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MICROSTRUCTURAL AND MECHANICAL CHARACTERIZATION OF HARDOX 450 STEEL

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Abstract Hardox steels are characterized by high resistance to abrasive wear allied with good toughness. These properties enable the Hardox steel to work under severe conditions such as the manufacture of mining excavator buckets, tippers, crushers, wheel loaders, demolition tools, hammers, shears, gears, cogwheels or in any application requiring high wear and impact resistance. This work aims to evaluate Hardox 450 steel microstructure and its mechanical behavior through, mechanical testing and microanalysis making use of techniques such as scanning electron microscopy and energy-dispersive x-ray spectroscopy. The mechanical tests used were pin-on-disk, charpy impact and tensile tests.

Keywords: Hardox,TiC, excavator bucket, wear, toughness.

1. INTRODUCTION

In mining industries there is a constant source for developing new materials which will coat the surfaces of the equipment submitted to wear and impact, such as excavator buckets. According to Kapciska-Popowska, et al. (2014) Hardox 450 steel is widely used by mining industries due to its good combination of hardness and toughness, which provides wear resistance, weight reduction, longer lifespan and reduced machines maintenance cost. Hutchings (1992) affirm that wear and impact resistance can be predicted and controlled in a way to not compromise the production

process quality, as a predictive maintenance. In this sense this work aims to evaluate the evaluated the mechanical performance of Hardox 450 steel summited to wear, tensile and impact tests, and also correlate this data to its microstructure and chemical analysis.

2. EXPERIMENTAL PROCEDURE

Pin-on-disk wear testing was carried out using a Microtest Pin on Disk Tribometer MT/60/Ni, according to the ASTM G99 standard (2017), to evaluate Hardox 450 steel wear caused by slip contact at reduced areas. It was used a hard metal pin with 6 mm diameter and 400 rpm rotating at room temperature. The Hardox 450 samples used during this test were 45 x 45 x 12 mm.

The experimental value of the wear coefficient was determined using the Archard equation Eq. 1, considering the volume loss in function of traveled distance, as shown:

$$K = Ks \ x \ HB = \frac{HB}{P} \ x \ Q = \frac{HBxV}{PL} \tag{1}$$

Charpy impact test was carried out using an Instron-Wolpert PW30, according to the ASTM E23-12C standard, from -196 to 97°C to determine brittle-ductile transition temperature of Hardox 450 steel. Machining of type A notches (ASTM E23-12c) was performed on twenty Hardox 450 steel samples. The specimens were submerged in different liquid solutions, during for 10 minutes, to reach the thermal equilibrium. For temperatures lower than 25ºC a solution of liquid nitrogen and ethyl alcohol was used. For temperatures higher than 25°C, water was used, heating it to the desired temperature, keeping the specimen submerged for 10 minutes as well. Temperatures were measured using a K-type thermocouple sensor.

Tensile tests were performed on four Hardox 450 steel samples, using a universal machine for mechanical testing INSTRON/EMIC 23-300, according to the ASTM-E8M standard. The mechanical properties evaluated such as yield stress, strength stress, failure stress, elongation and strain hardening exponent as well as the strength coefficient.

In order to calculate the strain hardening exponent and the strength coefficient, it was used the Hollomon (1945) equation, Eq. 2, at the true stress (σ) and true strain (ε) curves.

$$\sigma = \left[K \times \varepsilon^n \right] \tag{2}$$

The parameter "σ" is the true stress, "K" is the strength coefficient, "ε" is the true strain and "n" is the strain hardening exponent.

In order to calculate the true stress, "σ", the engineering stress it was used the Eq. 3.

$$\sigma = S \times \left[1 + e \right] \tag{3}$$

The parameter "S" is the engineering stress and "e" is the engineering strain.
In order to calculate the true strain, "ε", it was used the Eq. 4.

$$\varepsilon = \ln \left[1 + e \right] \tag{4}$$

Scanning Electron Microscope (SEM) JEOL JSM-T300 was used to analyze the failure surfaces after mechanical tests. Energy-Dispersive X-Ray Spectroscopy (EDS) was also used to verify the chemical composition in each interest region after the tests.

3. RESULTS AND DISCUSSION

The track generated on pin-on-disk wear testing, with diameter of 33,8mm, was analyzed. The specimen mass lost was 0.001 g. This value was used to determine the wear coefficient (K) of HARDOX 450, which was found to be 0.026, considering wear in stable graph region.

According the studies by Yang, L and Hutchings , the coefficient of friction variation according to the sliding distance during pin-on-disk wear test is displayed in the Fig. 1. Coefficient of friction varies due to debris on the pin and to surface oxidation.
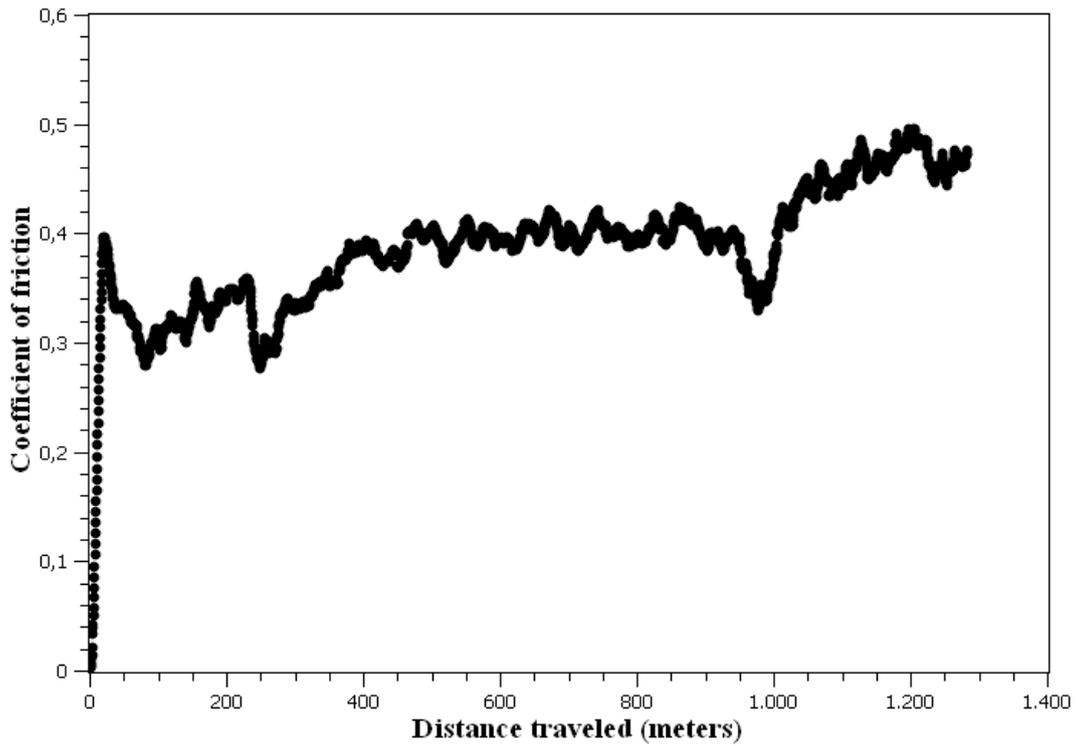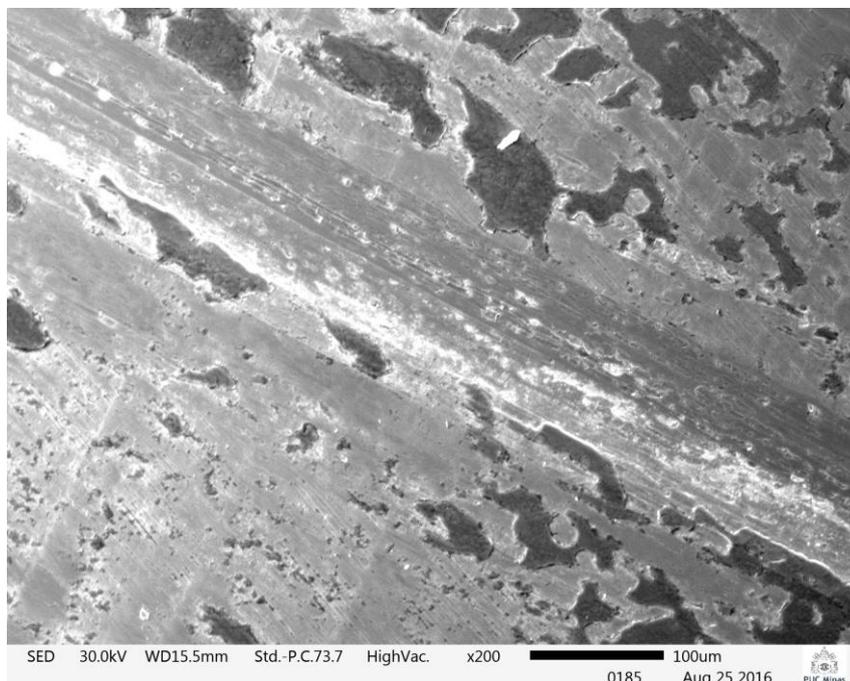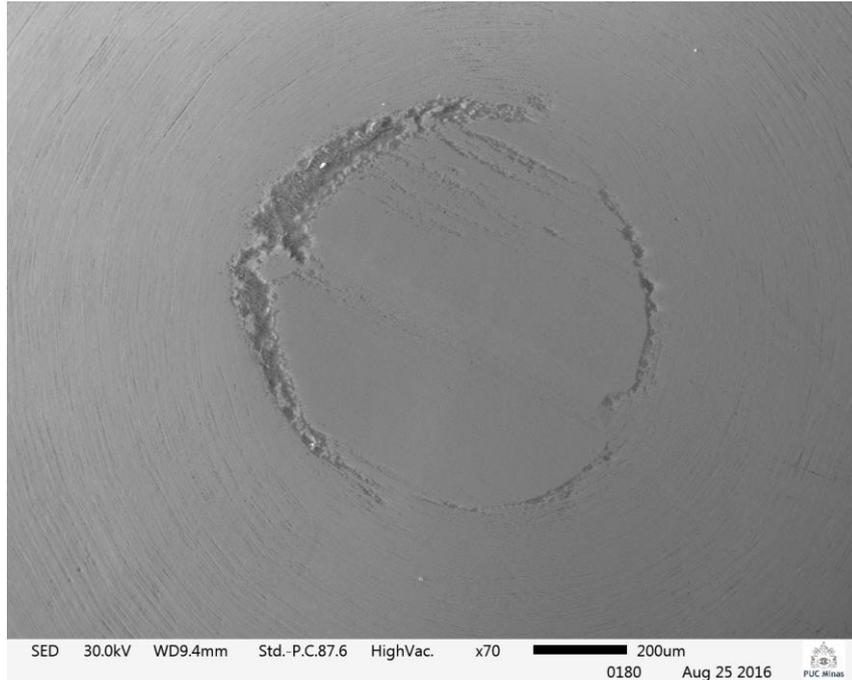
Figure 1. Coefficient of friction *versus* sliding distance in the pin-on-disk wear testing.

Figures 2(a) and 2(b) shows the track left by hard metal pin on HARDOX 450 and the wear pin surface after the test, observed using scanning electron microscopy (SEM):


a)

(b)

Figure 2. (a) Wear track in Hardox 450 steel, 200X magnification (b) Top of wear pin, after test in HARDOX 450, with 70X magnification.

It can be observed in figure 2(a) that the specimen surface has shown marks of wear. Brighter regions indicate that there was overlapped material and darker regions indicate that there was material removing withdrawal. Figure 2(b) proves that there was no significant wear on pin.

Figures 3(a) and 3(b) show that chemical composition on analyzed regions did not belong to the original composition of the pin. This proves that there was just adhesion of Hardox material at the top of the pin.
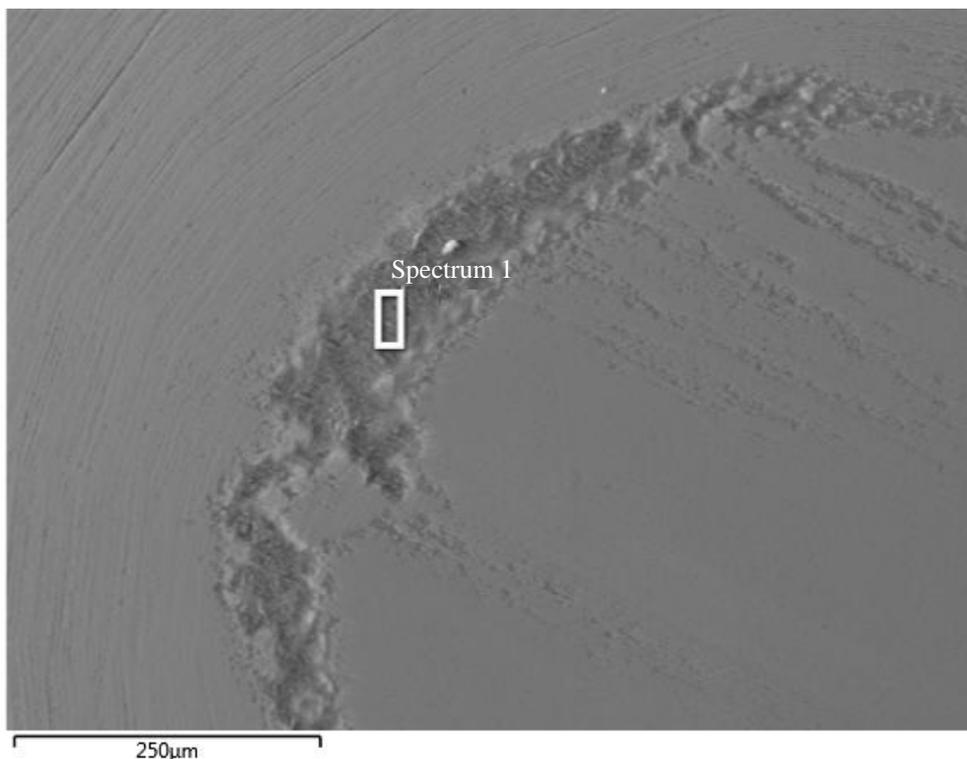
a)
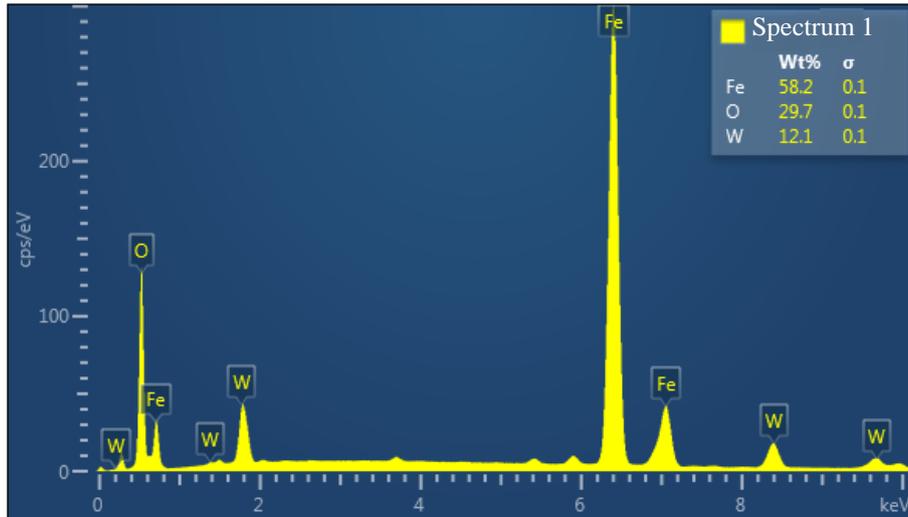
b)

Figure 3. a) Area analysed by EDS; b) EDS analysis

According to values of absorbed energy obtained during Charpy impact test, the graph shown by Fig. 4 has been plotted to determine the brittle–ductile transition temperature of the HARDOX 450 steel.
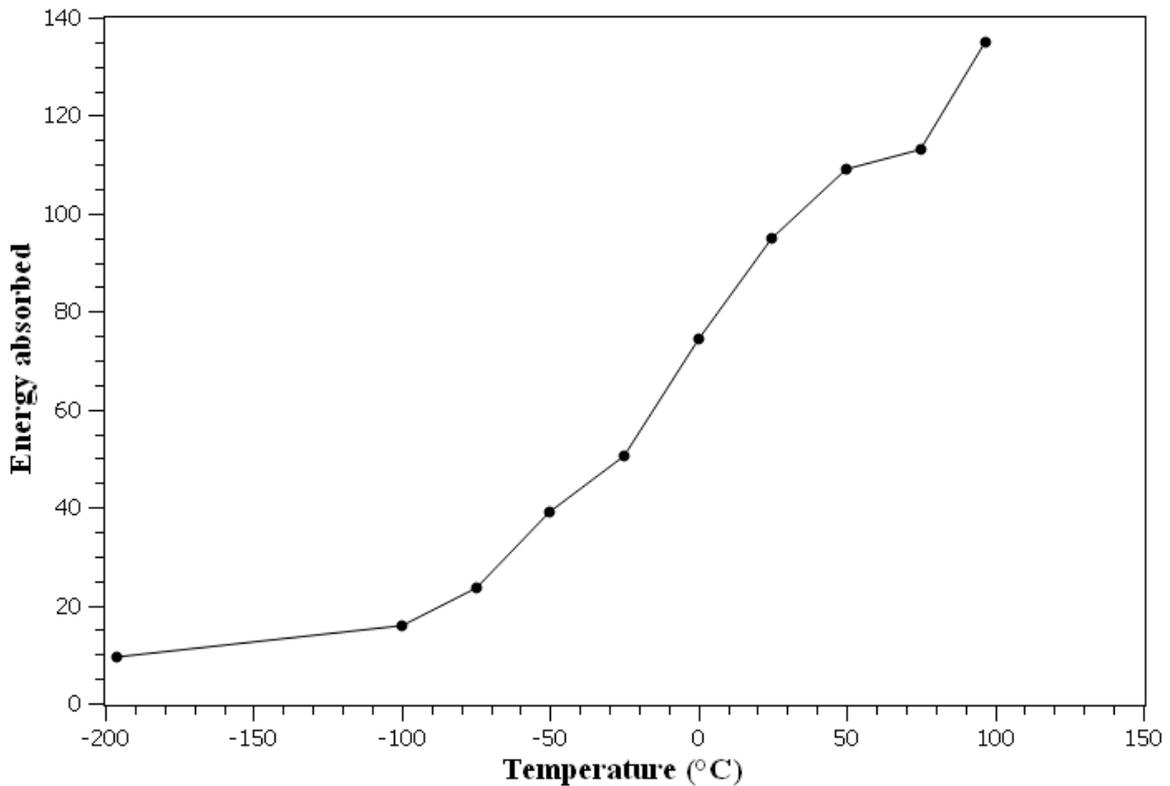

Figure 4. Hardox 450 steel behavior subjected to the Charpy impact test

It can be observed in Fig. 4 that the transition range occurs among the temperatures of -25ºC and +25ºC. At temperatures below -25ºC the material fracture is fragile and for temperatures higher than +25ºC the fracture is ductile.

Figure 5 shows a SEM image fractured surface by Charpy impact test for -100 and 97°C. It is possible to associate cleavage characteristics to the first image (Fig. 5(a)) and ductile failure to the second one (Fig. 5(b)) due to its dimples.
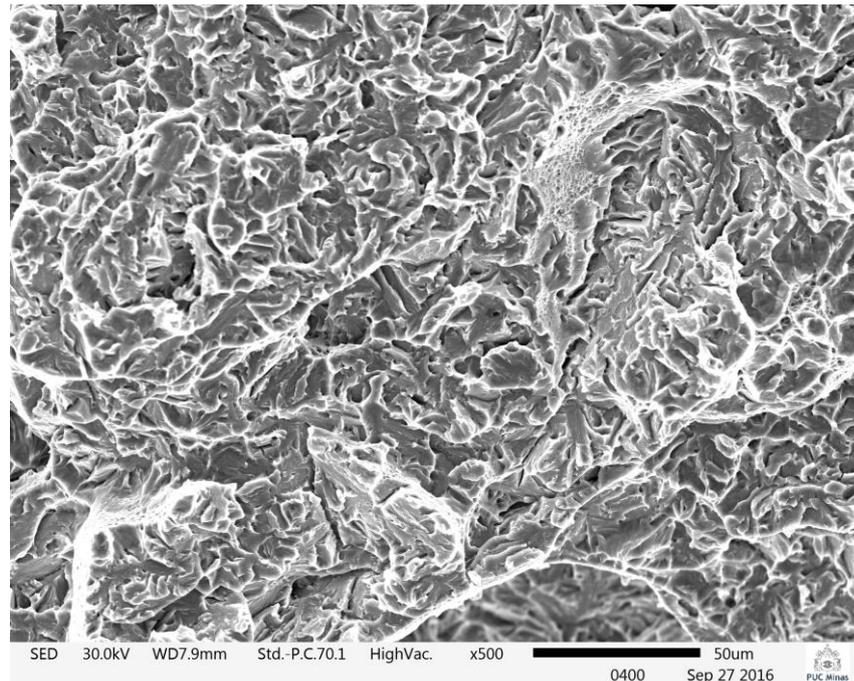
a)
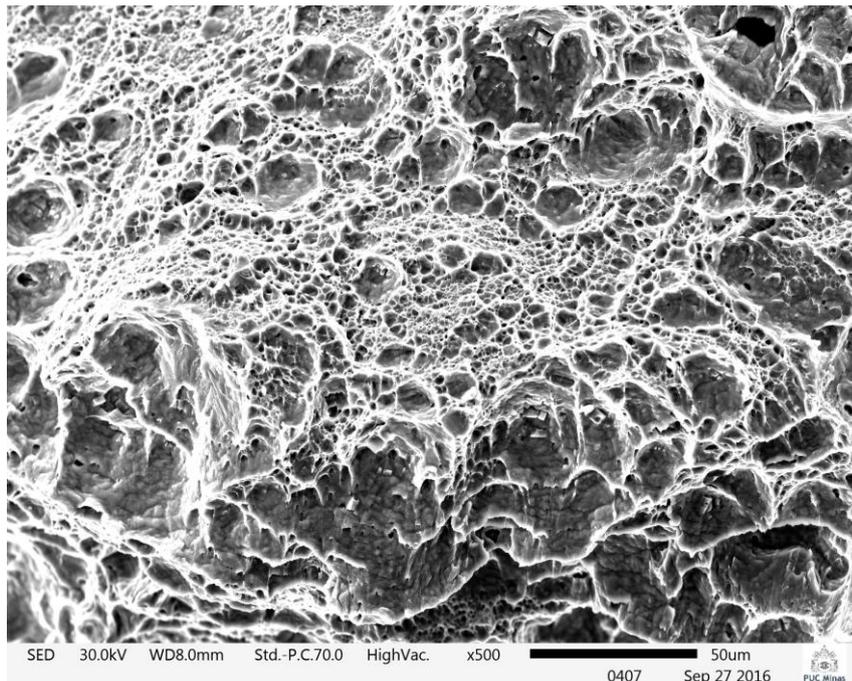
(b)

Figure 5. (a) SEM Microfractography of -100ºC Charpy sample; (b) Microfractography of 97ºC Charpy sample. SEM, 500X magnification

The 0ºC Charpy test sample, Fig. 6, shows the presence of a small faceted constituent within the dimples which resembles the titanium carbide, according to its cubic crystalline structure as proposed by Nie, et al. (2011) and Zhou and Sun (2000).

In order to prove its presence, an analysis was done by energy dispersive x-ray spectrometer (EDS) in these constituents. This chemical composition proves that the precipitate is titanium carbide which corroborates the great toughness of Hardox 450 steel even in low temperatures although the manufacturer (MTL) does not mention titanium in its chemical composition presented in the datasheet.
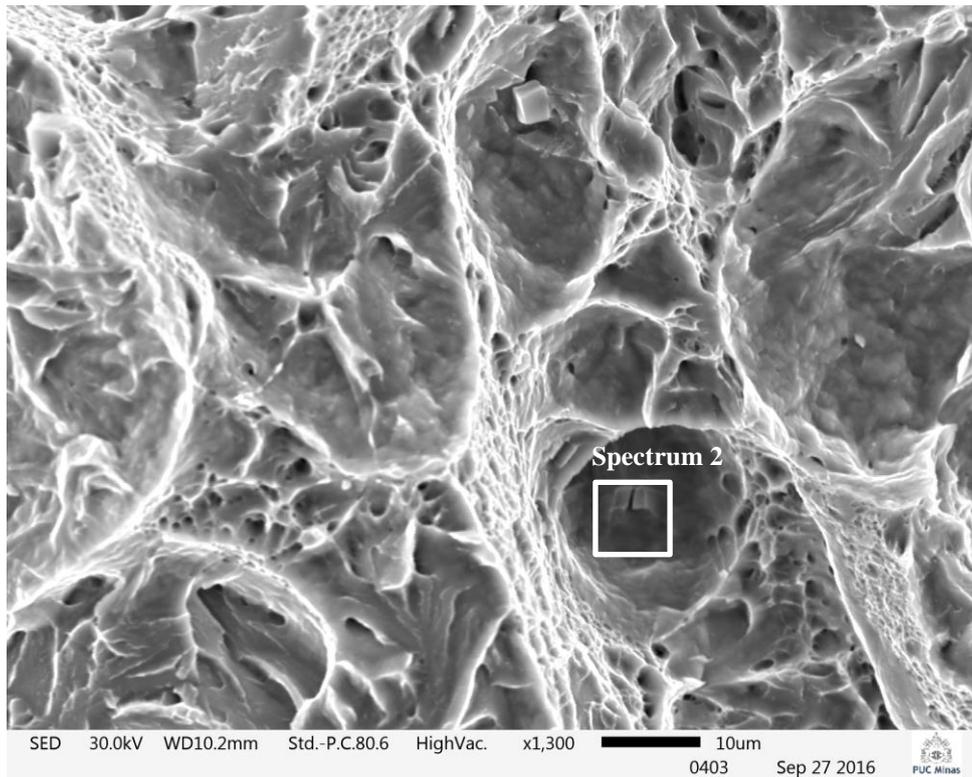
(a)
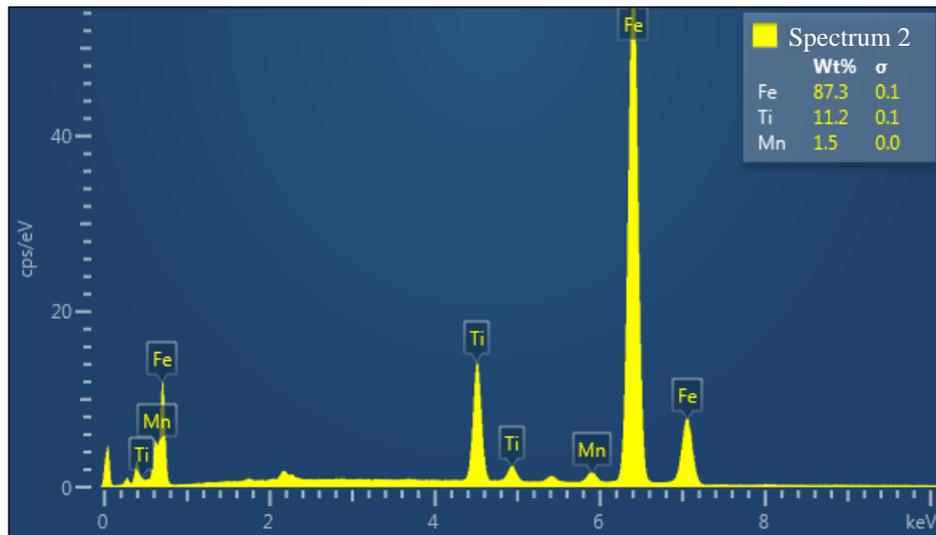
(b)

Figure 6 – (a) SEM microfractography with 500X magnification; (b)Analysis by EDS of the cubic constituent.

After the tests had been carried out, results were plotted in a stress-strain diagram, represented in Fig. 7, and the mechanical properties were analyzed.
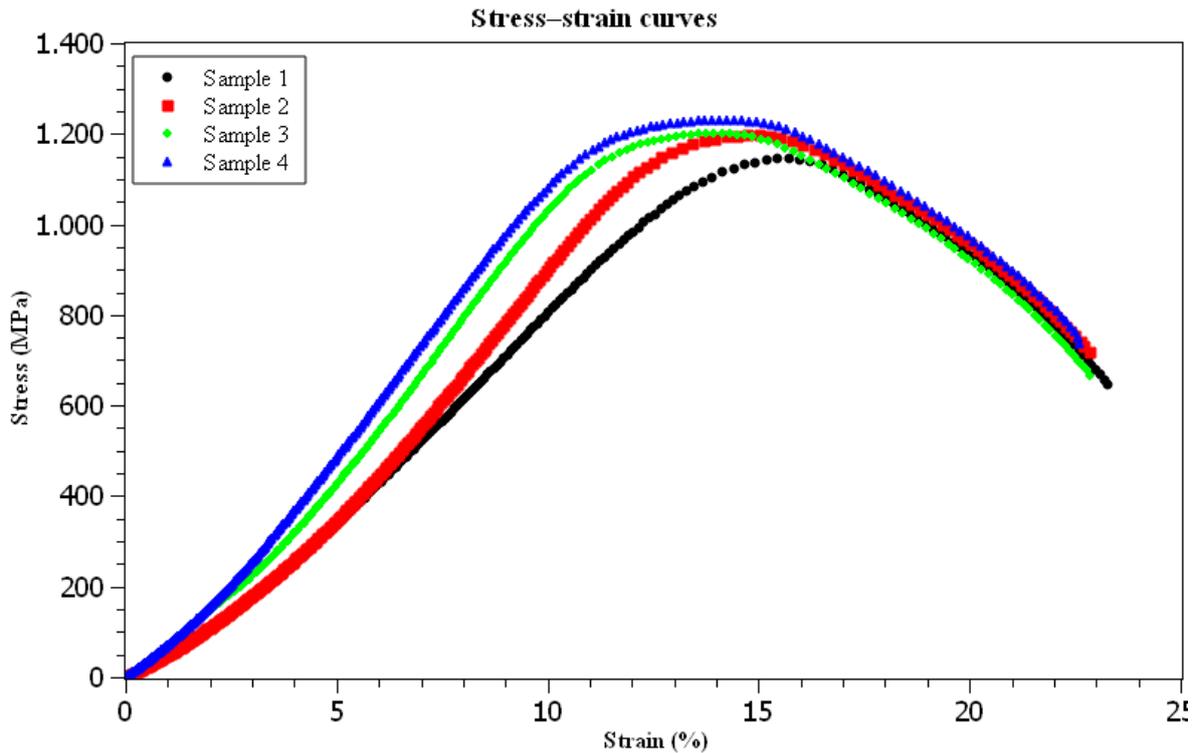
Figure 7. Stress-strain curves of Hardox 450 steel.

Table 1 shows the mechanical properties associated to each curve obtained during the tensile tests, as well as the arithmetic average and the associated standard deviations.

Table 1. Results obtained in tensile tests of Hardox 450 steel.

	Yield Stress (MPa)	Strength stress (MPa)	Failure stress (MPa)	Strain Hardening Exponent	Strength Coefficient (MPa)	Elongation (%)
Sample 1	993.52	1144.78	645.28	0.73	5540.79	23.26
Sample 2	1022.81	1197.21	717.38	0.66	5115.05	22.86
Sample 3	1078.79	1201.20	666.03	0.48	3705.15	22.26
Sample 4	1092.18	1229.96	737.03	0.47	3683.92	19.62
Average	1046.82	1193.29	691.43	0.58	4511.23	22.00
Standard Deviation	46.54	35.47	42.92	0.13	958.96	1.64

It was observed, as expected, that Hardox 450 presented high yield, strength and failure stress. These values are close to that suggested by MTL (2014), as well as from its direct competing steels.

Strain hardening exponent, calculated using the Hollomon Equation, Eq. (1), presented an average of 0.58. This value is considered to be high according to Dieter (1988) when compared to other steels.

The elongation during the tests had an average of 22%, which promotes a high toughness associated to its high mechanical strength. These values only demonstrate the excellent mechanical properties of the Hardox 450 steel, which exceed its excellent wear resistance and toughness.

4. CONCLUSION

The pin-on-disk wear testing, charpy impact test and tensile testing measurements and SEM analysis enabled the Hardox 450 steel characterization. The wear coefficient value obtained (K = 0.026) justifies its greater wear resistance when compared to other steels of same application. Charpy impact test showed that the fragile-ductile temperature transition of the material occurs between -25ºC and +25ºC. Therefore, for room temperature, the fracture is ductile. The tensile tests proved that the Hardox 450, in addition to the excellent toughness and wear resistance, has other excellent

mechanical properties, such as its high yield stress, strength stress and its hardening exponent. It was also observed that this steel presents titanium carbide in its microstructure, which explains its excellent mechanical properties, and until then, it has not been informed by the manufacturer.

5. ACKNOWLEDGEMENTS

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