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Effect of Distilled Water and Kerosene as Dielectrics on Machining Rate and Surface Morphology of Al-6061 During Electricdischarge Machining

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ABSTRACT
Electric Discharge Machining (EDM) is widely used for manufacturing complex metal parts. The machining parameters like dielectric fluid, electrode material, current, voltage and pulse rate during EDM are controlled to obtain desired Material Removal Rate (MRR) and it also affects the surface morphology of manufactured components. In this research, effect of changing machining parameters, dielectric fluid (distilled water and kerosene) and electrode materials (copper and graphite) on surface morphology of Al 6061 T6 alloy during EDM is investigated. It is observed that the distilled water reacts with the molten aluminum and produces deep pits / voids on the surface due to liberation of hydrogen gas. A micro crack network is seen radiating from the edge of these pits. It is believed that the very high thermal conductivity of distilled water is responsible for the micro crack network and reduced material removal rate when compared with non-reactive kerosene oil.

Keywords: aluminium alloy 6061 T6; dielectric; electric discharge machining; electrode; surface morphology

INTRODUCTION

Electric Discharge Machining (EDM) is a non-conventional machining process, most often used for very hard alloys and for developing complex geometries [1-4]. The process may also be used for machining light alloys especially when complicated shapes and thin sections are required [5, 6]. Most of the researchers have worked on the surface integrity of hard alloys machined by the EDM process [7, 8]. The white layer thickness, surface roughness and general surface morphology are mostly studied [9, 10]. The effect of dielectrics and different electrode materials on the surface morphology has also been studied [11, 12]. Some researchers have worked on EDM machining of aluminium alloys [6]. Although most of the research is focused on the process parameters, some research is also done on the surface integrity issues [13, 14]. During EDM, the dielectric fluid has been shown to largely influence many machining parameters such as material removal rate [15, 16], electrode wear rate [17], surface roughness [18]. Most researchers have already compared the performance of distilled water and kerosene as dielectric [1, 11, 19, 20], but it is still unclear how they influence the machining parameters when used in combination with different electrodes. In steels it is typically seen that material removal rate is higher using water as dielectric [18, 21], yet, studies for machining of aluminium are missing. Considering the abundant use of aluminium now a days for light weight structural applications [22-27], this study focuses on EDM of aluminium.

John Petrovic and George Thomas [28] evaluated the aluminium water reaction to produce hydrogen. At room temperature reaction of aluminium with water forms aluminium hydroxide and hydrogen as shown:

$$2Al + 6H_2O = 2Al(OH)_3 + 3H_2$$

Although this interaction is thermally thermos-active, but at room temperature it does not occur due to the presence of cohesive aluminium oxide layer that prevent water from coming in direct contact with aluminium. In case of EDM, the affinity of this reaction to occur is very high due to direct contact of molten aluminium surface with distilled water present around as dielectric media. It was expected that due to the reactivity, higher machining rates would be achieved as is in case of steel. During research it was observed that the reactivity produces sharp pits and micro cracks on the surface, however, material removal rate (MRR) is even lower.

In this research water and kerosene is used as dielectric during EDM of Al6061-T6 alloy. Copper and graphite are used as electrodes and their effect on MRR and surface morphology with both dielectric media is studied.

Experimentation

Specimens of Al 6061 T6 cylindrical shape having 22 mm diameter and 20 mm height were manufactured. The tests were carried out on Die-Sinking EDM, the machine is of 24KVA power. The machine is capable of 1D machining with high precision of large components.

Kerosene is recommended as dielectric fluid in the machine, therefore, to keep the machine isolated from water contamination a specially designed machining fixture shown in Figure 1(a) was developed for machining of components using water as dielectric fluid. The fixture contains a small tank in which specimen is clamped for machining, fluid is constantly pumped to the small tank from the large tank. Different machining parameters which were changed to study their effect on machining are listed in Table 1.

Copper and graphite electrodes were used to machine the specimens under different conditions, keeping in view the interchangeability and alignment of the electrode a fixture was developed to hold electrodes with a provision to supply dielectric fluid from centre for better chip flushing at constant pressure (0.9 kg/cm^2). The tool holding fixture and electrodes are shown in Figure 1(b).

The difference in physical and chemical properties of water and kerosene are listed in Table 2. The thermal conductivity and specific heat of water are 74% and 52% higher than that of kerosene. This large difference of two key properties plays a critical role during EDM machining which is discussed in the next section.

To calculate MRR and EWR at different machining parameters, samples and electrodes were weighed before and after EDM. For SEM the samples were prepared by ultrasonically cleaning and drying by hot air. TESCAN MIRA 3 FE SEM was used for studying the surface morphology of the prepared samples.

To prepare samples for optical microscopy, the machined specimens were sectioned, embedded in epoxy, ground using 100, 300, 600, 800, 1000, 1200, 1600, 2000 dpi sand papers and were polished using 3µm and 1µm diamond paste. For studying surface roughness and white layer thickness these samples were observed under Olumpus BX51 optical microscope at different magnifications.

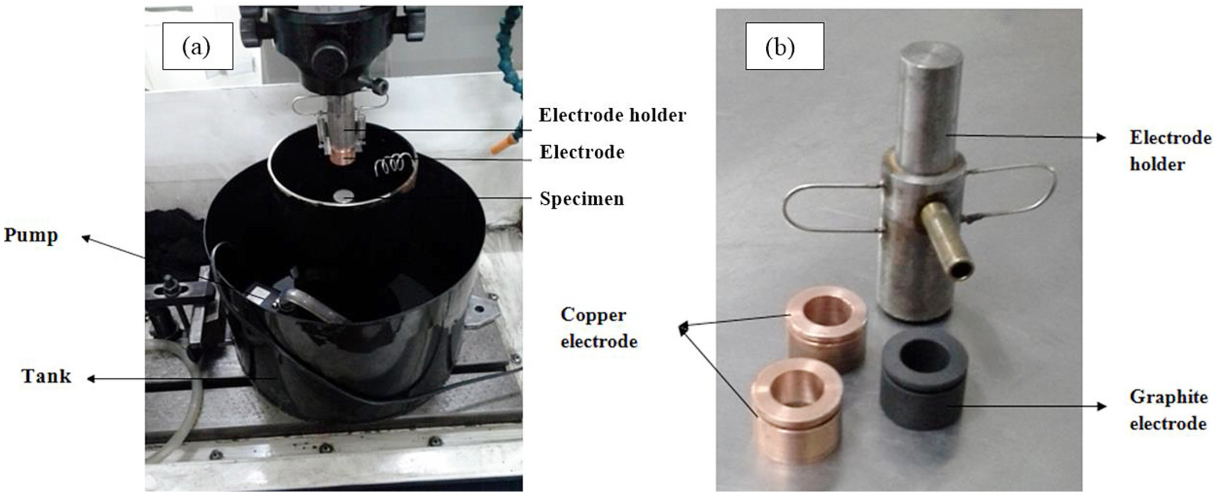

Figure 1. Experimental setup (a), Copper and graphite electrodes (b)

RESULTS AND DISCUSSION

In this research effect of using copper or graphite electrodes on surface morphology in the presence of water or kerosene as dielectric fluid in varying machining parameters has been studied. Graphs of MRR versus different machining parameters have been plotted for different dielectric fluids. The EDMed surfaces have been observed under Olumpus BX51 metallurgical microscope and MIRA3 Tescan FE SEM to discuss surface roughness and morphological attributes.

The effect of graphite electrode on MRR using kerosene and distilled water as dielectric liquids is given. It is seen that kerosene oil gives higher MRR as compared to distilled water. The effect of increasing P_{ON} time on MRR is negligible.

Figure 2 presents the results of MRR with changing current values and P_{ON} time when copper electrode is used in water and kerosene as dielectric. It is observed that MRR is highest with kerosene and copper pair. It is observed that generally while using copper electrode, increase in P_{ON} time and current increases the material removal rate. In case of copper and water pair it was observed that MRR increases up to 30μs P_{ON} time but decrease when P_{ON} time is further increased. Similar trend is observed but MRR increases with increase in applied current value.

Although less pronounced, same effect is observed for graphite electrode with water and kerosene as dielectric. A 67% drop in MRR can be observed in Figure 3 when all other machining parameters are kept constant. It is observed that the MRR generally is lower when using graphite electrode as compared to copper electrode and using distilled water and dielectric reduces MRR with both electrodes. Hence, graphite and water pair is least efficient in removing material at these machining parameters.

The effect of copper electrode on MRR using kerosene and distilled water as dielectric liquids is given. It is observed that using kerosene improves MRR when compared with distilled water and the effect is more pronounced at high energy machining parameters.

It is interesting to mention that the thermal conductivity of aluminium (227 W/ m-K)

Table 1. EDM parameters set during experimentation

Parameters	Value
P_{ON} (μs)	15,20,30,45,60 (copper); 60,90,120,150,200 (graphite)
Current (A)	6,9,12
Gap (μm)	10
Dielectric Fluids	Water, Kerosene
Electrode Material	Copper, Graphite

Table 2. Physical and chemical properties of Kerosene and Water [29, 30]

Specification	Density kg/m³	Molar mass g/mol	Conductivity		Viscosity mPa.s	Specific heat kJ/kg K
			Thermal W/m.K	Electrical kΩ.m		
Water	1000	18.015	0.58	182	1.002	4.19
Kerosene	800	170	0.15	1×10⁹	1.64	2.01

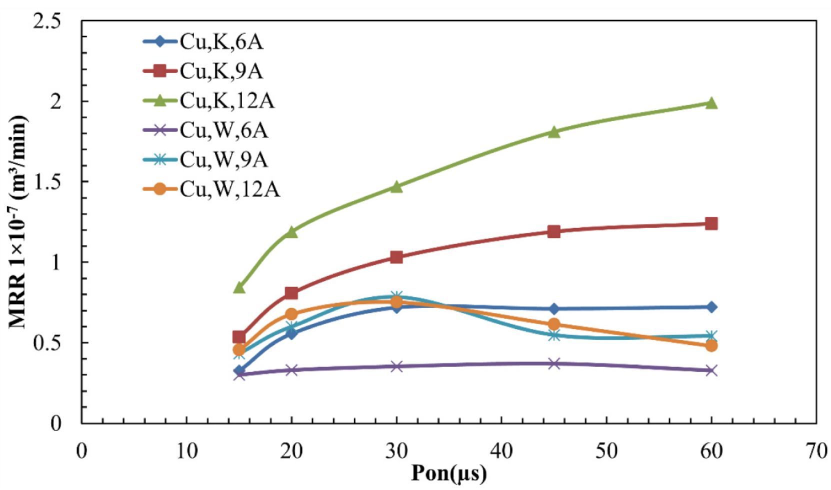

Fig. 2. MRR with copper electrode in kerosene and water as dielectric fluids

is almost four times to that of steel (51.9 W/ m-K). The thermal conductivity of water (0.58 W/ m-K) is almost four times to that of kerosene (0.15 W/ m-K). As a result the heat generated during the process is more quickly dissipated when water is used as dielectric liquid. The rapid quenching of molten aluminium alloy in water causes deposition of relatively thicker recast layer. The sudden quenching of material right after liquefaction is the reason for reduced MRR as compared to kerosene. This result were found to be in agreement with previous studies [31, 32].

Figure 4 shows the surface morphology produced by the EDM process in distilled water with copper electrode. Figure 4(a) shows that apart from macro EDM effects like craters and globules small pits are distributed all over the machined surface. It is perceived that the molten aluminium reacts with the distilled water and causes these pits (highlighted with red inset arrows). Figure 4(b) shows magnified view of the same surface, a large number of micro cracks emanating from these reaction pits can be observed. The cracks have been highlighted with inset yellow arrows. This is due to the high cooling rate of the recast layer due to flushing of distilled water dielectric because of its high thermal conductivity and high specific heat. The micro cracks can be seen at all current values tested. However, they are higher in density for higher current. Hence using water as dielectric in EDM not only reduces the MRR but also affects the surface finish and integrity of the machined components.

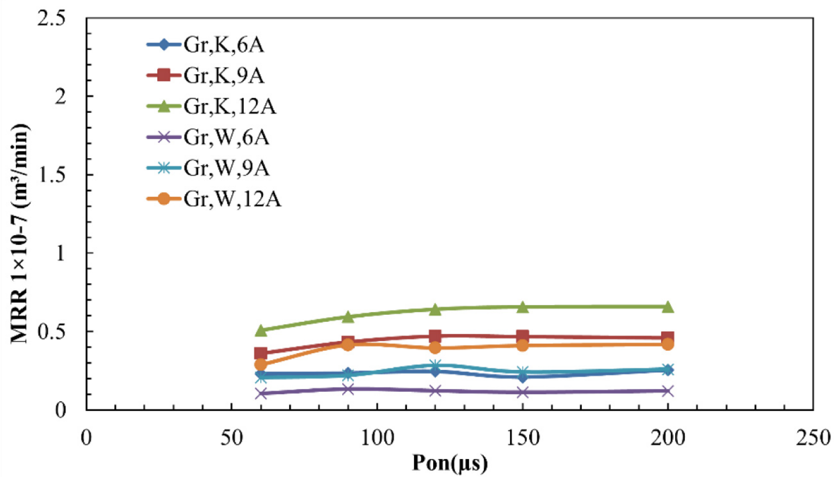

Fig. 3. MRR with graphite electrode in kerosene and water as dielectric fluids

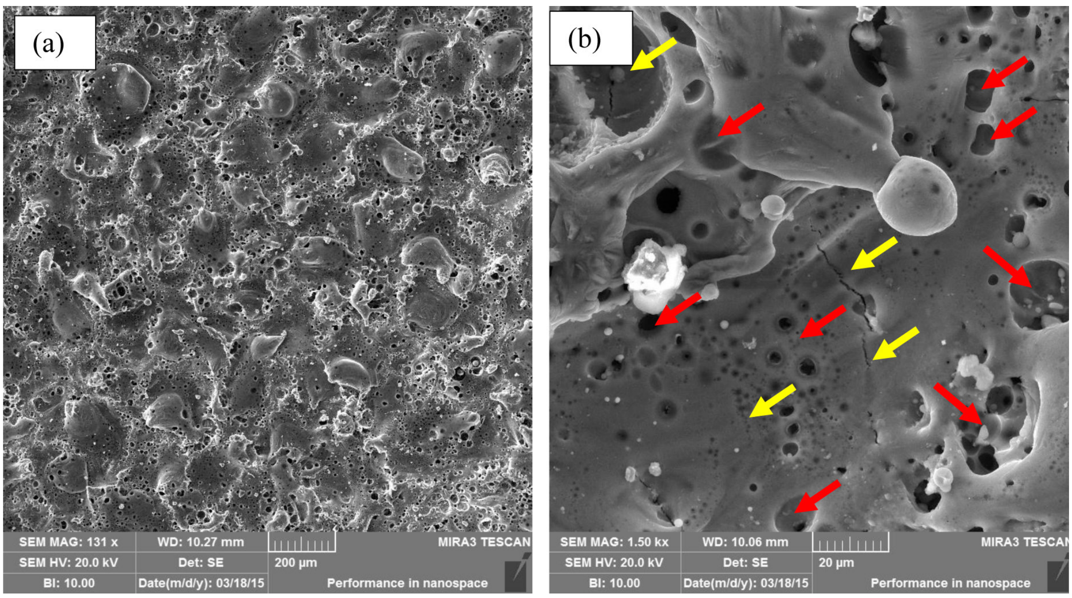

Fig. 4. Surface morphology of specimens machined with copper-water pair at 12A current and 60μs P_{ON} time (a) 131X image showing small micro pits produced due to reactivity with water (b) 1.50kX image showing micro pits (red arrows) and cracks (yellow arrows)

Figure 5 shows the same surface morphology for kerosene dielectric. A higher amount of machining debris can be observed, however, no pits or micro cracks are visible on the surface. In Figure 5(a) it can be observed that the machined surface is smooth when compared with copper-water pair. Figure 5(b) shows magnified image of copper-kerosene machined surface. As MRR is highest in this case, larger globules can be observed and the recast layer is free of micro pits which proves that molten aluminium in recast layer does not react with kerosene.

Similar micrographs for graphite-water pair are obtained and micro pitting due to high reactivity of water with molten aluminium in recast layer is observed as shown in Figure 6(a). The effect of micro pitting is much more pronounced with pits having larger diameter as compared to copper electrode as shown in Figure 6(b), the pits have been highlighted with inset red arrows. Micro cracking is also visible in these specimens, which have been highlighted with inset yellow arrows. The density of pits created due to reaction of water has greatly increased and the larger pits tend to have micro cracks parallel to the periphery of the reaction pit.

Figure 7 shows the surface morphology of specimen after being machined by graphite electrode in kerosene as dielectric. In Figure 7 (a) is can be observed that larger craters are produced at high current due to high energy discharge at material surface which becomes more rough when compared with surface prepared by copper-kerosene pair. It can be observed in Figure 7 (b) that the recast layer is extremely rough with smaller size of globules sticking back to the surface which reduces MRR as well. Micro cracks were not seen for the graphite kerosene pair although the machining debris is higher.

Prepared samples for surface roughness testing were keenly observed under metallurgical microscope at 50X magnification and the results are shown in Figure 8. It is observed that the surface roughness of copper-water pair in Figure 8(a) is very high and the thickness of recast layer is very less. Figure 8(b) shows the surface roughness of specimen machined using copper-kerosene pair which has relatively less surface roughness and gives maximum material removal rate. Figure 8(c) shows the machined surface with graphite-water pair and Figure 8(d) shows the machined surface with graphite-kerosene pair. It is observed that due to very high discharge of energy in the case of graphite electrode apart from a thick recast layer deposited over the surface a major heat affected zone is also formed. This results in poor surface finish and integrity of the Al6061 T6 components during EDM machining.

CONCLUSION

In this research water and kerosene were used as dielectric during EDM of Al6061-T6 alloy. Copper and graphite were used as electrodes and

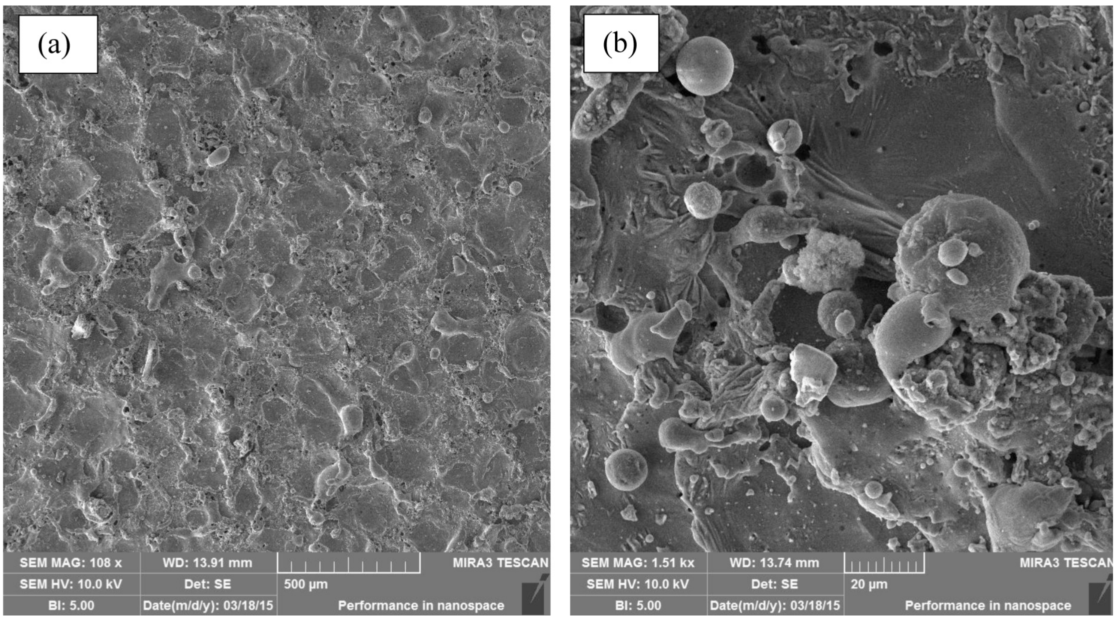

Fig. 5. Surface morphology of specimens machined with copper-kerosene pair at 12A current and 60µs P_{ON} time (a) 108X image showing surface of machined sample (b) 1.51kX image showing large craters and globules

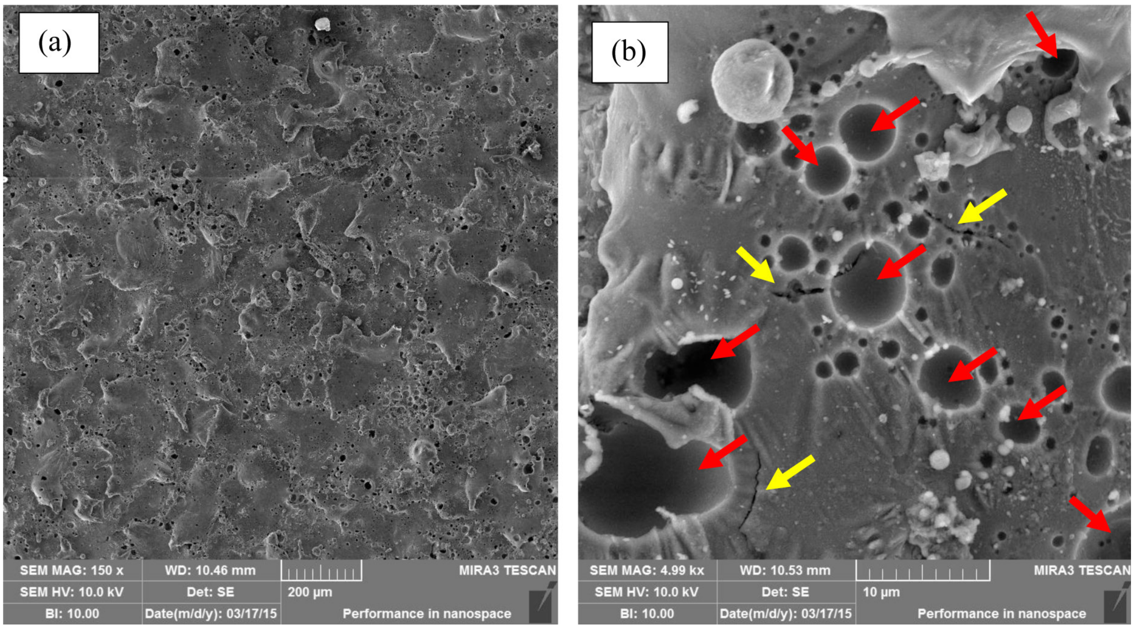

Fig. 6. Surface morphology of specimens machined with graphite-water pair at 12A current and 60µs P_{ON} time (a) 150X image showing small micro pits produced due to reactivity with water (b) 5kX image showing micro pits (red arrows) and cracks (yellow arrows)

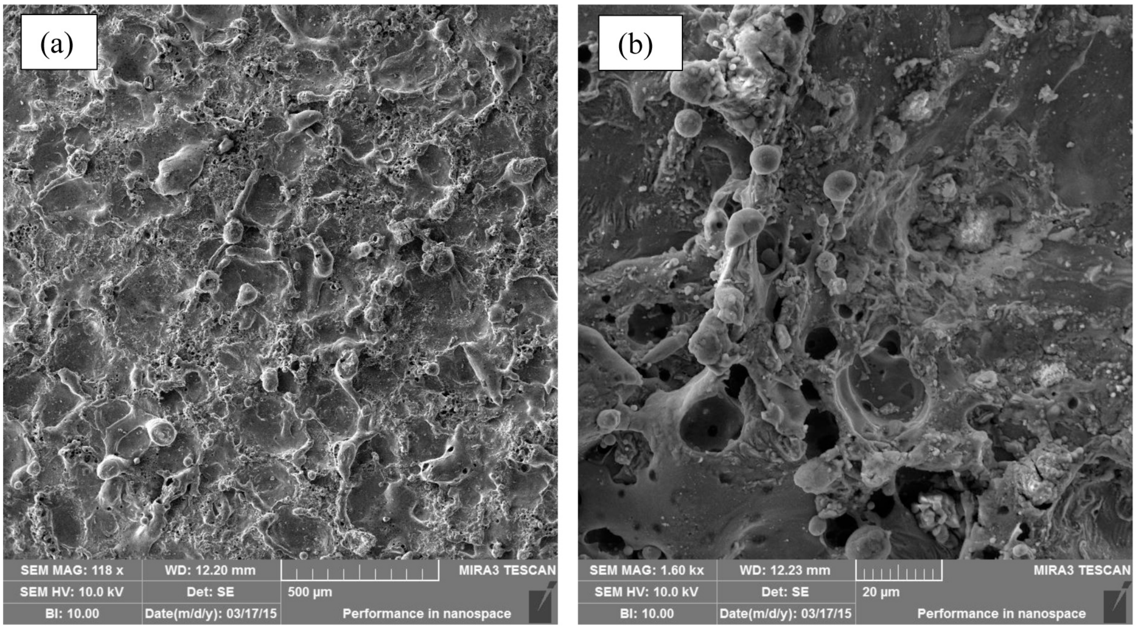

Fig. 7. Surface morphology of specimens machined with graphite-kerosene pair at 12A current and 60µs P_{ON} time (a) 118X image showing rough machined surface with large craters and globules (b) 1.6kX image showing large craters and small globules.

their effect on MRR and surface morphology with both dielectric media was studied.

Contrary to findings of other researchers with steel, the distilled water showed slower material removal rate when compared to kerosene. It is believed that the high thermal conductivity of aluminium and distilled water contribute to the higher recast layer deposition rates leading to lower material removal rates. The reaction of recast aluminium and water dielectric is evident. This causes pits in the machined surface. The quick cooling effect of the distilled water also causes severe thermal stresses causing micro cracks at the surface. These micro cracks are important from a service point of view especially on components exposed to fatigue loading. The

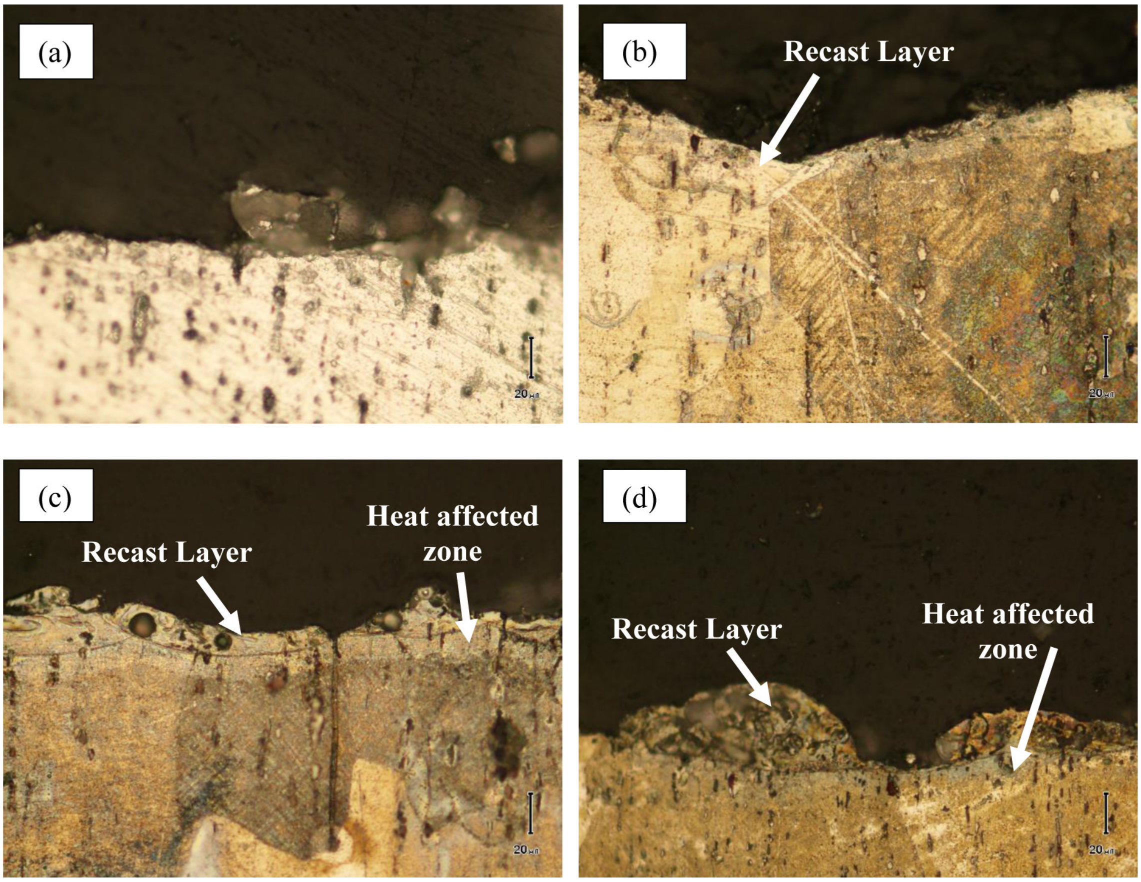

Fig. 8. Micrographs of surface roughness at 12A current and 60µs P_{ON} time (a)copper and water (b) copper and kerosene (c) graphite and water (d) graphite and kerosene

graphite and distilled water pair causes more severe pitting and cracking, which is due to higher temperatures achieved when graphite electrode is used for EDM.

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