Nitriding process of SAE 4140 steel using FJEDM.

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Abstract. *The SAE 4140 steel is widely used in the manufacturing of shafts, pins, gears, etc., having an adequate structure for nitriding processes. The purpose of this paper is to verify the availability of the surface hardness ability in this steel's samples, using an electrical discharge machining process, with assistance from a dielectric fluid jet FJEDM, using as fluid urea and deionized water. The tests were made in a machine of penetration EDM, with an adapted hydro jet machine, to apply the dielectric fluid with a pressure of 230 bar during the machining. The characterization techniques used were: Micrographic analysis, micro hardness, EDX specter analysis and X-ray diffraction analysis. The results showed the formation of a hardened layer between the bulk and the recast layer on the surface. The hardness on the recast layer is about 50% higher than the one of the bulk. The repetition of these results was verified in 5 tests. It can be concluded that the FJEDM process used was efficient on the superficial hardening of the SAE 4140 steel.*

Keywords: *FJEDM, SAE 4140 steel, Nitriding, Surface hardening.*

1. INTRODUCTION

The enhancement of the surface with nitrogen is defined as nitriding according to Thelning (1975), it's a thermo chemical treatment that involves the introduction of nitrogen in the atomic form, by diffusion, in the inner part of the crystalline reticule of ferrous alloys, in the ferrite stability field, in temperatures usually on the range from 500 to 590 ºC. The nitriding of metals is a process that allows altering the properties of superficial hardness, wear, corrosion, thermal resistance of the material and resistance to cavitation erosion. The nitriding process of surfaces applies to the treatment of injection molds, automotive parts, extrusion aluminum molds, cutting tools, piercers and matrixes for general cutting, etc.

Yan *et al*. (2005) studied the enrichment of surfaces with nitrogen in parts of Ti_6Al_4V, where were verified the effects of the urea solution dissolved in distilled water, as a dielectric fluid in the process of electrical erosion by penetration. The experimental results indicate that the nitrogen decomposed in the dielectric fluid migrated to the surface of the part making a hardened layer of TiN, which presents good wear resistance. Under satisfactory conditions of machining, the modifications on the surface showed improvements in the friction and wear resistance and these modifications are quite simple, not requiring special equipment, on the other hand of the usual nitriding methods.

The technique of enriching surface with nitrites using electrical discharges was also studied by Camargo *et al.* (2006). The tests consisted in using as a dielectric fluid 90% of deionized water and 10% urea, in static regime, in the electrical erosion of samples of the Ti_6Al_4V alloys, with operation parameters extracted from the existing technical literature. The results showed the formation of a layer enriched by nitrides with around 7µm thick.

The machining process by electrical discharges (EDM) is quite complex and has been studied thoroughly in the last years. According to McGeough (1988), it consists in the material erosion mechanism, done firstly by the use of electrical energy and modifying it internally to thermal energy, completing a series of discrete electrical discharges, occurring from the electrode to the piece immersed in a dielectric fluid. The thermal energy generates a plasma channel between the cathode and the anode with ultra high temperatures, initiating substantially the heating and the fusion in the surface of each pole. When the direct pulsation current is stopped, the plasma channel collapses and causes a sudden drop in the temperature, allowing some movement of the dielectric fluid, withdrawing the cast material from the plasma channel and transporting it in the form of microscopic particles. After an electrical discharge, occurs the formation of a crater and part of the cast material places itself on the crater's surface, due to the superficial tension and the cooling effects, forming a layer throughout the whole machined surface, which some researchers name recast layer. This layer is usually fragile and presents fissures and pores, and usually needs to be removed. Underneath this layer is a zone called heat affected zone (HAZ), which is only partially affected by the high temperatures. The hardness of the recast layer and the HAZ depend on the EDM parameters used, the thermal conductivity capacity and the material itself.

The electrical discharges need to be pulsating, because if they are continuous they would generate high temperatures in the surface of the piece that would cause it to fusion and vaporize in a disorderly fashion. The discharges last for only millionths of a second and this time gap is called T_{on}. When the discharges are ceased, begins, also for millionths of a second the time gap called T_{off} or DT (%) of T_{on}. This process is used on the manufacturing of stamping matrixes and injection molds, appliances that have as main characteristic for its proper working with high hardness materials. Besides machining materials with high hardness, other advantages of this process are: Manufacturing of appliances with very thin walled cavities, of complex geometry and free of rough edges.

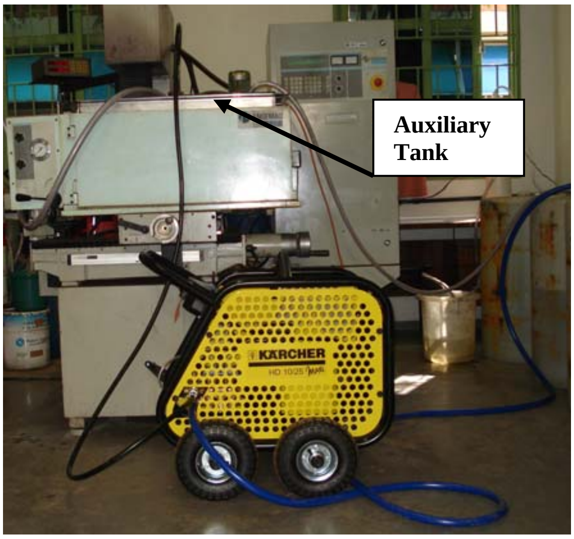
According Drozda (1998) and Oarmoldworks (2007), the copper works very well as material for the electrode and is widely used when low roughness are necessary for the piece's surface. The cost of the electrode is always the most critical factor in EDM operation. Material, manufacturing and wear must be thoroughly evaluated to determine which material is most appropriated. Such electrode must have high electrical conductivity, high machinability, high temperature of point of fusion point and have a good dimensional stability when worked on the usual process.

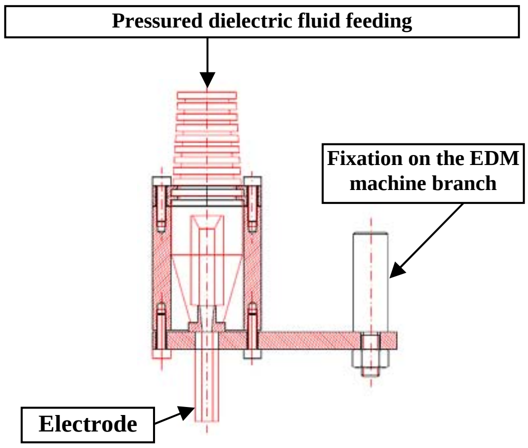
The required characteristics for the dielectric fluids are that, after the first electric discharge, they are easily ionizable and have high dielectric stiffness to be good electrical isolator before the unbalance tension, where the plasma channel is formed. Good cooling capability with good viscosity, are also considered to allow the removal of the machining residues from the work gap region (McGeough, 1988). According to Fuller (1989), the dielectric fluid has an important role in the process of controlling the discharge opening power. The use of kerosene was highly accepted due to its low cost and its good performance on EDM operations, but due to problems with occupational health and the aggressive behavior of this dielectric, researches point towards the change and substitution of it for modified oils both mineral and vegetal, deionized water or certain aqueous solutions (Arantes, 2007).

The purpose of this paper is to verify the viability of the superficial enrichment of steel samples used in the nitriding processes, through the process of EDM with dielectric fluid jet (FJEDM), using deionized water and urea at a concentration of 10 g/l.

2. METHODOLOGY

The samples were manufactured in SAE 4140 steel, with 19 mm diameter and 12 mm long, and the electrodes were made in electrolytic copper, in tubular shape, with 22 mm external diameter, 2.5 mm internal diameter and 25 mm long, using conventional machining process. A negative polarity was used for the electrode during the EDM testing. The conductivity of the dielectric fluid was measured at 1170 µS as a mean. The work pressure, adjusted for testing, was of 230 bar. The figure 1 shows the adaptations and the assemblies made on the EDM machine for the utilization of the FJEDM system, giving special attention to the hydro jet machine, which has a pressure of 250 bar, and the auxiliary box which was made in AISI 304 stainless steel. In that same figure is also shown a sketch of the electrode bearer device, which was designed to enable the application of the dielectric fluid jet along with the EDM process.





Electrode bearer device

Figure 1: Adaptations made on the EDM machine for the FJEDM process.

The tests lasted for five minutes each and the feeding of the dielectric fluid had a constant flow of 16.7 l/m. The EDM parameters were established based in information from the existing literature and in the EDM machine's (EDM 440NC) manual, with T_{on} = 100 µs, T_{off} or TD of 50%, TS = 6 (approximately 18A), erosion time = 5 s, electrode distancing = 1mm and with no time gap between erosion and distancing.

After the tests, the samples were prepared by metallographic techniques and analyzed by optical microscopy. The Vickers micro-hardness was measured with a Shimadzu micro-hardness, with a 25 grams load, to evaluate the hardening of the nitrides layer formed. The analysis of the chemical elements was made by EDX specter analysis in a Scanning Electron Microscopy and X-ray diffractometer.

3. RESULTS DISCUSSION

The figure 2 shows the micrographic analysis of the SAE 4140 steel samples and the micro hardness impressions, with the average values measured. One can notice the presence of the recast layer, with an average 8 µm thick, and a darker region, between the recast layer and the bulk, around 8 µm thick, having a distinct and uniform morphology, it can be both the HAZ or a nitride enriched region.

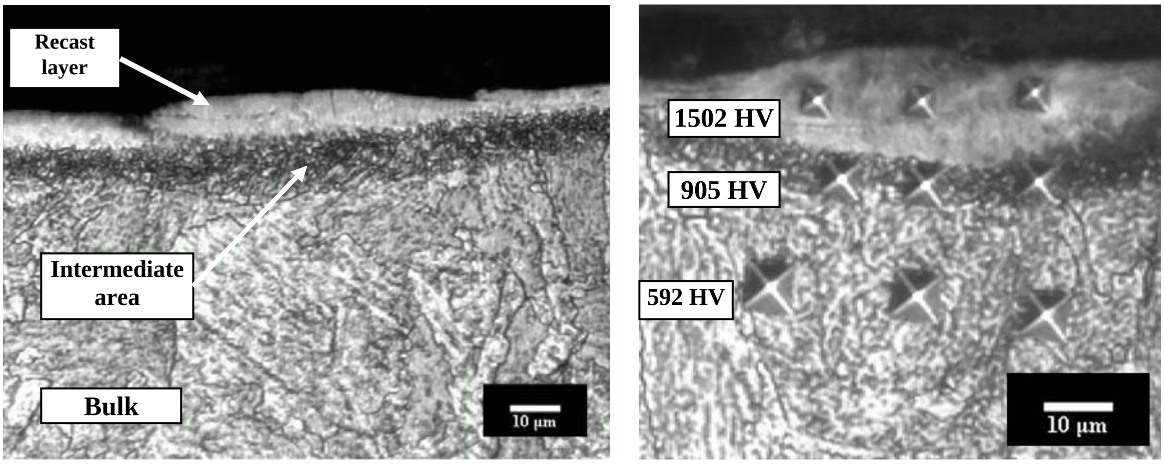


Figure 2: Optical microscopy and micro-hardness of the SAE 4140 steel machined by the FJEDM process.

The presence of this intermediate zone can be credited to the incorporation of nitrogen released by the urea and its thickness is measured very near the one measured by Camargo *et al.* (2006) on the titanium alloy. The figure 3 shows the EDX specter chemical analysis. In this analysis, the peak representing nitrogen points the possibility of this element being incorporated to the sample's surface. So far, the preliminary analysis made by x-ray diffraction showed in the spectrum, peaks of iron nitride formed on the surface machined by the process FJEDM, when a solution of deionized water and urea was used as a dielectric fluid. The peaks found in spectra of samples of SAE 4140 steel, with no machining and machined only with deionized water as dielectric fluid are related to alpha iron.

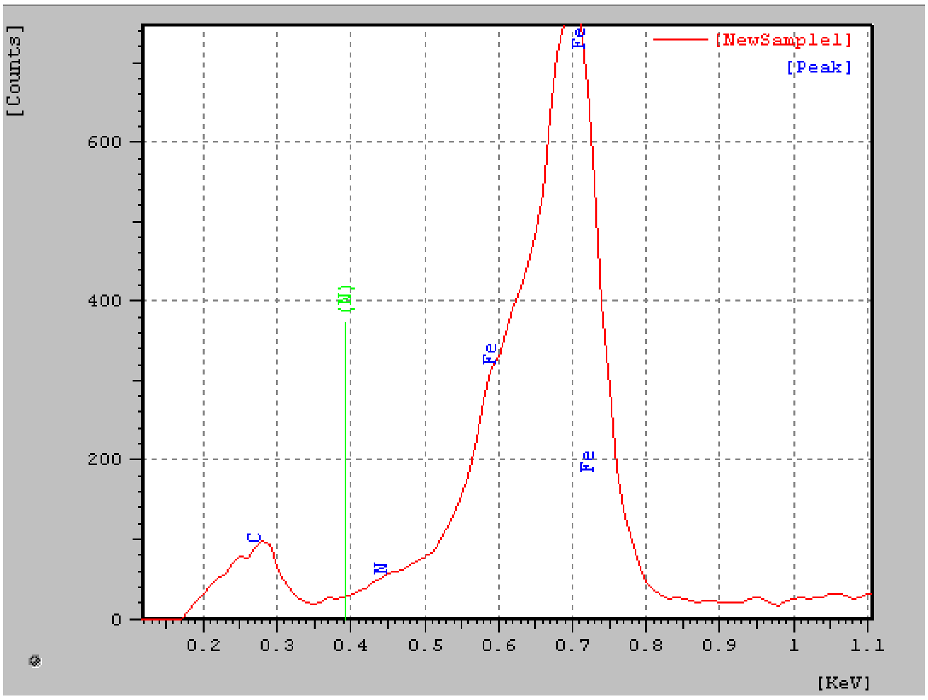


Figure 3: EDX specter analysis.

The figure 4 shows us the Scanning Electron Microscopy (SEM) image pointing the recast layer, the nitride enriched zone and the bulk. The area analyzed by the EDX is shown in this picture in the region limited by the green square.

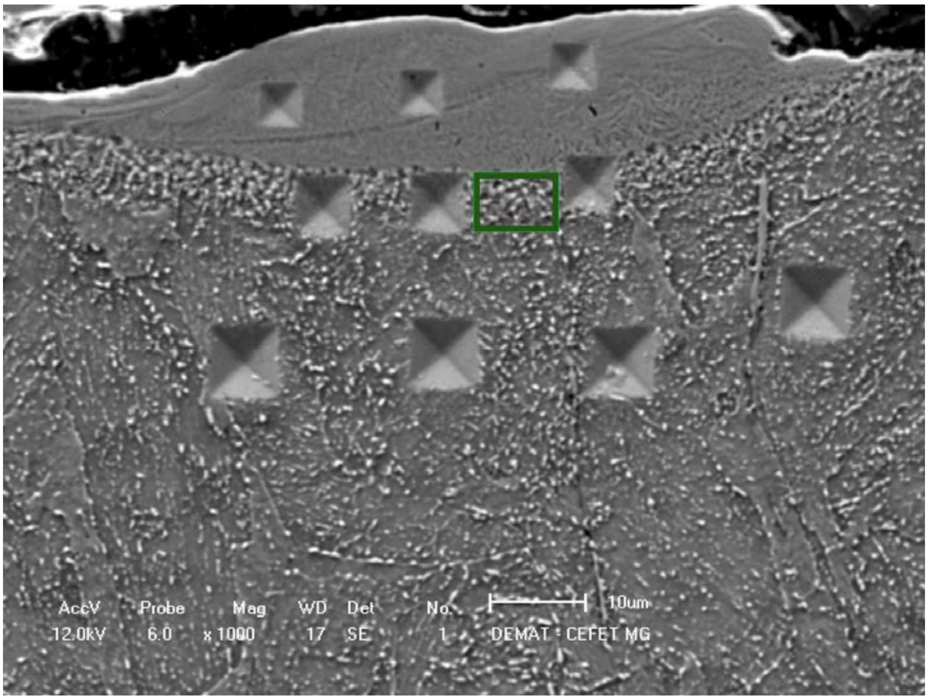


Figure 4 – SEM image of the SAE 4140 steel machined by FJEDM process.

The figure 5 shows the spectrum with the peaks of the measurements made by X-ray diffraction. The result of the analysis shows formation of iron nitride peak ε type. This analysis was performed on the sample surface SAE 4140 steel machined by FJEDM process.

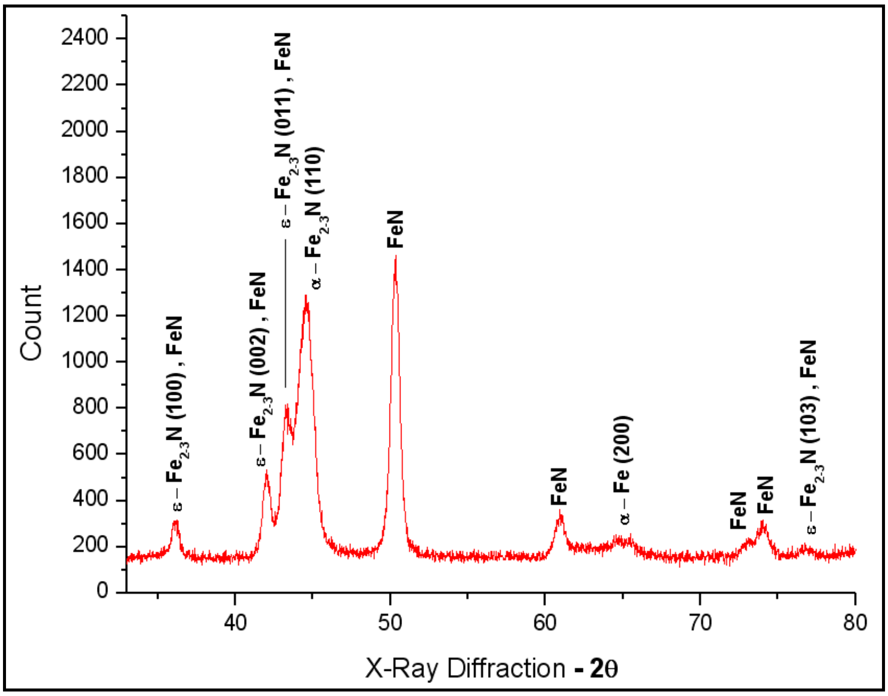


Figure 5 - XRD pattern of the SAE 4140 steel machined by FJEDM process.

The figure 6 illustrates the surfaces of the electrodes used and right below its respective SEM images. The surface of the electrode employed in the FJEDM process presented itself cleaner, with less oxidation, and more uniform than the one machined by EDM process, using the same parameters. In the SEM images, the intense formation of craters on and a very rough surface on the electrode used in static regime can be observed.

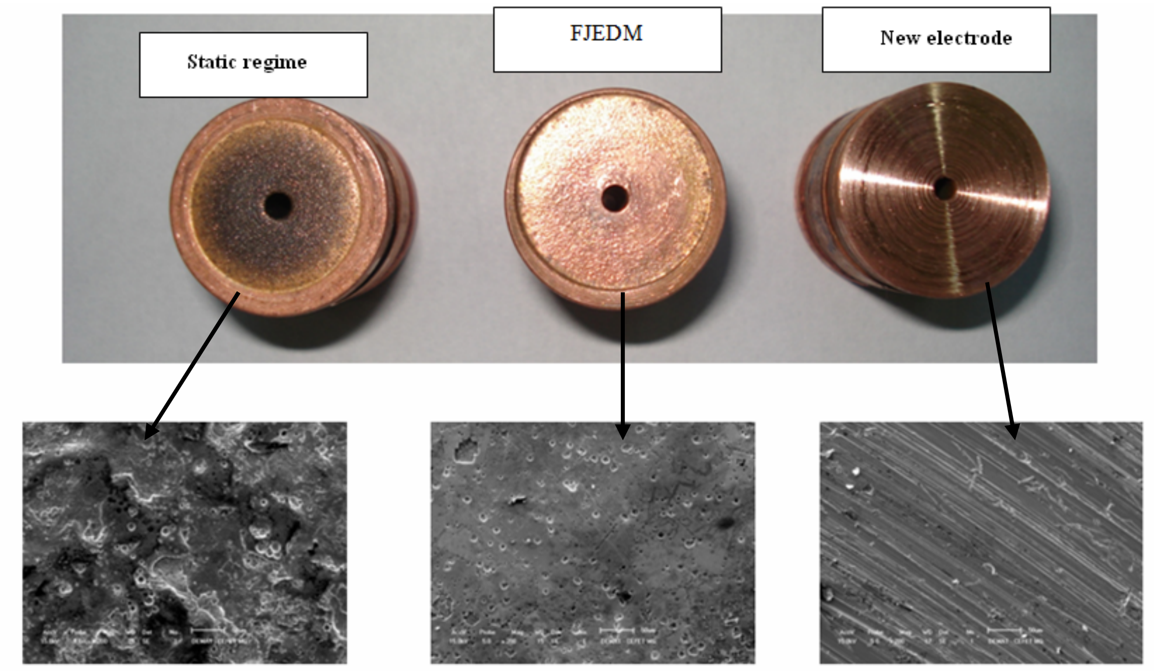


Figure 6 – Electrodes used in the FJEDM process in static regime with its respective SEM images.

4. CONCLUSIONS

The results show the formation of an uniform layer enriched with nitrides, between the recast layer and the bulk, with an average of 8 µm thickness.

The micro-hardness measured in the intermediate zone presented values approximately 50% bigger than in the bulk.

The results of analysis by EDX showed discreet presence of nitrogen in the sample surface. The preliminary analysis of X-ray diffraction results showed the presence of iron nitrides formed on the surface machined by the process FJEDM.

The surface of the electrode used on the FJEDM was cleaner and more uniform than the electrode used in static regime

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