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STUDY OF MECHANICAL BEHAVIOR AT CRYOGENIC TEMPERATURE OF AISI 430 WITH DIFERRENT STRAIN RATES

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Abstract. *Recent researches about cryogenic deformation show a possibility of improvement of mechanical properties when the metal is submitted to different strain rates and temperature conditions. In this research, specimens of AISI 430 were tensile tested in order to identify the conditions that allow the highest improvement of strength and ductility. Microstructural characterization was carried out by conventional metallography. Fractography images were obtained using a scanning electron microscope with field emission gun (SEM-FEG). It was observed that fracture behavior of AISI 430 is highly dependent of strain rate at cryogenic temperature, where partially ductile behavior, with dimples at fracture surface, was observed of lower strain rates.*

Keywords: *AISI 430, cryogenic deformation, fractography, tensile tests, strain rete*

1. INTRODUCTION

There are several studies that search the increase mechanical strength of metals materials, but its ductility is impaired, since are competitive properties. Thus, strategies have been pursued to improve strength and ductility simultaneously (Panigrahi and Jayaganthan, 2010).

As Kon'kova, Mironov and Korznikov (2010) declare, an approach to obtain theses properties simultaneously is to produce micro to nanoscale structures throught severe plastic deformation (SPD), since this method is to mechanically deform the material promoting the increase in the density of dislocations and defects, forming substructures or cells of the order of the micro or nanometric, achieving a good grain refining. The boundaries of these substructures and grain act as barriers to the slip dislocations. Twin boundaries can also obstruct the slip dislocation (Bahmanpour *et al*, 2011).

In study of Xiao, Tao and Lu (2009) mentioned that there are several techniques that can be used to reach those dimensions of structures, such as cold rolling, equal channel angular pressing, high pressure torsion, ball milling. But these processes present limits in higher stresses, becoming inefficient the rate of grain refinement.

So the deformation at cryogenic temperatures (CT) has been a promising field of great interest, because the activation of alternative mechanisms deformation occurs with temperature change, since the slip dislocations is a thermally activated mechanism (Meyers, Vöhringer and Luberda, 2001). Thus at low temperatures occurs the supression of dinamic recovery and twinning is more pronounced, resulting in a higher density of defects that are converted into grain framents or ultrafine grain structures and/or nanostructures (Markushev *et al*, 2011; Magalhães, Hupalo and Cintho, 2014). Therefore, the decrease temperature at 100 K promotes the supression of dynamic recovery, increasing dislocation density and promotion of twin activity, dislocation annihilation, partial recovery e precipitation hardening, and ultimately increasing simultaneous strength and ductility. (Bahmanpour *et al*, 2011; Kon'kova, Mironov and Korznikov, 2010; Kula and Desisto, 1966; Panigrahi and Jayaganthan, 2010). But the formation of these structures is still little comprehend (Markushev *et al*, 2011).

Thus, strain rate and process temperature are the most important extrinsic factors that affect the refine grain and de deformation mechanical behavior for substructures in SPD. High strain rates and/or low temperatures is an effective approach to promote the grain refinement, as already mentioned, these methods can suppress the recovery momentum of the slipping of disagreements and activate the twinning, resulting in the highest density of defects and cell sizes and finer grain (Kula and Desisto, 1966).

The application of the SPD at CT has been used in copper alloys, titanium, aluminum alloys and stainless steels. A SDP example in cryogenic temperature was made by Magalhães, Hupalo and Cintho (2014), who studied Al alloy processing is rolling at cryogenic temperature managed to get an increase in your strength and ductility better compared with room temperature rolling. There are also cases with a subsequent heat treatment can have excellent results (Panigrahi and Jayaganthan, 2010).

Other parameter that hinders the dislocation slip is the decrease stacking fault energy (SFE), which this is a parameter intrinsic and is very sensitive to chemical composition, it can indicate the evolution microstructure and subdivision grain. Thus, materials with high SFE mainly deform by slip dislocations, however with the suppression of dynamic recovery. Materials with low SFE presented deformation by twin in deformation cryogenic. As mentioned these differences in deformation mechanisms as well as the suppression of dynamic recovery have great reflexes in mechanical properties (Tamura *et al*, 2013).

In this way this work was studied the AISI 430. It is a commercial ferritic stainless steels and can have a good ductility, its crystal structure is body centered cubic (BCC), wich presents low SFE. It is an iron alloy that content essentialy chromium, that is responseble for the formation of an chromium oxide surface film, thus help to corrosion resistence. For this alloy its chemical composition is 0.12% C; 1.00% Mn; 1.00% Si; 16.00-18.00% Cr; 0.004% P and 0.03% S (ASM Handbook, 1990). Was evaluated on cryogenic conditions using 3 different strain rates by means of tension testing.

As mentioned by Kula and Desisto (1966), BCC metals show a strong increase yield stress with a decrease in temperature, i.e. has a great sensitivity to temperature, and can decrease the size of the dislocation cell with the temperature decrease. Due to the ductile-brittle transition temperature (DBTT), which substantially decreases plastic deformation capacity.

2. EXPERIMENTAL PROCEDURE

The starting samples of AISI 430 were rolled from 3 mm to a thickness of 1.5 mm in order to adequate to the developed cryogenic tensile test system. The samples were annealed at 705 °C during 15 min with heating rate of 10 °C/min, according to literature (ASM Handbook, 1991). After heat treatment, the initial microstructure was by conventional metallography. Samples were electropolished, and chemically etched with Vilela's solution and the microstructure specimens was observed by optical microscopy.

Annealed specimens were machined in adapted subsized samples from ASTM E8M. The tensile tests were carried out at room temperature (RT) and CT (dipped in liquid nitrogen, temperature around -150°C) using an universal test machine at different rates ($6\times10^{-3}s^{-1}$,$6\times10^{-4}s^{-1}$and $6\times10^{-5}s^{-1}$). Engineering Stress-strain curves were acquired by the testing machine. Fracture surfaces were observed by means of SEM - FEG.

3. RESULTS AND DISCUSSION

3.1 Starting material

Figure 1 exhibit the micrography of AISI 430 that receive the anneling treatment. This treatment was performed to obtain axial grains, because after the lamination the grains were elongated and accumulated tension, which could influence their properties. So it is possible to observe equiaxial grains, indicating that the treatment was effective.

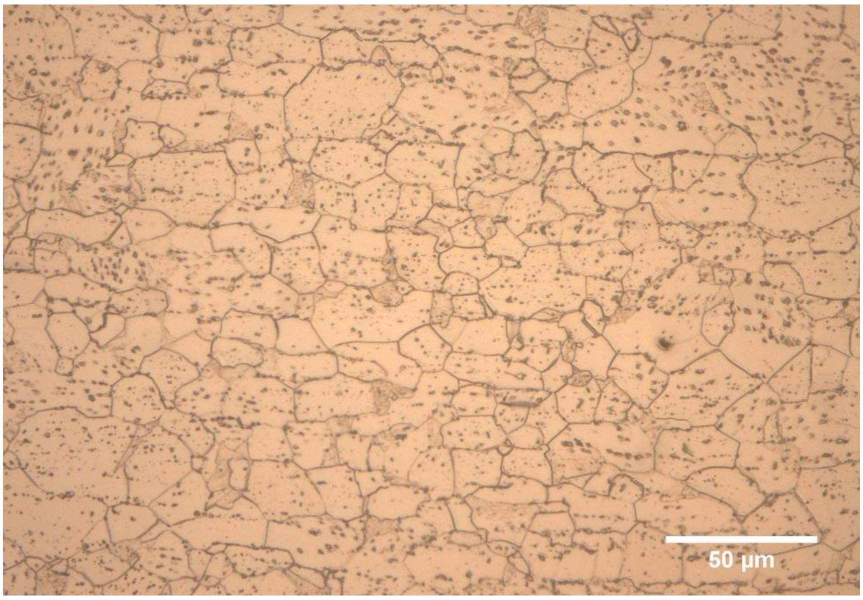

Figure 1: Micrography of AISI 430.

3.2 Tensile tests

Figure 2 shows the stress-strain curves obtained using 6×10^{-4} s^{-1} strain rate at room temperature and cryogenic temperature. As is shown, the UTS (ultimate tensile strength) is higher at CT than RT. But AISI 430 presented higher elongation at RT. The higher UTS may be associated to the partial inhibition of thermal activated deformation mechanisms (cross-slip and climb) as well as the dislocation slips for this strain rate. The inhibition of preferential deformation mechanisms possibly led to a strengthening and a decreasement in final elongation.

Figure 3 presents engineering stress-strain for the three strain rates tests realized at CT. Table 1 presents values of elongation and UTS for all the tested conditions. For CT, the elongation increased with the strain rate, exhibiting a remarkable level of ductility. A different shape is verified for all the cryogenic curves in a comparative analysis with RT test showing a fracture nearly UTS. On the other hand, significant values of UTS is verified at CT.

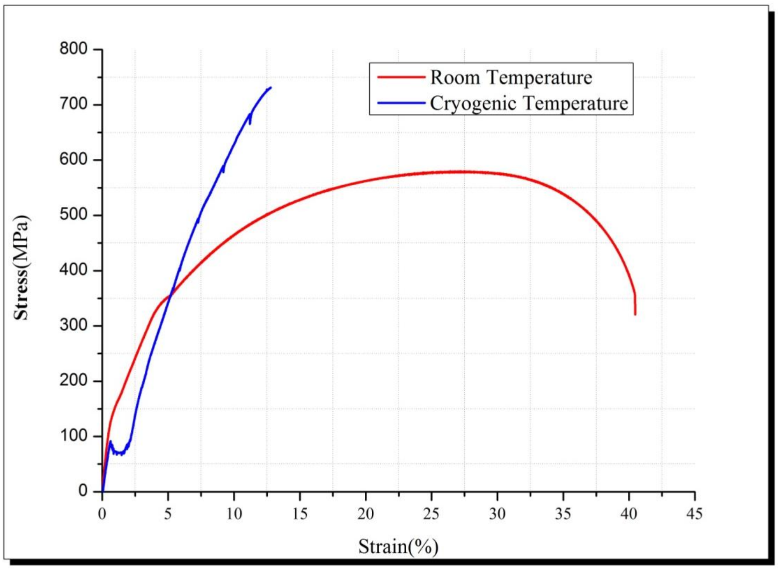

Figure 2: Engineering stress-strain curve with rate $6\times10^{-4}s^{-1}$.

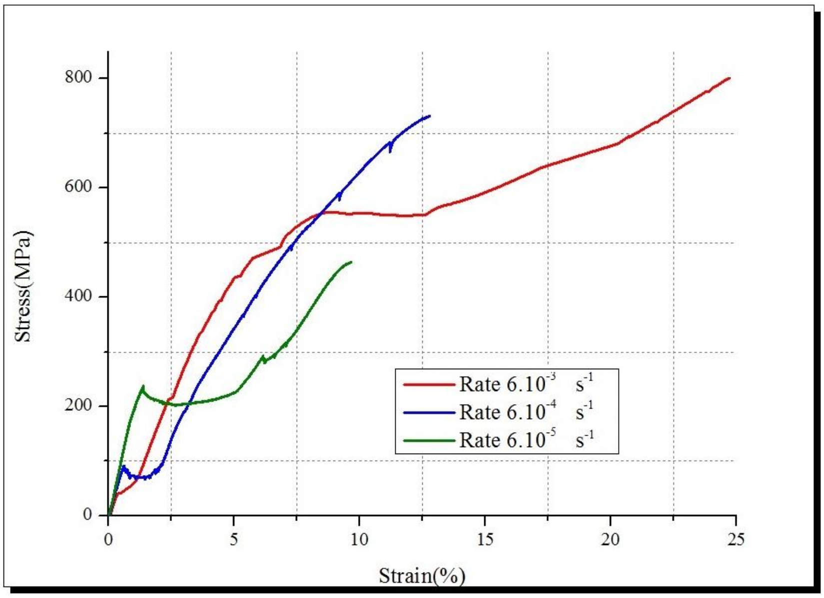

Figure 3: Engineering stress-strain curves for different strain rates (rates 6.10^{-3} s^{-1}, 6.10^{-4} s^{-1} and 6.10^{-5} s^{-1}).

Table 1 – Values of elongation, ultimate tensile strength for each temperature with differents rate strain.

Rate(s^{-1})	*Temperature*	*Elongation (%)*	*UTS (MPa)*
6×10^{-3}	Cryogenic	24	800
6×10^{-4}	Cryogenic	12,8	731
6×10^{-4}	Room	40,5	321
6×10^{-5}	Cryogenic	9,7	465

3.3 Fractographys

Figures 4 (A) and (B) show the fracture surfaces for the $6\times10^{-4}s^{-1}$ tested samples at room and cryogenic temperatures respectively. It is very clear in these surfaces a typical ductile behavior on (A), there are the great presence of dimples in your fracture surface. And a typically brittle fracture on (B) presenting cleavage areas, plane surfaces and river markings. Thus, the deformation mechanism was changed by lowering the operating temperature.

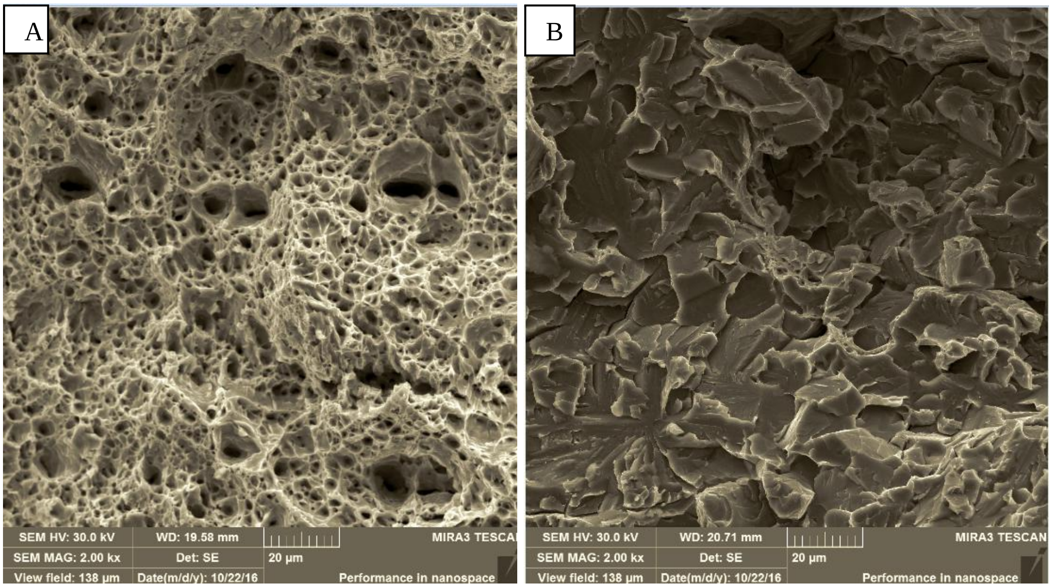

Figure 4: Fracture surfaces for the 6×10^{-4} s^{-1} tests at: (A) room temperature and (B) cryogenic temperature.

Figure 5 show fracture surface at CT using 6×10^{-5} s^{-1} strain rate. A very interesting mix of ductile and brittle characteristics is verified on this image with dimples colonies, cleavage regions and intergranular fracture. This behavior can be connected with curve shape in tensile test. On this conditions, few grains with preferential orientations can deform by dislocations slip process and promote ductile fracture regions while the other grains have difficult to deform and fracture by cleavage and intergranular processes.

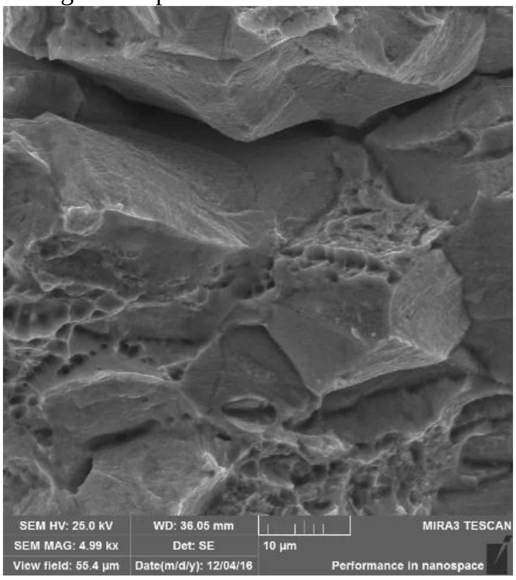

Figure 5: Fracture surface for the 6×10^{-5} s^{-1}test at cryogenic temperature.

4. CONCLUSIONS

The study allowed the following conclusions:

- The strain rate has great importance on AISI 430 deformation at cryogenic temperature;
- It is possible to obtain a considerable level of ductility with increasing strength of AISI 430 at cryogenic temperatures.

5. ACKNOWLEDGEMENTS

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