Study on Machinability of Aluminium Silicon Carbide Metal Matrix Composites

Rabindra Behera [a*], S.Kayal [b], N.R. Mohanta [c], G.Sutradhar [d]

[a*]Asst. Professor, Mechanical Engineering Department,Seemanta Engg. College, Mayurbhanj, Odisha;
[b]Research scholar, Mechanical Engineering Department, Jadavpur University, Kolkata,
[c] Faculty,Mechanical Engineering Department,Seemanta Engg. College, Mayurbhanj, Odisha;
[d]Professor,Mechanical Engineering Department, Jadavpur University, Kolkata.
Corresponding Author: E-mail: rabi_lisha@yahoo.com, Cell.: 09438461747

ABSTRACT

This paper presents the influence of machining parameters such as cutting forces and surface roughness on the machinability of LM6/ SiCp metal matrix composites at different weight fraction of SiCp. Machining tests were carried out at different cutting speed (i.e.30, 68 &103 m/min) and different depth of cuts (i.e.0.5, 1.0 & 1.5mm) at constant feed rate i.e. 0.05 mm/rev to study the machinability of as cast composites. It is observed that the depth of cut and the cutting speed at constant feed rate affects the surface roughness and the cutting forces during dry turning operation of cast MMCs. It is also observed that higher weight percentage of SiCp reinforcement imparts a higher surface roughness and needs high cutting forces. This experimental analysis and test results on the machinability of Al/SiC-MMC will provide essential guidelines to the manufacturers.

Keywords: Metal matrix composites, SiCp, Machinability, Surface roughness, Cutting forces.

INTRODUCTION

The applications of metal matrix composites (MMCs) are being increasing day to day in both the aerospace and automobile industries, because of their improved properties compared to monolithic metals. Today, among various metal matrix composites (MMCs) synthesized, aluminum metal matrix composites in general and discontinuously reinforced aluminum metal matrix composites, such as Al-SiCp/Al_2O_3 in particular, are emerged as the forerunner for a variety of general and special applications. This trend has been attributed to their superior specific strength and specific stiffness, high temperature capability, lower coefficient of thermal expansion, better wear resistance, improved dimensional stability, and amenability to conventional metal forming techniques [1-4]. In addition, development of stir casting route for synthesis has brought down their cost to an acceptable level compared to those processed by powder metallurgy and spray casting. However, the presence of discontinuous second phase particles offers superior mechanical and physical properties but on the other hand, it significantly influence their "machinability" as the presence of hard reinforcement particles makes them extremely difficult to machine as they lead to rapid tool wear. Although attempts were made to eliminate machining operation, such as near net shape forming and modified casting, they are limited and therefore machining is still an integral part of component manufacture. In addition, for many components, the production of good surface finish is essential [5–7].

Studies on machinability of light alloy composites reinforced with Al_2O_3/ SiC fibers/particles [8-12] indicate poor machinability due to abrasive wear of tools. Moreover, quality of the machined surface also deteriorates with tool wear [8].

Published literature on the machinability of particulate reinforced MMCs indicates that only polycrystalline diamond tools (PCD) provide a useful tool life when machining these materials with PCD tools, which is harder than alumina Al_2O_3 and silicon carbide (SiC) and it also does not have a chemical tendency to react with the work piece material. However, due to the extremely high cost of PCD tools, less expensive tools like cemented carbides and ceramics were also tried to machine these materials.

The present study has been carried out to study the machinability of the LM6/SiCp metal matrix composites at different weight fraction of SiCp with the help of tungsten carbide tool. The influence of machining parameters such as cutting speed and depth of cut at constant feed rate on surface roughness and the cutting forces (tangential, feed and radial forces) are also studied.

EXPERIMENTAL SETUP

The cylindrical SiCp reinforced LM6 MMCs are cast by stir casting method. The as cast MMCs are cut and the required samples (shown in Fig.1.) are prepared for machining purpose. Machining tests of the specimens is carried out in a conventional universal lathe machine (Golden Machinery Corporation, 8speeds ranges from 30 to 750 rpm). The cutting tool is fitted in a rigid tool holder SYSCON made SPL 20083. The selected cutting tool material is uncoated tungsten carbide. Chip breaker was not used during the experimental study and the machining tests are conducted under dry cutting process.

The cutting forces (Ft, Ff and Fr) are 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) are measured by using MITUTOYO make portable surface roughness tester. The selected machining parameters and the details of cutting tool used for experimentation are shown in Table 1 & Table 2.

Table- 1: Experimental Conditions

Cutting tool	Uncoated WC (K30)
Cutting speed(m/min)	30-68-103
Feed rate(mm/rev)	0.05 (Constant)
Depth of cut(mm)	0.5-1.0-1.5
Reinforcement ratio i.e.SiC_p (wt. %)	7.5-10-12.5

Table-2:Details of Cutting Tool Used for Experimentation

Tool material and grade	Uncoated tungsten carbide(WC)(K30)
Rake angle(^{0})	5
Clearance angle (^{0})	7
Cutting edge angle(^{0})	80
Nose radius (mm)	4

Fig. 1: As cast MMCs Samples Used for Testing of Machinability.

RESULT AND DISCUSSION

Cutting Forces

In the present investigation, dry turning operations have performed to evaluate the cutting forces. The cutting force 'Ft' (tangential component), feed force 'Ff' (thrust component) and 'Fr' the radial component are measured for analyzing the machinability characteristics of LM6/SiC-MMCs at different weight fraction of SiCp. The tangential component Ft, acts in the direction of cutting velocity vector is the main cutting force and is responsible for the cutting power needed. Figure 2 shows the effect of cutting speed on the cutting force (Ft), feed force (Ff) and radial force (Fr) at constant feed rate i.e.0.05 mm/rev and different depth of cut i.e.0.5mm, 1.0mm & 1.5mm, during machining of LM6/SiC-MMC reinforced with 7.5,10 and 12.5 wt% of SiCp respectively. The result shows that the cutting force components Ft, Ff and Fr were decreases on increasing the cutting speed of the composites i.e. reinforced with 7.5 wt%, 10 wt% and 12.5 wt% of SiCp. The figure also reveals that on increasing the weight fraction of SiCp in the matrix alloy the cutting forces are increases at the same cutting conditions, as on increasing the percentage of SiCp in cast MMCs, the hardness of the composites increases linearly.

Figure 3 shows the effect of depth of cut on the cutting force (Ft), feed force (Ff) and radial force (Fr) at constant 0.05 mm/rev feed and different cutting speed. The experimental results represent that for all the cast composites the cutting force components Ft, Ff and Fr were increases on increasing the depth of cut. The cutting force components i.e. Ft, Ff & Fr are higher at depth of cut 1.5mm comparison to 0.5 and 1.0mm depth of cut for the same conditions i.e. constant cutting speed and constant feed rate. This figure also shows that the cutting force components are increases on increasing the weight fraction of SiCp in the cast MMCs at the same cutting conditions. The cutting force components i.e. Ft, Ff & Fr are higher for the composite having 12.5wt% of SiCp comparison to composite having 7.5wt% and 10 wt% of SiCp at a constant cutting condition. The results shows that on increasing the weight percentage of SiCp in cast MMCs the required cutting forces are increased during machining of cast MMCs at dry condition.

Prof. A. Manna *et al.*[13] reported that during dry turning of Al/SiCp/15p with the help of uncoated tungsten carbide (WC) cutting tool, the cutting forces (i.e. feed force, Px & cutting force, Pz) are increases on increasing the feed rate and depth of cut at constant cutting speed. They also reported that on increasing the cutting speed, the cutting forces are decreases at constant feed (i.e. 0.5mm/rev.) and depth of cut (0.5 mm). This result (i.e. relation between cutting forces and cutting speed) is almost same to our result.

Surface Roughness

Surface roughness is one of the most important cutting parameter which evaluates the machinability of metal matrix composites. Surface roughness is the final surface quality formed after the machining on a specimen. The surface quality of a specimen is directly related with cutting speed, depth of cut and feed rate.

In the present study, the value of surface roughness of cast SiCp reinforced LM6-MMCs at different ratios has been investigated at selected cutting speed and depth of cut, keeping feed rate constant. The Fig. 4 shows the relationship between surface roughness and cutting speed at different depth of cut and constant feed rate of 7.5 wt%, 10 wt% and 12.5 wt % SiCp reinforced MMC material. It has found that both the value of surface roughness i.e. Ra & Rz decreases on increasing the cutting speed at different depth of cut and constant feed. The surface roughness is higher in case of samples having higher percentage of reinforcement compare to samples having relatively low percentage of reinforcement particles, that means the surface roughness values i.e. Ra and Rz are higher for composite material LM6/12.5wt%SiCp compared to LM6/10wt%SiCp and LM6/7.5wt%SiCp.

Figure 4 shows the relationship between surface roughness and depth of cut during dry turning operation of cast composites at different cutting speed and constant feed rate. The machining result shows on 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 samples having higher percentage of reinforcement particles i.e. SiCp have high surface roughness compare to MMC samples having lower percentage of reinforcement particles at constant cutting condition.

Chip Formation

The chip formation during machining has accompanied by very severe plastic deformation at the shear zone and owing to the lack of sufficient ductility of the work material. The addition of SiC particle reinforcement into the aluminium alloy matrix has caused 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 has also affected by the percentage of reinforcement particles in cast MMCs. It is observed that the sizes of chips are decreases on increasing the weight percentage of SiCp in cast MMCs. The photographs of turning operation in dry condition of the aluminium alloy MMCs are shown in Fig. 6. Figure 7 (a), (b) and (c) shows, the photographs of chips produced during machining of as cast LM6/ SiCp metal matrix composites.

The size of chips produced during machining of LM6/ SiCp metal matrix composites reinforced with 7.5 wt% SiCp are longer in comparison to the size of chips produced in case of 10 and 12.5 wt% SiCp reinforced

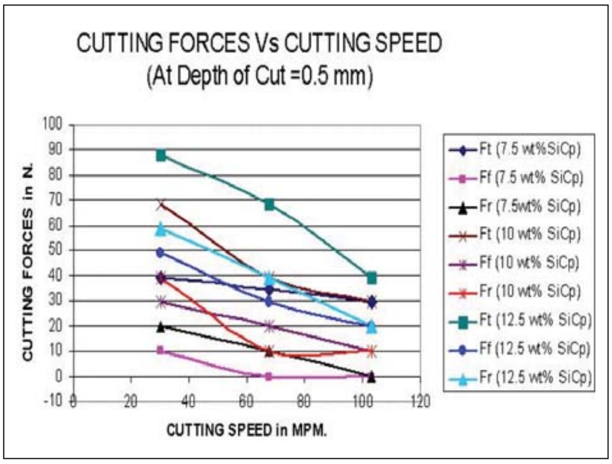

Fig. 2(a)

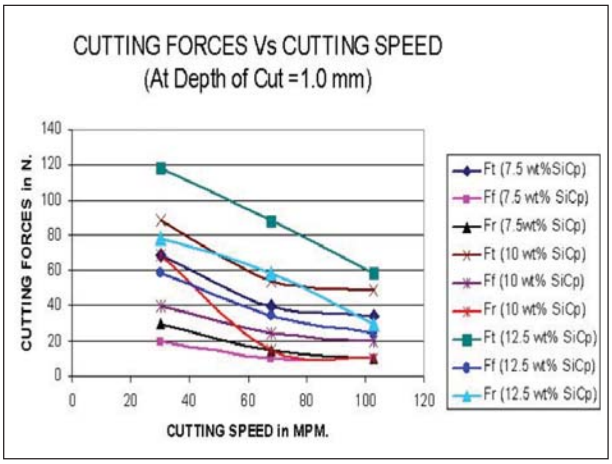

Fig. 2(b)

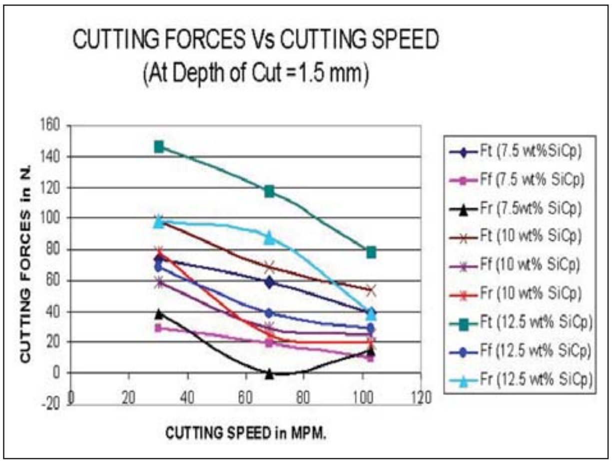

Fig. 2(c)

Fig. 2: Effect of cutting speed on cutting forces (Ft), (Ff) and (Fr) during machining of LM6/SiCpMMCs reinforced with 7.5,10& 12.5wt%SiCp at constant feed rate 0.05mm/rev and at (a) Depth of cut =0.5mm; (b) Depth of cut =1.0mm. and (c) Depth of cut =1.5mm.

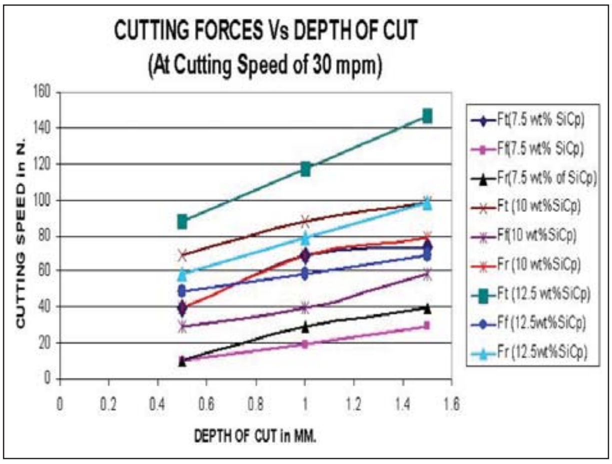

Fig. 3(a)

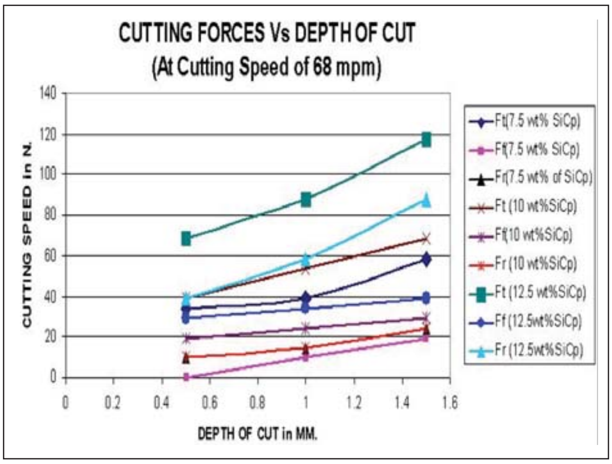

Fig. 3(b)

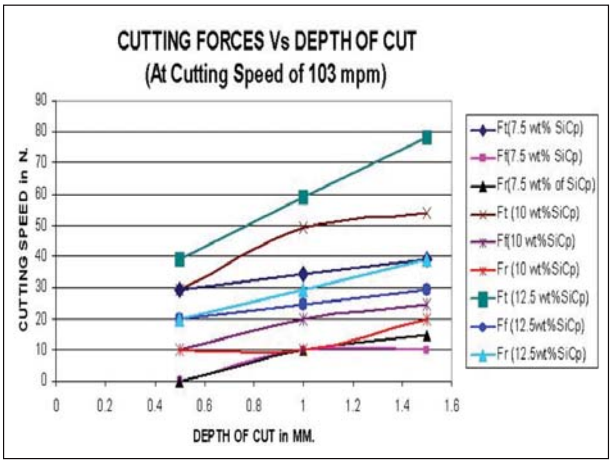

Fig. 3(c)

Fig. 3: Effect of depth of cut on cutting forces (Ft), (Ff) and (Fr) during machining of LM6/SiCp MMCs reinforced with 7.5,10& 12.5wt% SiCp at constant feed rate 0.05 mm/rev and at (a) Cutting speed =30mpm; (b) Cutting speed =68mpm and (c) Cutting speed =103mpm.

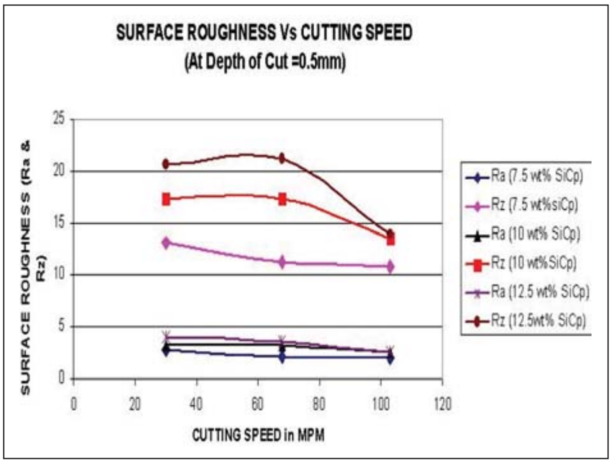

Fig. 4(a)

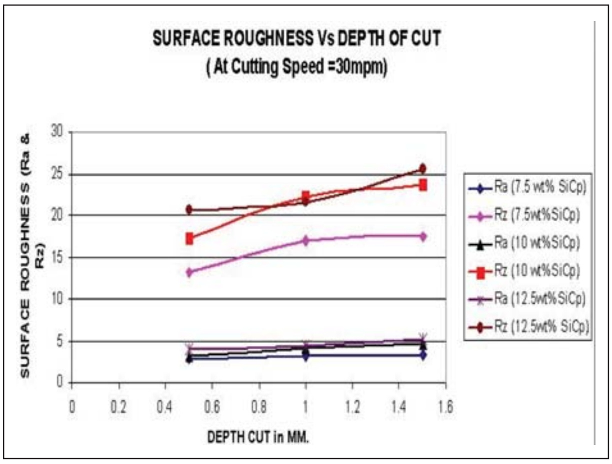

Fig. 5(a)

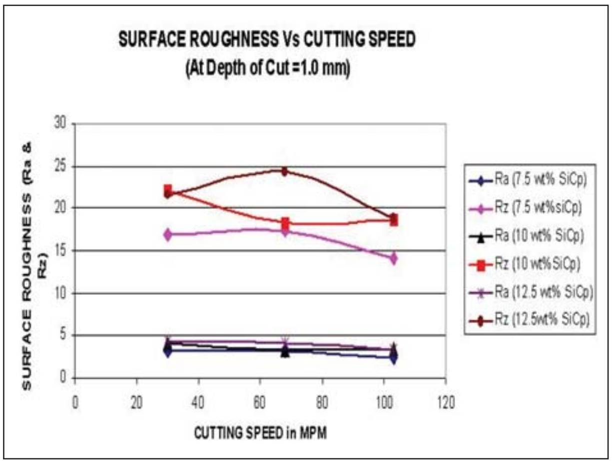

Fig. 4(b)

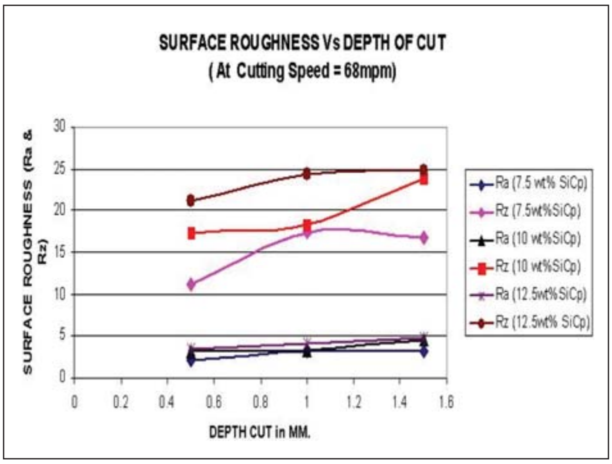

Fig. 5(b)

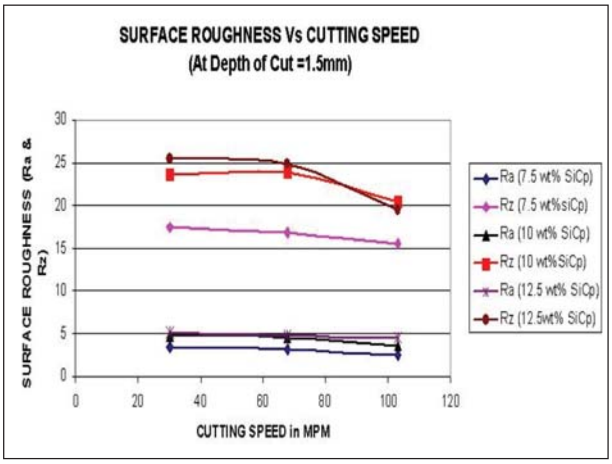

Fig. 4(c)

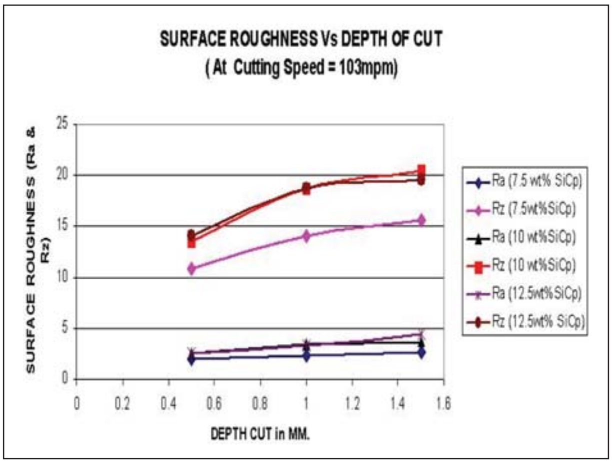

Fig. 5(c)

Fig.4: Effect of cutting speed on surface roughness (Ft), (Ff) and (Fr) during machining of LM6/SiCp MMCs reinforced with 7.5,10 & 12.5wt%SiCp at constant feed rate0.05mm/rev and at (a) Depth of cut =0.5mm; (b) Depth of cut =1.0mm. and (c) Depth of cut =1.5mm.

Fig. 5: Effect of depth of cut on surface roughness (Ft), (Ff) and (Fr) during machining of LM6/SiCp MMCs reinforced with 7.5,10 & 12.5wt%SiCp at constant feed rate0.05mm/rev and at (a) Cutting speed =30mpm; (b) Cutting speed =68mpm and (c) Cutting speed =103mpm

MMCs. As the presence of SiCp in cast MMCs increases the brittleness of the material, so the sizes of chips are gradually decreases. The results reveal that the cast MMCs reinforced with 7.5 wt% of SiCp is having good ductility property compared to MMCs reinforced with 10 and 12.5 wt% of SiCp.

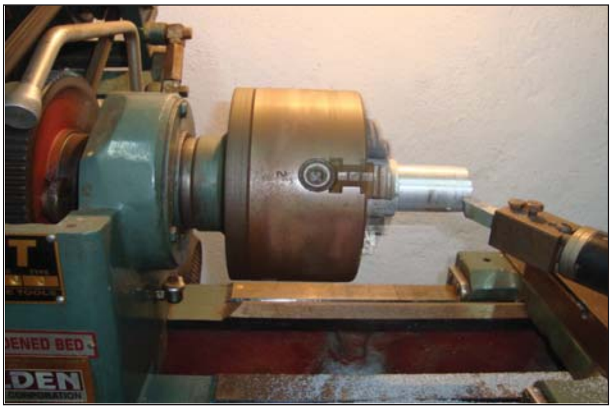

Fig. 6: Machining of as cast MMCs.

CONCLUSIONS

The experimental study on the machining parameters such as cutting forces and surface roughness of the as cast composites at different weight fraction of reinforcements, during dry machining of MMCs by using tungsten carbide cutting tools concludes the following points:-

§ The cutting forces (Ft, Ff &Fr) increased on increasing the depth of cut at constant feed rate and different cutting speed.

§ The cutting force components Ft, Ff and Fr were decreases on increasing the cutting speed of the composites at constant feed rate and different depth of cut.

§ The surface roughness of MMCs increased on increasing the weight percentage of SiCp in the matrix metal and it increases on increasing the depth of cut at constant feed rate and different cutting speed.

§ On increasing the cutting speed at constant feed rate and different depth of cut, the surface roughness decreases.

§ The sizes of chips are decreases on increasing the weight fraction of SiCp in the matrix metal

ACKNOWLEDGEMENTS

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.

I would also be thankful to Seemanta Engg. College, Mayurbhanj, Odisha, for providing financial assistance to attend this conference.

REFERENCES

1. Dinwoodie J. 1987, Automotive Applications for MMCsbased on Short Staple Alumina Fibres, SAE Technical Paper Series, Int Con Exp. Detroit, MI, February. p. 23-27.

(a) (b) (c)

Fig. 7: Size of Chips during machining of as cast LM6/ SiCp MMCs reinforced with (a)7.5 wt% SiCp, (b) 10 wt% SiCp and (c) 12.5 wt% SiCp.

2. Joshi S.S., Ramakrishnan N., Sarathy D. and Ramakrishnan P. 1995, Development of the Technology for Discontinuously Reinforced Aluminium Aomposites. In: Integrated Design and Process Technology. The First World Conference on Integrated Design and Process Technology, Austin. 1: 492-497.

3. Kocazac M.J., Khatri S.C., Allison J.E. and Bader M.G.1993, MMCs, for ground vehicle, aerospace and industrial applications. In: Suresh *et al*., (Eds). Fundamentals of Metal Matrix Composites. Butterworth, Guildford, UK. p. 297.

4. Rohatgi P.K. 1991, Cast Aluminium Matrix Composites for Automotive Applications, J. Organomet Chem. pp. 10-15.

5. Cronjager L and Meister D. 1992, Machining of Fibre and Particle Reinforced Aluminium. Ann CIRP. 41(1): 63-66.

6. Weinert K and Konig W. 1993, A Consideration of Tool wear Mechanism Metal Matrix Composite (MMC). Ann CIRP. 42(1): 95-98.

7. Loony LA, Monaghan JM, O'Reilly P and Toplin DRP.1992, The turning of an Al/SiC metal matrix composite. J.Mater Process Technol. 33(4): 453-468.

8. Lane C.T. 1990, Machining Characteristics of Particle reinforced aluminium. In: Proceedings of the Conference Fabrication of Particulate Reinforced Metal Composites, Montreal, Canada, 17-19, September. p. 204.

9. Chadwich G.A. and Heath P.J. 1990, Machining of Metal Matrix Composites. Met Mater. 2-6: 73-76.

10. Saga T. and Ikeda S. 1991, Turning Machinability of Al2O3-SiC short Fibre Reinforced ADC12 Aluminium Alloy Composites. J. Jap Inst Light Metals. 41(4): 264-269.

11. Tomac N. and Tonnessen K. 1992, Machinability of Particulate Aluminium Matrix Composites, Ann CIRP. 41(1): 55-58.

12. Chandrasekaran H. and Johansson J.O. 1997. Influence of Processing Conditions and Reinforcement on the Surface Quality of Finish Machined Aluminium Alloy Matrix Composites. Ann CIRP. 46(1): 493-496.

13. Manna A. and Bhattacharyya B. 2003, A study on machinability of Al/SiC-MMC, Journal of Materials Processing Technology. 140: 711-716.