

SURFACE HARDENING OF AL-CU ALLOY BY ELECTRICAL DISCHARGES

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Abstract. *In the last decades the interest in improving the nonconventional methods of machining has grown, modifying them to an innovative process. The EDM process has a new emphasis on surface modification. The objective of this present study was the process of aluminum nitriding by electric discharges using the EDM machine. The nitrogen used is present in the unconventional dielectric fluid, a solution of deionized water with urea, the nitrogen source. The electrode used is electrolytic copper and as part electrode, the aluminum was used AA 2011. This process allows the implantation of nitrogen ions on the surface of the material, promoting a protective layer, against oxidation and improvement in the mechanical properties of the material. It has been proven that the influence of distortion generation on the crystalline network of the material in the process facilitates the ion exchange between the electrodes and the dielectric fluid. Thermal treatments were carried out on the samples before the application of electrical discharges, such as annealing and artificial aging, also samples were hardened with work hardening (plastic deformation). In the work hardened samples oxygen was found in the surface layer that could indicate the incorporation of this through the plasma channel, which could be due the presence of a type of Al_2O_3 aluminum oxide, or an ALON composite. A 1100 % gain in the surface hardness was evidenced in comparison to the microhardness of the substrate.*

Keywords: Surface Hardening, Work Hardening, Nitriding, Duraluminum, EDM.

1. INTRODUCTION

As engineering advances, the importance of component weight reduction in mechanical designs is evident. This creates the need to produce new composite materials or treatments for improving the surface resistance of some material while maintaining the weight and composition of its matrix. Various surface treatments have been used to improve the performance of materials for different applications, surface hardening, for example, decreases surface wear and increases the shelf life of the treated material. Other factors such as the reduction of the coefficient of friction or the resistance to fatigue are influenced by the superficial treatments. Nitriding is a physico-chemical treatment that promotes the creation of nitrides, in this case superficially in the form of a layer, keeping the substrate with its normal properties and the surface hardened. In the aluminum nitriding process, various techniques such as plasma nitriding, gas nitriding, salt bath nitriding (or liquid nitriding) and ion implantation are used, resulting in thin layers up to 20 μm , as in the case of Okumiya et al. (2009).

The EDM process utilizes electric discharges between two electrodes (part and tool) submerged in a dielectric fluid for subsequent removal of material by sublimation. This process has emerged as one of the most common in the manufacture of metal molds and dies (SANTOS et al., 2016). It has been demonstrated that the plasma channel generated in the process promotes the ion exchange between both the electrodes and the suspended particles in the dielectric fluid. The use of alternative dielectric fluids and mixtures with powdered material shows ionic deposition, in which case a mixture of deionized water with urea ($\text{CH}_4\text{N}_2\text{O}$) was used.

In the current work, the nitriding of the aluminum AA 2011 (aluminum-copper alloy) was carried out through the sink-electrodischarge machining process (sink-EDM). This process allows the implantation of nitrogen ions on the surface of the material, promoting a protective layer, against oxidation and improvement in the mechanical properties of the material.

2. METHODOLOGY

The method was to implement surface enrichment by nitrides in duralumin using electric discharge machining (EDM). The samples were tested after artificial aging treatment in a muffle furnace at a temperature of 160 °C for 14 hours with cooling in the oven for another 12 hours, the heat treatment scheme is shown in Fig. 1. In this process, an unconventional dielectric fluid, a solution of deionized water with urea was used, with urea being the source of nitrogen. In the research conducted by Santos (2013) observed that the urea concentration in the deionized water has no significant influence on the creation of the nitride layer or the thickness of the same nitridation of a carbon steel AISI 1040. This indicates that the amount of nitrogen absorbed by the plasma channel is limited. According to the results obtained by Santos (2016), the samples do not present physical or mechanical changes with different concentrations of urea and the Vickers microhardness values obtained are very close to each other.

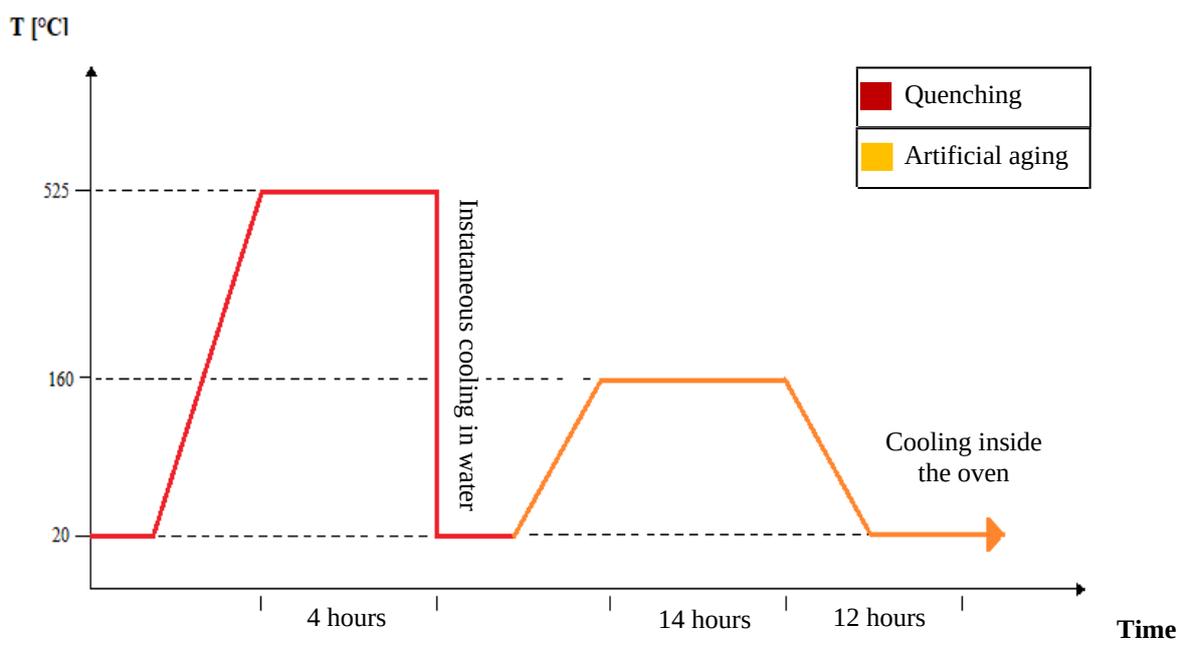


Figure 1. Heat treatment scheme for artificial aging on AA 2011 aluminum alloy

The nitriding tests were performed on a sink-EDM manufactured by Engemac 440NC model available in the laboratory of tribology and material (LTM-FEMEC) of the Federal University of Uberlândia. The machine has a tool holder electrode head, with Z axis movement, through linear guides and recirculating ball screw, driven by stepper motor and capacity for tool electrodes up to 60 kg. The work tray, also called the main tank, has a 180-liter side and front opening. The total power described in the machine manual is 6.5 KVA.

The operating parameters for the use of the EDM machine are: the polarity of the tool electrode, voltage, current, pulse time (T_{on}), the relationship between the pulse time and the total time (DT), the gap (gap), sensitivity, time erosion, periodic removal of the electrode tool, interval between erosion and remoteness.

The electrode used was of ultrafine grain graphite with a diameter of 10 mm and a length of 150 mm. In order to perform the nitriding process by electrical discharges it was necessary to prepare the samples to be submitted to the process, they were taken from an aluminum bar AA 2011 and cut to a standard size of 20 mm x 20 mm x 10 mm and were subjected to aging in a muffle furnace at 160 °C for 14 h before nitriding to prove the influence of distortion generation on the crystalline network of the material in the process.

In the process of nitriding by electrical discharges, the main tank of the machine was not used, but an auxiliary recipient of stainless steel of 150 ml of capacity, which was filled with the solution of water deionized with 5 g/l urea concentration. The parameters with influence on the process are current (i), pulse time (t_{on}), working time (Dt), electrode material, dielectric fluid, polarity and erosion time. These parameters were selected from several bibliographic sources, for example, in the work of Yan et al. (2005), Santos et al. (2016), Souza (2016) pulse times were used (T_{on}) 100 μ s, also in all cases is recommended to use the machine with reversed polarity, that is, negative polarity to the

electrode tool and positive polarity to the workpiece electrode. The other parameters vary depending on process performance and the creation of a more continuous plasma channel, varying current and electrode materials.

The parameters used in the process are shown in Table 1.

Table 1. Parameters inserted on EDM machine for nitriding process.

Parameter	Description/magnitude
Current (i)	30 A
Pulse time (t_{on})	100 μ s
Working time (Dt)	50 %
Dielectric fluid	Deionized water + urea (5 g/L)
Erosion time	60 s
Tool material	ultrafine grain graphite

All samples were subjected to cross-sectional metallographic analysis after electrodischarge nitriding. The metallographic preparation consisted of cross-section of the machined area, followed by metallographic inlay with bakelite and manual sanding with silicon carbide sanding mesh in the following sequence: 320, 400, 600, 1000 and 2000, followed by polishing with alumina oxide and last chemical etching with reactive Keller for the development of grain boundaries and highlight the observations interest areas.

After the metallographic preparation the samples were subjected to observations and analysis using optical microscopy, scanning electron microscopy (SEM) and energy dispersive X-ray spectrometry (EDS). In the optical microscopy the different phases created in the process were evaluated, due to the melting and resolidification of the surface of the material. Using the SEM connected to the EDS system, the chemical composition of the zones of interest was evaluated, assessing if there was nitriding in the process.

For the evaluation of the surface hardness, a Vickers (HV) microhardness equipment with a load of 40 gf was used, analyzing the remelted zone and the matrix for comparison.

3. RESULTS AND DISCUSSIONS

Figure 2 shows the images acquired by optical microscopy of the samples submitted to the nitriding process by electrodischarge for each condition.

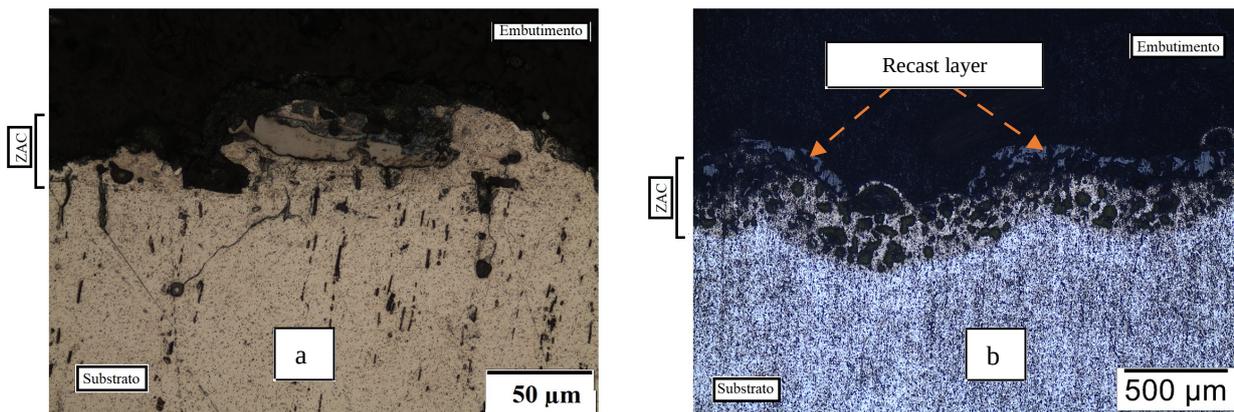


Figure 2. Cross-sectional images of the samples after being submitted to the electrodischarge nitriding process A) artificial aged (50 x magnification) B). work hardened (5 x magnification)

Through the images obtained with optical microscopy shown in Fig. 2 can differentiate the different phases created in the process due to the melting and resolidification of the material. The aged sample (Fig. 2a) presented a heat affected zone (HAZ) with a thickness of $130 \pm 26 \mu\text{m}$. The corrugated sample (Fig. 2b) presented a HAZ with a thickness of $722 \pm 36 \mu\text{m}$ with a hardened surface layer of $260 \pm 9 \mu\text{m}$ with ceramic appearance. The thickness of the HAZ in the samples is considerably different, this can be attributed to the effect of stacking failure generated in the work hardening, generating a greater amount of distortions in the crystalline network of the material and thus facilitating the ion exchange between the electrodes.

After evaluation of the thickness of the HAZ of the samples, these were taken to the analysis of chemical composition using SEM connected with the EDS. Figure 2 shows the result of the EDS analysis of both the surface

layer and the substrate, where the presence of oxygen in the ceramic-like areas was evidenced while in the substrate there was no presence of this.

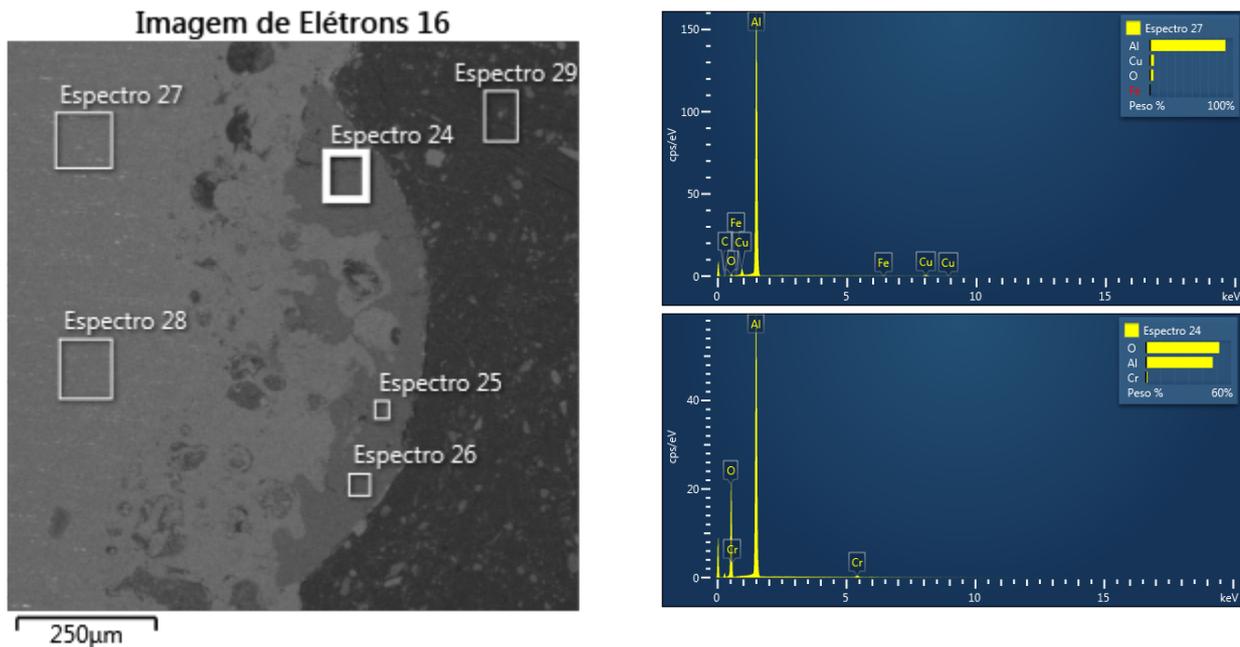


Figure 2. Analysis of chemical composition of the substrate and HAZ of the sample in the condition as work hardened (WH)

The presence of oxygen in the surface layer could indicate the incorporation of this through the plasma channel, which could be a type of Al_2O_3 aluminum oxide, or an AlON composite.

After evaluation of the composition, Vickers microhardness tests of the corrugated sample were performed in order to know if the surface treatment had any effect on the mechanical properties of the material. Figure 3 shows the profile of Vickers microhardness made in the surface layer, the tests were done with a load of 40 gf.

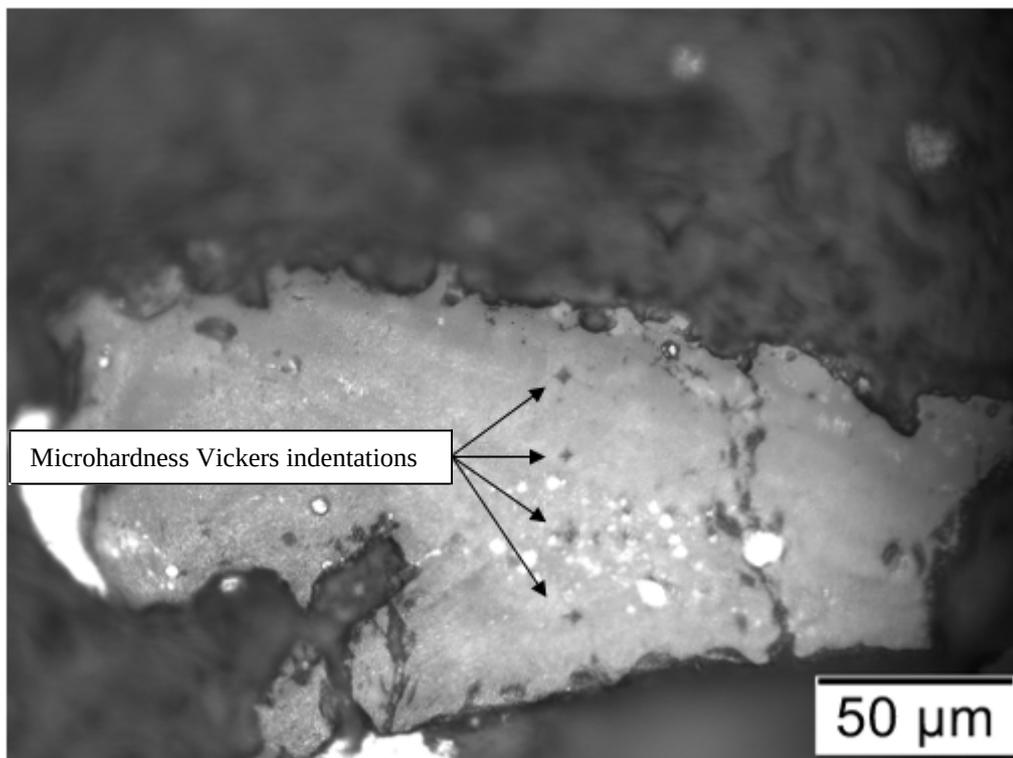


Figure 3. Vickers microhardness profile of the surface layer of the sample in the condition as work hardened. Charge: 40 gf

The results of Vickers microhardness for the cross-hardened sample are presented in Fig. 4 with a mean microhardness of 1600 ± 35 HV, where a about 1200% gain in surface hardness was evidenced in comparison to the microhardness of the substrate of 116.43 ± 4 HV. The large variance presented in the microhardness results of the surface layer can be attributed to the creation of an unstable composite, but nevertheless quite hard when compared to the substrate.

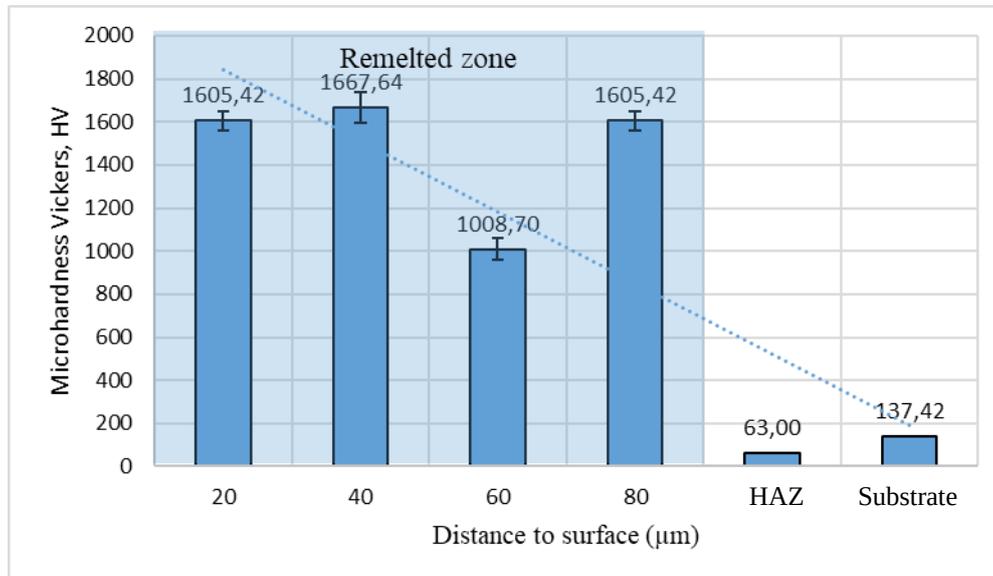


Figure 4. Vickers microhardness profile values of the hardened remelted layer for the sample in the condition as work hardened

4. CONCLUSIONS

This study sought to demonstrate the viability of the nitriding process by electrodischarges, although the process continues in studies, these results presented here elucidate a way forward, that intends to lead the process of aluminum nitriding, which is usually performed with the plasma technique gas, from a few hours to a few minutes, and could increase the thickness of the hardened surface layer.

It has been shown that the generation of dislocations and distortions in the crystalline lattice of the material in the process, and the influence of the stacking failure produced by the hardening in the ion exchange between the electrodes and the dielectric fluid.

The best development of this technique could provide a light material with low surface wear, important properties in the design of machines in different areas, among them the aerospace and aeronautics.

5. ACKNOWLEDGMENTS

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6. REFERENCES

- CHEN, H.; STOCK, H.; MAYR, P. Plasma-assisted nitriding of aluminium. *Surface and Coatings Technology*, 1994. V. 64, p. 139 – 147.
- CZERWIEC, T.; RENEVIER, N.; MICHEL, H. Low-Temperature Plasma-Assisted Nitriding. *Surface and Coatings Technology*, 2000. V. 131, p. 267 – 277.
- FITZ, T. *Ion Nitriding of Aluminium*. 2002. Forschungszentrum Rossendorf. 107 p.
- GREDELJ, S. et al. Plasma nitriding and in situ characterisation of aluminium. *Applied Surface Science*, 2002. v. 199, n. 1–4, p. 234–247.
- OKUMIYA, M.; TSUNEKAWA, Y.; SUGIYAMA, H.; TANAKA, Y.; TAKANO, N.; TOMIMOTO, M. Surface modification of aluminum using ion nitriding and barrel nitriding. *Surface and Coatings Technology*, 2005, 200, 35–39. <https://doi.org/10.1016/j.surfcoat.2005.02.110>

SANTOS, R. Nitretação por EDM do Aço AISI 4140. Tese de Doutorado, Universidade Federal de Uberlândia, 2013.

SANTOS, R.; SILVA, E.; SALES, W.; RASLAN, A. Influence of urea content blended with deionized water in the process of nitriding using electrical discharge machining on AISI 4140 steel. *The International Journal of Advanced Manufacturing Technology*, 2016.

SOUZA, D. M. Nitretação De Alumínio 2011 Utilizando Usinagem Por Descargas Elétricas. 2016. 62 f. Projeto de Conclusão de Curso, Graduação em Engenharia Aeronáutica, Universidade Federal de Uberlândia, Brasil.

VISUTTIPITUKUL, P.; AIZAWA, T. Plasma nitriding design for aluminium and aluminium alloys. *Surface Engineering*, 2006. v. 22, n. 3, p. 187–195.

YAN, B. H.; TSAI, H. C.; HUANG, F. Y. The Effect in EDM of a Dielectric of a Urea Solution in Water on Modifying the Surface of Titanium. *International Journal of Machine Tools & Manufacture*. N. 45, p. 194-200. 2005.

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