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# COMPARISON OF THE PERFORMANCES TO ABRASIVE AND ADHESIVE WEAR OF COATING APPLIED ON DUCTILE CAST IRON

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***Abstract.*** *The present study aims to analyze and compare the abrasive and adhesive wear behavior of two different types of surface layers produced on a substrate of normalized nodular ductile iron alloyed with copper. The first process used was liquid boronizing, in which a sample was borided for 2 hours at a temperature of 950 ° C. The second technique for surface coating is thermal spraying, where a fusible NiCrBSi alloy was deposited on the surface of the material and subsequently melted in a conventional furnace at 1000 ° C. For comparison, we performed the same wear tests on an uncoated nodular cast iron sample. The wear tests were conducted in "calotest" type machines. Based on these results, it can be concluded that the resistance to abrasive and adhesive wear of cast iron has increased considerably for both treatments.*

***Keywords:*** *ductile iron, thermal spray, boronizing net, wear resistance.*

## 1. INTRODUCTION

Nodular cast irons are used in the automotive industry (cams, pistons, cylinders and gear), mining (mud pumps and ball mill), sugarcane (milling rolls), among others applications. Compared to carbon steel, this material has a lower melting point, good fluidity, higher fatigue resistance and a good combination of tensile strength and toughness. These characteristics and properties together with the low cost advantage inherent in the casting process, has resulted in an increased usage over the years, even in the replacement of forged steel components because of its high vibration absorption and weight reduction (10 % less dense than steel) (Zhou *et al*., 2007; Celik *et al*., 2005).

Surface engineering techniques can be applied to this material in order to improve their tribological characteristics, thus further expanding its advantages and consequently their usage range. In this paper boronizing and thermal spraying layers are applied over nodular cast iron, to verify the effectiveness of such treatments on its wear performance.

The liquid boronizing treatment is a thermo chemical process carried out in metallic materials. This simple and low-cost method involves the delivery of boron to the substrate surface at high temperature, through the use of a molten salt bath, forming a layer of high hardness (1600 - 2100 HV), which is wear and corrosion resistant. This layer is formed by iron borides (FeB and $Fe_2B$) and borides of other alloying elements that may be present in the substrate. The molten bath is typically composed of $Na_2B_4O_7$ (sodium borate) and aluminum or iron-silicon (activator). The thickness of the layer depends directly on the alloying elements present in the material, treatment time (1 to 12 hours) and boronizing temperature (700 to 1000 ° C). This treatment is used in axles, gears, injectors, matrices, among other components (Allaoui *et al*., 2006; Ipek *et al*., 2000; Sahin and Meric, 2002).

Another treatment for improving surface characteristics is thermal spraying. This is a general term used to identify a set of processes in which a material, metallic or nonmetallic, is propelled and deposited in the molten state, semi-molten or solid state on the substrate surface. Depending on the type of spray, the applied material can be in the form of powder or wire. Efficient and convenient, this method has been employed to improve the corrosion and wear resistance as well as a thermal barrier in gas turbine blades. Unlike boronizing, in thermal spraying no reaction occurs for the formation of the metal layer and its adhesion to the substrate previously prepared with the appropriate level of surface roughness, occurs mechanically. A major advantage of this treatment is that there is no limitation on the size of the component to be coated as well as its geometry, being possible to coat or repair components and parts in the workplace, with little or no disassembly, as well as an immense variety of coatings that can be applied on a large numbers of substrates. The cost is relatively low and the deposition rate of the material is high. This low temperature process ensures heating of the part below 120 ° C. Coating processes at lower temperatures opens many possibilities such as the recovery of used parts

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without interfering in the dimensional stability of other areas (Akebono *et al.*, 2008; Gonzalez *et al.*, 2007; Kulu *et al.*, 2006).

## 2. MATERIALS AND METHODS

The material used in this work is a pearlitic matrix nodular cast iron. Table 1 shows its chemical composition. Three samples of this material with dimensions of 30 x 30 x 4 mm were used. Of these, one was used for boronizing, one for thermal spray and other was not treated, for comparative analysis. The three samples underwent a normalization treatment, in order to obtain a homogeneous grain structure.

Table 1. Chemical composition of nodular cast iron with copper addition.

| Chemical Element | wt% |
|---|---|
| Carbon | 3.70 |
| Silicon | 2.73 |
| Manganese | 0.21 |
| Copper | 0.71 |
| Carbon Equivalent (C+Si/3) | 4.61 |

For liquid boronizing the sample was sanded to 600 mesh sandpaper and cleaned with acetone in ultrasound. Before treatment, it was placed in a conventional oven at 110 ° C for 1 hour. This procedure was performed to ensure that the body was totally moisture free. The thermo chemical treatment was performed in a bath of sodium borate (borax) with the addition of 10% aluminum at 950 ° C for 2 hours. After the boronizing treatment the material was air-cooled and then cleaned in hot water.

In the thermal spray process, the surface of the substrate was sprayed with a NiCrBSi fusible alloy whose chemical composition is shown in Table 2. The sprayed sample was heated in a conventional furnace at 1000 ° C for 20 minutes to fuse the coating. A wire brush was used to remove surface oxides afterwards.

Table 2. Chemical composition of the alloy NiCrBSi fuse.

| Chemical Element | Chromium | Iron | Nickel | Silicon | Boron | Carbon |
|---|---|---|---|---|---|---|
| Concentration range (%) | 10 – 30 | 3 – 7 | 60 – 100 | 3 – 7 | 1 – 5 | 0,1 – 1 |

The three samples for micrographic analysis were sectioned transversely to the layers. One of the sections of each sample was embed in resin, sanded to 2000 mesh sandpaper, polished with alumina 0.3 and 0.05 μm, cleaned with acetone in ultrasound and attacked with Nital 2%. The other section had its surface sanded with 600 mesh sandpaper and polished with alumina 0.3 and 0.05 μm for the micro abrasive and adhesive wear tests.

An optical microscope with image analysis system was used to determine the average proportion of graphite nodules in cast iron and the porosity in thermally sprayed coating.

Two types of hardness tests, Vickers and Brinell were performed. The Vickers tests used two loads: 200 gf for analysis of the coatings and a 50 gf to obtain a hardness profile of the boride layer. The second test used a ball indenter with Ø 2.5 mm and a load of 187.5 kgf for the analysis of the matrix together with the graphite nodules, as to obtain a representative average hardness. In both cases, a total of 15 measurements for each material were performed.

The abrasive wear resistance was evaluated in a machine of the type free- ball, using an abrasive solution of silicon carbide diluted in distilled water in proportion 0.1 g / ml, with the sphere rotating at 300 rpm. For the evaluation of adhesive wear the fixed sphere test method was used. The test load was 160 gf and the rotation speed was 400 rpm. Both calotest type tests used a hardened AISI 52100 steel ball with a diameter of 25.4 mm and a hardness of 63 HRC. For each specimen 4 run times (5, 10, 15 and 20 minutes) and a sphere were used. The result of this test is a worn region in the form of a spherical cap having geometric relationships with the ball that generated them. Thus, knowing the diameter of the cap, the volume of material removed during the test can be determined according to Eq. (1) where V: volume removed b: diameter of the dome shape and r: radius of the sphere.

$$V = \pi b^4/64R \quad (1)$$

## 3. RESULTS AND DISCUSSION

In Figure 1 is shown the normalized microstructure of the nodular cast iron with copper addition.

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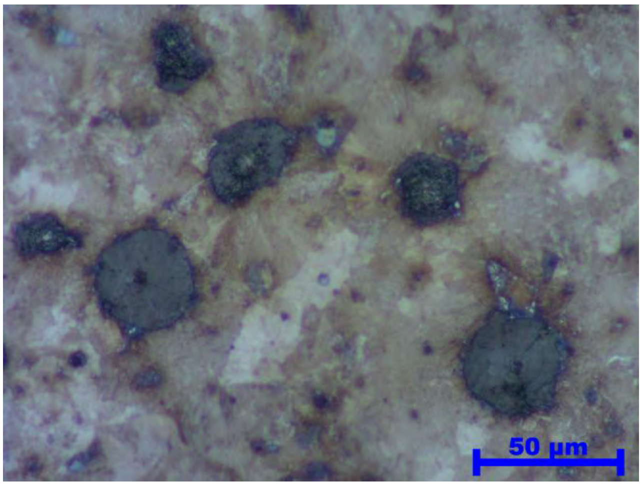


Figure 1. Nodular cast iron – Normalizing heat treatment at 950 ° C. Etch: Nital 2%. Matrix consisting of fine pearlite with graphite nodules.

Figures 2 and 3 show, respectively, the micrographs of the layers obtained in the liquid boronizing and thermal spraying treatments.

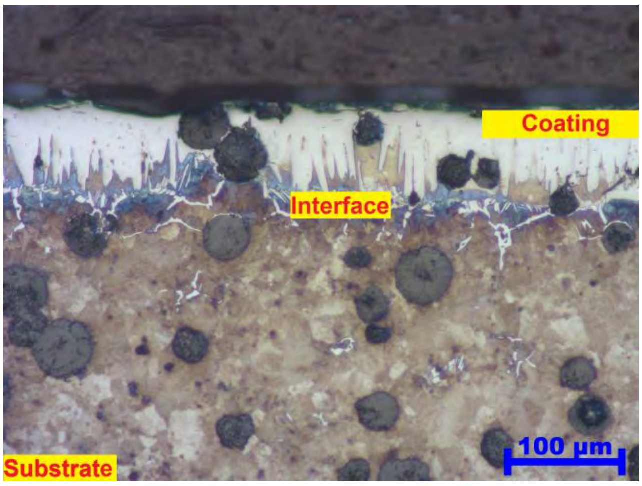


Figure 2. Nodular cast iron – Thermo chemical treatment of liquid boronizing at 950 ° C. Residence time of 2 hours. Etch: Nital 2%.

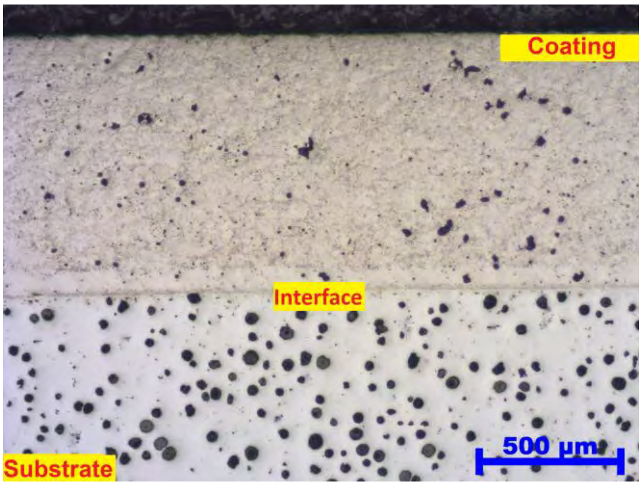


Figure 3. Nodular cast iron – Thermal sprayed NiCrBSi alloy. Coating melting temperature of 1000 ° C. Permanency time in the oven 20 minutes. No chemical etching.

In Figure 2, two distinct regions were identified in the cross section of the sample. These are: (I) Layer and sub layer of borides, with graphite nodules and (II) the matrix of nodular cast iron (Sem *et al.*, 2004). The average thickness of the layer obtained by boronizing treatment was 75 micrometers.

Observing the sprayed layer, as illustrated in Figure 3, it can be seen that it exhibited good adhesion to the substrate and the occurrence of pores, which is normal for this process. The average thickness of the layer was 900 micrometers.

Figure 4 shows an example of the processed image used to analyze the graphite nodules proportion. The result was 11.30 ± 0.82% of graphite nodules.

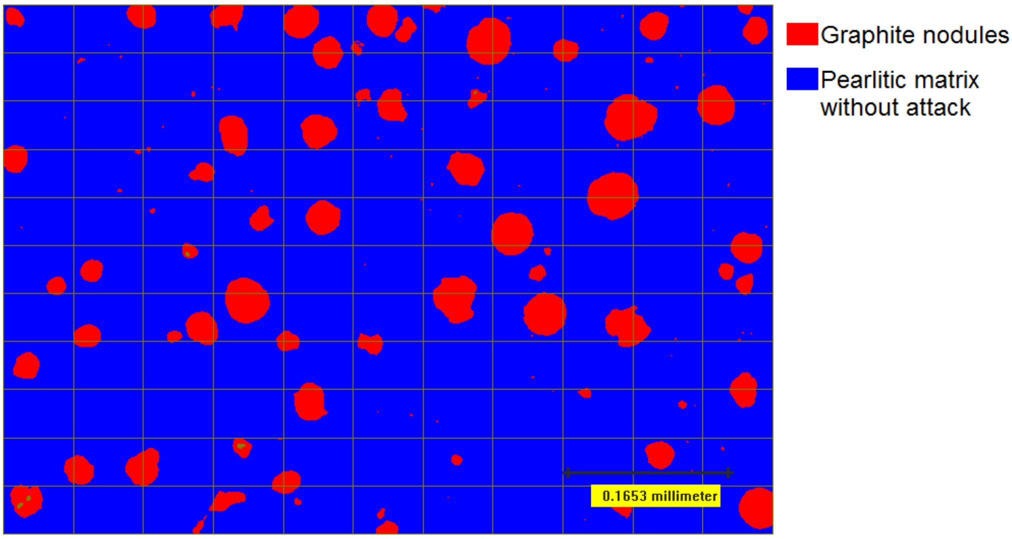


Figure 4. Quantitative evaluation of graphite nodules in nodular cast iron. Matrix without etching.

Table 3 shows the morphological classification of graphite in various positions of the ingot used, according to ASTM A-297 Standard (Mattar, 2009).

Table 3. Morphological evaluation of nodular graphite in the cast iron.

| | Centre | Half radio | Surface |
|---|---|---|---|
| Type | I and II | I and II | I and II |
| Size | 5 | 5 | 6 |
| Nodules / $mm^2$ | 212 | 180 | 312 |
| Nodularisation | 85% | 85% | 80% |

The shape of the graphite type I is the most desired in nodular cast iron, although the Type II carries virtually no adverse effect on their properties and characteristics. The sizes of graphite nodules found are considered small, providing a considerable number of nodules per $mm^2$. Furthermore, a better distribution of the graphite nodules favors the diffusion of carbon in austenite during austenitization, since there is a shorter distance between the graphite nodules which acts as a carbon source. The density of nodules found meets the recommendations for a nodular cast iron of good quality (Reesman and Loper, 1967). For Luo, *et al.* (1995) and Zhang, *et al.* (1993), the number of nodules per $mm^2$ has a very important effect on the mechanical properties of the ADI and can directly affect the wear resistance.

The porosity determination by image analysis of the sprayed coating indicated an average porosity of 1.6%. The level of porosity present in the sample is in the range stipulated by the manufacturer and in the literature (Kulu *et al.*, 2005).

Table 4 shows the results for Vickers microhardness of the coatings produced and Brinell hardness, in the case of the substrate.

Table 4. Results of microhardness Vickers and Brinell hardness.

| Material | Hardness |
|---|---|
| Coating produced by boronizing | 1455.2 ± 29.4 [HV] |
| Coating produced by thermal spray coating | 862.9 ± 27.6 [HV] |
| Ductile iron standard | 325 ± 28.2 [HB] |

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High levels of hardness were obtained in the layers in comparison with the substrate. The high hardness of the boride layer is in agreement with findings in the literature (Ipek *et al*., 2000). The hardness obtained in the thermal sprayed coating was within the range specified by the manufacturer.

The microhardness profile of the boride layer deposited in the cast iron is shown in the Figure 5.

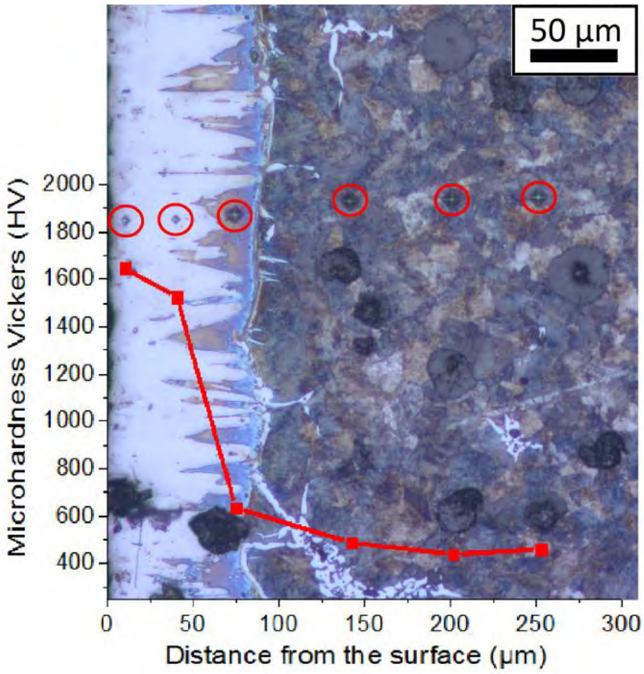


Figure 5. Vickers Microhardness profile of the boride layer obtained in boronizing of nodular cast iron. Etch: Nital 2%.

It is noted that the hardness of the layer near the surface is around 1700 HV, decreasing towards the substrate.

Figure 6 presents the wear surfaces of the cap formed with 20 minutes of abrasive testing.

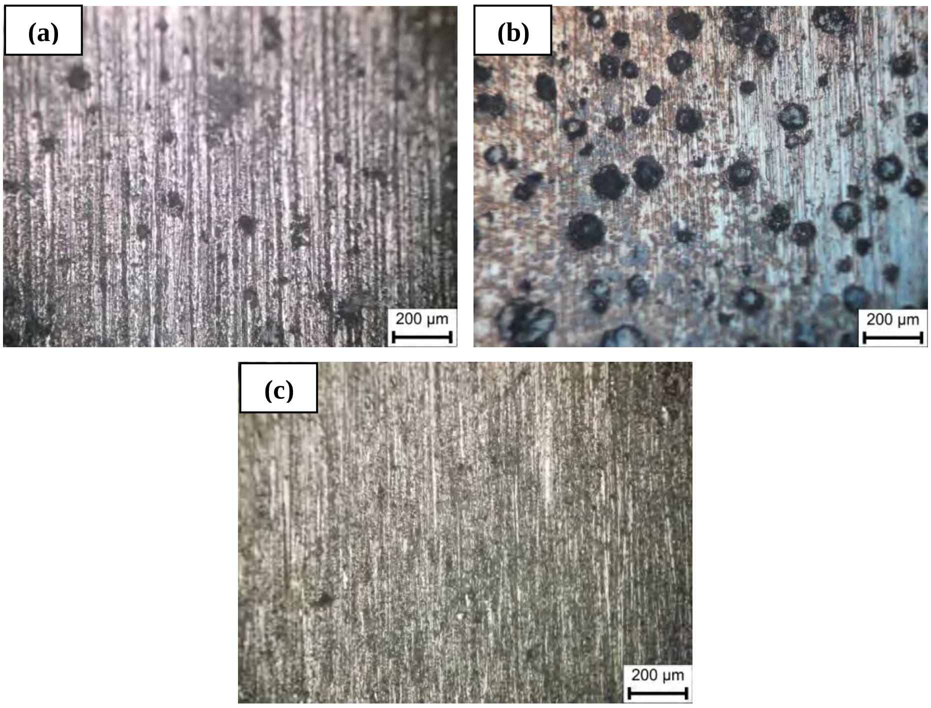


Figure 6. Aspect of the interior of the abrasive wear cap. Distance traveled: 481.58 m (last run). (a) Ductile iron, (b) borided ductile cast iron and (c) ductile iron with thermally sprayed layer.

It is verified, in all cases, that the wear mechanism was two bodies abrasion, characterized by the grooves present in the direction of relative motion.

Figure 7 presents the wear surfaces of the cap formed within 20 minutes of the adhesive testing.

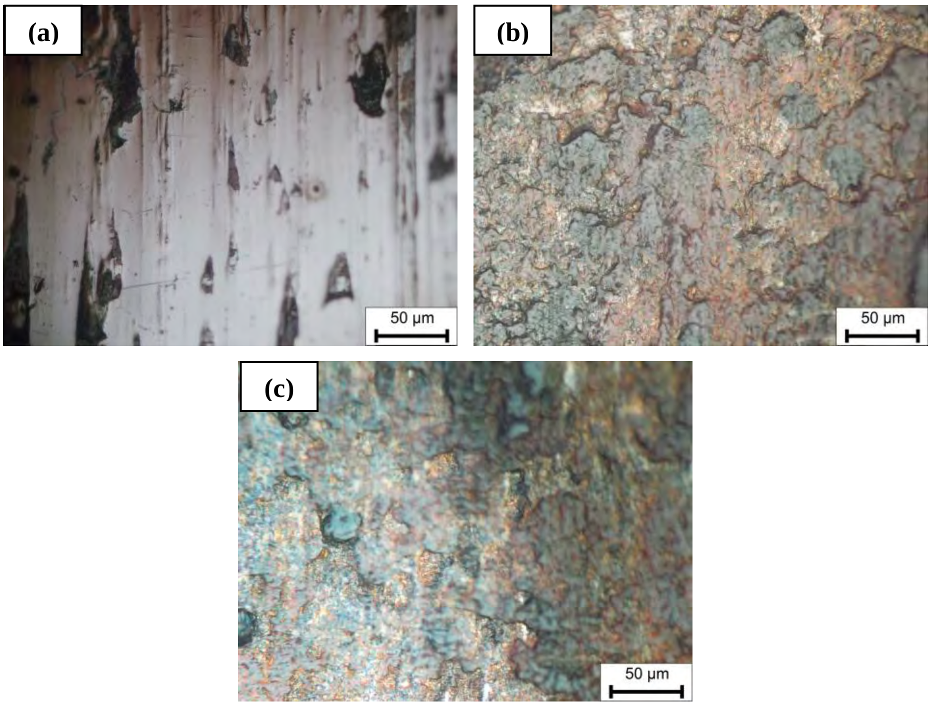


Figure 7. Aspects of the interiors of the adhesive wear caps. Distance traveled: 642.11 m (last run). (a) Ductile iron, (b) borided ductile cast iron and (c) ductile iron with thermally sprayed layer.

It is verified that the wear mechanism of the type two bodies abrasion was active in the case of the substrate 7 (a). Samples 7 (b) and 7 (c) show the mechanism of adhesive wear.

In Figures 8 and 9 show the results from tests of abrasive and adhesive wear, respectively.

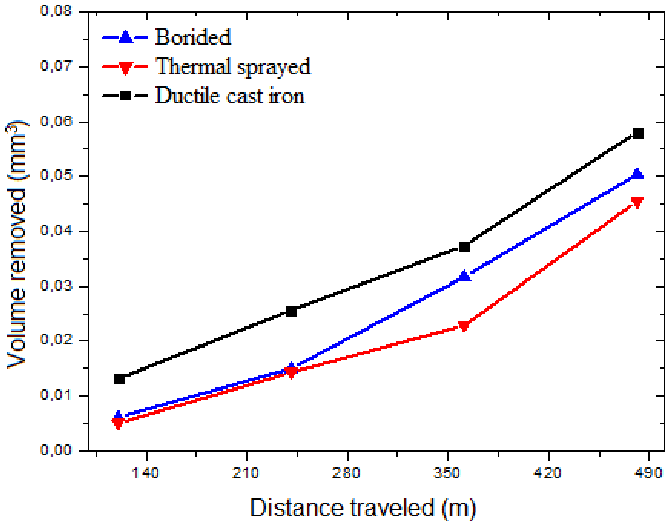


Figure 8. Plot of abrasive wear for the normalized nodular cast iron and for the boronized and thermal sprayed samples.

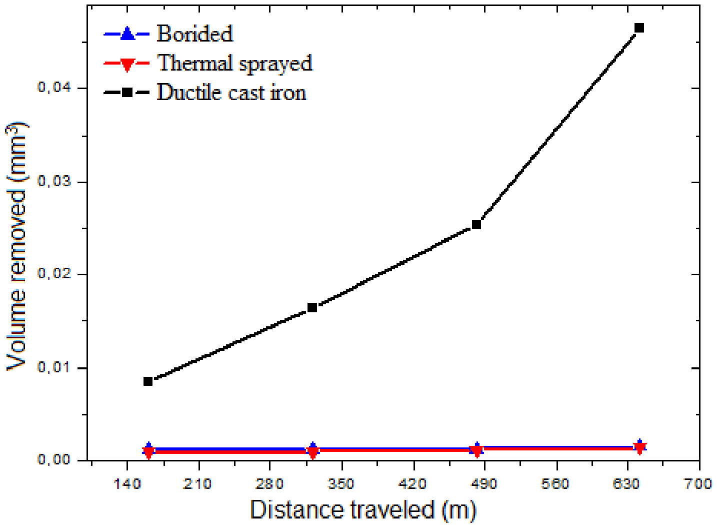


Figure 9. Plot of adhesive wear for the normalized nodular cast iron and for the samples boronized and thermal sprayed.

In both abrasive and adhesive tests, the two coated samples showed higher resistance to wear, when compared with the normalized cast iron.

For abrasive test times of 5 and 10 minutes, both coated samples (boronizing and thermal spray) showed similar performance, but with increasing testing time the sample sprayed with the NiCrBSi alloy showed higher wear resistance than the borided sample. In the adhesive wear test, coated samples showed similar wear behavior, and very superior to the substrate.

## 4. CONCLUSIONS

The boronizing treatment presented the greatest increase in hardness of the substrate, followed by thermal spray process NiCrBSi alloy in second, when compared to the normalized nodular cast iron.

Boronizing treatment and thermal spraying increased the wear resistance of ductile iron, particularly in the case of adhesive wear, in which the performance of both coatings were similar and much higher than that of the substrate. This indicates that the treatments carried out are particularly suitable for applications where this type of wear occurs.

In the abrasive wear tests, even having similar behavior at the beginning of the test, the sprayed sample had the best performance when compared to the borided sample.

Therefore, both treatments showed good potential for protection against the surface wear of cast iron, which could increase the life of components made from this material and reduce maintenance costs over time.

## 5. REFERENCES

Allaoui, O., Bouaouadja, N. and Saindernan, G., 2006. “Characterization of boronized layers on a XC38 steel”. Surface & Coatings technology, Vol. 201, p. 3475.

Akebono, H., Komotori, J. and Shimizu, M., 2008. “Effect of coating microstructure on the fatigue properties of steel thermally sprayed with Ni-based self-fluxing alloy”. Internationa Journal of Fatigue, Vol. 30, p. 814.

Celik, O., et al., 2005. “High temperature abrasive wear behavior of an as-cast ductile iron”. Wear, Vol. 258, p. 189.

Gonzales, R. et al., 2007. “Wear behavior of flame sprayed NiCrBSi coating remelted by flame or by laser”. Wear, Vol. 262, p. 301.

Ipek, R. et al., 2000. “An evaluation of the possibilities of using boride GG25 cast iron instead of chilled GG25 cast iron (surface properties)”. Journal of materials processing technology, Vol. 105, p. 73.

Kulu, P., Hussainova, I. and Veinthal, R., 2006. “Solid particle erosion of thermal sprayed coatings”. Wear, Vol. 258, p. 488.

Luo, Q., Xie, J. and Song, Y., 1995. “Effects of microstructures on the abrasive wear behavior of spheroidal cast iron”. Wear, Vol. 184, p. 1.

Mattar, A. R., 2009, “Influência dos elementos de liga Cu-Ni-Mo nas propriedades mecânicas e na austemperabilidade do ADI”. Master's degree dissertation. Universidade de São Paulo. Sao Paulo.

Reesman, R.W. and Loper, J. C. R., 1967. “Heavy section ductile iron as affected by certain processing variables”. AFS Transations, Vol. 67-75, p. 1.

Sahin, S. and Meric, C., 2002. “Investigation of the effect of boronizing on cast irons”. Materials research bulletin,Vol. 37, p. 971.

ISSN 2176-5480



Sen, U., Sen. S. and Yilmaz, F., 2004. "Effect of copper on boride layer of ductile cast iron". Vacuum, Vol. 72, p. 199.

Zhang. Y., et al. 1993. "Investigation of tribological properties of brake shoe materials phosphorous cast irons with different graphite morphologies". Wear, Vol. 166, p. 179.

Zhou, Y., Lu, Z. and Zhan, M., 2007. "An investigation of the erosion–corrosion characteristics of ductile cast iron". Materials and Design, Vol. 28, p. 260.