EDM machinability of SiCw/Al composites

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Machinability of high temperature composites was investigated. Target materials, 15 and 25 vol % SiC whisker–2124 aluminium composites, were machined by electrodischarge sinker machining (EDM) and diamond saw. The machined surfaces of these metal matrix composites were examined by scanning electron microscopy (SEM) and profilometry to determine the surface finish. Microhardness measurements were also performed on the as-machined composites.

1. Introduction

A demand for a high strength and toughness material has led to the development of a new generation of materials, known as high temperature composites, metal matrix composites and ceramic matrix composites. These advanced composites are considered an excellent candidate for high temperature structural materials [1–5]. However, the properties that make them appealing to use also create a major challenge in machining, due to their brittle behaviour and hardness. The difficulties experienced in machining must be minimized to ensure their use. Hence the improved machining of these composites is now considered to be one of the urgent manufacturing science areas that needs to be addressed.

Since high temperature composites are relatively new material systems, their machinability has not been studied except for recent work by Utsunomiya *et al.* [6] and Wallace *et al.* [7] by laser machining, Manami *et al.* [8] and Ramulu [9] by electro-discharge machining, and McGinty *et al.* [10] by modified traditional machining techniques. Machining of ceramics has recently attracted a great deal of attention from the materials science community [11–15] and several non-traditional methods seem to have emerged as promising machining methods for hard to machine materials [4–19]. Among various machining methods, electro-discharge machining (EDM) is one of the most versatile and useful technological processes for machining intricate and complex shapes in various conducting materials, including high-strength temperature-resistant alloys [5]. Since no work has been reported on the machinability of metal matrix composite materials having a 2124 aluminium alloy matrix reinforced with SiC whiskers in volume fractions of 15% and 25% by EDM, an attempt here is made to investigate the EDM characteristics of the SiCw/Al.

This paper focuses on the machinability of metal matrix composites by the EDM method. The results of the machining of these high temperature composites will be discussed in terms of the material removal rate surface finish against the machining conditions. Based on the results of conducted experiments, some concluding remarks are given as to the feasibility of EDM machining method.

2. Experimental procedure

The metal matrix composites used in this study are 15% vol. and 25% vol. SiC whisker/2124 aluminium matrix (SiCw/Al) composites, and were procured from ARCO Chemical Company in plate form with a thickness of 6.3 mm. Typical microstructures of as-received 15 % vol. SiC/Al and 25 % vol. SiC/Al composites are shown in Fig. 1. Arrows in the photomicrographs denote the direction of extrusion. From the photomicrographs, it can be seen that more SiC whiskers in the 25% vol. SiC/Al composite lay along the extrusion direction than in the 15% vol. SiC/Al composite. The intensity of the SiC whiskers at different orientations with respect to the extrusion direction is shown in Fig. 2 for both composites, and was reported elsewhere [20].

Two geometrically identical tools made of brass and copper were used as electrodes for cutting samples. Tool and workpiece material and the weight were recorded prior to EDM cutting. The electrodes were 0.625 mm thick sheet stock used on edge to cut through the workpiece. The EDM used was of ram type Hansvedt model SE-380. In this EDM machine the electrode is basically fed downward under servo-control into the work to produce a mirror image of the electrode shape. A built in vibrator is attached to the tool holder with a provision to adjust the frequency of vibration. This introduces the vibration to the tool to help circulate electrolyte. The dielectric fluid used was Cutzol EDM 220-30 fluid made by Devcon Corporation. It has a dielectric strength of 47 kv and a viscosity of 33 SSU. The process parameters, current and voltage were monitored while machining by using Gould model 4035 digital storage oscilloscope, a Fluke model Y8100 inductive current probe, and a Hewlett Packard model 7470A pen plotter. The experimental set up of EDM process is schematically shown in Fig. 3 and the details are given in the reference [9].

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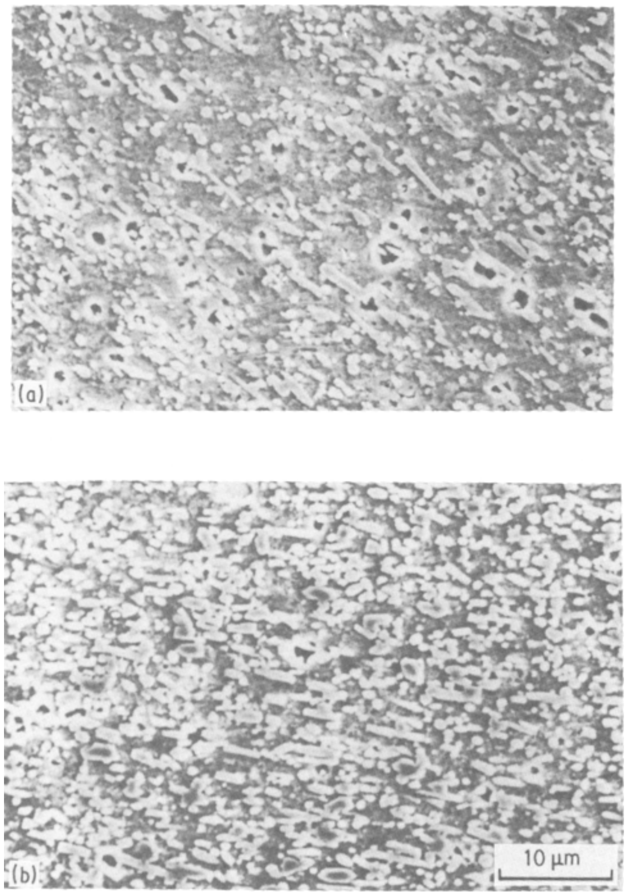

Figure 1 Microstructure of as-received SiCw/Al material (a) Al 15% SiC, (b) Al 25% SiC.

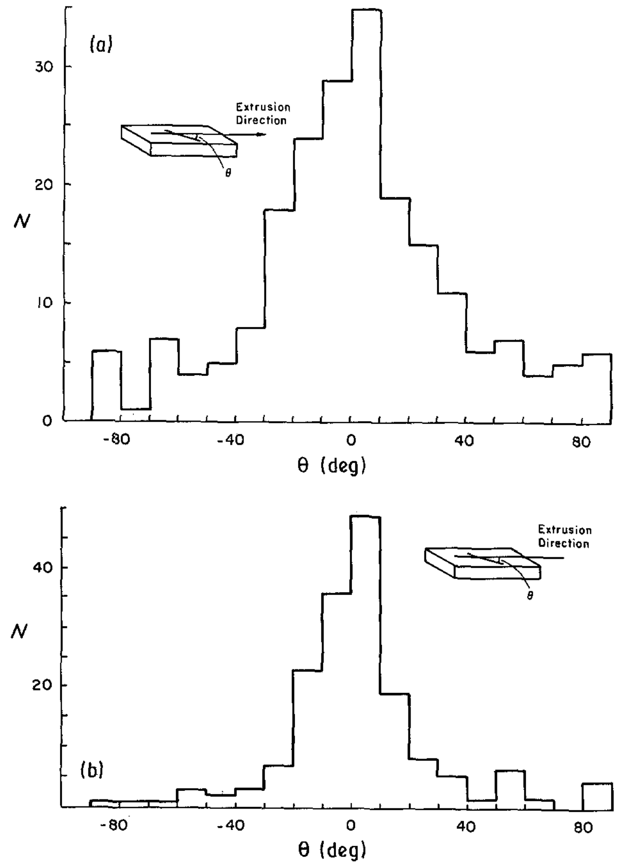

Figure 2 Number of whiskers, N plotted against fibre orientation angle, θ for SiCw/Al sample. (a) 15% SiCw/2124Al, total sample 208 (b) 25% SiCw/2124Al, total sample 170.

The 120 V R–C circuit generator provided three different current and voltage conditions which we classified as coarse, medium, and fine cutting conditions. These three processing conditions have average current values of 6, 1 and 0.333 A, respectively. A typical current and voltage against time record under fine conditions is shown in Fig. 4. This represents a typical trace of pulsed energy. The bottom portion shows voltage marked with channel 1 (CH1), and the top portion shows corresponding amperage marked with Channel 2 (CH2); both are shown against a time base. Table I shows the EDM process conditions in machining SiCw/Al composites.

The SiCw/Al sample was cut at coarse, medium, and fine conditions using copper and brass tools. Under each cutting condition, two cutting experiments were conducted using copper, brass electrodes with 25% vol. SiCw/Al and two cutting experiments of 15% vol. SiC/Al using only brass electrodes. After each cut, the change in tool weight, work weight, and time elapsed, were recorded. Material removal rates and wear rates were evaluated for each cutting condition by averaging measured amounts of material and cutting time.

The surfaces of the composites machined by EDM were evaluated by using scanning electron microscopy

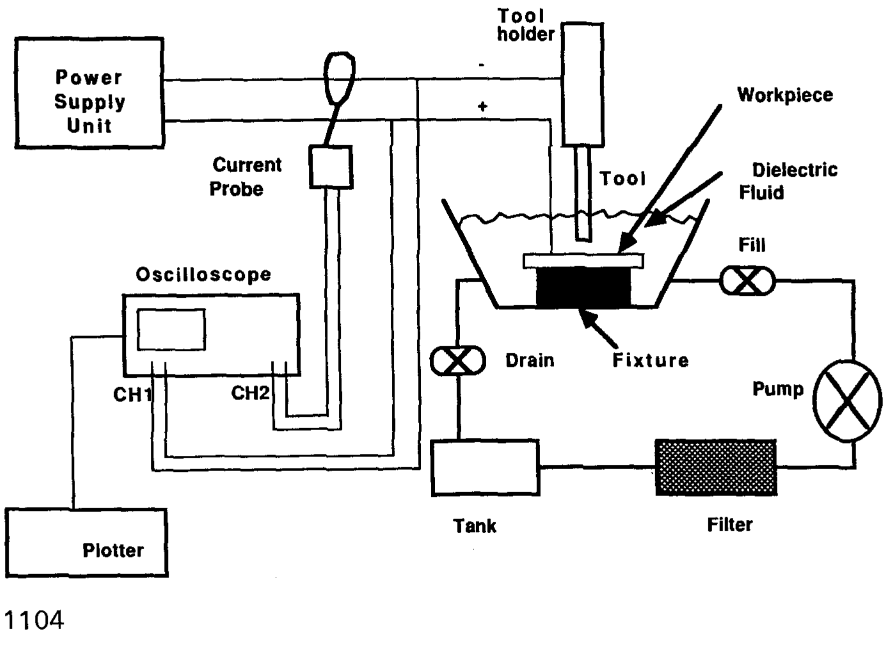

Figure 3 Schematic diagram of EDM experiments.

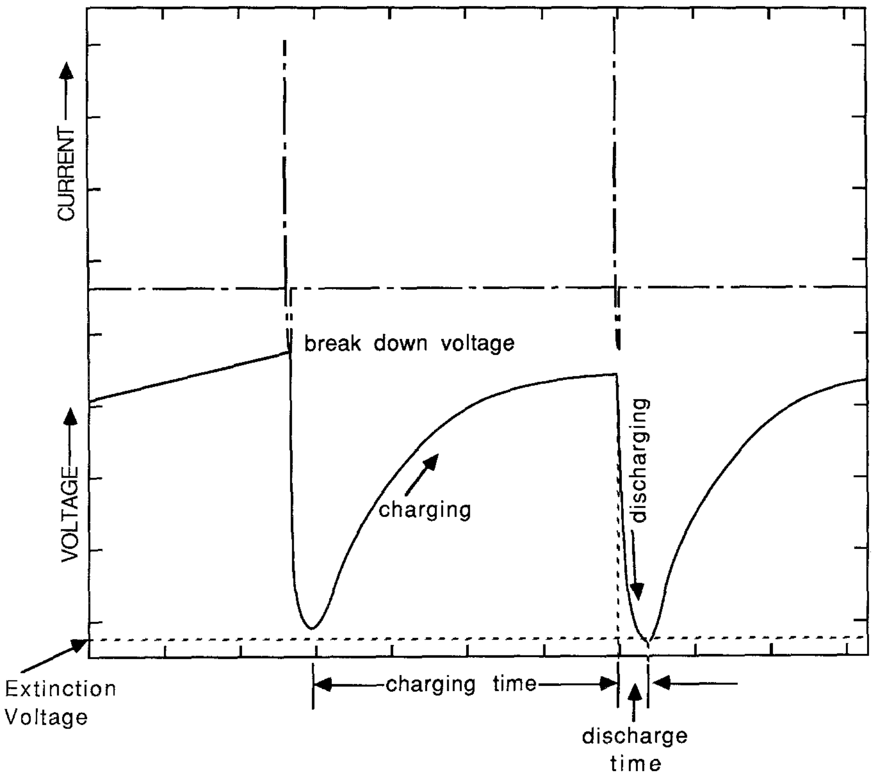

Figure 4 Voltage and current plotted against time record under fine EDM cutting conditions using brass electrode (25% SiCw/Al sample). (CH1) 20 V/div, 1 μs/div; (CH2) 0.1 amp/div, 1 μs/div.

(SEM), optical microscope and profilometry. The computer interfaced profilometry was used to evaluate the surface finish of the machined composites. Microhardness measurements were also performed on the surfaces and subsurfaces of the machined composites, to examine the effect of the machining on the microstructures.

3. Results and discussion

Fig. 5 shows the average Material Removal Rates (MRR) of 15% vol. and 25% vol. metal matrix composite samples under varying process conditions with copper and brass electrodes from six cutting experiments. The average MRR data plotted is connected with a smooth curve fitting for clarity. Material removal rates increased with an increase of power to the electrode. Material removal in 15% vol. SiC Whisker/2124 Al is greater than the 25% vol. SiCw/Al. The MRR obtained by brass electrodes is 5–10% greater than the MRR obtained by copper electrode

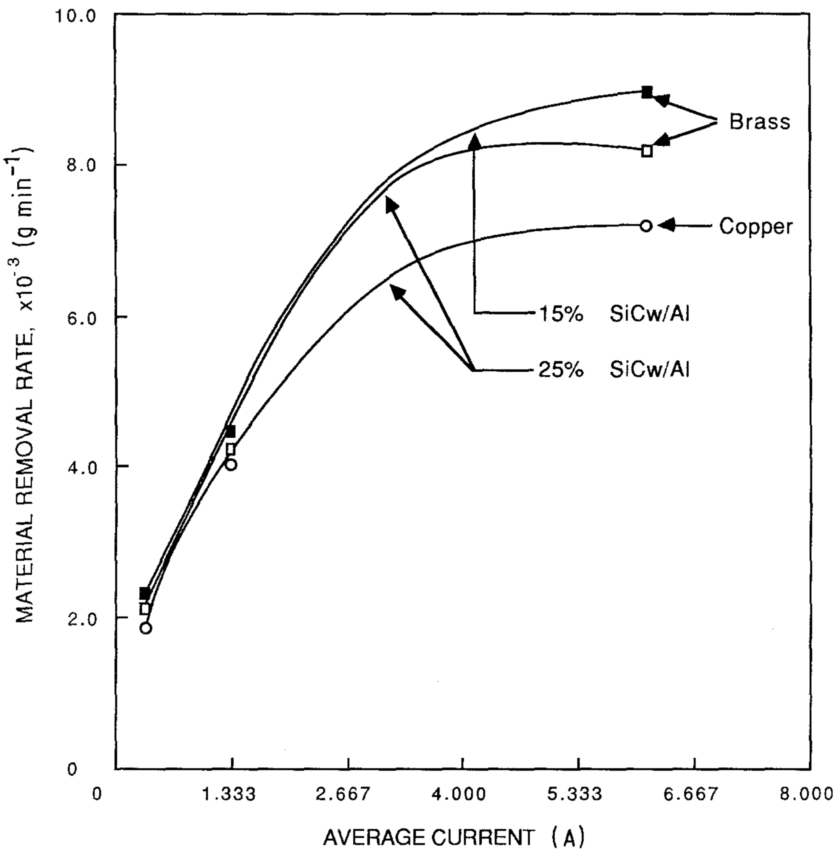

Figure 5 Material removal rates at varied cutting conditions.

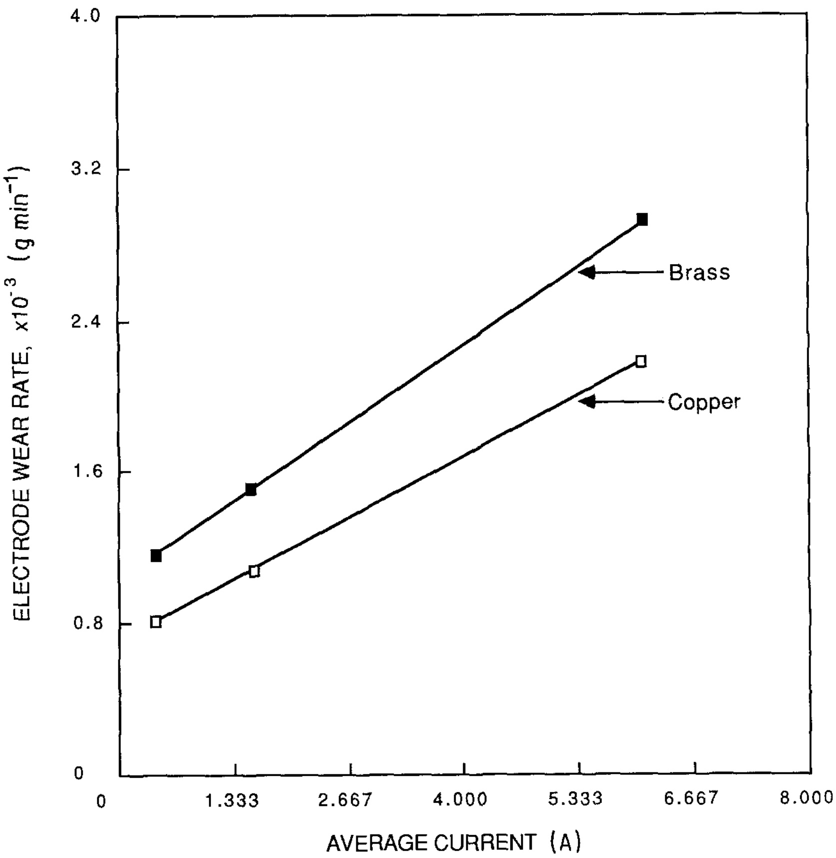

Figure 6 Electrode wear rate in machining 25% SiCw/Al.

under medium and rough cut conditions in 25% vol. SiCw/Al. MRR decreases as the speed of cutting decreases from the coarse to fine cutting conditions with both copper and brass electrodes. The electrode or tool wear rate (EWR) in machining 25% vol. SiCw/Al is shown in Fig. 6. Tool wear rate in brass is found to be generally higher than copper within the permitted experimental conditions. This is not surprising, since the brass electrode melting point used in this investigation is lower than that of the copper electrode and hence, the higher melting and wear rates are expected. It is interesting to see, however, the remarkable reduction in the electrode wear rate from rough cut conditions to fine set conditions. With copper electrodes, tool wear rate appears to decrease rapidly with the reduction in speed of cutting. Table II shows the EDM machining characteristics of SiCw/Al using brass electrode. Note that the machining time for 25% SiCw/Al is almost double the machining time for 15% SiCw/Al and in machining of 15% vol. SiCw/Al, electrode wear in percent was found to be less than the 25% SiCw/Al composite.

The results of the surface finish evaluations for 15 and 25% SiCw/Al composites machined by EDM at three different cutting speeds are summarized in Table III. The surface finish parameters include roughness, waviness, and lay. When subsequent finishing operations are required, the waviness rather than roughness is more important. Roughness becomes important if no subsequent surface finishing follows. In the present study, surface finish is expressed in terms of average waviness height measurement which is described in detail by standards [21]. It follows from Table III that 25% SiCw/Al appears to give better surface finish than the 15% SiCw/Al under fine finish conditions.

SEM micrographs from EDM cut 15 and 25% SiCw/Al composite surfaces at lowest, medium and highest cutting speeds are shown in Figs 7 and 8 respectively. Note that the surface damage and crater size increased with the cutting conditions. These micrographs indicate the formation of craters as a result of material removal process by EDM. It was also observed that the average diameter of the crater increased with the cutting speed. Surface roughness increased with the increase of cutting rate regardless of the volume fraction of the composite. From Figs 7

TABLE I Electro-discharge machining conditions

Rate of cutting	Process conditions	Power (A)	Frequency (Hz)
Rapid	Coarse	6	50
Medium	Medium	1	300
Very slow	Fine	1/3	600

TABLE II EDM machining characteristics of SiCw/Al using brass electrodes

Material	Process conditions	Cutting time (min)	Relative electrode wear (%)
15% SiCw/Al	Fine	69	28
	Medium	32	29
	Coarse	15	32
25% SiCw/Al	Fine	110	44.5
	Medium	71	30.47
	Coarse	32	39.10

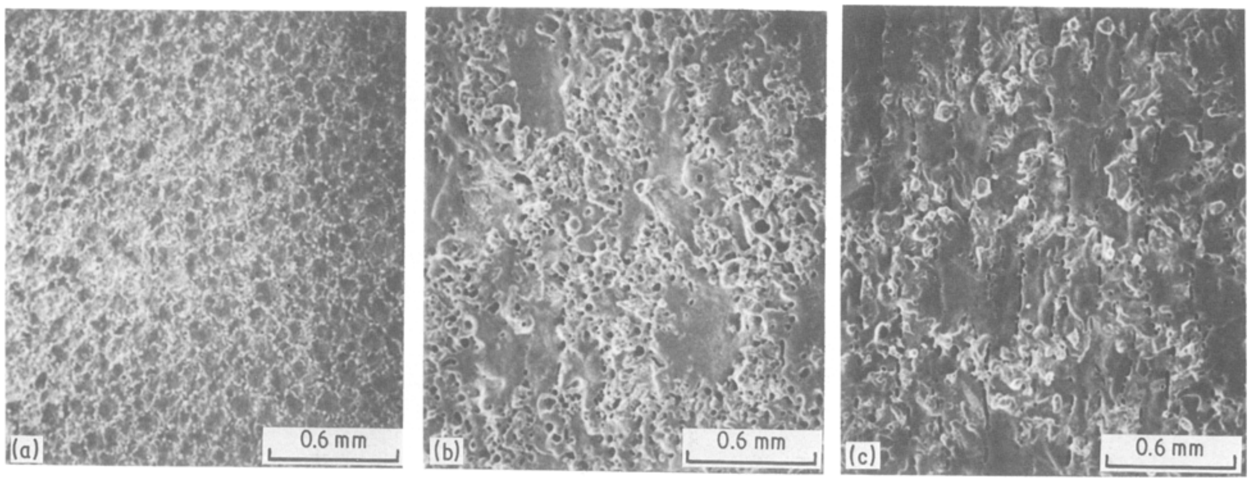

Figure 7 SEM photomicrographs of 15% SiCw/Al EDM surface (a) fine (b) medium and (c) coarse.

TABLE III The surface finishes of SiCw/Al composites cut by EDM

Materials	Rate of cutting	Process conditions	Surface finish (μm)
15% SiCw/Al	Very slow	Fine	3.56
	Medium	Medium	3.68
	Rapid	Coarse	6.99
25% SiCw/Al	Very slow	Fine	3.05
	Medium	Medium	3.73
	Rapid	Coarse	6.99

TABLE IV The results of microhardness measurements on SiCw/Al composites cut by EDM

	Distance from surface (μm)	Microhardness (Knopp)
15% SiC–Al	50	180
	230	180
	3000	180
25% SiC–Al	50	178
	150	206
	3000	220

and 8 it is observed that the surface finish in 25% SiCw/Al EDM is better than the 15% SiCw/Al and the observations are consistent with the surface finish measurements of Table III. Fig. 9a shows the photomicrograph of the cross-section of the 25% vol. SiC/Al EDM rough cut surface by diamond saw. An enlarged view of the damaged surface of Fig. 9a is shown in Fig. 9b. Note the damaged zone and the heat affected zone. Under fast cut conditions the material was severely damaged. Noting that the magnifications of Figs 7 and 8 are all the same ($\times$ 30), and from the observations made in the enlarged view of Fig. 9, we can conclude that EDM cutting at highest speed can damage the surface significantly, causing microcracking.

In order to determine the effect of the EDM cutting on the microstructure of SiCw/Al composites, microhardness measurements were conducted on various points in the composites cut at the intermediate cutting speed from the very surface to the mid-depth across the thickness. The results of the microhardness tests are summarized in Table IV. The micro hardness variation in 25% SiCw/Al composite significantly varied with the process conditions.

4. Concluding remarks

Based on the preliminary results of current investigation to determine the feasibility of machining selected high temperature composites of SiCw/Al by EDM; the following concluding remarks can be made.

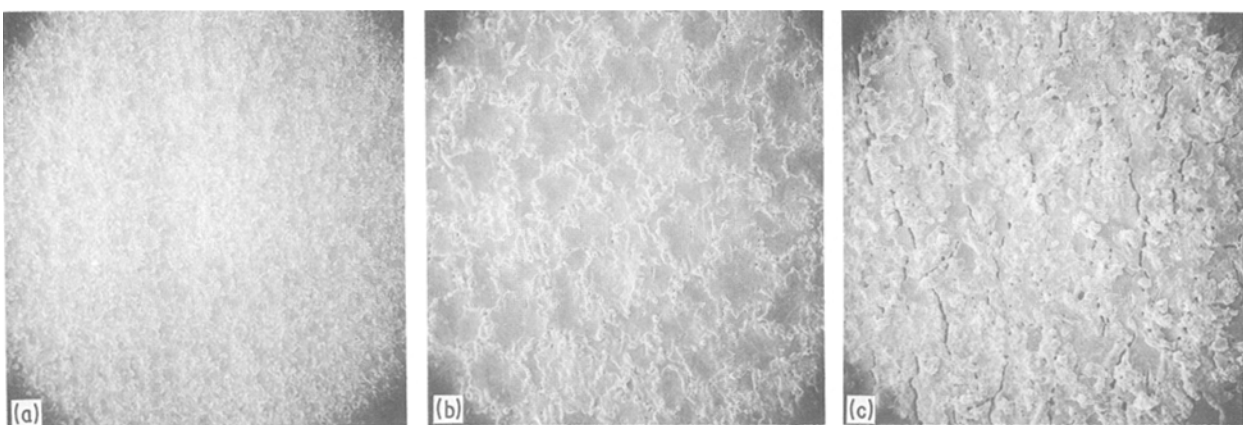

Figure 8 As Fig. 7 for 25% SiCw/Al EDM surface. (a) Fine, (b) medium, (c) coarse.

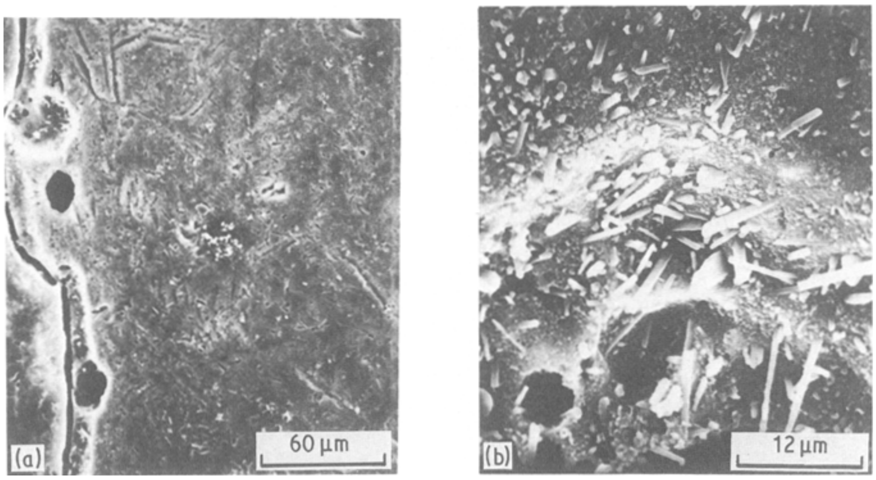

Figure 9 Surface damage in 25% SiCw/Al under coarse cutting condition. (a) EDM surface cross-section and (b) enlarged view of (a).

(1) SiCw/Al is easily machineable by EDM and better surface characteristics can be obtained by controlling the cutting conditions.

(2) Material removal rate obtained by using brass electrode is greater than using copper electrode in 25% vol. SiCw/Al. Machining times appear to be higher in 25% vol. SiCw/Al than in 15% SiCw/al composite.

(3) The microhardness tests on SiCw/Al composite have revealed that EDM appears to cause surface softening at slower cutting speeds.

(4) EDM at higher cutting speeds causes severe microdamage in the surface and subsurface area.

Acknowledgements

The present work was supported in part by the SME Education Foundation Award and also by the NASA Ceramics Program at the University of Washington. We sincerely acknowledge the help rendered by Dr Yoon and graduate student Mr Govindaraju in this investigation.

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Received 28 October 1987
and accepted 25 February 1988