An experimental investigation on the machinability of powder formed silicon carbide particle reinforced aluminium metal matrix composites

Sujit Das, R. Behera,G. Majumdar,B. Oraon,G. Sutradhar

Abstract-The paper attempts to study the machinability issues of aluminium-silicon carbide (Al-SiC) metal matrix composites (MMC) in turning using HSS cutting tool. SiCp-reinforced metal matrix composites (MMCs) containing SiC particles (5wt%-20wt %) of 400mesh size were prepared by powder metallurgy (P/M) route and used as work material for turning. Experiments were conducted at various cutting speeds and depth of cuts at constant feed rate and parameters, such as cutting forces and surface roughness were measured. It was found that higher weight percentage of SiCp reinforcement produced a higher surface roughness and needs high cutting forces during machining operation of MMCs. It was also observed that surface roughness and the cutting forces are also depending upon the depth of cut and the cutting speed at constant feed rate. This paper present a reliable set of parameters as the result of an experimental investigation that demonstrate versatility, and numerous and diverse range based on experience and technology during the machining of aluminium-reinforced silicon carbide metal matrix composite (Al-SiCp MMC) which will provide valuable guidelines to the manufacturing engineers.

Keywords- Metal matrix composites, Machining, Surface roughness, cutting forces Machining, Depth of cut, Cutting speed.

1. INTODUCTION

Composite materials are a result of the continuous attempts to develop new engineering materials with low weight to strength ratios and improved properties. Composite materials are important engineering materials due to their outstanding mechanical properties. Metal matrix composite (MMC) materials are one of the widely known composites because of their superior properties such as high strength, hardness, lighter weight, stiffness, wear and corrosion resistances. Since 1970s, MMCs have successfully applied in the aeronautic and aerospace industries [1] and nowadays their use is gaining importance. As these composites contain very high hardness strengthening particles, the cutting tool tends to wear severely resulting in difficulties in machining [2]. Due to their superior strength and stiffness than those of conventional materials.MMCs have good potential for application in the automotive and aerospace industries [3-5]. Aluminium reinforced with SiC particles is one of the best materials to substitute the conventional structural alloys, which has more significance in the areas of aerospace and automotive engineering components and other diverse industries [6-9]. Powder forging is particularly attractive because it blends the cost and material-saving advantages compared to the conventional castings and forgings through better dimension and weight control. Powder forged parts can even outperform parts machined from a forged blank, probably as a consequence of fully dense, absolutely uniform and very fine grained microstructure. Machinability of metal matrix composites (MMCs) has received considerable attention because of the high tool wear associated with machining. Although efforts have made to produce MMCs by casting, or hot forging, the resulted near-net-shape products still have to machine into the designed shape, and dimension. MMCs reinforced with silicon carbide particles (SiCp), are notorious for high tool wear due to the inherent abrasiveness of the hard SiC particles. From some early conventional turning tests on Al-SiCp MMCs, it has found that the tool wear is excessive and surface finish is very poor while carbide tip tools are used for machining. The hard SiC particles of Al-SiCp MMC, which intermittently come into contact to the hard surface, are act as small cutting edges like those of a grinding wheel on the cutting tool edge which in due course is worn out by abrasion and resulting in the formation of poor surface finish during turning [10]. The processing parameters affecting machinability of a material are the values of cutting speed according to

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selected set of material properties of work piece and machining parameters. In the investigation of machinability, the cutting speed, feed rate and the cutting depth are important parameters. El-Gallab et al. has emphasized on the surface roughness in their study on the machinability of the 20% of SiCp reinforced Al-MMC. By performing dry turning tests with different cutting parameters, they have investigated the effect of processing parameters on surface roughness. They have found that large chip depths and high cutting speeds reduce the surface roughness. Bergman et al. investigated the machinability of Al-MMC by cutting tools. For this purpose, they used HSS and coated–uncoated hard metal cutting tools (WC) [11-13]. In addition, for many components, the production of good surface finish is essential Cutting speed is the most significant variable affecting tool life, while feed rate and depth of cut are less important. This leads to the softening of the metallic matrix enabling easier removal of the embedded SiC particle in the work piece [14-18].

2. Planning for experimentation:

2.1. Production of metal matrix composite:

Air atomized aluminum powder having an average particle of 400 mesh and SiC particulates with an average size of 400mesh are mixed corresponding to Al–5% SiCp, Al–10% SiCp, Al–15%SiCp and Al–20% SiCp were blended on a pot mill (diameter 40 mm, height 35 mm), at a constant speed of 1500 rpm for 1h to obtain a homogeneous powder blend.. Blending is one of the crucial processes in P/M where the metallic powders have mixed with the ceramic reinforced particles and the binder (Zinc Stearate). Several parameters such as particle size, blending speed and duration should be taken into consideration to ensure the SiCp particles distributing homogeneously in the matrix powders. The powder blending parameters are listed in Table 1. A mixture of the particles) has poured into a cylindrical die with 110 mm. high 25 mm. inner diameter and 75 mm outer diameter.

After pouring, the Green compacts of the powder blend were prepared on a hydraulic press (Manual Type, Capacity 8.0 KN. Ram stroke 300 mm.).The compacting pressure applied was2.1 KN, which has maintained for 5min to obtain green compacts for all composition of SiCp composites. The various steps involved in this experiment for manufacturing of P/M components has shown in Fig.1.The green compacts are then subsequently baked at

300˚C and followed by sintering in a induction type floor stand tube vacuum furnace . Fig.2,3,4 and 5 show the metallic die-and punch ,green compact , induction type floor stand vacuum furnace and sintered compact accordingly. To avoid the oxidation of Al alloy powders at high temperature and to abbreviate the preparation procedures, the degassing and sintering procedures of the green compacts were incorporated together. The stepped heating procedures of the degassing and sintering have introduced into the experiment. The sintering parameters have given in the Table2.

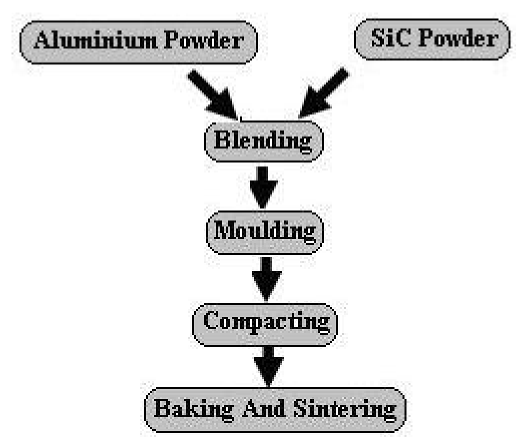


Fig.1: Various steps involved in synthesis of Al-SiCp composites in P/M technique.

Table 1: Powder blending parameters

	Filling of mixer (vol.%)	Operation	R.P.M	Time (min)
400mesh pure Al,400mesh SiC and Binder (Zinc Stearate)	50	Blending	1500	10
	75	Blending	1500	10
	100	Blending	1500	10
		Rest		15
		Blending	1500	15

Table 2: Sintering parameters

Operation	Temperature		Duration
	From	To	
Heating	Ambient (30˚C)	300˚C	40 min
Soaking	300˚C	300˚C	30 min
Heating	300˚C	500˚C	30 min
Soaking	500˚C	500˚C	30 min
Heating	500˚C	600˚C	30 min
Soaking	600˚C	600˚C	40 min
Cooling in furnace	600˚C	Ambient (30˚C)	

Fig.2: Metallic Die with Punch.

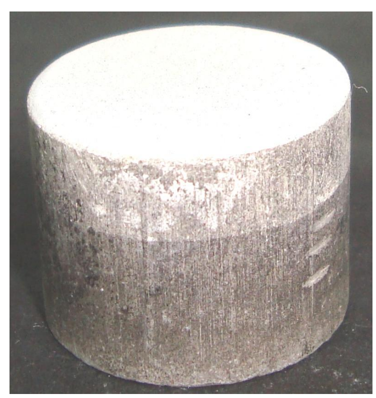


Fig.3: Compacted green component.

Fig .4: Induction type floor stand tube vacuum furnace.

Fig.5: Sintered Component.

2.2 Performing Experiments:

The sintered SiCp composite compacts were prepared for machining purpose. The turning tests of specimens were carried out in a conventional universal lathe machine (Golden Machinery Corporation) with the following specifications.

Height of center 177.5 mm

Swing in gap 520 mm

Spindle speed range 8speeds ranges from 30 to 750 rpm

Main motor 2.25 kW

The HSS cutting tool is fitted in a rigid tool holder SYSCON made SPL 20083. The machining tests were conducted under dry cutting process without using chip breaker. The selected machining parameters were given in Table 3. The cutting forces (Ft and Fr) were measured at different cutting speed and depth of cut at constant feed rate by using SYSCON Instrument made LATHE TOOL DYNAMOMETER. The surface roughness values (Ra and Rz) were measured by using MITUTOYO make PORTABLE SURFACE ROUGHNESS TESTER.

Table-3: Experimental conditions

Cutting tool material	HSS
Cutting speed (m/min)	27.64-61.82-118.62
Feed rate (mm/rev)	0.05 (Constant)
Depth of cut (mm)	0.5-1.0-1.5
Reinforcement ratio SiCp (wt. %)	5-20

3. Results and Discussion:

3.1. Micro structural Examination and Phase Analyses:

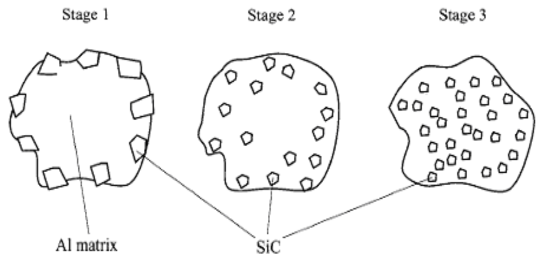


Fig.6: A schematic view of the evolution of distribution of the SiC particulates in Al matrix.

The polished and etched surface reveals voids around the SiC particles in Fig.6.For metallographic examination the sintered samples have prepared has prepared by grinding through 320, 400,600, 800, 1200 and 1500 grit papers followed by polishing with 6-µm diamond paste. Then the samples have etched with the etchant (2.5 ml Nitric acid, 15.0 ml Hcl, 1.0 ml HF and 95.0 ml Water). The etched samples were dried and the microstructure observed by using microscope (Olympus, CK40M) at different magnification. Figures 7-10(A) and (B) shows the fractograph and metallograph of the cold isopressed green compacts and followed by sintered Al-SiCp composites. So far, it indicates that the plastic deformation is beneficial to improve the homogeneity of the reinforcement. Particle matrix debonding and particle agglomerate decohesion are the two mechanisms are of secondary importance when the particles are well distributed and strongly bonded. Particles enhance the relative density of the materials and refine the metal matrix grains, which consequentially result in the increase of mechanical properties of the composites.

Fig.7: A&B Optical micrographs of the metal matrix composites Al&5 wt% SiCp.

Fig.8: A&B Optical micrographs of the metal matrix composites Al&10-wt% SiCp.

Fig.9: A&B Optical micrographs of the metal matrix composites Al &15wt% SiCp.

ISSN 2229-5518

Fig.10: A&B Optical micrographs of the metal matrix composites Al&20wt% SiCp.

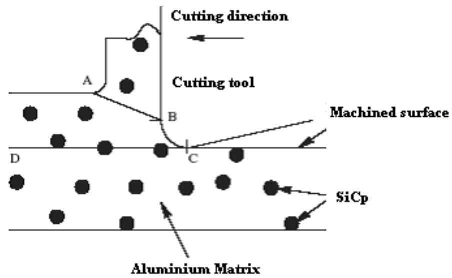
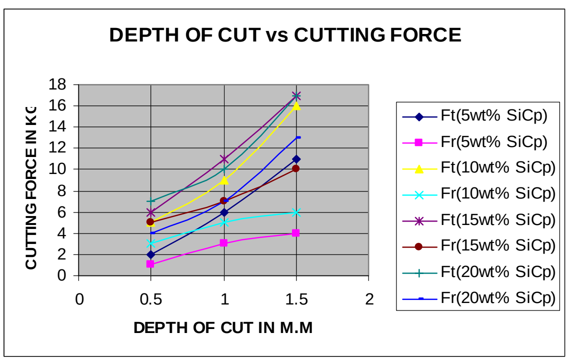


Fig. 11: Machining Process of Al- SiCp MMC.



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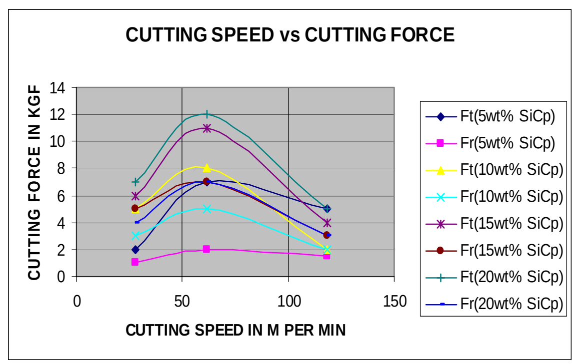

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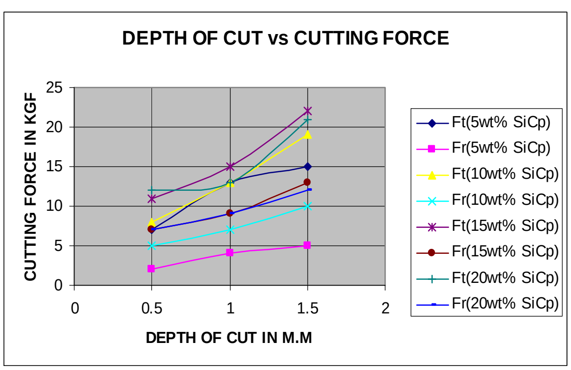

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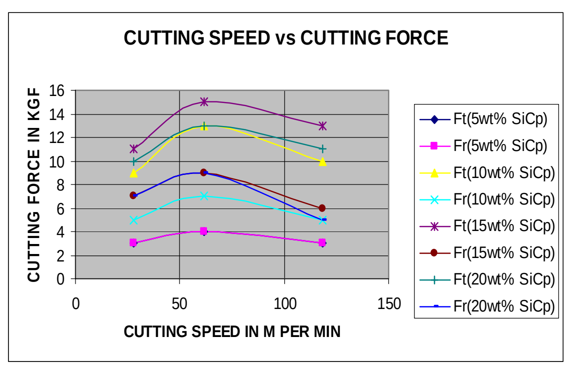

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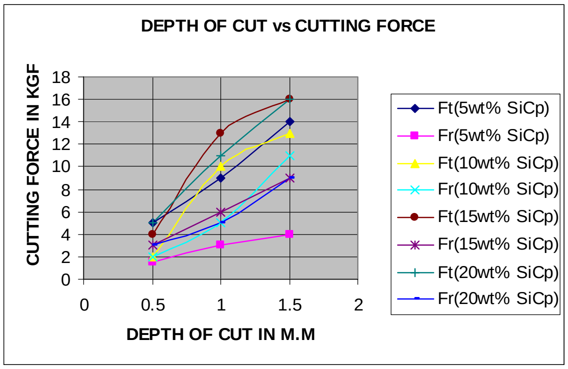

(C)

Fig.12. Effect of depth of cut on cutting forces (Ft)and (Fr) at constant feed rate i.e. 0.05 mm/rev.:
(A) Cutting speed = 27.64 m/min.;
(B) Cutting speed=61.82 m/min.;
(C) Cutting speed=118.62 m/min.

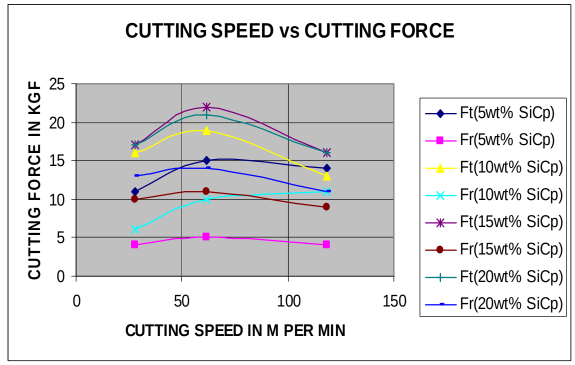

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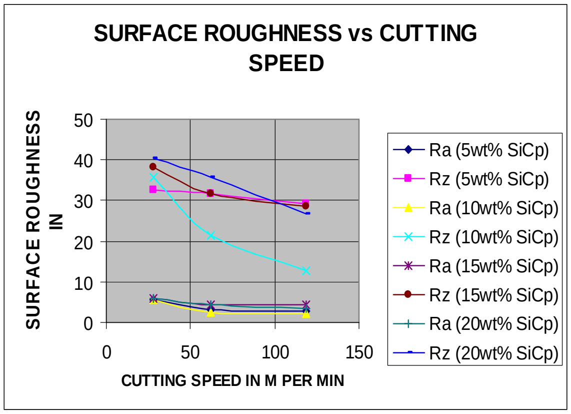
Fig.13. Effect of Cutting speed on forces (Ft)and (Fr) at constant feed rate i.e. 0.05 mm/rev.:
(A) Depth of cut=0.5 mm;
(B) Depth of cut=1.0 mm;
(C) Depth of cut=1.5 mm;

3.2. Cutting Forces:

To analyze the machinability factors of Al- SiCp MMC measurement of the cutting force Ft, the tangential component and Fr, the radial component was necessarily measured. In the present investigation turning operations were performed in dry condition to evaluate the cutting forces. The tangential component Ft, acts in the direction of cutting velocity vector are the main cutting force and is responsible for the cutting power needed. Fig.12. shows the effect of depth of cut on the cutting force (Ft) and radial force (Fr) at constant feed rate and different cutting speed. The results shows that for the composites i.e. reinforced with 5 wt% & 20wt% of SiCp the cutting force components Ft and Fr increases on increasing the depth of cut at constant feed rate of 0.05 mm/rev. and at different cutting speed. Fig.13. shows the effect of cutting speed on the cutting force (Ft) and radial force (Fr).The turning operations were performed at constant 0.05 mm/rev feed and different depth of cut i.e.0.5mm, 1.0mm & 1.5mm. The experimental results represent that for both the composites i.e. reinforced with 5 wt%, 10 wt%, 15 wt%, 20 wt% of SiCp, the cutting force components Ft and Fr increases initially on increasing the cutting speed and decreases on further increasing the cutting speed after certain speed. The cutting force (Ft) and radial force (Fr) are maximum at cutting speed of 61.82 m/min and then decreases on further increasing the cutting speed at constant depth of cut and feed.

3.3. Surface Roughness:

In the present study, the value of surface roughness of sintered SiCp reinforced Aluminum MMCs by powder metallurgy process with different ratios of SiCp have been investigated at selected cutting speed and depth of cut, keeping feed rate constant. The Fig.14. shows the relationship between surface roughness of Al-SiCp MMC with different wt %of SiCp and cutting speed at different depth of cut when feed rate is constant. It has been observed at constant feed that both the value of surface roughness i.e. Ra & Rz decreases with increase of cutting speed and vice versa at different depth of cut. But the higher cutting speed was found to cause a higher interface temperature and severe tool wear. Fig 15.shows the relationship between surface roughness and depth of cut in dry cutting operation Al-SiCp composites at different cutting speed and constant feed rate. The machining result shows that increasing the depth of cut at constant feed rate and different cutting speed, the surface roughness values i.e. Ra & Rz increases. It has been also observed that the percentage of reinforcement SiC particles plays an important role for deciding the surface roughness. The surface roughness is higher in case of samples having higher percentage of reinforcement particles compare to samples having relatively low percentage of reinforcement particles.



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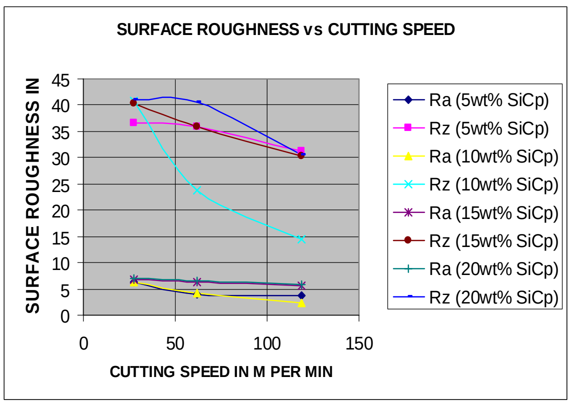

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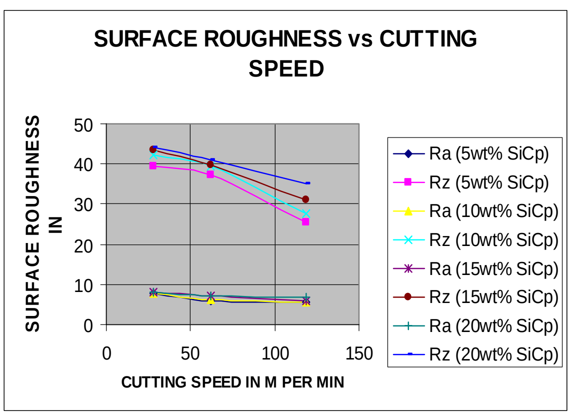
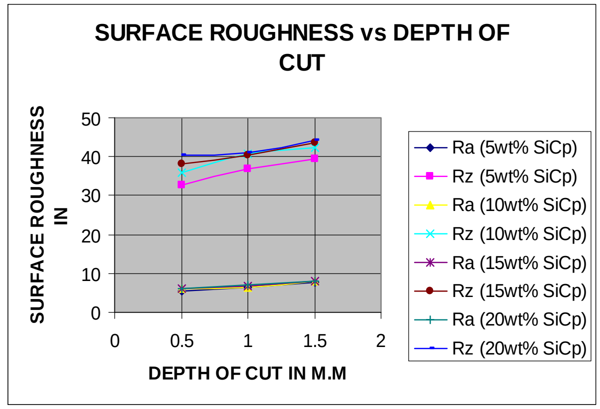
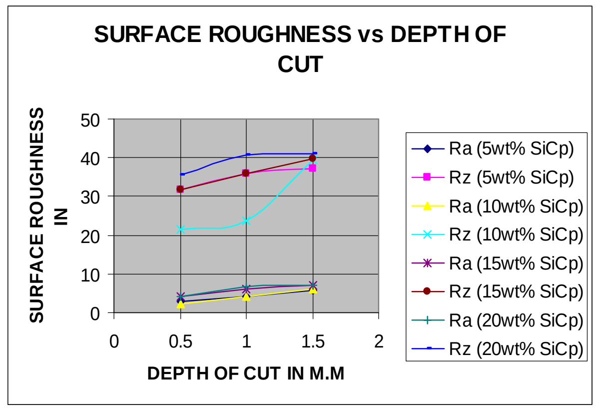


(C)

Fig. 14. Effect of Cutting Speed on Surface Roughness at constant feed rate i.e. 0.05mm/rev.
(A) Depth of Cut = 0.5mm
(B) Depth of Cut = 1.0mm.
(C) Depth of Cut = 1.5mm.



(A)



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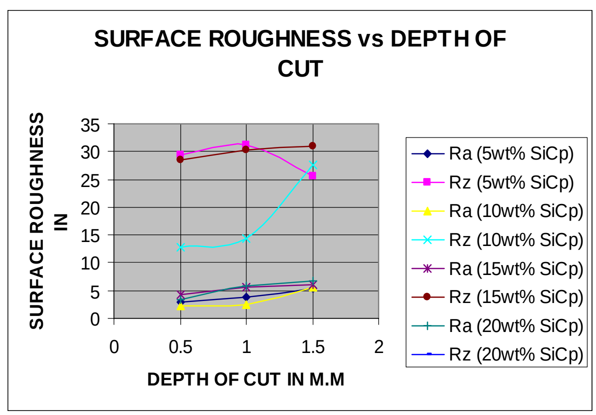


(C)

Fig. 15. Effect of Depth of Cut on Surface Roughness at constant feed rate i.e. 0.05mm/rev.
(A) Cutting speed = 27.64 82m/min.
(B) Cutting speed = 61.82m
(C) Cutting speed = 118.62 m/min.

3.4. Chip Formation:

During machining chip formation is accompanied by very severe plastic deformation at the shear zone. Addition of SiC particle for reinforcement into the aluminium alloy matrix results a reduction in its ductility and produced a semi-continuous type of chip during machining of these MMCs without chip breaker. This could be beneficial to the machinability point of view. It not only improves the machinability of this composite, but also enhances its applicability in various industries. The size of chips is also affected by the percentage of reinforcement particles in MMCs. It has been observed that the sizes of chips are decreases on increasing the weight percentage of SiCp in MMCs. The photographs of the chip formation during machining of this aluminium MMCs are shown in Fig.16. The Fig.17 (A), (B), (C) and (D) shows the photographs of chips produced after machining of sintered Al-SiCp metal matrix composites.

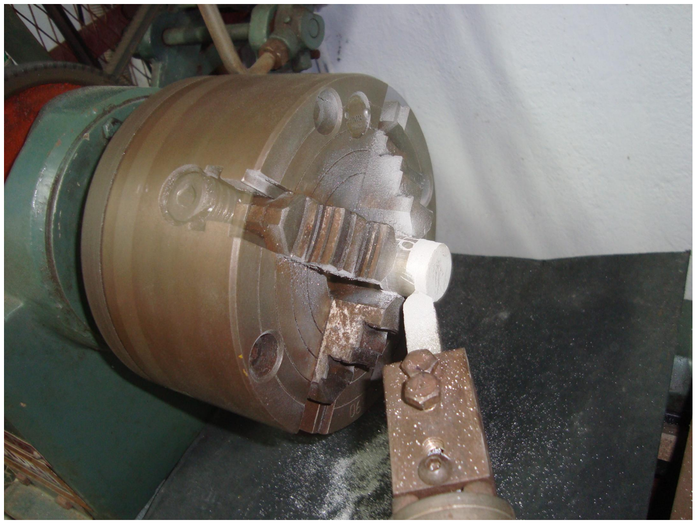
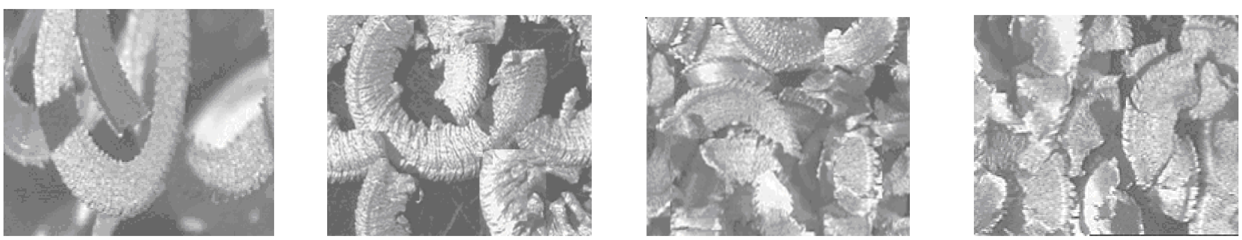


Fig.16. Machining of P/M components.



(A) (B) (C) (D)

Fig.17. Chips metal matrix composites (A) Al&5wt% SiCp (B)Al&10wt% SiCp(C)Al&15wt SiCp(D) Al&20wt% SiCp.

4. Conclusions

In this study, machinability of sintered SiCp reinforced Aluminum MMCs has been evaluated. SiCp reinforced Aluminum MMCs with 5-20 wt% SiCp is examined. The effect of machining parameters like cutting speed and depth of cut on machinability has also studied at constant feed rate.

During dry turning at constant feed rate, constant cutting speed, constant depth of cut turning operation, the cutting forces (Ft &Fr) increased with the increase in weight percentage of abrasive reinforcement particles SiCp.

During machining SiCp reinforced Aluminum MMC at constant feed rate and different cutting speed, the cutting forces are increases on increasing the depth of cut. That indicates the power consumption during machining of aluminium alloy MMCs increases on increasing the depth of cut at the same condition.

The surface roughness of SiCp reinforced Aluminum MMCs enhanced on increasing the weight percentage of SiCp. During turning of MMC samples, the surface roughness increases on increasing the depth of cut at constant feed rate and constant cutting speed.

Surface roughness is also affected by cutting speed during dry turning of aluminium MMCs that is on increasing the cutting speed at constant feed rate the surface roughness decreases.

Ductility of the aluminium alloy is reduced by the addition of SiC particles which enhanced the machinability .It also helps to produce a semi-continuous type of chip during machining of this MMC and also achieves better chip control to render the material very suitable for machining .

The weight percentage of SiCp of metal matrix composites affects the size of chip formation during dry machining operation. It has been observed that the sizes of chips are decreases on increasing the weight percentage of SiCp.

Acknowledgement:

Authors thankfully acknowledge the financial support provided by U.G.C, New Delhi under Major Research Project Grant [F.No. – 32-88/ 2006 (SR) dated 09.03.2007] without which this work could not be attempted.

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