of design. Currently, most of the processes employed in the synthesis of MMCs involve the incorporation of ceramic particles such as carbides borides into the matrices. Reinforcements like alumina have high yield strength and high modulus of elasticity. It also improves the hardness of the composite. The addition of graphite makes it act like a self-lubricant preventing the need of supplying separate lubricants while machining. The importance of chip formation has been well recognized and studied by other researchers. Problems with surface finish, work piece accuracy and tool life can be caused even by minor changes in the chip formation process. Hence, it is necessary to understand the chip forming mechanism for this material through further investigation. Based on the available literature, it is clear that various factors like cutting speed, feed rate, depth of cut, volume of reinforcement and nose radius greatly influences on the chip formation mechanism. Said et al. (2013) were worked on chip formation in the milling process of Al-SiC/AlN matrix metal composite using the uncoated of carbide tool. They studied the effect of the cutting parameter on the morphology and the microstructure of the chip. The analysis of the chip formation was also done by Radhika et al. in machining aluminium hybrid composites. They have concluded that feed rate is a major factor in chip formation mechanism. At higher feed rates, the number of chip curls found is more than for a lower feed. This may be attributed to the increased deformation volume and tool-chip contact length. It increases the machining temperature and thereby the ductility and increases the number of chip curls. However, at lower feed rate, the chip cross-sectional area is very small due to which flake, needle type segmented and small radii curled chips are generated. Astakhav et al. were studied on chip structure classification based on mechanics of its formation. This paper is generalized chip formation in metal cutting. Shetty et al. preformed experimental and analytical study on chip formation mechanism in machining of DRACs. In this paper discusses experimental work and finite element analysis to investigate the mechanism of chip formation during machining of DRACs. Focus of this paper is on understanding the influence of different cutting parameters on mechanism of machining. Mahanama and Mavahhedy worked on application of FEM simulation of chip formation to stability analysis in orthogonal cutting process. They carried out mesh adaptation technique to simulate the chip formation within an FEM elastoplastic analysis with dynamic effects and frictional contact. The combined modeling predicts the occurrence of process damping at low cutting speeds, which other models are generally unable to predict. Though, the extensive investigations on mechanism of chip formation in homogeneous material have been carried out. The mechanism of the chip formation in metal matrix composite was studied for various values of cutting parameters and tool conditions. The aim of this study is to present the mechanism of the chip formation while machining aluminum metal matrix composites. Therefore, it is envisaged that a fundamental study of chips and mechanism of their formation could be very useful in analyzing the machining process.

Material and Methods

The Aluminium metal matrix composites studied in this paper consists of aluminium alloy 6061 base alloy reinforced with 3% and 6% by weight of silicon carbide (SiC) particles (ref. table 1). Eight cylindrical bars were manufactured using stir casting process. Al alloy was heated to a temperature of 750 ˚C in a graphite coated crucible. In furnace both material particles aluminium and silicon carbide are mixed and heated at high temperature. The pre heated mixture was then added to the melt and mixed thoroughly by stir rod rotating by electric motor. 1% by weight of boron in the form of powder was added to improve wettability of the melt. The mixture was stirred with a stirrer at 200 rpm for three minutes. The green sand mould which was prepared for the preferred dimension and tolerance was pre heated using a flame heater for 2 min to remove moisture. The melt was then poured into the mould using a ladle and allowed to solidify. The work pieces were then cooled in air for three hours after solidification and removed from the mould.

Table 1: Details of the composition of composite material

Matrix	Reinforcement	Weight fraction of SiC (%)	Shape	Size
Al 6061	SiC	3	Cylindrical rod	ϕ15 mm x 50 mm
6061	SiC	6	Cylindrical rod	ϕ15 mm x 50 mm

The main objective of the paper was to understand the mechanism of the chip formation and study the effects of various cutting conditions on chip formation while machining aluminium metal matrix composites. Accordingly experiments were conducted under varying machining conditions (coolant, SiC percentage, spindle speed, feed rate, depth of cut and nose radius). Based on the preliminary study and literature review set of experiments performed on the machining of aluminium composite two levels of each independent machining parameters has been selected as shown in table 2. Taguchi L_{16} orthogonal array was used to design experiments. Total of 16 experiments were carried out on the metal matrix composite. Cutting tool life is a most important consideration in metal cutting operations. The major parameters which affect the tool life are the tool angle (rake angle), cutting speed and the feed rates. The use of very low speed and feed to give maximum tool life is uneconomical because of the low production rates. Tool rake angles can be positive or negative, the latter increases the number of usable cutting edges by allowing the insert to be inverted to utilize the edges on the lower insert face; but on the other hand produces thicker chips resulting in higher cutting forces. An increase in the rake generally tends to improve the cutting conditions leading to longer tool life. However it is evident that the usage of larger rake angles makes the cutting edges mechanically weak. Hence coated tungsten carbide insert DCMT 11 T3 08-PM and DCMT 11 T3 04-UM with nose radius of 0.4 mm and 0.8 mm and SDJCL 2020K 11 (SANDVIK make) type tool holder were chosen for the present work. The turning operation on MMC's was performed on CNC lathe of HASS make under with and without coolant. Each experimental run was continued of a length of 10 mm. Large numbers of chips were collected for various experiments. The surface roughness of work pieces were taken after each experiment using TURBO RAUHEIT V6.14 surf tester with sample length and cutoff length being 8 mm and 4 mm respectively. The surface roughness of the work piece after each experiment was recorded. The images of the chips were captured using a digital camera and inspected. The observations made on them were used to classify according to their physical structure and appearance.

Table 2: Turning Process Parameters With Their Levels

Factors	Levels	
	-1	+1
Coolant	with	without
SiC %	3	6
Spindle speed (rpm)	1500	2500
Feed rate (mm/rev)	0.1	0.2
Depth of cut (mm)	0.75	1
Nose radius (mm)	0.4	0.8

Result and Discussions

Depending on the composition of composite and machining conditions, various types of chips are formed such as, thin flakes, needle type, segmented, continuous, spring and helix type. Table 3 shows the experimental trail condition with observed values. The effect of change in spindle speed and feed rate is more dominant on physical form of the chips generated during machining of Al/SiC composites (ref. figure1). At lower spindle speed chips generated are such as c- type or spring type. The thicker c-types chip are generated at the low cutting speed, high feed rate with 0.4 tool nose radius, see figures. 1(a & g). The length and thickness of chip segment reduces with a decrease in feed rate (0.1) and generates ½ curled segmented to flake type chips under, see figures. 1(c & e). For high feed rate and low cutting speed with 0.8 tools nose radius generates the small and thin segmented types of chips, see figures 1(b & h). Also the segments size also decreased with decreased feed rate see figures 1(d & f). Also observed under dry condition the chip thickness are more and with coolant chip size thickness is less. Figure 1a) to d) are without coolant and figure 1e) to h) with coolant at lower spindle speed of 1500 rpm.

During machining at lower cutting speed, composite material behaves in a brittle manner with little influence of either temperature or strain rate. Moreover, at lower spindle speed, the displacement of reinforcement particles is less, which generates voids by either displacement or fragmentation of reinforcement particles hence brittle failure becomes more prominent and segmented chips are formed. These chip form change to very small curled, segmented type and smaller radii c-type chips with a decrease in feed rate at lower spindle speed.

Table 3: Taguchi L_{16} Orthogonal Array With Observed Values

Expt. No.	Coolant	SiC %	Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	Nose radius (mm)	Ra (µm)
1	with	3	1500	0.1	0.75	0.4	1.71
2	with	3	1500	0.1	0.75	0.8	1.85
3	with	6	2500	0.2	1	0.4	4.55
4	with	6	2500	0.2	1	0.8	2.43
5	without	3	1500	0.2	1	0.4	4.79
6	without	3	1500	0.2	1	0.8	2.68
7	without	6	2500	0.1	0.75	0.4	4.44
8	without	6	2500	0.1	0.75	0.8	2.33
9	with	3	2500	0.1	1	0.4	1.59
10	with	3	2500	0.1	1	0.8	0.64
11	with	6	1500	0.2	0.75	0.4	4.67
12	with	6	1500	0.2	0.75	0.8	2.56
13	without	3	2500	0.2	0.75	0.4	4.86
14	without	3	2500	0.2	0.75	0.8	2.75
15	without	6	1500	0.1	1	0.4	4.37
16	without	6	1500	0.1	1	0.8	2.26

Further, increase in spindle speed to 2500 rpm generates tubular helix and large c-type chips at higher feed rates (0.2mm/rev). However, reduction in feed rate (0.1mm/rev) at 2500 rpm spindle speed generates the chips of continuous and semi-continuous type. This trend is more prominent especially in finer reinforcement composites; see Fig. 2(a–b). But, in coarser reinforcement composites, the length and number of chip curls are lower than finer reinforcement composites at same machining conditions, compare figure 2(a–b) with figure 2(c–d). The change in form of chips from partially c-type to washer c-type and helix type chips as the spindle speed increases (from 1500 rpm to 2500 rpm) is due to increased ductility of the work material because of the high machining temperature at higher cutting speed, see figure

2. At higher feed rate, 0.2mm/rev, the number of chip curls observed is more than lower feed rate and is attributed to the increased deformation volume and tool-chip contact length. It increases the machining temperature, which improves the ductility (especially in finer reinforcement) and increases the number of chip curls. The effect of a change in size and volume fraction of reinforcement is also evident on chips at lower as well as at higher feed rate. At lower feed rate (0.1 mm/rev), i.e. during finish turning operation, the coarser reinforcement particles themselves act as a chip breaker and produce both segmented and small curled chips. As compared to the coarser reinforcement, the chips of finer reinforcement composites are semi-continuous and spring type; compare Fig. 2(e–f) and (g–h). The variation in the number of chip curls can be attributed to the variation in mechanical and physical properties of composite materials with change in composition. At higher weight fraction and a given size of reinforcement, the number of chip curl is lower; compare Fig. 2 (a) and (c). This could be attributed to the higher ductility and lesser hardness of finer reinforcement composite. At the same time, the finer reinforcement composites will have a greater tendency to stick to the tool face for longer duration. This may force the chips to take a longer path by curling through a larger diameter circle. Figure 2a) to d) are without coolant and figure 2e) to h) with coolant at lower spindle speed of 2500 rpm.

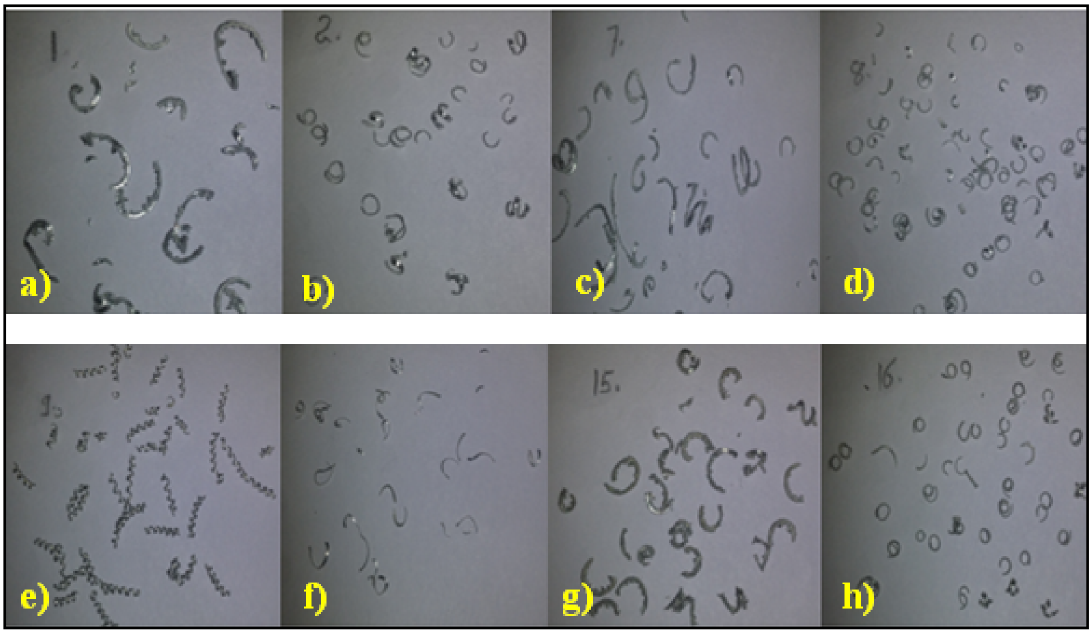

Figure 1: a) connected c-type chips, 3% SiC, 0.4 mm nose radius, 0.2 mm/rev, 1 mm dof, **b)** small circle segmented chip, 3% SiC, 0.8 mm nose radius, 0.2 mm/rev, 1 mm dof, **c)** small thick c-type chips, 6% SiC, 0.4 mm nose radius, 0.1 mm/rev, 1 mm dof, **d)** segmented chips, 6% SiC, 0.8 mm nose radius, 0.1 mm/rev feed rate, 1 mm dof, **e)** spring curl type chips, 3% SiC, 0.4 mm nose radius, 0.1 mm/rev, 0.75 mm dof, **f)** thin segmented, 3% SiC, 0.8 mm nose radius, 0.1 mm/rev, 0.75 mm dof, **g)** c-type thick chips, 6% SiC, 0.4 mm nose radius, 0.2 mm/rev, 0.75 mm dof, **h)** segmented chips, 6% SiC, 0.8 mm nose radius, 0.2 mm/rev, 0.75 mm dof

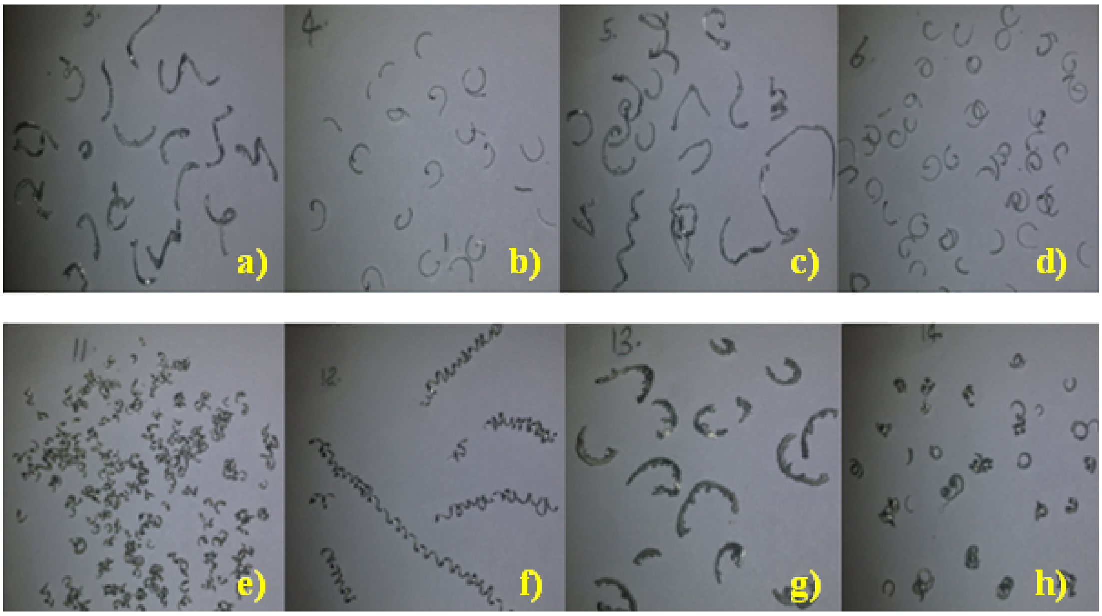

Figure 2: a) curl c-type chips, 3% SiC, 0.4 mm nose radius, 0.2 mm/rev, 0.75 mm dof, **b)** thin radius c-type chip, 3% SiC, 0.8 mm nose radius, 0.2 mm/rev, 0.75 mm dof, **c)** connected c-type chips, 6% SiC, 0.4 mm nose radius, 0.1 mm/rev, 0.75 mm dof, **d)** c-type washer chips, 6% SiC, 0.8 mm nose radius, 0.1 mm/rev feed rate, 0.75 mm dof, **e)** segmented chips, 3% SiC, 0.4 mm nose radius, 0.1 mm/rev, 1 mm dof, **f)** tubular helix chips, 3% SiC, 0.8 mm nose radius, 0.1 mm/rev, 1 mm dof, **g)** larger c-type thick chips, 6% SiC, 0.4 mm nose radius, 0.2 mm/rev, 1 mm dof, **h)** segmented chips, 6% SiC, 0.8 mm nose radius, 0.2 mm/rev, 1 mm dof

The surface roughness obtained during a practical machining process may be considered as sum of two independent effects, one resulting from the geometry of the tool, feed or spindle speed and the other being natural surface roughness which being a result of irregularities in the cutting operation (Uday and Suhas, 2009). After visual inspection of chips shown in figures 1(a–h) to 2(a–h), the chips formed at processing conditions (0.2 mm/rev, 1 mm depth of cut and spindle speed of 1500 rpm) are of continuous, spring type and c-type curl chips, refer figures 1(a–h). Such types of chips deteriorate the quality of machined surfaces. Whereas, the chips formed at (0.1 mm/rev, 0.75 mm depth of cut and spindle speed of 2500 rpm), have different forms like thin segmented, larger c-type thin chip, and tabular helix type chips, refer figures 2(a–h), which are desirable to reduce the surface roughness on the machined surfaces. A comparison of surface roughness obtained at the processing conditions mentioned above, are investigated as a part of present research work and presented in Table 3. Based on the obtained Ra values from the experiments, the chips were segregated as favourable chips and unfavourable chips. The maximum value of Ra was obtained for experiment number 3 (Table 3). The presence of graphitic film in the composite greatly influences the surface roughness while machining. Table 4 shows the effect of chips on surface roughness.

Table 4: Effect of surface roughness on chip formation

Expt. No.	Chip conditions	Spindle speed (rpm)	Feed rate (mm/rev)	Ra (µm)
1	Favourable chip	1500	0.1	1.71
2	Favourable chip	1500	0.1	1.85
3	Unfavourable chip	2500	0.2	4.55
4	Favourable chip	2500	0.2	2.43
5	Unfavourable chip	1500	0.2	4.79
6	Favourable chip	1500	0.2	2.68
7	Unfavourable chip	2500	0.1	4.44
8	Favourable chip	2500	0.1	2.33
9	Favourable chip	2500	0.1	1.59
10	Favourable chip	2500	0.1	0.64
11	Unfavourable chip	1500	0.2	4.67
12	Favourable chip	1500	0.2	2.56
13	Unfavourable chip	2500	0.2	4.86
14	Favourable chip	2500	0.2	2.75
15	Unfavourable chip	1500	0.1	4.37
16	Favourable chip	1500	0.1	2.26

Conclusion

Based on the experimental investigations on chip formation mechanism in machining of Al/SiC composites following conclusions can be drawn. At lower spindle speed continuous, spring type and c-type curl chips are formed, whereas at higher spindle speed thin segmented, larger c- type thin chip, and tabular helix type chips are formed. At lower cutting speeds and high feed rates the chips formed were found to be unfavourable as the surface roughness values were found to be larger. The length of chip and the number of chip curls increases with an increase in feed rate at given cutting speed and depth of cut. The weight fraction of reinforcement affects the chip formation mechanism. In case of finer reinforcement composites, the chip segments are longer in length and fracture occurs at outer surface of the chips only. Whereas in coarser reinforcement composites, complete fracture causes formation of smaller chip segments.

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