Electrical discharge machining behavior of hotpress $MoSi_2$

A. K. KHANRA
Department of Metallurgical and Materials Engineering, IIT Kharagpur, India-721302
E-mail: asit_iitkgp@yahoo.com; asit_metal@metal.iitkgp.ernet.in

A. KHANRA
Department of Mechanical Engineering, Jadavpur University, India-700032

Molybdenum disilicide ($MoSi_2$) is a candidate material for high temperature structural applications because of their good combination of high melting temperature, brittle to ductile transition, electrical conductivity, and excellent resistance to oxidation [1, 2]. The important properties of $MoSi_2$ are shown in Table I [3]. Its main applications are like components for high temperature aerospace and automotive applications involve both moving and static parts, rotating parts of a turbine aircraft engine, e.g., blades and vanes, or of an automobile engine, e.g., turbocharger rotors and valves. There is a 30% decrease in the density of $MoSi_2$ relative to nickel-based superalloys. An effective barrier against reactive environments improves the lifetime of static components, e.g., glow plugs in a diesel engine. Molybdenum disilicide can be used for heat exchangers, gas burners, lances for liquid metals and glasses, igniters and high temperature filters etc. Approaches to improving the low temperature toughness and high temperature creep properties of $MoSi_2$ have focused on compositing and on alloying [4]. Compositing strategies include additions of whiskers or particulates of hard materials, such as SiC, ZrO_2, Si_3N_4 [4], SiC–Si_3N_4 [5].

Conventional machining of $MoSi_2$ or $MoSi_2$ base composite is very difficult due to its poor machinability; but electro discharge machining (EDM) was found to be suitable for ceramics with a maximum resistivity of 0.17 $\mu\Omega$·m [6]. The principle components of EDM are two electrodes, a cathode and anode (workpiece and cutting tool), separated by a dielectric liquid. At the beginning of EDM operation, a high voltage is applied across the narrow gap of typically about 20–300 μm (depending on current) between the two electrodes (the scheme of the EDM is shown in Fig. 1). The high voltage induces an electric field in the insulating dielectric that is present in the narrow gap. This causes conducting particles suspended in the dielectric to concentrate at the points of the strongest electric field, which in turn results in a bridge being formed between the electrodes. At the same time, negatively charged particles are emitted from the cathode and collide with neutral particles in the gap between the electrodes, forming electrons and positively charged particles. This dielectric breakdown process spreads at an explosive rate, resulting in the formation of a conducting channel between the electrodes, called plasma channel. This channel conducts electricity between two electrodes, the voltage (V) drops within few mili-second and current increases. The channel grows with time called pulse on-time (t) which is set by operator. This channel creates a pressure rise of 10 kbar and a temperature of 60000 K respectively. At this condition localized evaporation of electrodes takes place in the plasma channel. Wire cut and die sinking are the two types of EDM machine [7, 8].

TABLE I Different properties of $MoSi_2$

Properties		Units	Value
Physical	Molecular weight	g/mol	152.11
	Theoretical density	g/cm^3	6.26
	Colour	–	Gray
Crystallographic	Crystal structure	–	Tetragonal
	Lattice parameter	nm	$a = 0.3203$
			$c = 0.7855$
Mechanical	Young's modulus	GPa	441
	Compressive strength	MPa	1500
	Hardness at 1 N Load	GPa	12–13.5
Thermal	Melting point	K	~2553
	Thermal expansion coefficient	10^{-6}/K	8.25
	Thermal conductivity	W/m·K	54
Electrical	Electrical resistivity, $\rho \times 10^8$	Ω·m	21.6

In the present investigation dense $MoSi_2$ was produced by hotpressing of elemental powders and EDM (die sinking type) studies of dense $MoSi_2$ has been investigated.

The stoichiometric composition of commercial grade Molybdenum (99.9% pure and particle size <44 μm, Alfa Aesar, Germany) and Silicon (99.9% pure and particle size <44 μm, Alfa Aesar, Germany) powder were dry mixed and later mixture was hotpressed at 1400 °C under a controlled atmosphere. Sintered density was measured with an accuracy of 1% by liquid immersion technique using Archimedes principle and hardness (load-50 kg and loading time-15 s) was measured by Vickers hardness tester (VM 50, India). The phase analysis of sample was investigated by the XRD (Philips PW 1840, Netherland). The morphology of the machined bar was studied by the Scanning electron microscope (SEM) [Jeol, JSM 840A]. The machining behavior of sintered $MoSi_2$ bar was carried out by EDM (Charmilles ELERODA 10, Switzerland). Copper electrode and BP cutting oil were used as tool material and dielectric liquid respectively. Study was carried out for different variable like metal removal rate

0022–2461

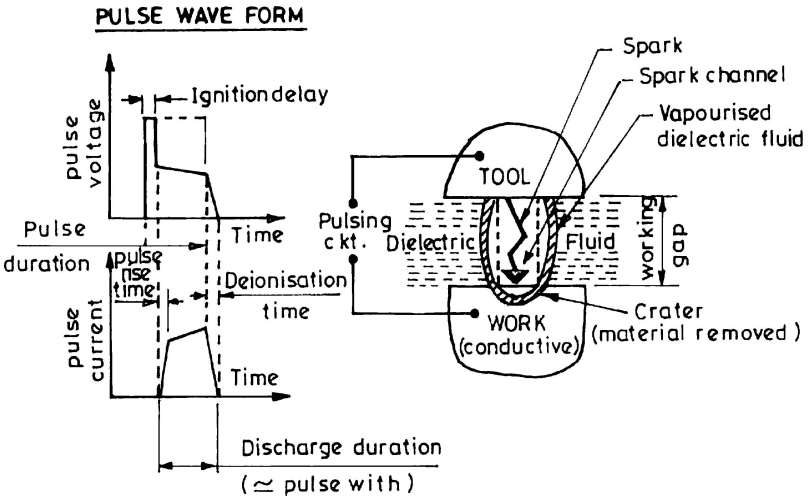

Figure 1 Scheme of EDM.

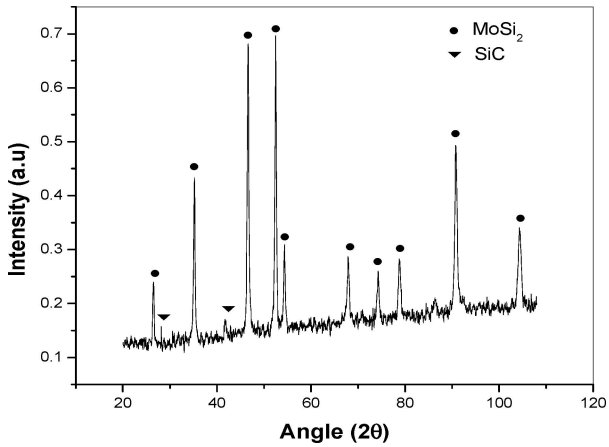

Figure 2 XRD pattern of hotpressed $MoSi_2$ sample.

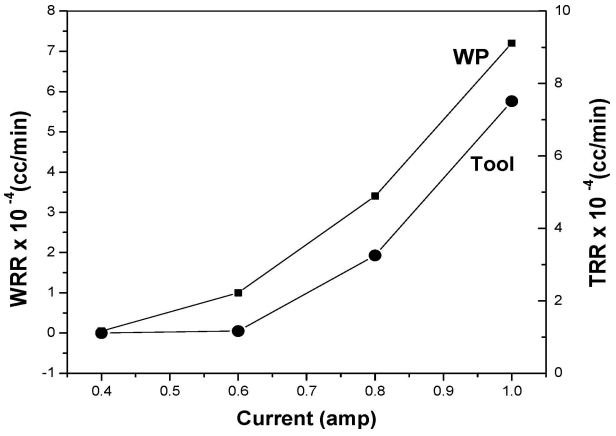

Figure 3 Removal rate of WP and Tool when WP and Tool materials were anode and cathode respectively.

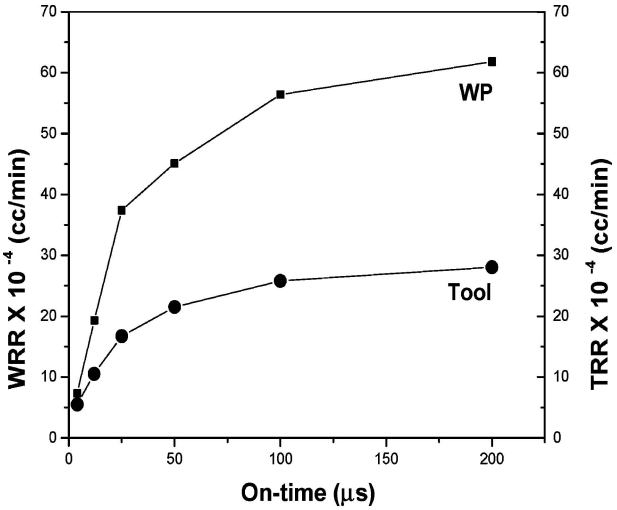

Figure 4 Removal rate of WP and Tool with different on-times.

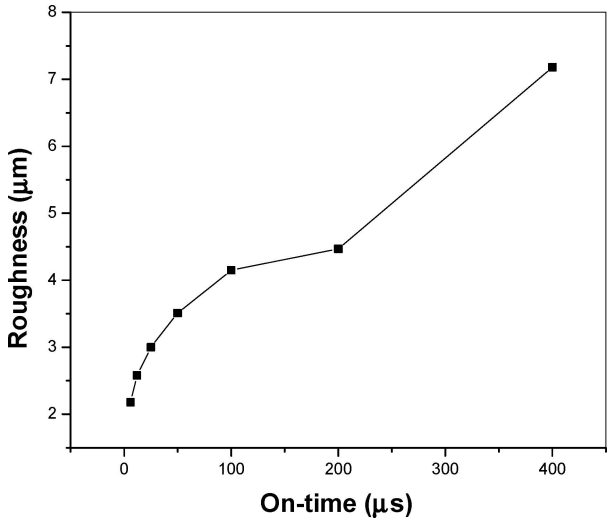

Figure 5 Surface roughness of WP with different on-time.

with applied current and pulse on-time. Surface roughness study with different pulse on-time was also investigated. Composition analysis of tool after machining was carried out by SEM/EDS.

The density and hardness of hotpressed $MoSi_2$ was found to be 96% of theoretical and 917 Kg/mm^2 respectively. The XRD pattern of the sample showed $MoSi_2$ as a major phase with SiC as a minor phase (shown in Fig. 2). The source of C was the graphite die during the hotpress. The different machining behavior of dense $MoSi_2$ for EDM are shown in Figs 3–5. The energy input in EDM ($P = VIt$ (directly depends on discharge voltage, current and pulse on-time [8]. Fig. 3 showed workpiece (WP) removal rate (WRR) and tool removal

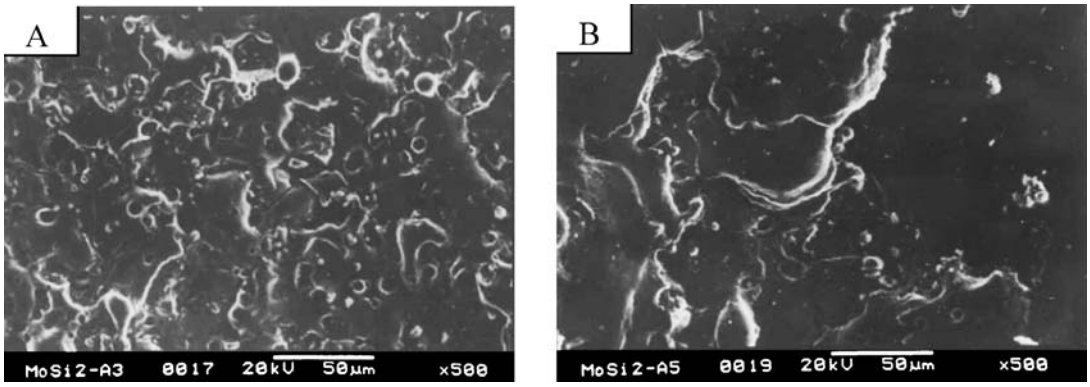

Figure 6 SEM images of machined surface of $MoSi_2$ sample at different pulse on-time (A– 4 μs and B– 12 μs).

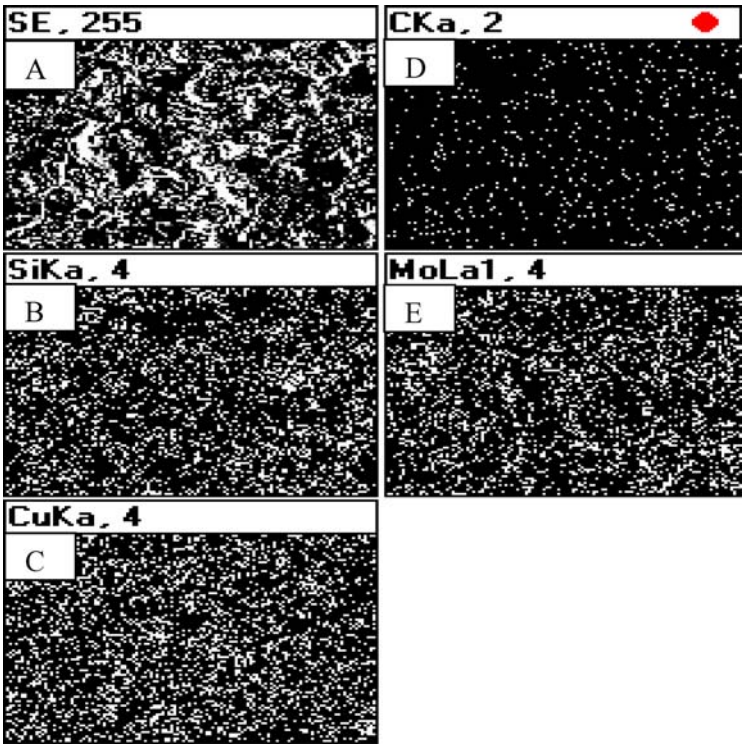

Figure 7 Elemental mapping of cutting tool.

rate (TRR) increased with applied current respectively. Similar behavior was observed while increase of pulse on-time (shown in Fig. 4). The increase of metal removal rate of WP could be due to flow of more number of positive ions from tool to WP, which caused more crater and simultaneously the surface roughness of WP increased due to more craters (shown in Fig. 5). It was found that surface roughness of WP increased drastically from pulse on-time 100 to 400 μs. The morphology of machined surface at different pulse on-time is shown in Fig. 6. Fig. 6 showed clearly that the surface roughness increased from pulse on-time 4 to 12 μs. During EDM study pulse off-time was kept as 6 μs. The X ray mapping of EDM tool (Cu) is shown in Fig. 7. It showed presence of Cu, Mo, Si and C. The source of Mo and Si was the wear of WP and carbon source was both WP and continuous burning of dielectric fluid. It has been also seen that EDM of $MoSi_2$ decreased with time. The continuous deposition of Mo, Si and C suppressed the metal removal rate during EDM.

The studies concluded that brittle and poor machinability material like $MoSi_2$ could be machined by EDM. Metal removal rate increased with applied current and pulse on-time respectively. The surface roughness increased with pulse on-time.

Acknowledgments

The authors are highly thankful to Prof. R. Mitra, IIT Kharagpur, for material development. We are also thankful to Shamu Hembram, B. P. Mirdha and S. Patra of IIT Kharagpur, for help in carrying out experiment.

References

1. Y. S. PARK, D. P. BUTT, R. CASTRO, J. PETROVIC and W. JOHNSON, *Mater. Sci. Engng. A* **261** (1999) 278.
2. J. J. PETROVIC, *Ceram. Eng. Sci. Proc.* **18** (1997) 3.
3. A. W. WEIMER, in "Carbide, Nitride and Boride Materials Synthesis and Processing," Ist ed. (Chapman and Hall Press, London, 1997) p. 640.

4. A. NEWMAN, S. SAMPATH and H. HERMAN, *Mater. Sci. Engng. A* **261** (1999) 252.
5. J. J. PETROVIC and R. E. HONNELL, *J. Mater. Sci. Lett*. **9** (1990) 1083.
6. A. M. GADALLA, B. BOZKURT and N. M. FAULK, *J. Amer. Ceram. Soc*. **74** (1991) 801.
7. S. NORASETTHEKUL, P. T. EUBANK, W. L. BRADLEY, B. BOZKURT and B. STUCKER, *J. Mater. Sci*. **34** (1999) 1261.
8. Y. M. CHENG, P. T. EUBANK and A. M. GADALLA, *Mater. Manuf. Proce*. **11** (1996) 565.

Received 20 February
and accepted 30 August 2004