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Study of the recast layer of a surface machined by sinking electrical discharge machining using water-in-oil emulsion as dielectric

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ABSTRACT

Electrical discharge machining (EDM) caused a recast layer to form at the machined surface of the workpiece. The characteristics of the recast layer have a great relationship with the type of dielectric. The research work in this paper aims to acquire a profound knowledge of the recast layers of a surface machined by sinking EDM using water-in-oil (W/O) emulsion as dielectric. Scanning electron microscopy (SEM), X-ray diffraction (XRD), energy dispersive spectrograph (EDS) and micro hardness analysis were performed. The characteristics of the recast layer formed in W/O emulsion were investigated by comparing them with those of the recast layer formed in kerosene and de-ionized water dielectric. It was found that the recast layer formed in W/O emulsion exhibited larger surface roughness, thickness and micro hardness compared with that formed in kerosene and de-ionized water. Both carbide and oxide were detected in the recast layer formed in W/O emulsion whereas only carbide was detected in the recast layer formed in kerosene. Due to the higher supersaturation of gases in the melted material, the recast layer formed in W/O emulsion was found to possess more micro-voids than that formed in kerosene and de-ionized water.

1. Introduction

Electrical discharge machining (EDM) is a thermoelectric process that erodes workpiece material by a series of discrete electrical sparks between the workpiece and electrode flushed by or immersed in a dielectric fluid. After EDM, a recast layer will be formed on the machined surface regardless of the type of dielectric. It is well known that the main mode of erosion is caused by the thermal action of an electrical discharge. The non-traditional manufacturing process of sinking-EDM possesses many advantages over traditional machining during the manufacture of the hard-to-cut materials. However, certain detrimental effects are also present and are due in large part to the formation of the recast layer.

The action of EDM has actually altered the metallurgical structure and characteristics of the recast layer. Micro-cracks can form in this very hard, brittle layer due to an increase in nonhomogeneities of metallurgical phases within the recast layer [1]. The recast layer is the result of the re-solidification of the melted material which did not sweep away from the component's surface by the dielectric during the EDM process and is known to exhibit high hardness, good adherence to the bulk and good resistance to corrosion. However, the recast layer formed by EDM process increases surface roughness, makes the surface become hard and brittle, and decreases the fatigue strength due to the presence of micro-cracks and micro-voids [2].

The composition of dielectric has an important influence on the characteristics of the recast layer since the discharge gap is partially filled by the dielectric during the EDM process which is also a chemical process [3]. The intrinsic nature of EDM process results in a material removal of both workpiece and tool electrode. Formation of the plasma channel consisting of material vapors from the eroding work material and tool electrode, and pyrolysis of the dielectric affect the surface composition after machining and consequently, its characteristics [4]. Deliberate material transfer may be carried out under specific machining conditions by either using composite electrodes [5–11] or dispersing metallic powders in the dielectric [12–14] or both.

In previous work, we studied the sinking-EDM performance using water-in-oil (W/O) emulsion as dielectric. The material remove rate (MRR) obtained in W/O emulsion is much higher than that obtained in kerosene, especially with rough machining parameters. In the sinking-EDM application, the traditional dielectrics are hydrogen–carbon oils. Normally water is not used as a dielectric for sinking-EDM. Although the use of plain water

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in sinking-EDM results in a better performance in some situations [15,16], hydrocarbon oils are superior in a wider range of machining conditions.

Guu et al. [17] investigated the effect of electrical discharge machining on surface characteristics of AISI D2 tool steel using kerosene as a dielectric. Experimental results indicated that the thickness of the recast layer, and surface roughness were proportional to the power input. Ekmekci [1] investigated the composition and crack formation of the recast layer formed in kerosene and water dielectrics. The results revealed that characteristics of the crack are mainly affected by the properties of base material and white layer composition which is partially determined by the type of dielectrics. Previous results presented by Chen et al. [18], Yan et al. [19] and Ekmekci et al. [20] also supported this conclusion. Additionally, operational parameters, such as average discharge current and pulse-on duration were also found to play an important role in the formation of cracks [1,21]. Cusanelli et al. [22] studied the microstructure of the recast layer produced by EDM technique using kerosene as a dielectric at submicron scale. They found that the recast layer was composed of sublayers with particular structures and phases which depending on the machining energy. Cabanillas et al. [23] studied the formation of carbide by electro-discharge machining of alpha iron using kerosene as dielectric. They found that the type of carbide formed on the machined surface was determined by discharge energy. Kruth et al. [24] studied the property of recast layer formed in standard oil dielectric (BP180) by comparing it with that formed in deionized water. He found that the use of an oil dielectric increased the carbon content in the recast layer, whereas a water dielectric caused a decarbonisation.

In our case, W/O emulsion was used as the dielectric, the simultaneous presence of water and oil in the discharge gap may contribute to a recast layer that is different from that formed only in water or oil-based dielectric. In this paper, the composition and crystallographical and metallurgical properties of the recast layer formed in W/O emulsion were studied by comparing them with those formed in kerosene and de-ionized water dielectrics.

2. Experimental procedures

The W/O emulsion used in this experiment was prepared using, for the oil phase, 66 vol% of machine oil, and for the water phase, 34 vol% of de-ionized water. In order to stabilize the emulsion, 2.5 wt% of Span80 was added to the oil phase. Emulsification was carried out with a homogenizer (FJ200, with 18 and 12.7 mm of stator and rotor diameters, respectively) at 3000 rpm for 20 min. The microstructure of W/O emulsion after homogenization is shown in Fig. 1. The samples were machined by a spark-erosion sinking machine (NH250). The experimental set-up is illustrated in Fig. 2. Since the viscosity of W/O emulsion is much larger than that of kerosene or water, the emulsion was compelled into the discharge gap through a hole (Ø4.2 mm) in the centre of the electrode by a micro diaphragm pump. Subject of the tests was the W/O emulsion. For comparison, the tests were also done with kerosene and de-ionized water as dielectrics. During the EDM process, the pulse interval (48 μs) was constant. Technologies going from roughing to half finishing have been used in order to produce a large range of the recast layer thicknesses. Samples were machined in a parametrical order using three different pulse-on durations and two different peak current settings (Table 1). A cylindrical copper rod of 30 mm diameter was used as the tool electrode. The material of the workpiece was ordinary carbon steel (C35) and the size of the workpiece was 75 mm × 35 mm × 4 mm. The machining depth was 1 mm. The copper electrode served as the positive polarity when machining was performed in W/O emulsion and kerosene, and negative polarity when machining was performed in de-ionized water during the EDM process.

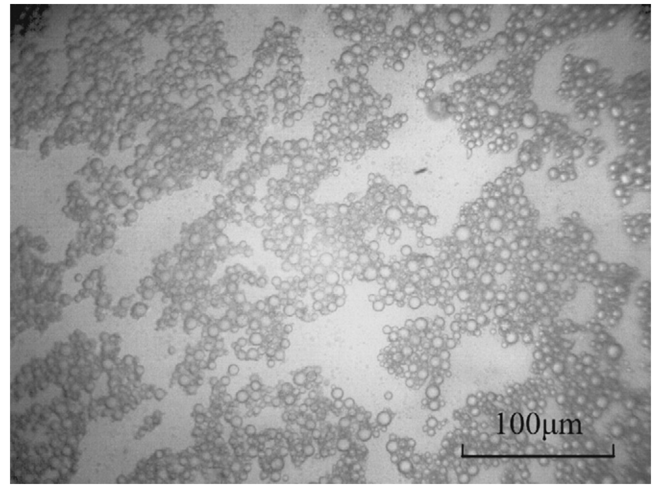

Fig. 1. Optical micrograph of the W/O emulsion used in this experiment.

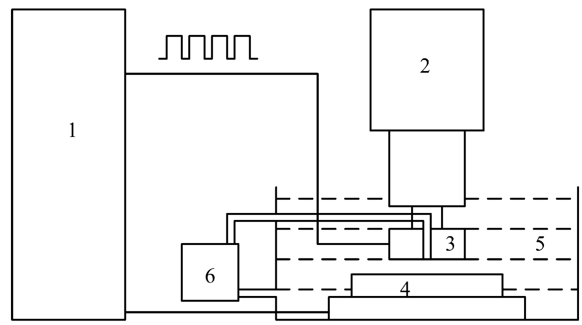

Fig. 2. Schematic representation of the EDM process (1, pulsed generator; 2, servo-control; 3, electrode; 4, specimen; 5, dielectric fluid; 6, micro pump).

After machining, the samples were cut using a wire-EDM machine to obtain a transversal cross-section. In order to observe the recast layer using metallographic microscope and scanning electron microscopy (SEM), the samples were mirror-polished down to 1 μm after having been embedded in epoxy, and then etched with nital. An energy dispersive spectrograph (EDS) associated with the SEM was also used to investigate the elements present in the recast layer after EDM. In order to identify the phases present in the recast layer, X-ray diffraction (XRD) tests have been performed with an OMNI diffractometer. The micro hardness was measured using a micro indentation device with a low load (100 mN) and a micrometric pyramidal imprint. The surface roughness (SR) was determined with a surface profilometer. The recast layer thickness (RLT) was measured with a metallurgical microscope (Nikon EclipseME600P) under a magnification of 200×. The RLT was measured at 40 locations across each cross-sectioned specimen, and an average value was calculated. The distance between the measured locations is uniform and is 50 μm.

Table 1
Experimental conditions of the samples.

Working parameters	Description		
Peak current (A)	9	15	
Pulse duration (μs)	76	150	308
Polarity	Positive (+)	Negative (−)	
Dielectric	W/O emulsion	Kerosene	De-ionized water