Material Science Research India Vol. **7**(2), 425-433 (2010)

Cylindrical grinding of Al/SiC metal matrix composites

C.THIAGARAJAN[1]*, R. SIVARAMAKRISHNAN[2] and S. SOMASUNDARAM[3]

[1]Department of Production Engineering, St. Peter's Engineering College, Chennai - 600 054 (India).
Email: thiaguresearch@gmail.com
[2]Department of Production Technology, MIT Campus, Anna University Chennai - 600 044 (India).
[3]Department of Mechanical Engineering,
National Institute of Technical Teachers Training and Research, Chennai - 600 113 (India).

(Received: August 15, 2010; Accepted: September 21, 2010)

ABSTRACT

This paper deals with an experimental study on the grindability of Al/SiC metal matrix composites in cylindrical grinding. Machining of metal matrix composites (MMCs) is an area to be focused and finishing processes such as grinding to obtain a good surface finish and damage-free surfaces are crucial for the application of these materials. Nevertheless, grinding of MMCs has received little attention so far, thereby a detailed study on that has been carried out. In the present work, experiments are carried out to study the effect of grinding parameters; wheel velocity, work piece velocity, feed and depth of cut and SiC volume fraction percentage on the responses; grinding force, surface roughness and grinding temperature. Surface integrity of the ground surfaces is assessed using a scanning electron microscope (SEM). There are no cracks and defects found on the cylindrical ground surfaces at high wheel and work piece velocities, low feed and depth of cut.

Key words: Metal matrix composites; SiC particles; Grinding force; Surface roughness; Grinding temperature.

INTRODUCTION

Aluminium metal matrix composites (MMCs) are superior to other MMCs due to their low cost. There has been an increased interest in the use of composite materials in the recent past due to its unique physical and mechanical properties. MMCs are increasingly used in aircraft, automotive components, structural and electronic applications and military industries. Though MMCs possess superior properties they have not been widely applied due to their higher manufacturing cost and also due to poor machinability[1,2]. Although components made of these materials, can be produced by near-net shape manufacturing, they usually require subsequent machining to achieve the desired geometry, assembling tolerance and surface integrity[3].

Main difficulties such as fabrication, machining and cost have to be overcome while applying composites in different applications[4]. While machining of MMCs the subsurface damages are caused due to conventional and unconventional processes, making it inevitable for finishing processes such as grinding to improve the surface integrity[5]. Grinding is particularly needed to acquire high dimensional accuracy and surface finish. However, grinding of silicon carbide is difficult because of its low fracture toughness, making it very sensitive to cracking[6]. This makes the grinding of aluminium MMCs a difficult and unpredictable process. Unlike the investigations into the machining of traditional metallic materials, relatively little study has been carried out on machining advanced composite materials.

Previous studies on grinding of composites have shown that Al/SiC composites exhibit an improved grindability with respect to non-reinforced aluminium alloy for the better surface finish and the lower tendency to clog the wheel[7]. Sun et al.[8] studied the grinding characteristics of SiC particle reinforced Aluminium based MMCs. He reported that grinding is one of the final processes for finishing aluminium composites to obtain good surface quality and high machining accuracy. The wide application of MMCs will not be possible without the solution of the grinding problems. Zhaowei Zhong et al.[9] and N.P Hung et al.[10] presented the study on grinding of aluminium composites reinforced with SiC particles. They recommended that rough grinding with a SiC wheel followed by fine grinding with a fine-grit diamond wheel are required for the grinding of alumina/aluminium composites.

Di Ilio[11] made a comparison between conventional abrasives and super abrasives in grinding of SiC-Aluminium composites. They revealed that among the types of grinding wheels employed in experimental tests, the wheels manufactured with conventional abrasives and open structure have given better performances than those with super abrasives in terms of low clogging, low grinding forces and better surface finish. Li *et.al.,*[12] reported a study on grinding forces and force ratio of the unsteady-state grinding technique. He found that accurate measurement of the grinding force has great research value and practical significance on studies in the field of grinding. The properties of a ground surface depend on the grinding temperature, knowledge of its magnitude is important to establish the grinding conditions[13-15].

However, reports on cylindrical grinding of composites are still very scarce. Therefore, a further study on the cylindrical grinding of these materials is an area to be focused to obtain damage-free surfaces for the application of these materials. Previous researches [5-8] were carried out the experimental work on the grindability of Al/SiC composites in surface grinding, where as this paper focuses the research work on the grindability of Al/SiC composites in cylindrical grinding.

Nomenclature

d	=	Depth of cut, mm
F_T	=	Tangential Grinding Force, N
f	=	Feed, m/min
G_T	=	Temperature, °C
P	=	Power, kW
Ra	=	Surface roughness, mm
Vs	=	Wheel Velocity, m/min
Vw	=	Work Piece Velocity, m/min

EXPERIMENTAL

Parameter Study and Volume Fraction Study

In this section, experimental procedure is explained with all the details which require producing experimental data to use in the parameter study and volume fraction study. The Al/SiC composite specimens are cast aluminium alloys reinforced with 13 µm SiC particles of the size diameter 30 X 200 mm. The details of the specimens LM25/SiC/4p (4Vol% SiC) and LM25/SiC/2p-12p (2 to 12 Vol% SiC) are shown in Table 1. Grinding experiments are carried out on a horizontal spindle cylindrical grinding machine (Type – G13 P HMT).

The experiments for parameter study are planned using a complete 3^4 factorial design. Based on this, a total of 81 experiments, each having a combination of different levels of variables are carried out and the details are shown in Table 2.A vitrified-bonded white aluminium oxide grinding wheel (AA60K5V8) is used to grind the MMC specimens LM25/SiC/4p (4Vol % SiC) at low, medium, and high levels of grinding variables for parameter study. The specimens LM25/SiC/2p-12p (2 to 12 Vol% SiC) are also ground with white aluminium oxide grinding wheel for volume fraction study at medium level grinding parameters of Vs 2026 m/min, Vw 12.72 m/min, f 0.09 m/min and d 20 µm as shown in Table 3

Measurement of responses

The responses tangential grinding force (F_T), surface roughness (Ra) and grinding temperature (G_T) are monitored and measured while grinding Al/SiC composite specimens. A Variable Frequency Drive (VFD) (ACS 350-03E–12A5–4 ABB Make) is attached to the grinding wheel motor so that the wheel is capable of changing speed. A VFD is a system for controlling the rotational speed of an alternating current (AC) electric motor by controlling the frequency of the electrical power supplied to the motor. The tangential grinding force (F_T), tangent to the wheel-work contact, when multiplied by wheel speed (V_S) and a constant, determines the power used by the operation (ASM Metals Hand book: Machining [16], Vol.16, 1989). The equation for Power is:

$$P = \frac{F_T V_S}{33000} \quad ...(1)$$

Equation (1) for power is valid for horse power, using pounds of force and feet per minute for F_T and V_S, respectively. And the VFD is utilized to measure the power of the grinding wheel motor, so that the tangential grinding force (F_T) can be calculated from the above Eq. (1).

The surface roughness of the cylindrical ground specimens is measured in the direction perpendicular to the grinding direction using a surface roughness tester (Kosaka Make–Surfcorder–SE1200). The cut-off is 0.8 mm and evaluation length is 4 mm. On each ground surface three values are measured to calculate the average surface roughness value (Ra). An infra red non contact Laser thermo meter (METRAVI MT-9) is used to measure the temperature generated during cylindrical grinding with a standoff distance of 15 cm from the wheel-work interface and emissivity correction of 0.02. Before every grinding experiment, dressing is carried out. A single point diamond dresser is used for the dressing of Al_2O_3 grinding wheels. Surface integrity of the cylindrical ground surfaces is assessed using a scanning electron microscope (SEM). The samples are observed in the as-ground condition.

RESULTS AND DISCUSSION

Effect of grinding variables on responses

The significance of the cylindrical grinding variables on the selected responses is evaluated by conducting experiments and the results are represented by graphs. The effect of grinding variables on tangential grinding force (F_T), surface roughness (Ra) and grinding temperature (G_T) is shown in Figs. 1 to 3.It is observed from the results shown in Fig. 1 that the tangential grinding force decreases with an increase in wheel velocity and work piece velocity. This could be attributed to the thermal induced softened matrix at high speeds. As the grinding wheel velocity increases, the heat generated in the deformation zone increases and thereby softening the aluminium matrix thus reducing the force required to remove the material.

Table 1: The details of metal matrix composites machined

Material	LM25 / SiC / 4p Parameter study	LM25 / SiC / 2p-12p Volume fraction study
Matrix	LM25 Aluminium alloy	LM25 Aluminium alloy
Reinforcement	4 Vol% SiC particulate particle size: 13 µm	2, 4, 8, 12 Vol % SiC particulate particle size: 13 µm
Process	Stir Casting Melting Al at 800°C Heating SiC at 1000°C Stirring speed: 125 rpm	Stir Casting Melting Al at 800°C Heating SiC at 1000°C Stirring speed: 125 rpm

Table 2: Grinding variables used for parameter experiment

Symbol	Variables	Levels		
		1	2	3
Vs	Cutting speed of grinding wheel (m/min)	1414	2026	2639
Vw	Cutting speed of work piece (m/min)	6.11	12.72	26.72
f	Feed- Work table traverse (m/min)	0.06	0.09	0.17
d	Depth of cut (µm)	10	20	30

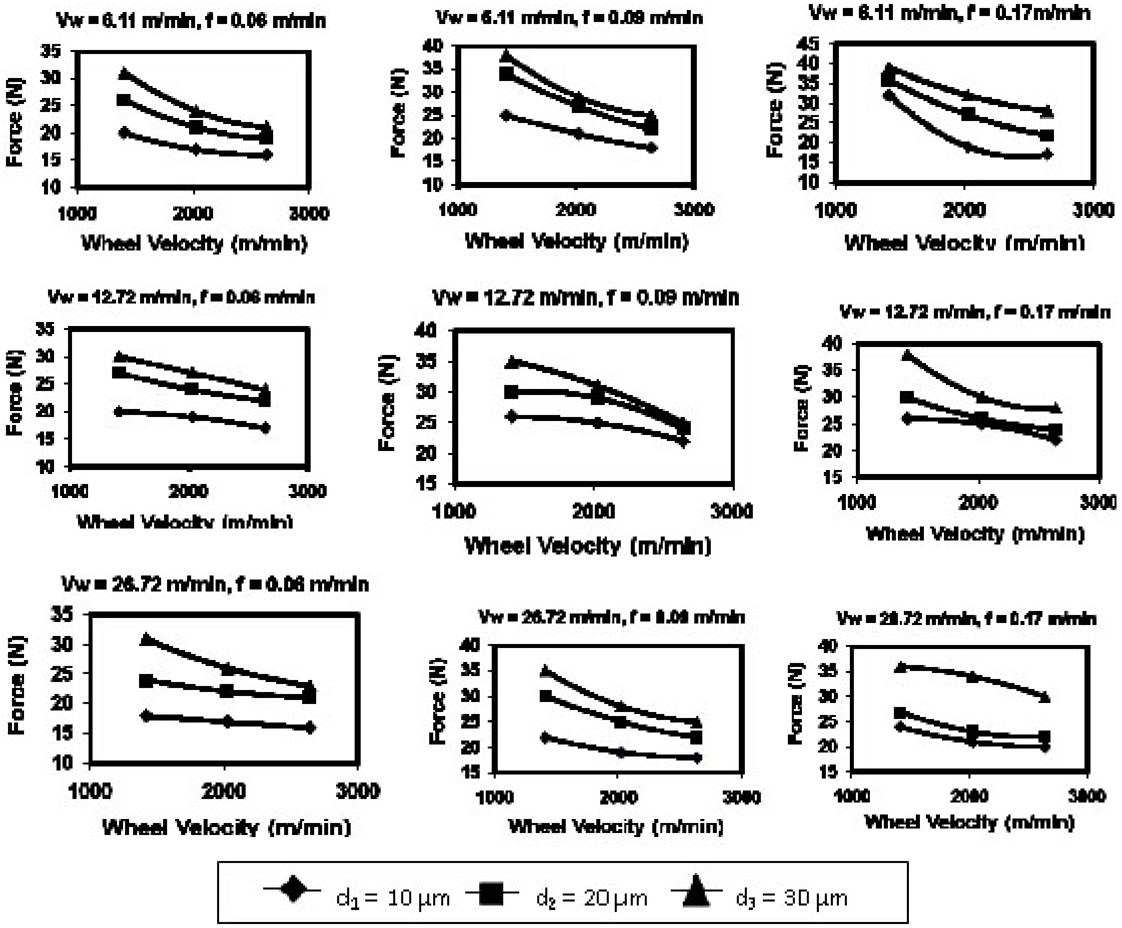
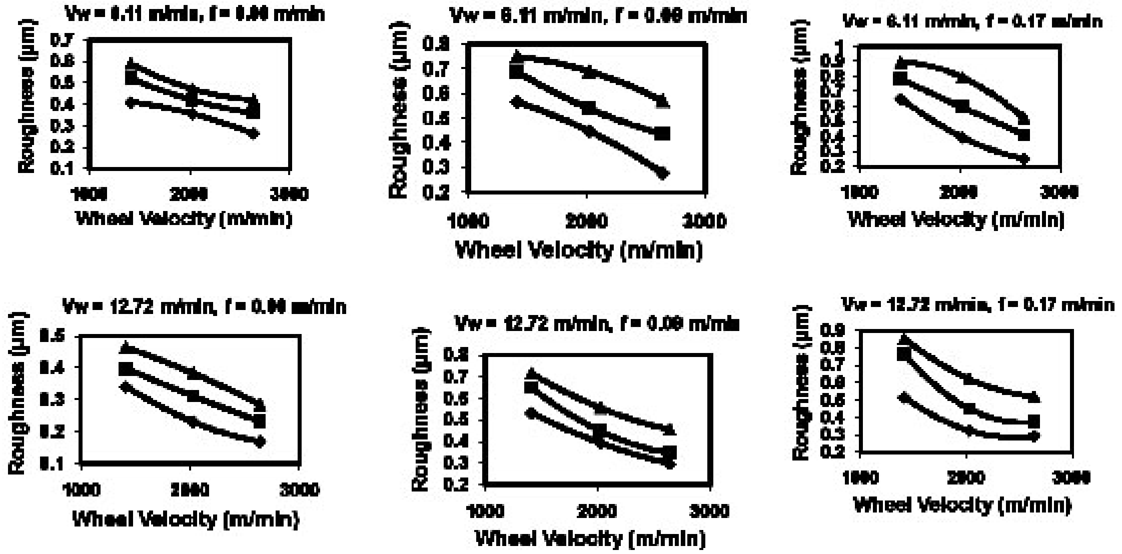


Fig. 1: Effect of grinding variables on tangential grinding force



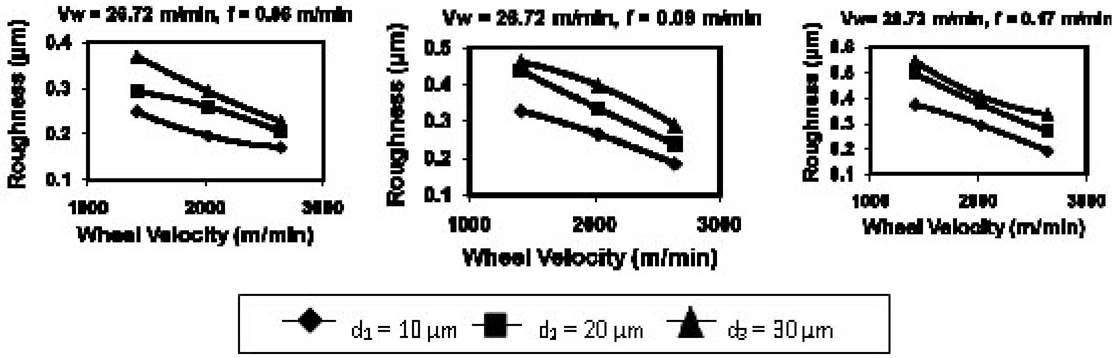


Fig. 2: Effect of grinding variables on surface roughness

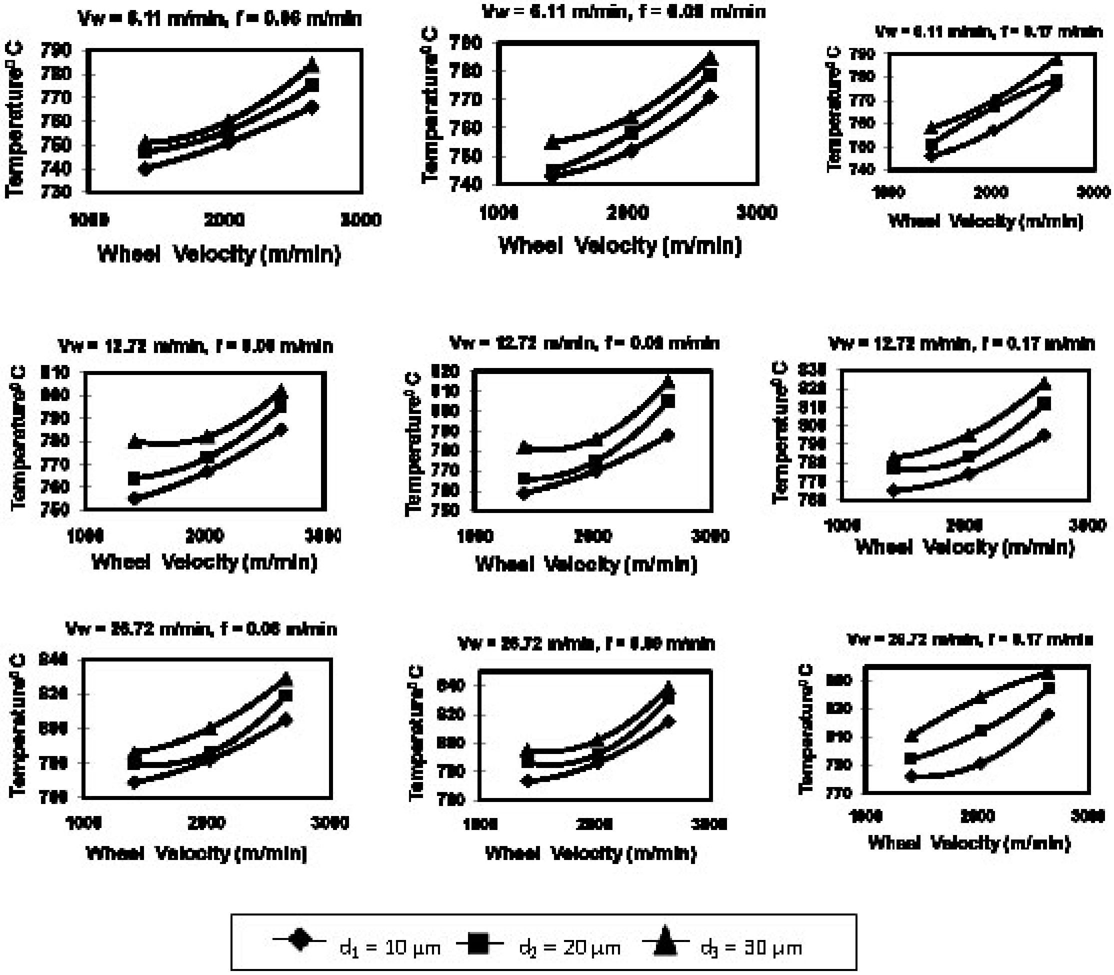


Fig. 3: Effect of grinding variables on grinding temperature

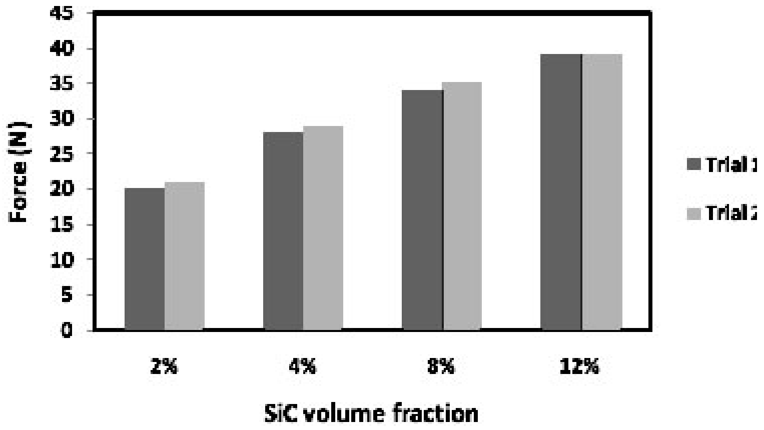


Fig. 4: Effect of SiC volume fraction percentage on tangential grinding force

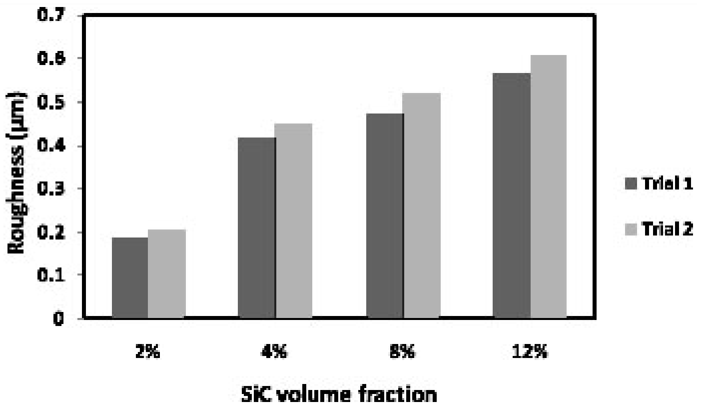


Fig. 5: Effect of SiC volume fraction percentage on surface roughness

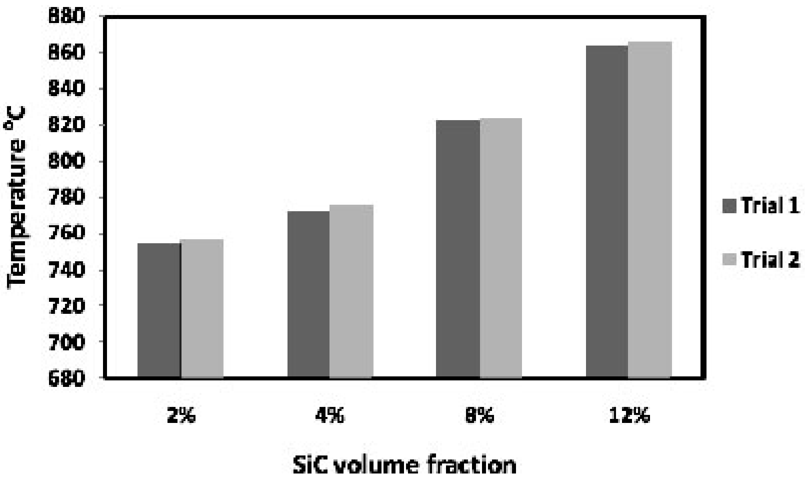


Fig. 6: Effect of SiC volume fraction percentage on grinding temperature

It is shown in Fig. 2 that the surface roughness decreases with an increase in wheel velocity and work piece velocity. This is due to the increase in relative velocity between the wheel and work piece and the reduction in contact time thereby reducing the chip thickness. It is also observed from the Figures 1 and 2 that the tangential grinding force and surface roughness increase with an increase in feed and depth of cut. When the feed and depth of cut are increased, the increase in material removal rate and the increase in chip thickness, account for the increase of the F_T and Ra values. The minimum and maximum values of F_T and Ra are obtained as 16N, 0.171 µm and 39N, 0.893 µm respectively at wheel velocities between 2639 m/min and 1414 m/min, work piece velocities between 26.72 m/min and 6.11 m/min, table feed between 0.06 m/min and 0.17 m/min and depth of cut between 10 µm and 30µm.

It is found from the results shown in Fig. 3 that the grinding temperature increases with an increase in wheel velocity (Vs), work piece velocity (Vw), feed (f) and depth of cut (d). The higher values

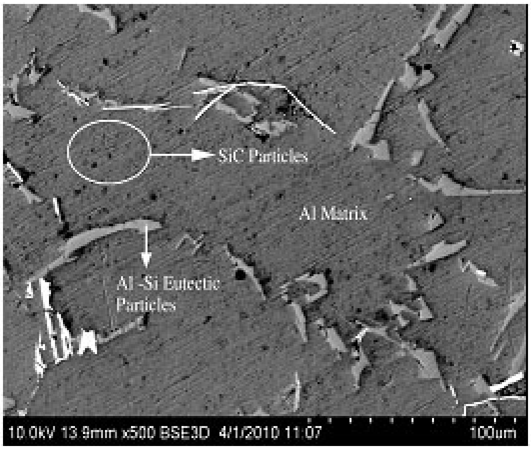


Fig. 7: Uniform distribution of the SiC particles in Aluminium Matrix

Fig. 8: Rough ground surface of LM 25/SiC/4p (Vs 1414 m/min, Vw 6.11 m/min, f 0.17 m/min, doc 30 µm)

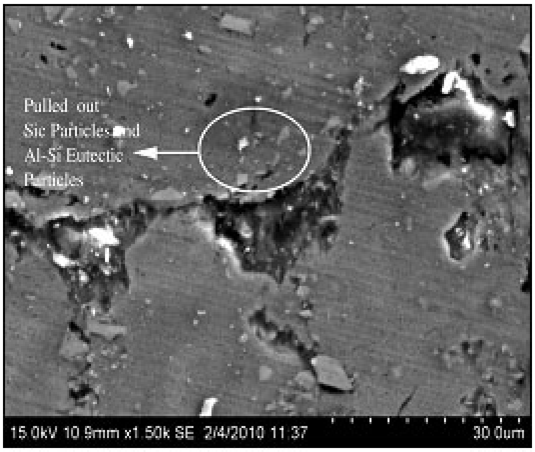


Fig. 9: Rough ground surface of LM 25/SiC/4p with high Magnification (Vs 1414 m/min, Vw 6.11 m/min, f 0.17 m/min, doc 30 µm)

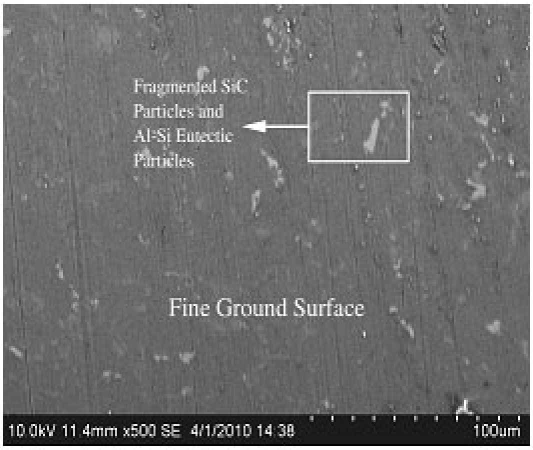


Fig. 10: Fine ground surface of LM 25/SiC/4p (Vs 2639 m/min, Vw 26.72 m/min, f 0.06 m/min, doc 10 µm)

of Vs, Vw, f, d results in higher grinding temperature due to the increase of the energy required to grind a unit volume of the metal. The G_T values are scattered in the range of 740°C-856°C at the lower and higher levels of grinding variables. The results comply with the trends available in the literature (6,13).

Effect of SiC volume fraction on responses

The effect of percentage of SiC volume fraction on tangential grinding force (F_T), surface roughness (Ra) and grinding temperature (G_T) is shown in Figs. 4 to 6. It is found from these figures that the F_T, Ra, G_T values increase with an increase of percentage of SiC volume fraction. This is mainly due to the increased resistance to material removal which is a result of increased amount of SiC particles in unit volume of the material. The minimum and maximum values of F_T, Ra and G_T are obtained as 20 N, 0.187µm, 754°C and 39N, 0.606µm, 866°C respectively for the specimens of 2% and 12% SiC volume fractions at constant medium level grinding parameter of Vs 2026 m/min, Vw 12.72 m/min, f 0.09 m/min and d 20 µm. The results comply with the trends available in the literature (5).

SEM analysis of cylindrical ground surface

The surface texture of the cylindrical ground specimens are assessed using a scanning electron microscope. The SEM micro structure of the specimen LM 25/SiC/4p in Fig. 7 shows the uniform distribution of the SiC particles in the aluminium matrix before grinding. In general, the SiC particle distribution is nearly identical in all the specimens observed. It also shows the presence of Al-Si eutectic particles in spike form. Figure 8 shows the SEM micrograph of rough ground surface. This figure shows that the Al_2O_3 grains of the wheel are embedded with the rough grinding marks on the surface of the work piece at low wheel and work piece velocities, high feed and depth of cut.

Table 3: Percentage variation of SiC used for volume fraction experiment

No	Aluminium %	SiC Volume Fraction %
1	98	2
2	96	4
3	92	8
4	88	12

Figure 9 shows the rough ground surface with high magnification (1500X). This micrograph clearly reveals that at low wheel and work piece velocities, high feed and depth of cut, the SiC particles are not ground but are fragmented and pulled out of the surface. Figure 10 shows the SEM micrograph of fine ground surface. The fine grinding marks shown on the SiC particles in this figure ensured that both the SiC particles and aluminium matrix are removed by cylindrical grinding at high wheel and work piece velocities, low feed and depth of cut. During the cylindrical grinding, the aluminium matrix has undergone plastic deformation and the SiC particles are covered by aluminium matrix. There are no cracks and defects found on the fine ground surfaces when observed with the SEM. Hence, the potential of using Al_2O_3 wheels, for the cylindrical grinding of Al/SiC composites is high. Grinding parameters should be optimized to make the cylindrical grinding using Al_2O_3 wheels more attractive.

CONCLUSIONS

The investigations of this study indicated that the grinding variables; wheel velocity, work piece velocity, feed and depth of cut are the primary influencing factors which affect the surface integrity of Al/SiC composites during cylindrical grinding. Based on the experimental results and discussions, the following conclusions are drawn:

- Better surface finish and damage free surfaces are obtained due to low grinding force at high wheel and work piece velocities with white Al_2O_3 wheels during cylindrical grinding.
- The surface finish and damaged surfaces are found to be high at high feed and depth of cut during cylindrical grinding.
- The experimental work demonstrates that the tangential grinding force developed during cylindrical grinding can be calculated from power measurements of the grinding wheel motor, using a Variable Frequency Drive (VFD).
- The approach presented in this paper for cylindrical grinding of Al/SiC composites can be extended with super abrasive grinding wheels like diamond and CBN.

REFERENCES

1. Adem Onat, Hatem Akbulut and Fevzi Yilmaz, 'Production and characterization of silicon carbide particulate reinforced aluminium-copper alloy matrix composites by direct squeeze casting method', *Journal of Alloys & Compounds*, **436:** 375-382 (2007).
2. Kwak J.S. and Kim Y.S.,'Mechanical properties and grinding performance on Aluminum-based metal matrix composites', *Journal of Materials Processing Technology*, **20:** 596-600 (2008).
3. Anand Ronald B., Vijayaraghavan L. and Krishnamoothy R,'Studies on the influence of grinding wheel bond material on the grindability of metal matrix composites', *Journal of Materials and design*, **30:** 679-686 (2009).
4. Manna B. and Bhattacharayya, 'A Study on machinability of Al/SiC-MMC', *Journal of Materials Processing and Technology,* **140:** 711-716 (2003).
5. Zhong Z.W.,'Grinding of Aluminium-based metal matrix composites reinforced with Al_2O_3 or SiC Particles', *International Journal of Advanced Manufacturing Technology,* **21**: 79-83(2003).
6. Anne Venu Gopal. and Venkateswara Rao, P.,'Selection of optimum conditions for maximum material removal rate with surface finish and damage as constraints in SiC grinding', *International Journal of Machine Tools & Manufacture*, **43:** 1327-1336(2003).
7. Di Ilio A., Paoletti A., Tagliaferri V. and Veniali F., 'An experimental study on grinding of silicon carbide reinforced aluminium alloys', *International Journal of Machine Tools Manufacturing*, **36**: 673-685(1996).
8. Sun F.H., Li X.K., Wang Y. and Chen M., 'Studies on the Grinding Characteristics of SiC Particle Reinforced Aluminium-based MMCs', *Key Engineering Materials*, **304-305**: 261- 264(2006).
9. Zhaowei Zhong. and Nguyen Phu Hung., 'Grinding of alumina/aluminum Composites', *Journal of Materials Processing Technology,* **123:** 13-17(2002).
10. Hung N.P., Zhong Z.W. and Zhong C.H., 'Grinding of Metal matrix composites reinforced with silicon carbide particles', *Journal of Materials and Manufacturing Processes*, **12**: 1075- 1091(1997).
11. Di Ilio A. and Paoletti A.,'A Comparison between conventional abrasives and super abrasives in grinding of SiC-Aluminium composites', *International Journal of Machine Tools & Manufacture*, **40:** 173-184(2000).
12. Li Z.C., Lin B., Xu Y.S and Hu J., 'Experimental studies on grinding forces and force ratio of the unsteady-state grinding technique', *Journal of Materials Processing Technology*, **129**: 76-80(2002).
13. Nee A.Y.C. and Tay A.O., 'On the measurement of surface grinding temperature. *International Journal of Machine Tools & Manufacture*, **21**: 279-291(1981).
14. Shaw M.C.,'The importance of temperature in grinding', *Journal of Mechanical Working Technology,* **17:** 343-355(1988).
15. Obikawa T. and Shinozuka J., 'Analysis of grinding temperature considering surface generation Mechanism', *Key engineering materials,* **291-292**: 97-102(2005).
16. ASM International Hand book committee., ASM Hand book: Vol.16 for Machining, Materials park: Ohio, USA, 421-429(1989).