journal of materials processing technology 200 (2008) 250–258

journal homepage: www.elsevier.com/locate/jmatprotec

Electrical discharge machining using simple and powder-mixed dielectric: The effect of the electrode area in the surface roughness and topography

*P. Peças**, *E. Henriques*[1]

IDMEC, Instituto Superior Técnico, TULisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal

ARTICLE INFO

Article history:
Received 7 March 2007
Received in revised form
27 July 2007
Accepted 7 September 2007

Keywords:
Electrical discharge machining
Powder-mixed dielectric
EDM polishing
Electrode area
Surface quality

ABSTRACT

Electrical discharge machining (EDM) is one of the most widely disseminated manufacturing technologies, in particular as regards the generation of accurate and complex geometrical shapes on hard metallic components. Nevertheless current EDM technologies have major limitations when dealing with fine surface finish over large process area. Indeed this is one reason that explains the need of final manual polishing of mould cavities performed by EDM. Recently EDM with powder-mixed dielectric (PMD-EDM) has been a focus of an intense research work in order to overcome these technological performance barriers. This paper presents a research work within the objective to acquire deep knowledge on EDM technology with powder mixed dielectric and to compare its performance to the conventional EDM when dealing with the generation of high-quality surfaces. In particular the analysis of the effect of the electrode area in the surface quality measured by the surface roughness and craters morphology was carried out for both technologies. The results achieved evidenced a linear relationship between the electrode area and the surface quality measures as well as a significant performance improvement when the powder mixed dielectric is used.

1. Introduction

Electrical discharge machining (EDM) is a widely used manufacturing technology. Its unique abilities to deal with complex geometries with high-accuracy level regardless the materials hardness impelled its consistent use in the precision and micro-machining applications of several manufacturing sectors (Schumacher, 2004). In particular, the EDM technology has one of its major application fields in the moulds and dies manufacturing sector (Kobayashi, 1995; Peças et al., 2001). In this sector the EDM deals with a large range of components dimensions with processing areas ranging from less than (10–5) $\times 10^5$ mm^2. As the processing component dimensions increases EDM keeps its performance as regards accuracy and complex geometries. Nevertheless the required process time and the surface roughness are affected. Actually, the mirror-like surface finishing is achieved only for an electrode area under 100 mm^2 (Konig and Jorres, 1993; Takawashi et al., 1983). The electrode area increasing promotes the occurrence of superficial heterogeneities and the increasing of the surface roughness (Mohri et al., 1987; Peças and Henriques, 2003).

In the several published research studies focusing this behaviour one can withdraw several explanations. In EDM polishing it is required to use low discharge energy that compels a low electrode-piece (gap) distance. With small gap it becomes difficult to remove the eroded particles. As the electrode area increases the particles tend to accumulate in the gap zone. The difficulty to assure a clean gap promotes the occurrence of

* *Corresponding author*. Tel.: +351 21 8417316/9573; fax: +351 21 8419058.
E-mail addresses: ppecas@ist.utl.pt (P. Peças), elsa.h@ist.utl.pt (E. Henriques).
[1] Tel.: +351 21 8417316/7556; fax: +351 21 8419058.
0924-0136/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmatprotec.2007.09.051

abnormal discharges, namely short-circuiting, due to metallic bridges between the electrode and the work piece, and long pause times due to the rising difficulty of discharge ignition (Hayakawa et al., 2004). These abnormal discharges endorse the occurrence of surface damages and a significant increase of the processing time.

The low gap is also responsible for the occurrence of the capacitive effect (Konig and Jorres, 1993; Tzeng and Lee, 2001). The electrode and the work piece behave as capacitive plates storing the discharge energy. In combination with the capacitive effect the decrease of the discharge transitivity also occurs (Luo, 1997). Uno and Okada (1997) registered that these discharging conditions can promote the occurrence of discharges with the double of the energy preset in the discharge generator. As a result of these phenomena as the electrode area increases the extension of the heterogeneous zones becomes more significant (Peças and Henriques, 2003; Mohri et al., 1988).

Several approaches have been pursued to deal with this EDM limitation. Luo (1997) proposed silicon electrodes since they allow the use of higher gap and minimize the capacitive effect. Another approach is based on an induced electrical field (Luo et al., 1988). The capacitive effect is avoided and the removing of the eroded particles is facilitated through the restriction of the electrical field to a small zone. These approaches had limited success.

A successful approach consists in the use of semi-conductive and conductive powder particles suspended in the EDM dielectric (Kobayashi, 1995; Peças and Henriques, 2003; Ho and Newman, 2003). The presence of such particles allows the increase of the gap distance due to the reduction of the dielectric strength. With a larger gap the eroded particles are easily removed and the probability of abnormal discharges occurrence is minimised. Moreover, the small powder particles contribute to an undemanding discharge ignition process due to their easy polarization and to the formation of electrical bridges among them (Chow et al., 2004). Therefore the increase of discharge transitivity and the reduction of the capacitive effect are observed (Luo, 1997; Uno and Okada, 1997; Mohri et al., 1988, 1991; Narumiya et al., 1989).

Furthermore Yan and Chen (1994) and Ming and He (1995) found that the powder particles contribute to the reduction of the surface cracks and to the smoothness and homogenisation of the white-layer. Uno and Okada (1997) and Tamura and Kobayashi (2004) presented studies dedicated to the analysis of the influence of the suspended powder in the discharge crater formation. There is no agreement about the actual influence of the impact forces in the discharge crater. Nevertheless the suspended powder contributes undoubtedly to the modification of the crater solidification process (Uno and Okada, 1997; Chow et al., 2004). Regardless the relevant contribution of these works there are no results presented related with the quantitative influence in the discharge diameter and deepness as well as the behaviour in the multi-discharge case.

A comprehensive analysis of the influence of the material powder type in the EDM polished surfaces was presented by Wong et al. (1998). Best surface finishing was achieved for silicon and graphite powders with low concentration. Additionally they conclude that the powder material must have a significant level of electrical conductivity but not too high since the increasing of the gap distance beyond a certain limit deteriorates the discharge process.

Moreover Tzeng and Lee (2001) and Zhao et al. (2002) found that the process performance strongly depends from the combination between the powder type, particle size and its concentration. Peças and Henriques (2003) confirmed the use of silicon powder reduces significantly the influence of the electrode area and promotes better surface finishing for the same polishing time. The authors also refer that the success of the process is highly dependent on the efficiency of the flushing system. It must assure a uniform powder concentration all over the processing zone and a complete removal of the eroded particles from the gap. These observations are also remarked by Tzeng and Lee (2001).

Klocke et al. (2004) presented a work where the influence of the suspended powder in the white-layer and in the heat-affected zone is qualitatively discussed. The use of silicon powder promotes a softer transition from the white-layer into the matrix material than the observed with powder-free dielectric. The authors attribute this behaviour to the balancing of the heat introduced by the silicon particles with the rapid cool down of the molten surface. Wu et al. (2005) found that the use of surfactant contributes to the particles separation and to their homogeneous distribution in the dielectric. As a result the work piece surface is improved and the white-layer thickness is reduced.

Despite the intense research covering the powder-mixed dielectric EDM (PMD-EDM) there is limit knowledge about its quantitative influence in the white-layer thickness and crater diameter and deepness. In this work, it were performed a set of EDM and PMD-EDM tests that allow to define a quantitative relation of those surface characteristics with the electrode area for the two process conditions.

2. Experimental procedure

An experimental setup was developed to run the research tests for the two different dielectric conditions. It supports the machining with simple dielectric (conventional EDM) and with powder-mixed dielectric (silicon powder at 2 g/l). It includes a dielectric circulation system based on a mud pump integrated with a small tank (Fig. 1). This configuration allows an efficient gap cleaning, avoids the silicon powder sedimentation and the contamination of the conventional equipment filters with the powder particles. The EDM tests were conducted using a standard sequence of machining regimes (Table 1). This sequence was the one generated by the EDM equipments expert system for a finishing electrode. The same 13 regimes programme was used for all the electrode areas and for the two dielectric conditions. The orbital movement was implemented after the first regime and electrode penetration was set to 0.5 mm. From regime 1–8 the pulse generator controls the process progress by the Z-axis position monitoring. In the polishing regimes (9–13) the pulse generator imposes a process time for each regime. The polishing time set for the polishing regimes was 100 min. During the preliminary experiments it was noticed in regimes 9 and 10 the occurrence of a slight electrode penetration. This generates the presence of eroded particles in these regimes. So in the PMD-EDM tests the silicon powder