Proceedings of the
International Conference on Mechanical Engineering 2003
(ICME2003) 26- 28 December 2003, Dhaka, Bangladesh

ICME03-TH-02

ANALYSIS OF TEMPERATURE DISTRIBUTION IN GRINDING OF COMPOSITES USING FINITE ELEMENT METHOD

Sundaram. S., Anantharaman. N., Ravikumar. K., and Vijay Anand. S.

Department of Manufacturing Engineering, Annamalai University, Annamalai Nagar – 608 002, INDIA

ABSTRACT
In this investigation, experiments were carried out to understand the influence of various grinding parameters like wheel speed, workspeed and depth of cut on the grinding temperature at the surface of the Al-SiC_P composite workpiece with different grinding wheels. The temperature distribution within the workpiece was studied by simulating the grinding process and using finite element analysis package with transient thermal analysis. Specific energy as the input, the temperature distribution for dry grinding condition and with coolant were analysed. The wheel loading was quantified by conventional methods. The temperature at the surface is much lower for composite materials than steel. The influence of various grinding parameters on the surface temperature are marginal. Eventhough partition ratio is lower for diamond, but the temperature developed at the surface is more for diamond compared with other wheels. The affinity to wheel loading is more for diamond wheels than other wheels. The CBN shows better results than other wheels. The influence of coolant is significant.

Keywords: Surface grinding, particulate composites, FEM, transient thermal analysis, wheel loading.

1. INTRODUCTION
Machining of metal matrix composites (MMC) is an area full of open questions such as assessment of machinability, and tool wear. Conventional cutting, turning, milling and grinding operations can usually be applied to MMCs, but there is often a problem of excessive tool wear [1]. Extremely high tool wear due to the abrasive action of the ceramic fibers or particulates necessitates materials of very high resistance to abrasive wear like polycrystalline diamond tipped tools. Aluminium reinforced with SiC whiskers has, for example been found to be more difficult to machine than other composites containing weaker fibers[1]

The grinding of MMCs has received little attention. A. Di Ilio et al [2] carried out experimental study on grinding of silicon carbide reinforced aluminium alloys and concludes that Al-SiCp 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. Z.W. Zhong et al [3] reports diamond grinding of aluminium based MMCs reinforced with either SiC or Al_2O_3 particles and concludes that grinding using diamond wheel at depths of cut of 1 or 0.5 μm produced ductile streaks on the Al_2O_3 particles and the SiC particles respectively and no subsurface damage except rare cracked particles. A Di Ilio et al [4] conducted experimental studies on the grindability of metal matrix composites, using conventional and super abrasive wheels, concluded that conventional abrasive grinding wheels have shown better results, in terms of grinding force, surface roughness and flat area percentage than super abrasive ones.

The high grinding energy required for the grinding process are converted into heat which produces various types of thermal damages. An estimation of abrasive machining temperature and an understanding of their role in producing residual stresses and metallurgical changes on machined surfaces are critical to the production of engineered components having controlled surface properties [5]. Malkin [6] notes that of the various techniques to measure grinding temperatures, only the embedded thermo-couple has been shown to provide a reasonable good indication of the workpiece temperature near the ground surface which correlates rather well with thermal damage.

J.C. Jaeger's [7] analysed the temperature distribution within the workpiece by employing a moving heat source on the surface of a semi-infinite body. A Misra et al. [8] used the same techniques to calculate the temperature distribution and applied Finite Element Technique to analyse the residual stresses.

An attempt has been made to understand the thermal aspects of grinding Al-SiCp composites and the influence of various grinding parameters on the workpiece temperature. The distribution of grinding temperature within the workpiece has been studied using Finite Element Packages.

2. EXPERIMENTAL SETUP AND PROCEDURE

The experiments were carried out in a horizontal hydraulic surface grinder with workspeed can be varied infinitely within a range and with grinding wheel speeds 2800, 3250 and 4450 rpm. The depth of cut or down feed can be controlled automatically. The forces were measured using strain gauge two component grinding force dynamometer within a range of 0.01mv – 3 v. The strain gauge dynamometer was calibrated by means of proving ring before carrying out the grinding tests. The power measurements were carried out using two watt meters connected at the spindle of the grinding machine.

The measurements were carried out at no load condition and load conditions.

The temperature measurements were carried out using a copper-constantan thermocouple embedded in a split workpiece as explained by Nee et al [9]. Prior to the tests, the thermocouples were calibrated.

Workpiece material LM-25 Aluminium metal matrix particulate composites with reinforcement of SiC of volume percentage 15 with workpiece dimensions 205 x 80 x 30 mm^3 supplied by the regional research laboratory (RRL) Trivandurm, India were used. The properties of the workspiece material are

Yield stress - 329 MN/m^2
Ultimate tensile stress - 336 MN/m^2
% Elangation – 0.3
Elastic Modulus - 91GN/m^2

Table 1: Characteristics of grinding wheels employed

Wheel type	Size of wheel	Grit Size	Bond type
SiC	150x31.75x13	46/60	vitrified
CBN	150x10x2	120/140	Resinoid
Diamond	175x10x2	100/120	Resinoid

The following dressing procedures were carried out in every test. A single point diamond dresser titled 15° inclined to the wheel radius and all the traces of wheel loading were removed. Then two consecutive passes with radial dressing at depth of 20μm were carried out followed by five spark out passes. The load was kept constant and for each measurement, three readings were taken to ascertain the repeatability and the average of the values was taken. The wheel loading were measured by conventional method.

3. RESULTS AND DISCUSSION

The calculated specific grinding energy from the power measurements using the relation

$$U = P/V_w ab \qquad (1)$$

were shown in graphs Fig (1) & (2). The variation of specific grinding energy against various depth of cut for different work speeds (Fig.1) shows increase in depth of cut (doc) results in decrease in specific

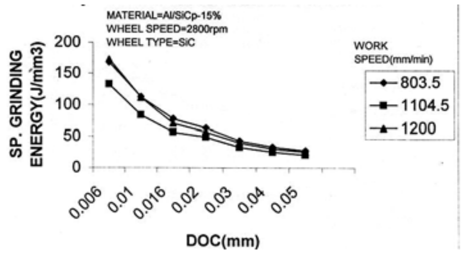


Fig. 1. Sp. Grinding Energy Vs. doc

grinding energy. The specific grinding energy is higher for low and higher work speeds and lower for medium work speeds. Since at lower work speeds the time of contact between the work and the wheel is more which could have been the reason for higher specific grinding energy. The increase in temperature is more for higher work speeds as shown in fig(5) resulting in increased wheel loading and consequent to that the energy required may be more. The variation of specific energy against different depth of cut for different type of wheels in Fig(2) shows higher specific grinding energy for SiC wheels followed by Diamond wheels and CBN wheels in that order.

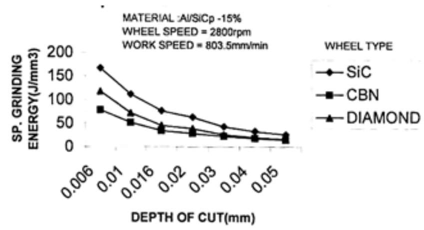


Fig. 2. Sp. Grinding Energy Vs. doc

4. INFLUENCE OF GRINDING PARAMETERS ON TEMPERATURE

The variation of temperature against depth of cut shows an increase in temperature upto a depth of cut of 0.02mm and then decreases for

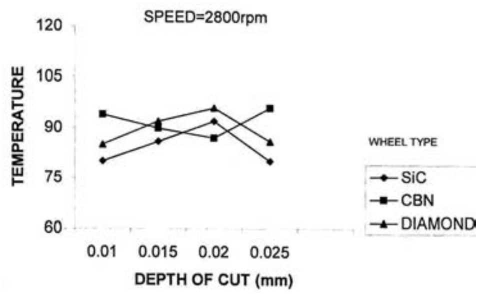


Fig. 3. Temperature Vs. Depth of Cut

both SiC and Diamond wheels. But for CBN wheels, the temperature decreases initially and then increases. It is observed that the wheel loading plays significant role in this phenomenon which will be discussed later. As the wheel speed Fig.(4) increases the temperature also

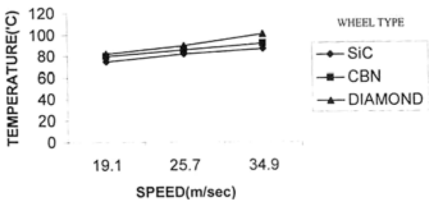


Fig. 4. Temperature Vs. Speed

increases linearly for all types of wheels. Similar trend exists against work speed also as seen in Fig.(5).

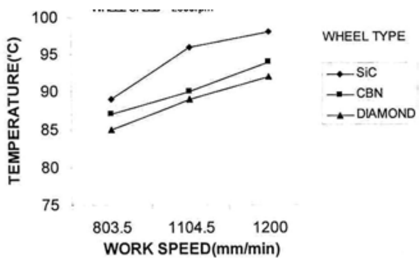


Fig. 5. Temperature Vs. Work Speed

The quantitative measurement of wheel loading phenomenon for different wheels are shown in Fig(6) which shows the

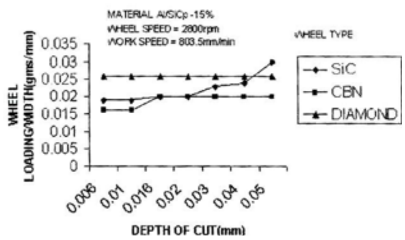


Fig. 6. Wheel Loading Vs. Depth of Cut

greater affinity of the diamond wheel for wheel loading, followed by SiC and CBN wheels.

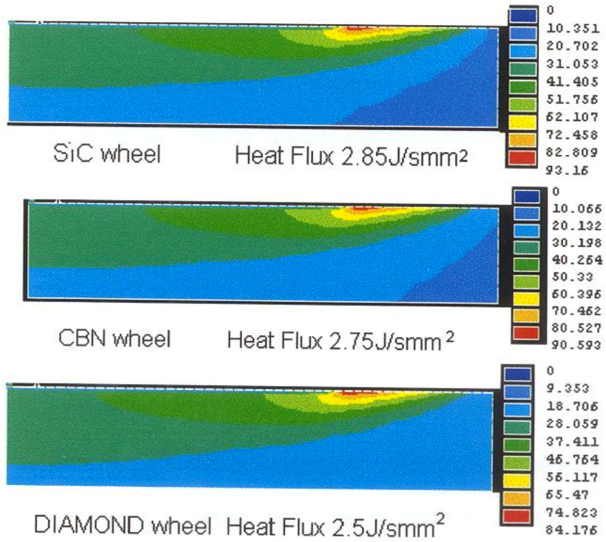
5. FEM ANALYSIS WITHOUT COOLANT

Conduction heat transfer that take space in the work-piece by virtue of temperature difference is analysed using plane 55 of ANSYS(5.4) for 2D elements of 4 noded rectangular type. The continuum was divided into 441 elements with totalling 500 nodes. The material properties of the workpiece were calculated using rule of mixtures [1] and the calculated material properties are shown in Table (2)

Table 2 – Properties of Al-SiC$_P$ composite

Properties	Values
Density	3210 kg/m^3
Specific heat	710J/kg 'K
Thermal Conductivity	100 J/s m 'K

The heat flue which enters the workpiece was calculated by multiplying the total heat input calculated from the measured power input with partition ratio of the grinding wheel which is arrived using the equation developed by Chandrasekar et al [5]. Since the ANSYS-5.4. doesn't have the provision for moving heat source, a programme was written to make the thermal load as a moving heat source. At the top of the workpiece the heat flux enters and the other sides are surrounded by atmospheric air. The calculated partition ratio are for SiC 0.81, for CBN – 0.59 and for Diamond 0.32. The temperature distribution in the workpiece is shown in Fig.(7) which indicate close agreement.



Depth of Cut 0.02mm, Work Speed 1200 mm/min
Fig. 7. Temperature Distribution Through FEM (With out Coolant)

with measured values and thus validate the usefulness of the above model. The results indicates that the workpiece is not much affected by thermal loading of the workpiece and the effect is confined to a very small depth of the workpiece.

6. FEM ANALYSIS WITH COOLANT FOR CBN WHEEL

The measured temperatures while grinding with mineral oil mixed with 20 times water is shown in Fig.(8). The temperature

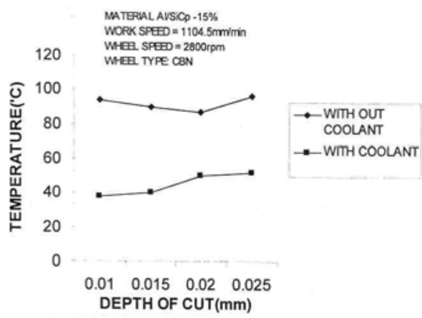
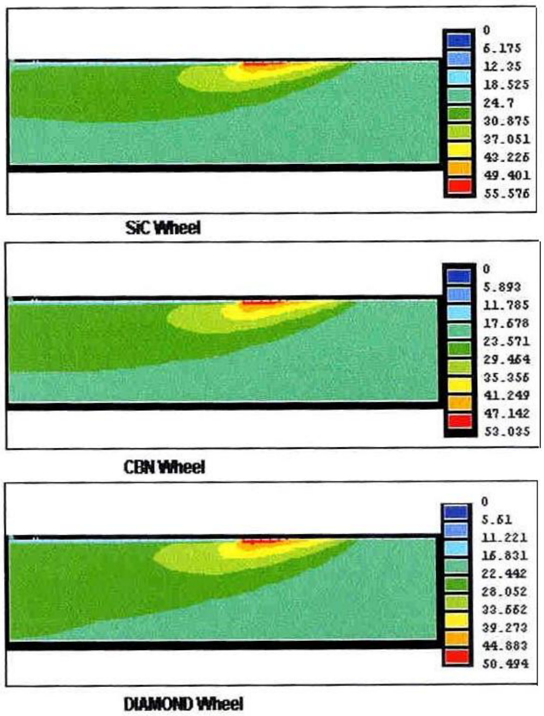


Fig. 8. Temperature Vs. Depth of Cut

are about 50% of the temperatures without coolant. The FEM temperature distribution within the workpiece is analysed using FEM package with the corresponding heat flux as input and the results are shown in Fig.(9)



Depth of Cut 0.02mm, Work Speed 1200 mm/min

Fig. 9. Temperature Distribution Through FEM (With Coolant)

7. CONCLUSION

Medium work speed requires lesser specific grinding energy, than low or high work speeds. The CBN wheel is better than diamond and SiC wheels considering the specific grinding energy, workpiece temperature and wheel loading. Diamond shows more affinity to wheel loading than other type of wheels. The thermal damage may not be severe in composite materials due to low surface temperatures compared with steel. The temperature distribution in FEM analysis shows smaller depth of penetration, thus the sub surface damage may not be severe. The use of coolant considerably improves grindability.

8. REFERENCES

1. Clyne T.W & Withers P.J., An introduction to metal Matrix composites, Cambridge University Press, 1993.
2. DiIlio, A., Paoletti, A., Taliaferri & Veniali,F., An experimental study on grinding silicon carbide reinforced Aluminium. Alloys International Journal of Machine Tool and Manufacture, Vol.36, No.6, pp 673-685, 1996.
3. Zhong, Z.W., and Hung N.P., Diamond Turning and Grinding of Aluminium based Metal Matrix composites., Materials and Manufacturing Processes, Vol.15, No.6, pp 853-865, 2000.
4. Di Ilio,A., and Paoletti, A., A comparison between conventional abrasives and super abrasives in grinding of SiC aluminium composites, International Journal of Machine Tool & Manufacture, Vol.40, pp 173-184, 1999.
5. Chandrasekar,S., Fawis,N., Bulsara,H., Hacher,A., Habbar,R and Mann., Thermal aspects of surface finishing processes, Advances in Mechanical Engineering, Narora Publishing House, New Delhi, pp 677-701, 1996.
6. Malkin,S., Grinding Technology-Theory and applications of machining with Abrasives, Ellis Harwood Limited, 1989.
7. Jaeger J.C., Moving sources of heat and the temperature at sliding contacts, J.Proc. Roy,Soc., New South Wales, 76, pp 203-24, 1943.
8. Mishra,A., and Prasad, T., Residual stresses due to a moving heat source, Int J. Mech, series, Vol.25, No.9 pp 571-581,1985.
9. Nee, A.Y.E and Tay, A.O, On the measurement of surface grinding Temperature, International Journal of Machine tool Design and Research, Vol.21, No.34, pp 279-291, 1981.

9. NOMENELATURE

Symbol	Meaning
P	Power in watts
a	depth of cut in mm
b	width of the grind in mm
v_w	work speed in mm/min