ISSN 2179-3956

CHARACTERIZATION OF HIGH CHROMIUM WHITE CAST IRON RESISTANCE TO ABRASIVE WEAR[1]

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Abstract

This study aims to verify the abrasive wear resistance, against two-body and three-body tribosystems, of high chromium white cast irons used in grate bars for sinter plants.Three alloys of high chromium white cast irons were chosen from grate bars applications in a sinter plant. The materials were tested in three different tribometers: scratch test, pin-on-disk test and LTM test. The first two simulate severe abrasive wear conditions and the latter simulate a non-severe abrasive wear condition. The wear rate for each test was measured. The most resistant material to the abrasive wear simulated by the scratch test and the pin on disk test was the C0 alloy. The presence of M_7C_3 carbides precipitated in the eutectic phase offered higher protection to the austenitic matrix against the microploughing mechanism. On the other hand, for the LTM test, the most resistant material was the J4 alloy. The higher capacity of the ferritic matrix to absorb plastic deformation offered the material a higher resistance to the multiple indentation events.

Key words: White cast iron; Wear rate; Grate bars; Sinter plant.

[1] *Technical contribution to the First International Brazilian Conference on Tribology – TriboBr-2010, November, 24th-26th, 2010, Rio de Janeiro, RJ, Brazil.*
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ISSN 2179-3956

1 INTRODUCTION

High chromium white cast irons (HCWCI) are materials widely used in heavy industries like mining, iron making and cement due to its high abrasive wear resistance and economical competitiveness.
The main input of the iron making industries is the iron ore. This product, in many plants, is supplied by a sinter plant basically composed by grate cars that travel along the furnace carrying the iron ore during the agglomeration process. The grate bars are the main components in direct contact with the raw material through the whole process they are designed to work under high loads and high temperatures.
At the end of the sinter furnace, the grate cars reach an inversion point that lead the agglomerated material, named sinter, to slide on the grate bars falling into the discharge process. When the sinter slides on the grate bars a severe abrasive wear mechanism takes place. This mechanism was the motivation to the work published in 2004 by Del Piero.[1] This author evaluated the abrasive wear resistance of different HCWCI alloys using the single pass pendulum technique.
The present work aims to continue this study by investigating the wear rate under three others tribometers named scratch test, pin-on-disk test and LTM test. The first two simulate severe abrasive wear conditions and the latter simulate a non-severe abrasive wear condition. The wear rate for each test was measured

2 MATERIAL AND METHODS

2.1 MATERIAL

2.1.1 High chromium white cast irons

High chromium white cast irons are alloys mainly composed by iron, carbon and chromium. They are characterized by an eutectic reaction during solidification.[2] Known by their wear resistance, plenty of studies[3-9] have been developed attempting to correlate the microstructures proprieties and the wear rate.
The microstructure is a function of the cooling velocity and the chemical composition. The ternary diagram Fe-Cr-C developed by JACKSON and later improved by Thorpe e Chicco[10] shows the phases that should be present as a function of carbon, chromium and iron concentrations. The addition of alloying elements, although it causes a few distortions on the ternary diagram,[11] it helps to control the solidified material microstructure.
The relation Cr/C is strongly related to the precipitated carbide fraction (K). Maratray and Usseglio-Nanot[12] developed a equation that predicts, with 2,13% of standard deviation, the fraction of carbides precipitated.

2.1.2 Characterization of C0, J0 and J4 white cast irons alloys

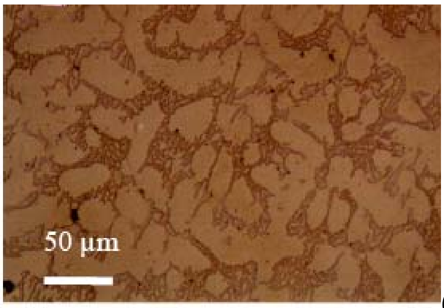
The white cast irons alloys used in this study were characterized by Del Piero.[1] The Table 1 indentifies each alloy and presents its hardness.

Table 1 - Identification of each white cast iron alloys

Material	Condition	Hardness [$HV_{0,2}$]
C0	As cast.	450,6
J0	As cast.	426,6
J4	After 3,5 year of work.	381,4

ISSN 2179-3956

The alloys C0 and J0 have and austenite and an eutectic phases. The eutectic is composed by austenite and M_7C_3 carbides. The J4 alloy, due to the working cycles, has a ferritic matrix and secondary carbides $M_{23}C_6$ precipitated through out the matrix. Metallographic pictures can be seen in the Figure 1.



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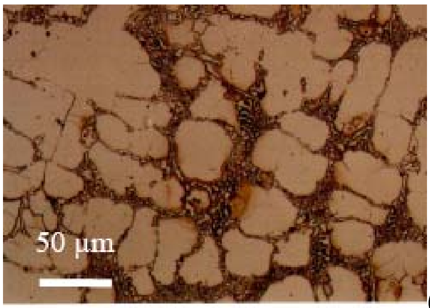

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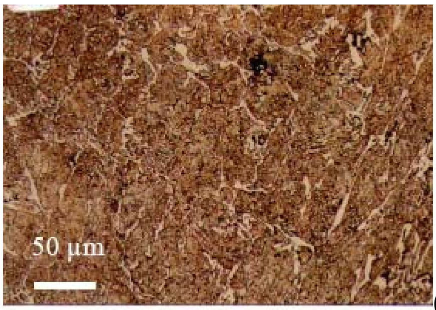

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Figure 1- (a) C0 alloy. (b) J0 alloy. (c) J4 alloy.

A chemical composition is presented in the Table 2, a quantitative metallographic in the Table 3 and phase volumetric fraction analysis through Mössbauer spectrometer in the

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Table 4.

Table 2 - Chemical composition of white cast irons specimens

Material	%C	%Cr	%Si	%Ti	%V	%Mo	%P	%S	%Mn
C	1,7-1,8	25-27	0,5-0,7	0,12-0,18	0,15-0,25	0,3-0,5	0,04	0,03	0,7-0,9
J	1,4-1,6	25-28	1,25	-	-	-	0,02	0,01	0,8

Table 3 – Fraction volume and average carbide diameter of white cast irons alloys. Data collected from the literature[1]

Material	% Vol carbides	Average dia. (µm)
C0	17,03 ± 2,78	8,77 ± 1,33
J0	16,21 ± 2,46	4,23 ± 0,57
J4	31,28 ± 8,15	7,21 ± 1,84

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Table 4 - Phase volumetric fraction analysis through Mössbauer spectrometer[1]

Specimen	Phase	Área [%]
C0	Austenite	72,6
	Ferrite	16,7
	M_7C_3	10,7
	$M_{23}C_6$	-
J0	Austenite	56,6
	Ferrite	34,6
	M_7C_3	8,8
	$M_{23}C_6$	-
J4	Austenite	3
	Ferrite	85,5
	M_7C_3	0,2
	$M_{23}C_6$	7,2

2.2 METHODS

2.2.1 LTM test

The LTM test is a non standardized tribometers developed at Uberlandia's Federal University. Usually it simulates a non severe abrasive wear. It's accepted by the scientific community[13,14] and has a low cycle time and high reproducibility.[15]

The Figure 2 presents an illustration of the LTM test. Three samples are pressed against a spinning grey cast iron plate. The rotation movement of the plate and the constructive system of the machine creates a relative motion between the samples and the plate. The wear rate is measured at steady state by the mass loss.

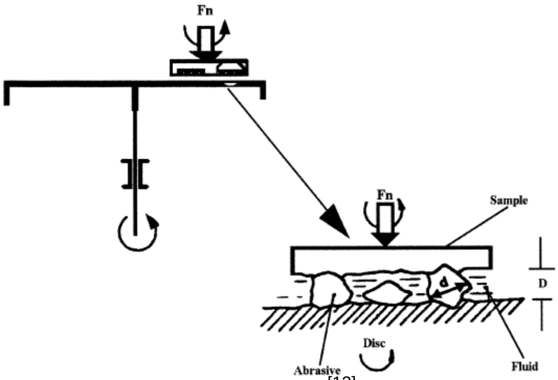

Figure 2 – Illustration of LTM test.[13] Fn is the normal force.

The Table 5 presents de parameters used in the test.

Table 5 - LTM test parameters

Normal pressure (KPa)	30,37
Abrasive	SiO_2
Abrasive size [µm]	150 a 300
Fluid	Air

2.2.2 Pin-on-disk

The pin-on-disk test is a standardized test[16] and widely used by the scientific community. It simulates a severe abrasive wear. Although there is a standard related to this tribometers many adjustments are usually made to reproduce a specific micromechanism.

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Uberlandia's Federal University has a pin-on-disk test developed by Pacca, Raslan and Mello.[17] It's a multiple tribometers once it can simulate two or three bodies tests depending on the configuration.
For this study a two body test was chosen. The pin travels on an abrasive paper and spins around its own axial. The normal force is given by a dead weight. The Figure 3 presents an illustration of the pin-on-disk test developed.

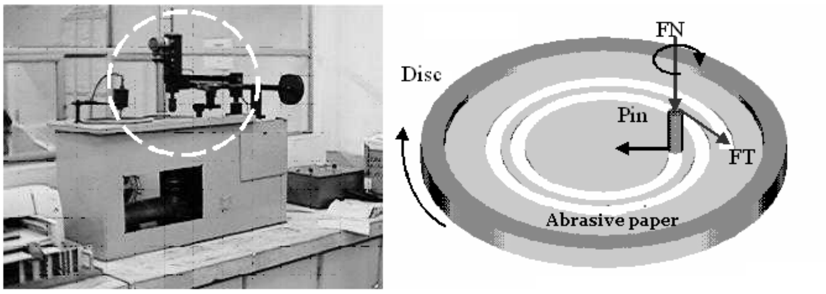

Figure 3 – Illustration of pin-on-disk test.[18]

The Table 6 presents the parameters used in this test.

Table 6 – Pin-on-disk test parameters

Disc velocity [rpm]	25
Sample velocity [rpm]	25
Distance [m]	3,2
Duration [s]	22
Abrasive	Al_2O_3
Abrasive size [µm]	14,1 ± 8,5

2.2.3 Scratch test

The scratch test is a mono event of grooving. One of the first studies regarding the ability of one material perform a grove in another was developed by Mohs[19] in 1824.
The scratch hardness and the indentation hardness are different proprieties. The indentation hardness has been adopted as a general rule for designs[20] and the scratch hardness has been normally used as a quality control technique.[20]
The scratch test consists of an indenter, used in indentation hardness tests, which sustain a normal load and assume a translation motion, see Figure 4. The wear rate is measure by the grove size (d).

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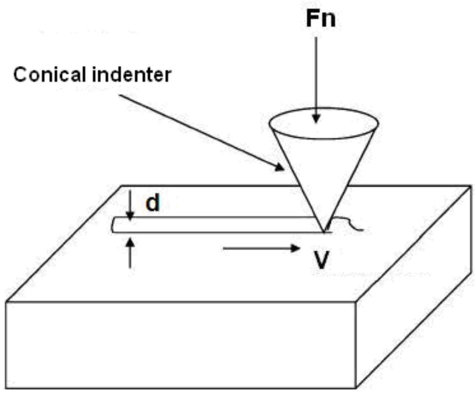


Figure 4 – Illustration of a scratch test. Fn is the normal load, d is the size of the grove and V is the velocity of the translation motion.[21]

For the white cast iron alloys it was used a Vickers pyramidal indenter with a 136° angle. The Table 7 presents the test parameters used in this test.

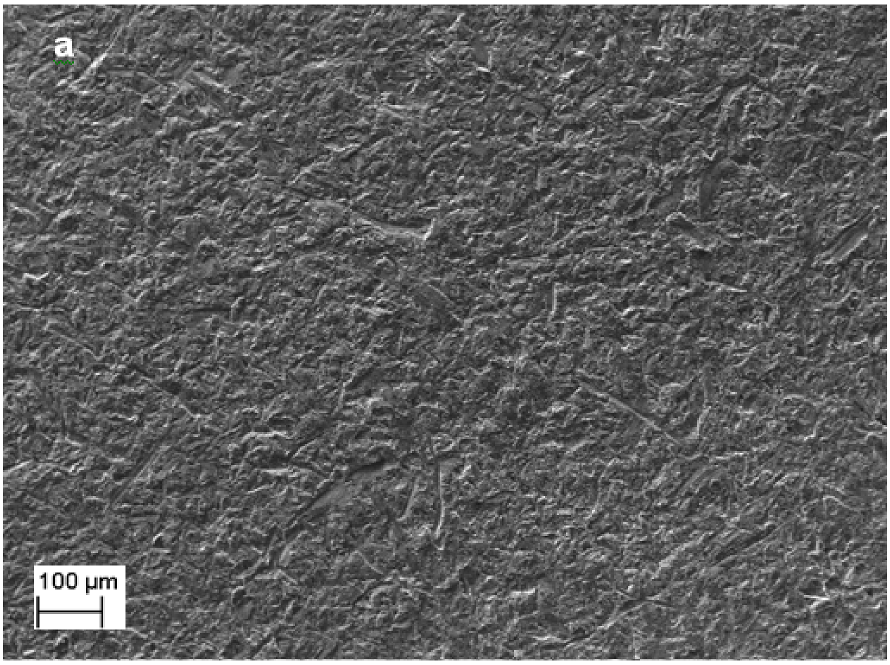
Table 7 – Scratch test parameter

Scratch velocity [mm s-1]	0,1
Normal load [N]	10

3 RESULTS

3.1 Micromechanisms

The Figure 5 and Figure 6 presents the micromechanisms observed in the specimens after tested in each tribometer.



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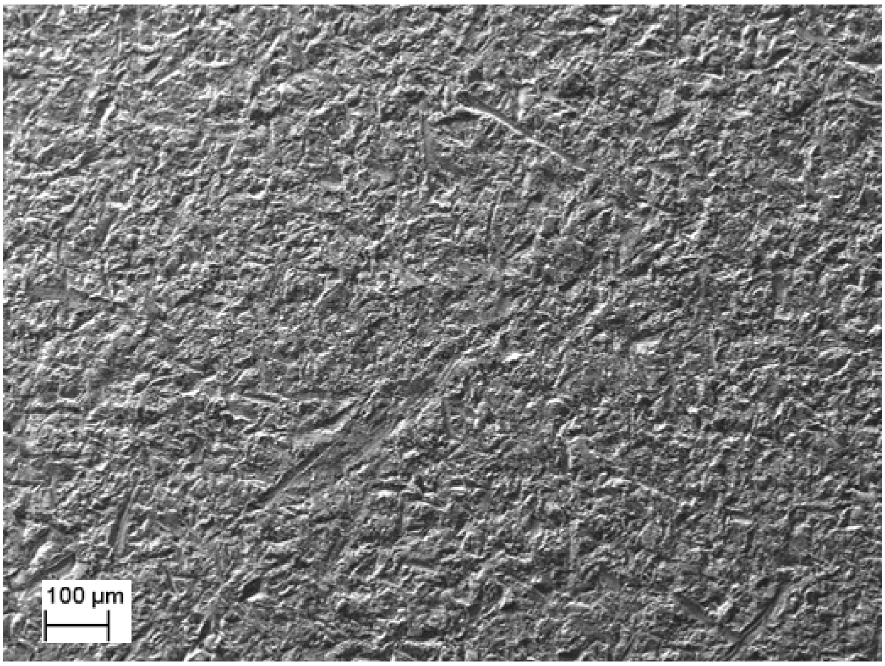

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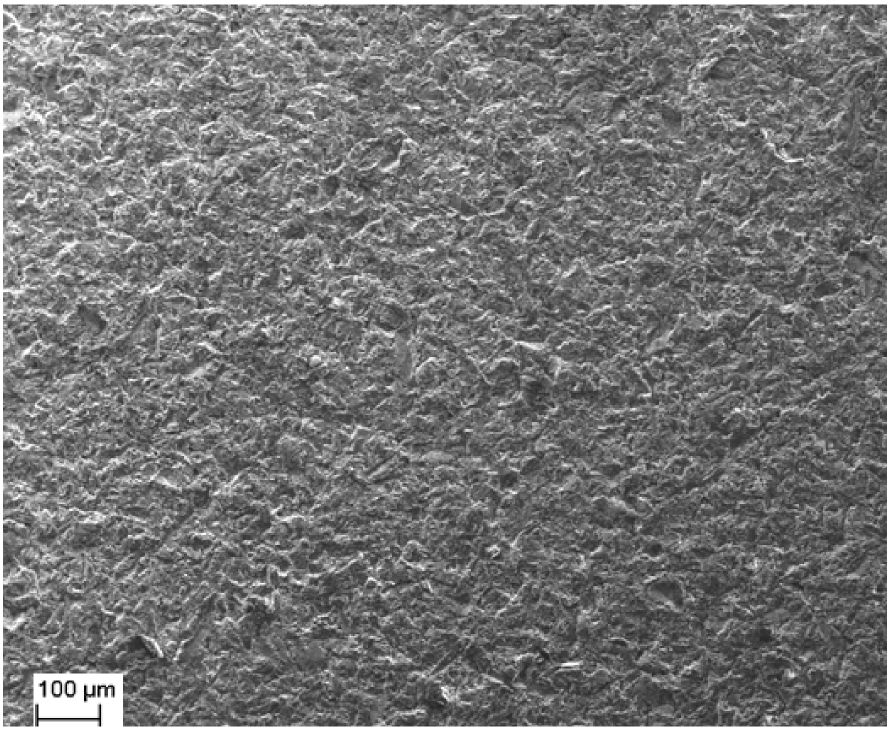

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Figure 5 - Micromechanisms of the LTM test. (a) C0 alloy. (b) J0 alloy. (c) J4 alloy.

ISSN 2179-3956

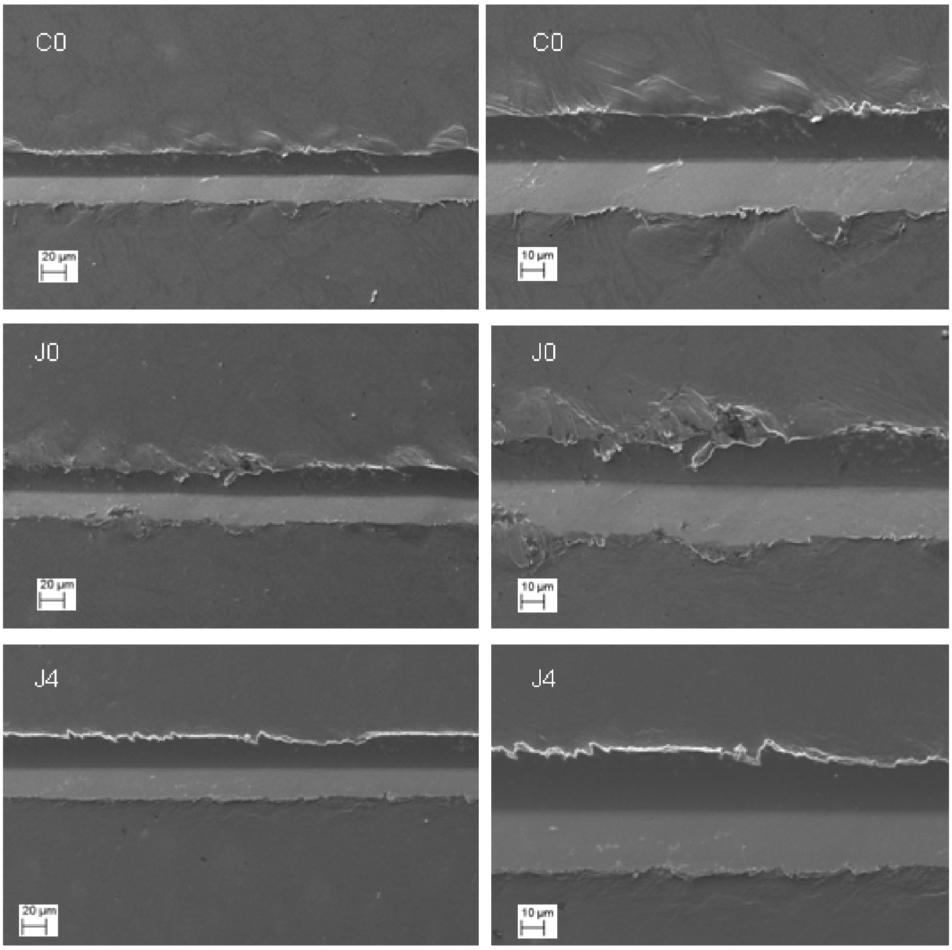

Figure 6 - Micromechanisms of the scratch test.

For the LTM test, the electron microscopy shows a mix of multiple indentation and microploughing mechanisms that lead to the material loss. The multiple indentation mechanism is predominant.

For the scratch test, it is observed a mechanism of microcploughing. The f_{ab} factor was never above 0.38. A typical profile is presented in the Figure 7.

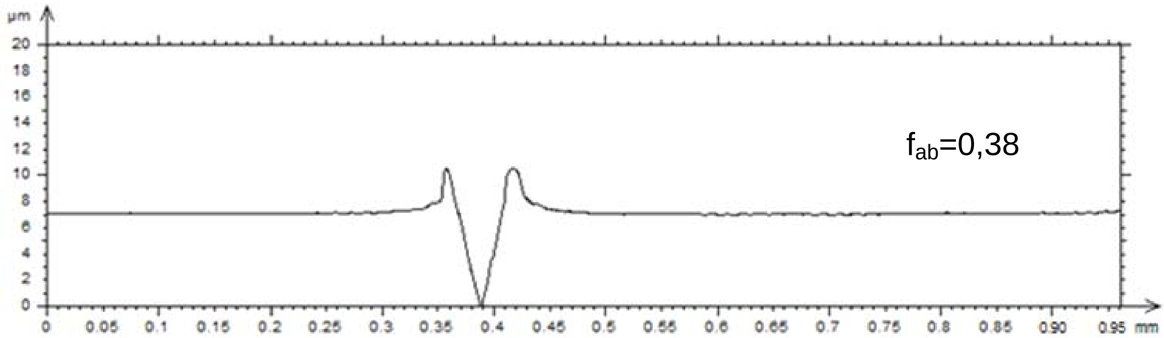

Figure 7 - Typical profile of the specimen J0.

3.2 Wear rate

The wear rate of each specimen is presented in the Figure 8.

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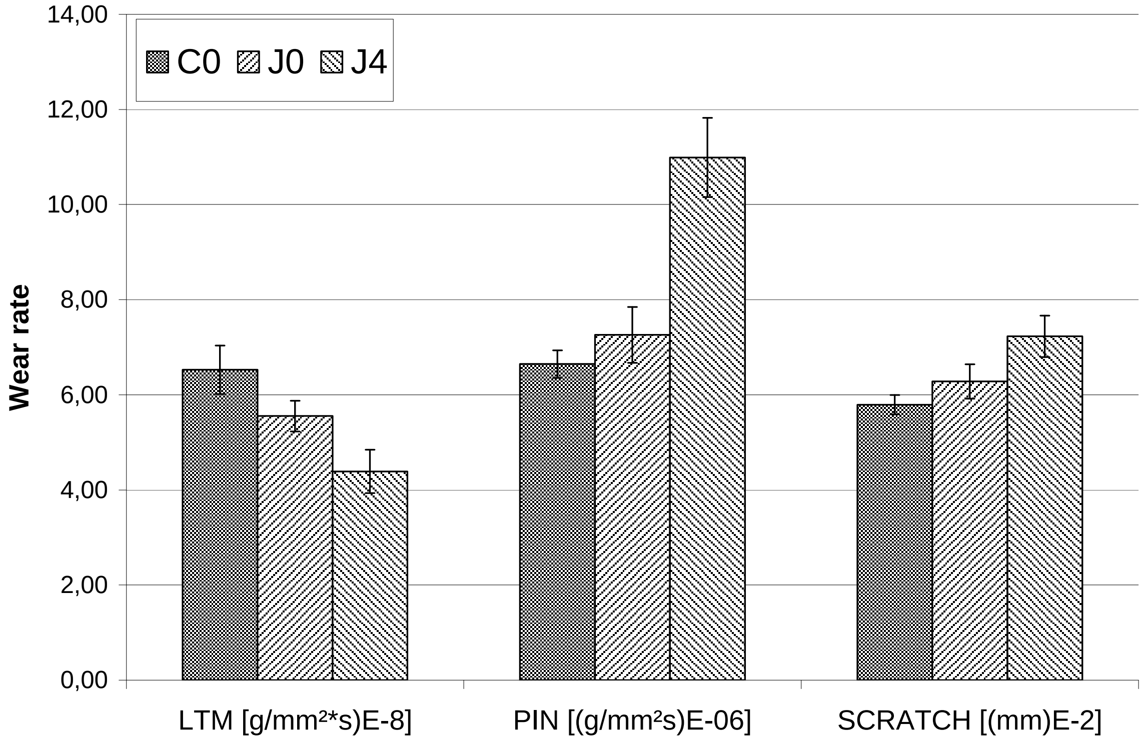

Figure 8 - Wear rate measured.

4 DISCUSSION

For the LTM test the micromechanism simulated in this tribometer is, predominantly, multiple indentations. Therefore the classification obtained will be strongly influence by the ductility of the alloys. The C0 and J0 alloys have similar chemical composition and very close hardness. The difference observed in terms of wear rate can be explained by the higher presence of ferrite in the J0 alloy, which will increase the ductility that allows the material to absorb more deformation. The J4 alloy has de lower wear rate once its matrix is mainly composed by ferrite.

The pin-on-disk and the scratch tests represent a global and local tribosystem respectively. The former simulates multiples events of cutting or ploughing and the latter, a single event. Therefore the same classification is expected. The alloy C0 has the lower wear rate which is explained by the higher content of M_7C_3 carbides which protects the matrix. As this protection decreases the wear rate increases.

When the wear rate behaviors of the scratch and pin-on-disk tests are compared it can be observed a higher increase of the wear rate as the hardness decreases on the pin-on-disk test. It can be explained by the multiple events interaction, a consequence of the global approach.

5 CONCLUSION

In the LTM test the J4 alloy presents the lower wear rate. The multiple indentation micromechanism predominates. The ferritic matrix offered a higher ductility and consequently a lower work hardening which increased the wear resistance.

In the pin-on-disk and scratch tests the C0 alloy presented the lower wear rate. The micromechanism is the microploughing. The presence of M_7C_3 primary carbides offered a higher matrix protection, which led to higher wear resistance.

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REFERENCES

1 DEL PIERO R. C., Resistência ao desgaste abrasivo a quente de ferros fundidos branco alto cromo, utilizados em barras de grelha na sinterização, Universidade Federal do Espírito Santo, (2004), Dissertação de mestrado.
2 SANTOS A. B., BRANCO C. H. C., Metalurgia dos ferros fundidos cinzentos e nodulares, IPT 100 (1989).
3 SINATORA, A. MEI P. R., TSCHIPTSCHIN A. P. Resistência ao desgaste de ferros fundidos broncos com 13% de cromo temperados. 45° Congresso anual da ABM, Vol 3, p.5-18, 1990.
4 TSCHIPTSCHIN, A. P., SINATORA, A. Comportamento em desgaste de ferros fundidos broncos de alto cromo revenidos contendo vanádio. 45° Congresso anual da ABM, Vol 3, p18-32, 1990.
5 DE MELLO, J. D. B, DURAND-CHARRE, M., MATHIA, T. A sclerometric study of unidirectionally solidified Cr-Mo white cast irons. Wear, 111. p.203-215. 1986.
6 CORONADO J.J., SINATORA A. Abrasive wear study of white cast iron with different solidification rates. Wear, 267. p.2116-2121. 2009.
7 ALBERTIN E., SINATORA A. Effect of carbide fraction and matrix microstructure on the wear of cast iron balls tested in a laboratory ball mill. Wear, 250. p. 492–501. 2001.
8 SCANDIAN C., BOHER C., DE MELLO J.D.B., RÉZAÏ-ARIA F. Effect of molybdenum and chromium contents in sliding wear of high-chromium white cast iron: The relationship between microstructure and wear. Wear 267. p.401–408. 2009
9 PINTAUDE G., BERNARDES F.G., SANTOS M.M., SINATORA A., ALBERTIN E. Mild and severe wear of steels and cast irons in sliding abrasion. Wear 267. p.19–25. 2009
10 THORPE W. R. and CHICCO B., The Fe-Rich Corner of the Metastable C-Cr-Fe Liquidus Surface METALLURGICAL TRANSACTIONS A VOLUME 16A, SEPTEMBER 1985 p1541-1549.
11 CARVALHO, S. Estudo microestrutural dos ferros fundidos brancos alto cromo e molibidênio, Tese M. Sc., PPGEM/UFES, Vitória, Abril 2005.
12 MARATRAY F., USSEGLIO-NANOT R., Facteurs affectant la structure des fonts blanches au chrome et au molybdène, 1° ed. Paris, France: Climax Molybdenum, 1970, p. 5-32.
13 BOZZI, A.C., DE MELLO, J.D.B., Wear resistance and wear mechanisms of WC–12%Co thermal sprayed coatings in three-body abrasion, Wear 233–235, p. 575 a 587, 1999.
14 COSTA, H., DE MELLO, J.D.B., Desenvolvimento de um novo abrasômetro a três corpos, XVI COBEM 2001, UBERLÂNDIA
15 SANTANA A.S., DE MELLO, J.D.B., Abrasão a três corpos de ferros fundidos brancos eutéticos, Procedings of the third Brasilian Seminar of abrasive, 1994.
16 ASTM G99-04, Standard test method for wear testing with a pin-on-disk apparatus.
17 PACCA, F.R., RASLAN, A.A., DE MELLO, J.D.B., Efeito do movimento relative da amostra na abrasão a dois corpo, II Seminário Brasileiro sobre materiais resistentes ao desgaste. Uberlândia, MG. Dezembro 1991.
18 REGATTIERI, C.N.B., Estudo da resistência ao desgaste abrasivo de ferros fundidos brancos alto cromo e molibdênio, Tese M. Sc., PPGEM/UFES, Vitória, Abril 2006.

ISSN 2179-3956

19 MOHS, F. Grundriss der Mineralogie, 1894 (English translation by Haidinger W. Treatise on Mineralogy, Constable, Edinburgh, 1925).
20 WILLIAMS, J. A. Analytical models of scratch hardness, Tribology International Vol.29 No. 8, pp 675-694, 1996.
21 HADAL, R. S., MISRA, R. D. K. Scratch deformation behavior of thermoplastic materials with significant differences in ductility. Materials Science and Engineering, v. 398, p. 252-261, 2005