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Analysis of the surface integrity when nitriding AISI 4140 steel by the sink electrical discharge machining (EDM) process

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Abstract

The aim of this this work is to demonstrate the feasibility of nitriding AISI 4140 steel using electric discharges produced by sink EDM equipment. This was performed using a copper electrode, and mixed deionized water and urea as the dielectric fluid. Techniques such as laser profilometry, x-ray diffraction (XRD), glow discharge optical emission spectroscopy (GDOES), scanning electron microscopy (SEM) and optical microscopy were employed. The proposed mechanism for this particular nitriding process was that of ion implantation and the layer under scrutiny was shown to have been hardened, however coming to beneath of the surface the hardness decreases, which coincides with the impoverishment of the quantity of nitrogen inserted.

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Keywords: Nitriding, sink EDM, AISI 4140 steel, surface integrity, microhardness, roughness.

Nomenclature	
EDM	electrical discharge machining
GOES	glow discharge optical emission spectroscopy
SEM	scanning electron microscopy
HAZ	heat affected zone
MZ	martensitic zone
RL	recasted layer
SSL	subsuperficial layer
XRD	x-ray diffraction
FEDX	fluorescence energy dispersive x-ray spectroscopy
DW	deionized water
DWU	deionized water + urea
RMS	root mean square
S_{ku}	kurtosis
S_{sk}	skewness
S_q	the RMS average height of the asperities
S_t	total height between the highest peak and the deepest valley within the sample interval
Sz	ten-point average height of the asperities

1. Introduction

EDM is a process where material removal is essentially related through the development of high temperatures. The energy source originates from electrical discharges generated in a plasma channel between two electrodes, the tool and the workpiece, submersed within a dielectric fluid. The plasma channel temperature is estimated to be between 8,000 and 10,000 ^{o}C. The high pressure, around 200 bar, and temperatures, around 20,000 ^{o}C, generated from the collision of ions and electrons with the electrodes, which can induce instantaneous fusion and evaporation from both the workpiece and tool electrodes, leading to material removal

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[1]. EDM is a relatively cheap and well-established manufacturing technique. However, it is also possible to envisage the use of EDM to promote surface modifications [2]. The enrichment alloy has been searched for the material transfer from electrode, powders diluted in dielectric fluid or both techniques. Due to the very high temperatures involved in EDM, the incorporation of elements from the electrode and/or dielectric fluid is unavoidable, even when using standard machining conditions, at a low level [3]. In one approach, insoluble powders are incorporated into the dielectric fluid [4, 5]. For example, SiC powder was mixed to deionized water during EDM of Ti-6Al-4V surfaces [4]. After machining, SiC particles were detected in the recast layer and the authors indicated the potential for the process to also be used as a surface alloying technique. Similarly, surface enrichment of die steels was investigated by mixing W, Si and graphite powders in the dielectric fluid (kerosene and commercial EDM oil) during EDM [5]. However, since the recast layer is very porous and brittle, and therefore is normally removed after machining, when enrichment occurs only within this particular layer it may not be very useful [7, 8]. The purpose of the present work is to incorporate nitrogen into the plasma channel in EDM in order to enrich AISI 4140 steel workpiece electrodes with nitrogen.

2. Materials and methods

Conventional die-sinking EDM equipment generated the electrical discharges, using deionized water as the dielectric fluid. Urea was diluted into the water at a proportion of 10 g/l as the nitrogen source. The tool electrode was constituted of electrolytic copper and the workpiece electrode constituted of AISI 4140 steel. The operational parameters used in the tests are shown in Table 1. The morphology of the machined surface was characterized by SEM. In addition, carefully prepared cross sections of the machined surfaces were observed through optical microscopy. A 3D laser interferometer was also used to assess the morphology and surface topography of the machined surfaces. The calculation of surface roughness parameters used a Gaussian filter, 0.08mm. The depth and diameter of the machined cavities were measured using a laser profilometer. Nitrogen concentration profiles were determined by GDEOS using the Horiba Jobin-Yvon. The argon plasma source was operated using a pressure of 650 Pa and a power of 35 W. The measurement time was 60s. Conventional Bragg-Brentano or θ-2θ XRD was used to detect and identify the types of nitrides in the machined surfaces. Tab. 2 shows its specifications and parameters. In addition, for a sample machined using urea, XRD measurements were carried out perpendicularly to the machined surface. In sequence, a 5 μm layer was removed from the machined surface by polishing with diamond paste using abrasive sizes of 3 and 1μm. This procedure was repeated five times, until a total thickness of 25 μm was removed. Low-angle XRD measurements were also carried out in order to investigate the most superficial layer of the machined surfaces, using an incidence angle of 2.5°. Knoop and Vickers microhardness tests with a load of 49 mN evaluated the occurrence of hardening on the machined surfaces. FEDX was used to identify residues in the deionized water after the machining tests. The heat-treating of tempering was performed in an electric oven without protective atmosphere and the electrical conductivity of fluids was monitored with a portable conductivity meter.

Table 1 - EDM operational parameters.

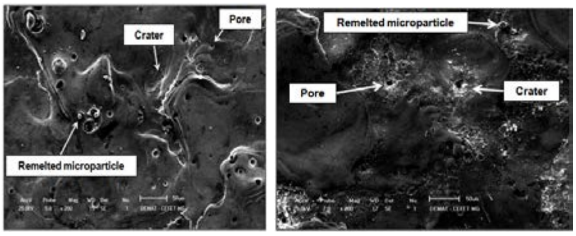
Parameter	
Tool polarity	Negative
Voltage	110 V
Current	30 A
Pulse time (T_{on})	100 μs
T_{on} / total time	0.5
Test duration	5 s
Length of intermittent tool drawback	1 mm

Table 2 - Technical parameters for XRD (θ-2θ).

Radiation	CuKα
Voltage	40 KV
Current	30 mA
Scanning mode	Fixed time
Spacing	0.02°
Scanning speed	2 °/min
Scanning time per point	5 s
Initial and final angle (*2θ*)	20° - 120°

3. Results and discussions

An example of a surface obtained with EDM tests using a mixture of deionized water and urea as the dielectric is shown in Fig 1. The surface morphology is characteristic of a surface machined by conventional EDM, where high temperatures lead to the formation of craters, pores and remelted particles. Figures 2 and 3 shows the results obtained with the topographic analysis of machined samples with DW and DWU. Noteworthy, are the significant differences in the parameters under consideration. Some surface roughness parameters were used to quantify their surface topographies and the results are shown in Fig 2, where, the amplitude is S_q, S_z, S_{ku}, S_{sk}. This figure reinforces the similarity of the surface morphologies both in terms of amplitude and of distribution of the irregularities, S_{sk} and S_{ku}, despite the addition of urea.



(a) (b)

Figure 1. Surfaces Morfology (a) – DW e (b) – DWU. MEV.

The presence of craters and pores may produce a stochastic microtexture that has proven to be beneficial in certain applications, such as the manufacturing of rolled sheets. Rolling mill rolls are currently textured by EDM to transfer to rolled sheets a certain roughness [9]. Another important niche for textured surfaces is found in tribological applications [10]. This is highly desirable in applications involving very high contact pressures, since raised areas of the surface, which support a larger proportion of the applied loads than do lower areas of the surface, wear more rapidly than the surrounding material [11].

A cross section image of a machined surface is shown in Fig 4, where two regions were identified: a subsuperficial Layer (SSL), and a Recast Layer (RL). The average thicknesses of the SSL was 10 ± 0.5 μm and of the RL was 13 ± 0.6 μm. This microstructure is typical of surfaces