INFLUENCE OF WELDING TECHNIQUE AND THE TYPE OF FILLER METAL IN THE WEAR RESISTANCE OF HARDFACING WELD DEPOSITS

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Abstract. *The Brazil's sugar/alcohol sector has presented a significant increase in the recent years getting the attention of his producers in the search to maintaining the lowest costs in the processing of sugar. Between production costs, the maintenance costs are one of the higher due to the metallic's mass losses in cut tools by wear. This research's objective is the study of wear resistance of three hardfacing alloys applied by Flux Cored Arc Welding process, and Flux Cored Arc welding (FCAW) process no-energized wire or cold wire. For this purpose, two commercial self-shield cored welding wires – FeCrC+Ti (Hardface TIC-O) and FeCrC+Nb (Hardaface CN-O) – with 1,6 mm of diameter were used, other (FeCrC) were also used like no-energized wire. The hardfacing alloys were deposited onto SAE 1020 steel plates. The self-shielded flux cored wires were welded in short-circuit transfer mode with the same current and voltage values. For the Rubber Wheel Test were made test bodies following the ASTM G65-00 recommendations. Wear evaluation was made by mass loss. The FeCrC+Ti alloy and the FeCrC+Nb had very close values of wear, and hardfacing applied by FCAW with not energized wire (FeCrC+Ti with addition of FeCrC) presented a slight increase (considering the average values) in wear resistance showing the technical viability of FCAW with no-energized wire.*

Keywords: *Hardfacing, Flux Cored Arc Welding, Wear Resistance, Welding process.*

1. INTRODUCTION

The Brazilian sugar/alcohol industries presented great expansion in recent years due to the increase in consumption of ethanol locally and the targeted increase of usage of biofuels in USA, Europe and Japan. Brazil is the world's greatest sugar producer and the second greatest producer of ethanol. Material losses due to wear represents a significant cost in operation of sugar/alcohol industries, where wear of implements is great and service life of the components is short.

It was verified that the equipments which are most critical in terms of wear by abrasion are: the feeder table, the leveler, the rollers, the bearings, the shredder knives, the shredder hammers and the mills. While the greater part of these equipments can be remanufactured between harvest, the shredder knives and the shredder hammers due their short service life are responsible for stoppage during harvest for their substitution. These tools are recovered by welding of hardfacing using different processes, techniques and consumables to replace the metal lost in service (Lima, 2008).

Traditionally in Brazilian industry the application of hardfacing has been either manually by shielded electrode process or automatically by submerged arc process when the geometry or dimensions are favorable. Due to a greater productivity when compared to the former and a greater adaptability in relation to the latter, flux cored arc welding has become an important alternative with a great variety of consumables for different applications of hardfacings (Lima and Ferraresi, 2009).

There are many papers about the effects of microstructure on wear resistance in literature. The majority of the authors are unanimous that the microstructure of the hardfacing has a preponderance paper on wear resistance. Fiorre et al. (1983) claims that high chromium white cast iron has many advantages in abrasion wear applications, since its composition can be adjusted to contain moderate amount of chromium. Thus producing on solidification, microstructure rich in massive chromium carbide and an austenite matrix of sufficient hardenability to transform in martensite with relatively simple heat treatments. The carbides affect the mechanical properties by their presence in the grains and at the boundary. Depending on the alloy composition and the heat treatment received destined types of carbides, such MC, M_6C, M_7C_3, $M_{23}C_6$ and Cr_2C_3, where M represents one or more types of metallic atom can be formed.

According to Hernandez (1997), the Fe-C-Cr-Nb alloys presents essentially the same type of microstructure as the Fe-C-Cr alloys, forming austenitic dendrites or massive M_7C_3 carbides, besides the presence of NbC carbides in primary form and/or in finer fractions, results of more complex reactions. Abrasion wear tests of these alloys indicated reduction in wear when chromium carbides are substituted partially by NbC carbide.

According to Martins Filho (1995), better abrasive wear resistance is obtained in tests with less heating, free from cracks and microstructure with high amount of austenite. In Hernandez (1997), the microstructure more resistant to abrasion was primary carbide in eutectic matrix of carbide and austenite obtained in hardfacing with higher amounts of Cr e C. This occurs with increase of volumetric fraction of carbides and with reduction in width of austenite dendrites.

According to Paranhos et al. (1998), the increase in amounts of C and Cr reduces the possibility of formation of primary austenite and increases the formation of microstructure composed of primary carbide of M_7C_3 type and austenite-carbide eutectic (M_7C_3), which presents greater resistance to low stress abrasion. The hardfacings rich in chromium with primary carbides in eutectic matrix show better resistance to abrasive wear than those composed of austenite and eutectics.

According to Buchely et al. (2005), the chromium carbides of M_7C_3 types have an important role in abrasive wear resistance due to their action as barrier to cut and grooving caused by abrasive particles. In his study of abrasive wear in Rubber Wheel Tests, the superiority of complex carbides in the third layer was verified, followed by hardfacing rich in chromium (second layer). For the first layers, the test result was the alloy rich in W, followed by the alloy rich in Cr and finally the alloy rich in complex carbides (NbC, M_7C_3 and Mo_2C). The first layers showed resistance to wear inferior to the other layers.

The objective of this study is to evaluate the abrasion wear resistance of two consumables (FeCrC+Ti and FeCrC + Nb) and hardfacing applied by FCAW with no- energized wire (FeCrC+Ti with addition of FeCrC) applied by welding using the Rubber Wheel Abrasion Tests in laboratory.

2. MATERIALS AND EXPERIMENTAL PROCEDURES

A multiple process electronic welding machine adjusted for constant voltage mode of flux cored arc welding. The consumables of FeCrC alloys were used: a covered three selfshielded flux cored wires of diameter 1.6 mm of different percentages of iron, chromium, carbon, silicon and manganese, beside niobium and titanium and molybdenum. These consumables will be named, FeCrC, FeCrC+Nb and FeCrC+Ti respectively. Table 1 shows the range of hardness obtained by the first weld layer as well as the chemical composition of the consumables given by the manufacturers.

Table 1. Consumable data (self shielded flux cored wires and covered electrode).

Electrode Type	Chemical composition (%)								Hardness [HRc]
	C	Mn	Si	Cr	Mo	Nb	Ti	V	
FeCrC+Nb	5,0	0,5	1,0	22,0	-	7,0	-	-	57-64
FeCrC+Ti	1,8	1,2	0,7	6,5	0,8	-	5,0	0,2	52-64
FeCrC	4,11	0,52	0,20	23,10	-	-	-	-	59-61

The welding was carried out in the flat position with the torch upright on a 90 degree angle with the surface of the plate. Was also performed a transverse oscillation of the welding torch *(frequency = 1,6 Hz)*. Figure 1 shows support for the addition of the wire not energized.

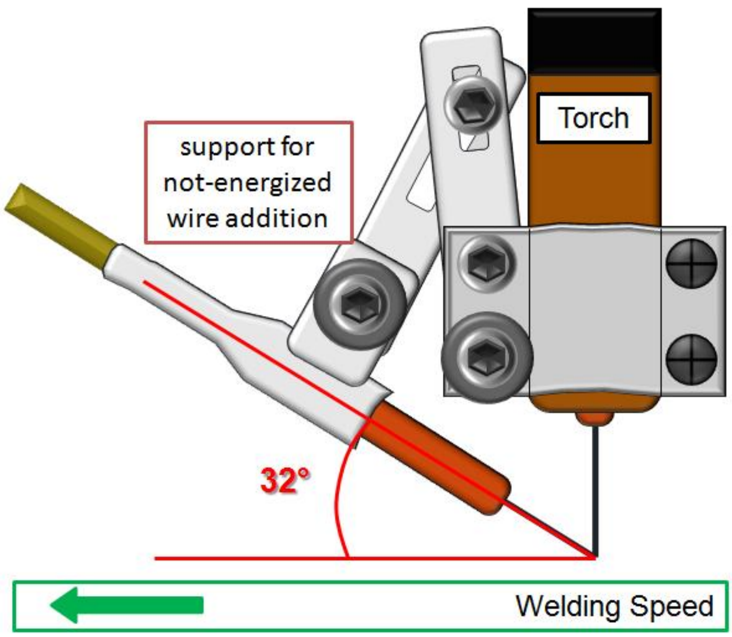

Figure 1. Support for addition of the wire not energized.

Table 2 shows the welding parameters used. For flux cored arc welding, the up-down inductance, wire feed rate (V_{alim}), weld speed (V_{sold}) and reference voltage (Ur) were maintained constant, in order to obtain metallic transfer in short-circuit mode.

Table 2. Welding parameters used to obtain the test specimens.

Electrode Type	V_{sold} [mm/min]	V_{alim} [mm/min]	$V_{alim}2$ [mm/min]	Ur [V]	CTWD [mm]	I_{des}(A)	P [mm]
FeCrC+Nb	200	8	-	28	30	290	12
FeCrC+Ti	200	8	-	28	28	260	12
FeCrC+Ti with addition wire not energized FeCrC	200	8	1,05	28	28	261	12

Where: I_{des} = Current desired; P = distance between center of adjacent weld beads; $V_{alim}2$: wire feed rate not energized and CTWD: nozzle contact tube-work distance.

The welding parameters (Table 2) were obtained from Lima and Ferraresi (2009). The nozzle contact tube-work distance (CTWD) was varied to obtain the same welding current with the same reference voltage. This procedure is important to evaluate the wear resistance of the weld deposit when using the same current and the same volume of metal deposited per length of bead (V_{alim} and V_{sold} constant). For the covered electrode process the welding parameters were the same as used in industry and as indicated by the electrode manufacturer.

For the Rubber Wheel Tests the weld was a single layer with beads of 150mm length (five weld beads per hardfacing) on SAE 1020 steel plates of 12.7 x 50.8 x 200 mm. Five plates were welded with each consumable. The test specimens for wear evaluation were obtained from the central region. Figure 2 shows the top view of a hardfaced test plate where the test specimen was obtained. The wear tests used a Rubber Wheel Abrasion Tester, recommended for simulation of low-stress abrasion wear by ASTM G65 (1991) standard. Specimen 10 x 25 x 55 mm, disk 12.7 x 228 mm, rubber 60 shore A hardness, Brazilian standard n^o 100 sand (0.15 mm), wheel speed 200 rpm, test duration 10 min (procedure B), and force against specimen 120 N. The specimens were weighed before and after the test with an electronic balance of resolution 10^{-5} g. Specimens were pre-worn during 5 minutes.

The wear was obtained as a function of the loss of weigh of the test pieces by a comparison of the weight before and after the test. Before being weighed, the samples were carefully cleaned by immersion in acetone, using ultra sound cleaning equipment, and then dried with warm air. The wear resistance was obtained by the inverse ratio of the wear divided by distance covered during the test.

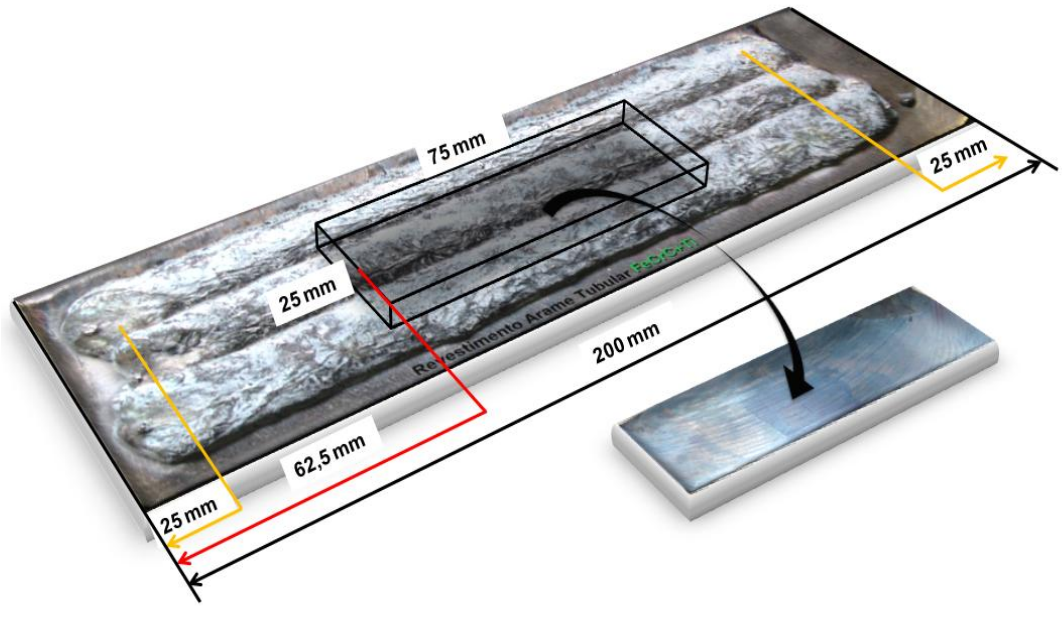

Figure 2. Test plate and region of the test specimen for wear and microstructure evaluation.

For microstructure evaluation of the hardfacing, samples were extracted from the welded plates (Figure 2). The samples were grinded with emery paper of grades 180 to 1000 and polished with diamond pastes of 3 μm, 1 μm and 0.25 μm. Subsequently etched in kalling for 10 seconds to reveal the microstructures under an optical microscope. To reveal the carbides the same grinding and polishing procedures were used and the etching was with Murakami at 60^0C for 10 seconds.

3. RESULTS AND DISCUSSIONS

3.1.Dilution

The evaluation of the dilution should be considered in hardfacing for being one of the parameters determining the chemical composition of the fusion zone, hardness and tribological properties of the deposits. Obtaining the dilution was through the relationship between the fused area of the base metal and the total area of the weld. Tab. (3) shows the vcalues of the dilution oh hardfacing obtained with each condition presented in Tab. (1). Five weld beads per hardfacing. Measurements were obtained at the beginning and end of the weld bead.

Tabela 3. Values of the dilution of hardfacing (five weld beads per hardfacing).

Consumable	C.P. #	Din	DM	DP	Dfi	DM	DP	Dilution	DP
		[%]			[%]			[%]	
FeCrC+Ti	1,1	30,18	30,63	0,96	30,02	29,95	1,79	30,29	0,59
	1,2	32,24			26,91				
	1,3	29,76			30,40				
	1,4	30,72			31,54				
	1,5	30,27			30,86				
FeCrC+Ti with addition wire not energized FeCrC	2,1	25,40	25,37	3,25	23,95	26,97	1,78	26,17	1,92
	2,2	29,79			28,40				
	2,3	25,24			26,83				
	2,4	20,63			27,93				
	2,5	25,76			27,75				
FeCrC+Nb	4,1	22,45	24,44	2,30	24,80	23,85	1,15	24,15	1,54
	4,2	28,03			25,21				
	4,3	25,35			23,70				
	4,4	23,52			23,10				
	4,5	22,85			22,44				

Where: C.P: Specimen; Din: Dilution at the beginning of the weld; DP: standard deviation; Dfi: Dilution at the end of the weld; DM: dilution medium.

Figure 3 shows the mean values for each dilution of the hardfacing condition. For the conditions of consumable FeCrC+Ti and FeCrC+Nb there is a greater dilution for cored wire FeCrC+Ti (24.15% FeCrC + Nb wire to wire FeCrC 30.29% + Ti. The addition of not energized wire reduces the dilution of the weld. Dilution values were close to that found by Lima (2008), where the dilution of wire FeCrC+TI was also higher than the alloy with Nb. This is due to increased fluidity of the weld pool with the alloy Ti.

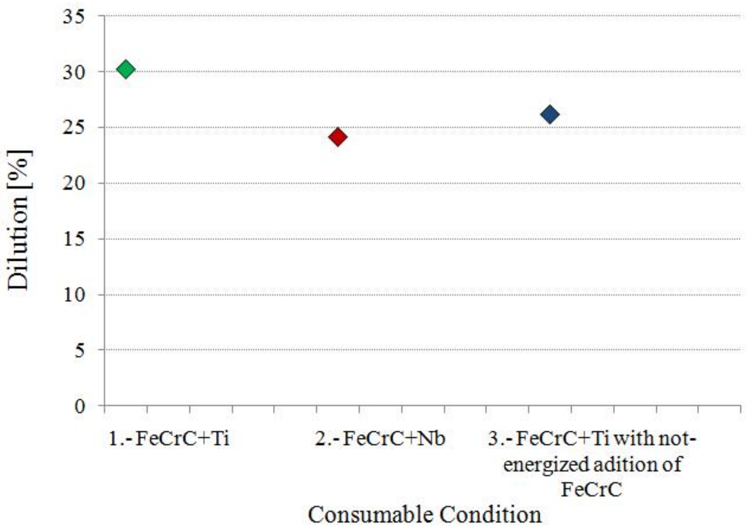

Figure 3. Mean values of dilution of the hardfacing condition.

3.2. Wear resistance

Table 3 and Fig. 4 shows the test results in terms of average wear resistance ($Rdesg_m$) for each consumable. Among the selfshielded flux cored wires, the best result was the FeCrC+Ti wire with addition wire not energized (FeCrC, followed by the FeCrC+Ti wire and FeCrC+Nb wire. Although were statistically equal (Hypothesis Test) and by superposition of standard deviation the results are similar.

Table 3. Wear data for each consumable.

Consumable	Desg [mg]	$Desg_m$ [mg]	DP desg	$Rdesg_m$ $[mg/m]^{-1}$	DP $Rdesg_m$
FeCrC+Nb	53.4	44.96	5.37	32.21	3.58
	41.1				
	40.5				
	47.1				
	42.7				
FeCrC+Ti	29.6	42.36	7.99	35.08	7.93
	43.3				
	49.4				
	48.7				
	40.8				
FeCrC+Ti com adição FeCrC	26.70	39.14	14.05	40.26	12.83
	43.30				
	27.50				
	61.00				
	37.20				

Note: Desg, wear per test piece (difference between the start and end weight of the test piece); $Desg_m$, average wear per consumable; $Rdesg_m$, average wear resistance per consumable; DP, standart deviation.

These survey results are similar to those obtained by Scandella and Scandella (2004) and Lima and Ferraresi (2009) for filler materials with similar composition to that used in this work. This comparison showed that in spite of different consumables and different welding parameters, proportionally the results presented in this study are in agreement with literature.

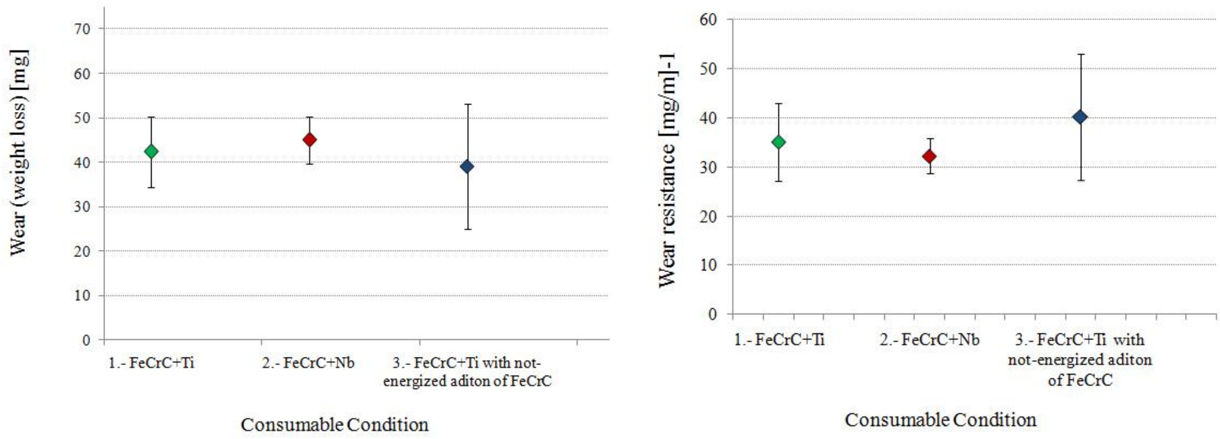

Figure 4. Analysis comparative of wear resistance**.**

Figure 5 illustrates the worn surfaces, at full size, of the test pieces, allowing the different behavior for each consumable. The arrow in the figure indicates the direction of entry of the abrasive particles during the test. Note that the FeCrC+Nb provide hardfacing with cracks perpendicular to the weld bead and that FeCrC+Ti hardfacing did not have visible cracks. All consumables showed dispersed porosities throughout the hardfacing, which may have contributed to the wear, mainly in the region of abrasion output. Visually, greater uniformity can be seen in the FeCrC+Nb hardfacing, which had a more finely scratched wear, while the test pieces clad with the FeCrC+Ti showed selective wear (marked regions with different resistance to wear).

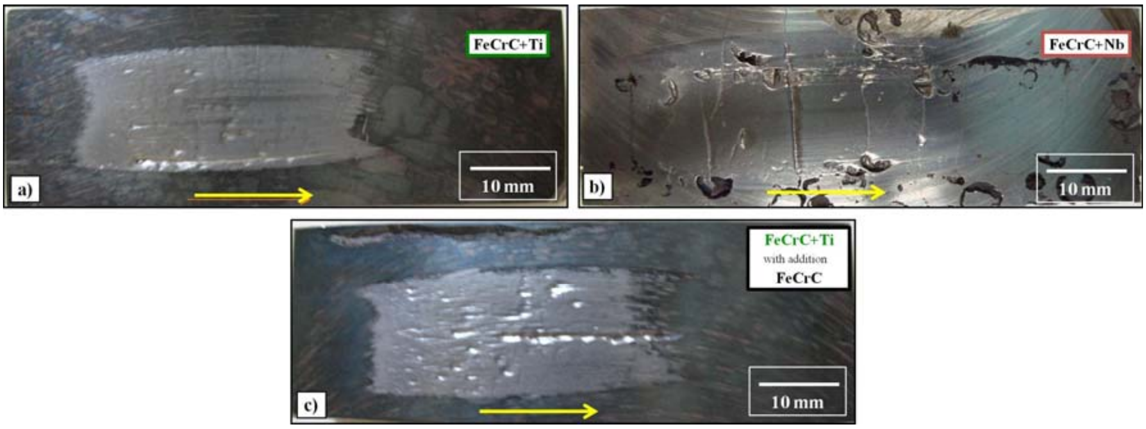

Figure 5. Test piece wear strips for each consumable: a) FeCrC+Nb, b) FeCrC+Ti and c) FeCrC+Ti with addition wire not energized of FeCrC.

The harfacing made with alloy FeCrC+Ti with addition of wire not energized FeCrC had the purpose to evaluate the wear resistance with mixtures of alloying elements, a fact that actually occurred, even with a quantity of metals (alloy FeCrC) added the weld pool of the alloy (FeCrC+Ti) be approximately 10%.

3.3. Microestructure of the Hardfacing

The microstructure of the FeCrC+Nb hardfacing in Figure 6 shows microstructure primary carbides (M_7C_3). The presence throughout the hardfacing (from interface to the outer surface) of small niobium carbides (5 to 10 µm) finely distributed in the eutectic matrix was observed. These carbides of various geometries are similar to that obtained in literature Buchely et al. (2005). Hernandez (1997) states that alloys of the FeCrC+Nb presents essentially the same type of microstructure as alloys with FeCrC, that is, austenite dendrites with massive M_7C_3 carbides, besides primary and secondary NbC carbides. The above results were also observed in this paper. This hardfacing provided a hardness of 64.10 HRc.

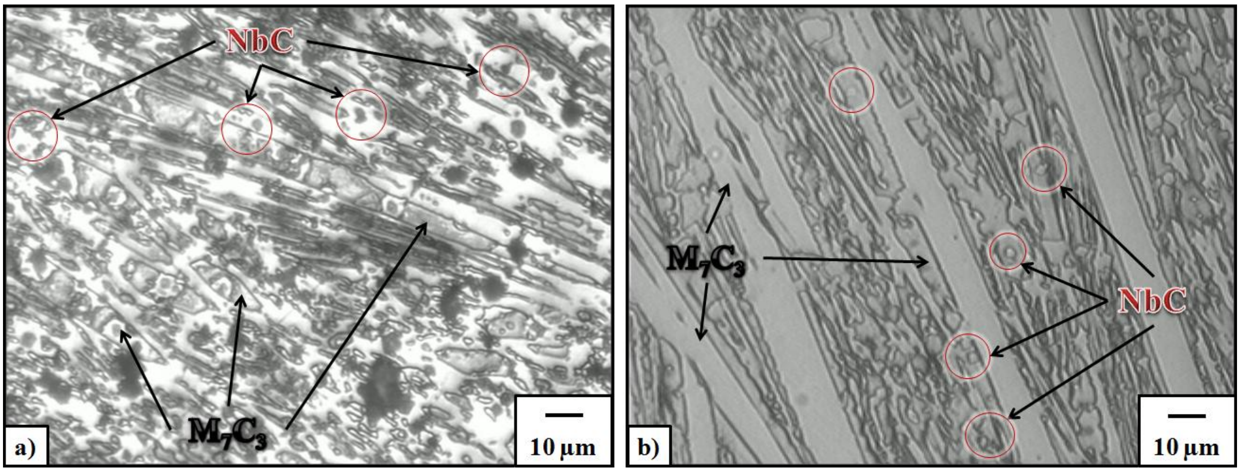

Figure 6. Microstructure of FeCrC+Nb alloy: a) etched with kalling for 10 seconds and b) etched wich Murakami at 60^0C for 10 seconds.

The microstructure of the FeCrC+Ti hardfacing in Figure 7 shows throughout the deposit a homogenous matrix (dart part) around large primary carbides (titanium carbides) varying from 1 at 8μm in an austenite-martensita matrix.. There is a lack of M_7C_3 type carbides due to the low content of chromium in the alloy (6.5% Cr by weight), because the formation of carbides of titanium and high temperature before the precipitation of primary carbides M7C3 type. This fact was also observed in the work of Zhi et al. (2007). This hardfacing provided a hardness of 64.69 HRc.

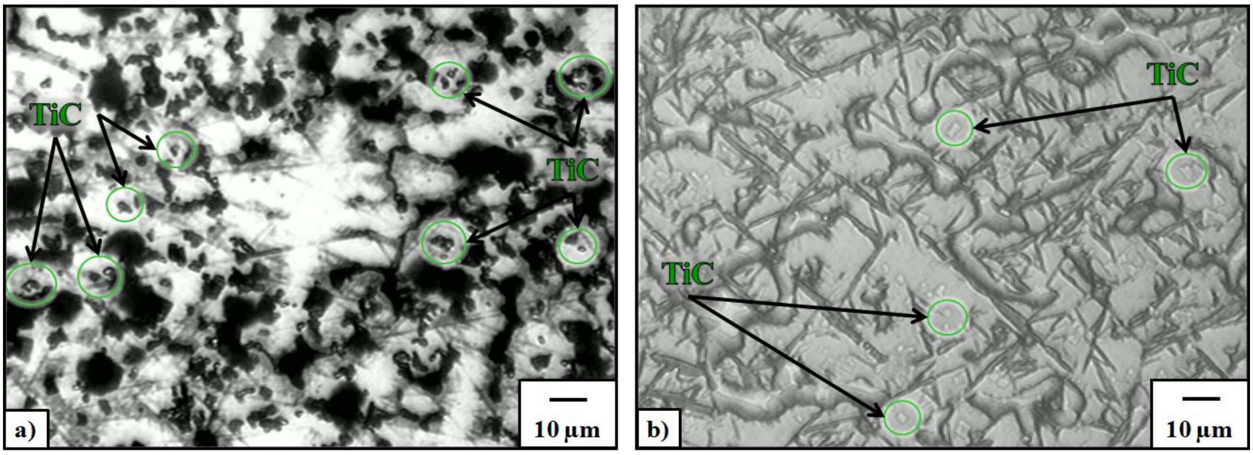

Figure **7.** Microstructure of FeCrC+Ti alloy. : a) etched with kalling for 10 seconds and b) etched wich Murakami at 60^0C for 10 seconds.

Figure 8 shows the microstructure obtained from the addition of wire not energized of FeCrC in alloy FeCrC+Ti where observes the presence of titanium carbides finely distributed in an austenite-martensita matrix. There exist no evidence clear (microscopic optical) of the presence of carbides M_7C_3 type. However, there were improvements (considering the average values) in wear resistance in the rubber wheel test. This hardfacing provided a hardness of 57.58 HRc.

4. CONCLUSIONS

An analys of the results allows the following conclusions to be drawn about the tubular consumable:

- The alloy containing FeCrC+Ti with addition of wire not energized of FeCrC showed greater abrasive wear resistence to low-tension in single layer deposits than the alloys of FeCrC+Ti and of FeCrC+Nb alloy.
- The harfacing of FeCrC+Nb alloy have cracks perpendicular to the weld bead, while the harfacing of FeCrC+Ti alloy did not have any visible cracks.
- All consumables showed dispersed porosities throughout the hardfacing.

- The hardfacing of FeCrC+Nb alloy provided a microstructure of primary chromium carbides (M_7C_3) and NbC in an eutectic matrix.
- The hardfacing FeCrC+Ti alloy provided a microstructure of TiC carbides in an austenite-martensita matrix. The same was observed in the hardfacing of FeCRC+Ti alloy with addition of wire not energized of FeCrC alloy.

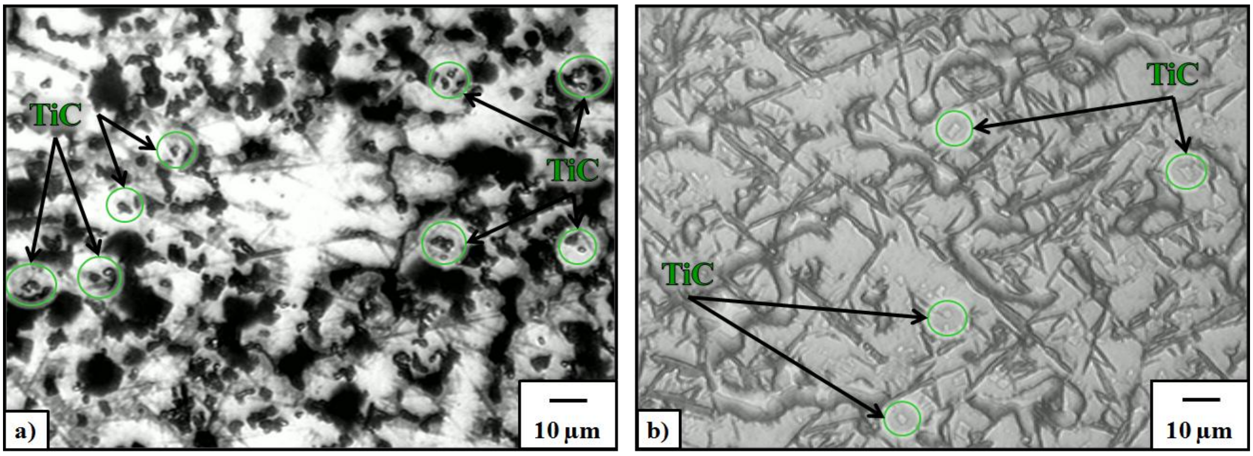

Figure **8.** Microstructure of FeCrC+Ti alloy with wire not energized FeCrC. : a) etched with kalling for 10 seconds and b) etched wich Murakami at 60^0C for 10 seconds.

5. ACKNOWLEDGEMENTS

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