COMPARISON OF ABRASIVE WEAR RESISTANCE OF AISI P20, NITRIDING AND COATED BY PLASMA TRANSFERRED ARC PROCESS

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Abstract*. Injection molding is the main process used for polymer processing. Within the items that add costs to this process, the manufacturing of molds has a significant contribution, reaching up to 30% of the final product cost. In order to prevent the premature discarding of the molds, their surface properties can be enhanced by thermochemical treatments or by hardfacing. This study compares abrasive wear resistance of AISI P20 in the as received tempered martensite condition, after nitriding treatment, and coated with cobalt based alloy (Stellite 6). Coatings were processed by plasma transferred arc (PTA) and a gaseous nitriding treatment was used to modify as received AISI P20surface. An experimental design was carried out to evaluate the influence of the different surfaces on abrasive wear resistance. Abrasive wear tests were performed according to the ASTM G65-91, and volume loss was measured. Materials microstructure was also evaluated. Results pointed out that the nitrited surface had the best performance, behavior associated with the microstructure of nitrides dispersed throughout the tempered martensite matrix.*

Keywords*: PTA, wear, mold, coating, injection, nitriding treatment.*

1. INTRODUCTION

In 2009 polymers industry accounted for around 5.19 million ton manufactured products, exhibiting a rising trend compared to 2005, when 4.2 thousand tons were produced. Polymers segment can be classified according manufacturing process in: injection (19%), extrusion (57 %) and blow moldings (16%) (Abiplast, 2009).

Thermoplastics injection molding consists basically in forcing the melted and homogenized polymer under high pressure into a mold cavity providing high accuracy and control of the shape of manufactured parts. It is a versatile process and high productivity rates, low labor cost, high automatization potential, and high quality features requiring little or none superficial finishing are among the main advantages of this manufacturing process. (Romanplast, 2010).

There is a wide range of polymeric composites available being fillers and reinforcements selected according to the application. The addition of different types of fillers in polymeric matrix make the composite more abrasive on the mold. Composite abrasive level is related to filler type, like polycarbonates reinforced by glass fiber, commercially known as LEXAN 341R-739. They exhibit high friction coefficient and are largely utilized injecting molds manufactured with AISI P20 steel, commercially known as P20 (Bergstrom et al, 2001; Mergler et al, 2005).

Wear may occur with material loss and surface damages causing. There are four wear mechanisms: adesion, fatigue, tribochemical and abrasion. Abrasive wear is material detachment caused by hard particles, free or attached to one or both surfaces in relative movement, or by the presence of hard protuberances at one or at both surfaces. Hard particles may be caused due processing or they may be inherent to material itself. On the contrary, protuberances like superficial roughness, usually derives for processing and they may act like hard particles if one of contact surface is softer than the other one during their relative movement (Gahr, Heinz 1987).

The high cost of molds manufacturing if of high importance in the production chain of injected parts and their premature disposal has to be avoided. Mold manufacture represents 30% of injection process cost and 5% of the final product is related to the steel that the mold is made of (Boujelbene et al., 2004). To extent mold service life, surface treatments such as Nitriding, chemical vapor deposition (CVD), physical vapor deposition (PVD), thermal aspersion and hardfacing can be applied. Mold areas in contact with the heated polymer are the most critical, guaranteeing final features of manufactured product. Nitriding refers to the diffusion of Nitrogen into mold surface at high temperature resulting on high superficial hardness and wear resistance. Pinedo (2004) refers that the nitriding processing parameters (temperature, time, and gaseous chemical composition), allow metallurgical surface control like the presence or not of a compound layer and hardness depth.

Repairing molds can be achieved by hardfacing techniques, like laser, that produces smaller heat affected zones (HAZ) and TIG (Tungsten Inert Gas). The welded layer produced during mold repair has to exhibit similar hardness to base material to guarantee that after polishing and texturizing there is no surface imperfection that may compromise product quality (Preciado e Bohorquez, 2006). Mold repair by Plasma Transferred Arc (PTA) can take advantage of the superior quality of coatings (Davis JR, 1993).

In this context, the aim of this work is to compare abrasive wear resistance of molds produced with as received AISI P20 steel, nitriding AISI P20 steel and AISI P20 steel PTA coated.

2. MATERIALS AND METHODS

2.1 Abrasive wear tests

Rubber Wheel abrasion tests, according ASTM G65-91 standards, were performed on 25 x 75 x 12,7mm AISI P20 steel, AISI P20 nitriding and PTA coated specimen. AISI P20 as received exhibited hardness of 34 HRC and tempered martensite microstructure. Chemical composition is showed on Table 1.

Table 1. Chemical composition of AISI P20 steel

Chemical element (%)	C	Si	Mn	P	S	Cr	Ni	Mo	Cu
AISI P20*	0,39	0,31	1,46	0,01	0,003	1,78	0,72	0,19	0,04

* Chemical composition provided by the fabricant.

Design of experiment 2^2, with 2 factors and 2 levels with posterior MINITAB software evaluation was performed, as described on Table 2. One replication was done and specimen volume wear loss was the studied response variable. Specimens were weight in a SHIMADZU – AY220 equipment before tests and after specimen ultrassom cleaning, conducted after wear tests. Volume loss was determined considering the density of the material: as received and nitriding AISI P20 ρ = 7,85 g/cm³ and AISI P20 PTA coated with Co ρ = 8,3 g/cm ³.

Table 2. Experimental factors and levels of experiment design performed for abrasive wear tests evaluation

Factor	Levels	
Abrasive flow rate (g/min)	30 (-)	323 (+)
Load (gf)	500 (-)	1000 (+)

2.2 Nitriding of AISI P20 steel

AISI P20 steel was submitted to gaseous nitriding process in Thermal Treatment furnace, installed at Sociesc, in a Nitrogen rich atmosphere, at 490°C, for 12 h, as suggested by Gilder (1964).

2.3 AISI P20 steel PTA coated

Coatings with two deposition currents (120 e 150A) with and without preheating were PTA processed for preliminary evaluation of PTA deposits on AISI P20 steel, Table 3. Welding AISI P20 steel is problematic due to equivalent carbon high level (1,11) that leads to HAZ hydrogen cracks. Base metals are easily welded when carbon equivalent levels are lower than 0,40. Above this level preheat is necessary to prevent cracks (Davis JR, 1993). Coatings were PTA processed at Surface Engineering laboratory of UFPR with an atomized Co-based alloy commercially known as Stellite 6, grain size in the range between 45 and 180µm and chemical composition shown on Table 4.

Table 3. PTA deposition parameters

Experiment	Electric Current (A)	Preheat (PH)	Layer Width (mm)
1	120	Without PH	10
2	150	Without PH	11
3	120	250 to 300°C	10
4	150	250 to 300°C	12

Table 4. Coating material chemical composition – Stellite 6

Chemical element (%)	C	Si	Mn	P	S	Cr	Ni	Mo	Cu
Stellite 6*	1,2	1,1	1,0	-	-	28,0	3,0	-	-

* * Chemical composition provided by the fabricant.

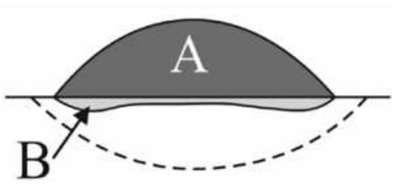
According to abrasive wear tests standards specimens with a minimum width (10mm) are required to guarantee specimen uniformly wear by the rubber steel apparatus. For this reason PTA coating were produced using a superposition of 30%, resulting on 10mm minimum width specimen, according to Table 3. For specimen produced without preheating, the second layer deposition was performed just after measured specimen temperature was bellow 100ºC. Preheated samples were soaked in induction furnace at temperature ranging from 250 to 270ºC.

2.4 Specimen characterization

Six hardness indentations were made with a Leitz Wetzlar Germany durometer on specimen surface obtained by PTA deposition. On nitriding specimen, six Vickers (HV0,2) indentations were made on surface with a Leitz Wetzlar durometer, due to the thinner layer obtained.

Specimen were ground and polished following standard metallographic procedures and microstructures were revealed with Nital 4% for nitriding samples and electrolytic attack with oxalic acid for PTA coated samples. Specimen cross section microstructures were analyzed by optical microscopy, Olympus BX51 microscope, and the ImageProplus software for image analysis. Interdendritic spacing was measured by the intersection method

Visual inspection for surface finishing, discontinuities, as well as the presence of melted particles around deposited layers was done. Dilution as the interaction between coating and metal base was measured by the areas ratio, Figure 1.



$$D = \frac{B}{A+B} \times 100$$

Figure 1. Dilution measurements

3. RESULTS AND DISCUSSION

3.1 Nitriding AISI P20 steel

As expected, Mehrkam et al (1991), nitriding AISI P20 specimen exhibited surface hardness of 800 HV (64HRC). Microstructure consists on dispersed nitrides into an annealed martensitic matrix. These nitrides may be Fe compounds or alloying elements with more affinity with nitrogen, like chromium (Davis JR, 1993), Figure 2.

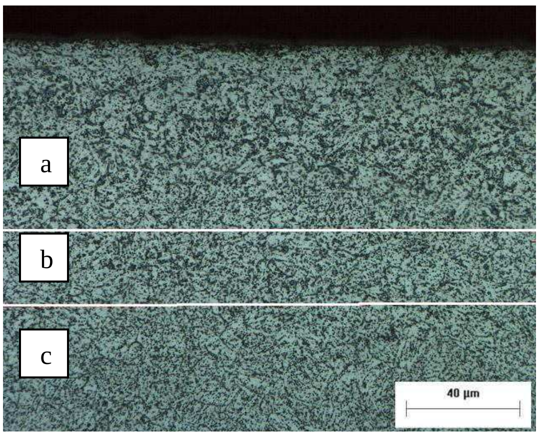


Figure 2. Nitriding AISI P20 steel microstructure
(a) diffusion layer – (b) transition layer – (c) base metal

3.2 PTA coated AISI P20 steel

Soundness and uniform coatings exhibiting good surface finishing were produced. Severe surface oxidation as well as porosities and cracks were not present.

The deposition current, hasa great influence on coatings features, and increasing current (welding energy) decreases the thermal gradient at the interface with the base material resulting on a lost of structure refinement and coating strength. Increasing the deposition current also produces coatings with higher dilution levels which also contribute to a strength reduction (Kou, 2002). Fe amounts diffusing from AISI P20 steel into the Cobalt based alloy coating compromiseits performance, as shown on Table 5. It is observed that lower dilution , coatings did not have better wear resistance in agreement with reported results of, D`Oliveira, Tigrinho and Takeyama (2008), that distinct contact areas between specimen and disc, due to alignment deviations between rubber wheel and the coatings, may explain this behavior. Smaller contact areas result on higher specific loads that lead to higher wear rates. Ribeiro (2004) concludes that dilution has a detrimental effect on abrasive wear resistance.

Table 5. Dilution, Hardness, Interdendritic spacing and specimen PTA coatings volume loss

Experiment	Electric Current (A)	Preheat (PH)	Dilution (%)	Hardness (HRC)	Interdendritic Spacing λ (μm)	Volume loss* (mm^3)
1	120	Without PH	7,4	43	5,7	3,7590
2	150	Without PH	29,8	42	6,2	3,6265
3	120	250 a 300°C	15,9	42	8,9	3,5663
4	150	250 a 300°C	38,5	41	9,4	4,0422

*Tested condition (2) – Abrasive flow 30 g/min and load 1000 gf.

Increasing the deposition current and preheating the substrate results on higher dilution levels , Figure 3. However, coatings processed with the higher deposition current (150A) exibited dilution levels much higher than those expected for PTA process (20%), 29,8% for coating obtained without preheat and 38,5 %for the preheated coating. As a high level of elements difused from substrate , coatings may have their performance compromisede. However, for the higher deposition currenty tested (150A), dilution level was much higher, 29,8% without preheat and 38,5 % preheat substrate, than those expected for PTA process (20%). This high dilution levels will certainly compromise coatings performance.

Substrate Preheating is carried out in high equivalent carbon materials to prevent hydrogen cracking. Preheating the base material decreases cooling rate preventing martensite transformation enabling hydrogen to diffuse to the atmosphere and therefore diminishing cold cracking (Davis JR, 1993). Lant et al (2001) studied tool steels noticed that preheating base material at temperatures in the range of 200°C a 250°C assures slow cooling of the welded region, preventing hydrogen cracks. These range of preheating temperatures was also adopted by Preciado e Bohorquez (2006) welding AISI P20steel by TIG (Tungsten Inert Gas) to prevent hydrogen cracks.

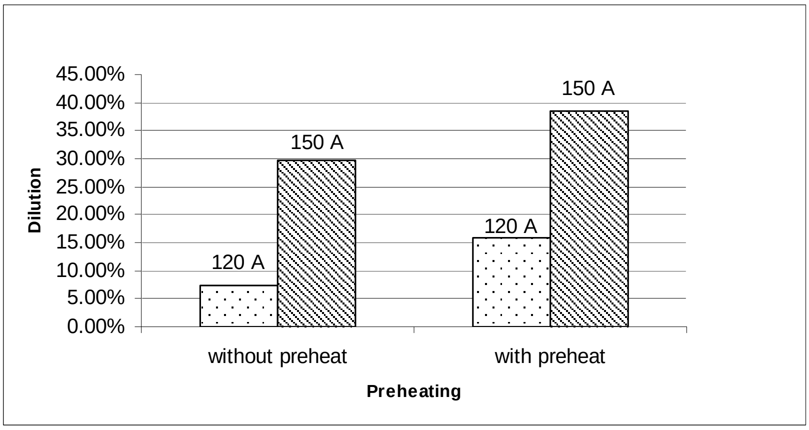


Figure 3. Dilution and pre heating

Microstructure of coatings consists on a rich Co solid solution dendritic region (α), and an interdendritic eutectic (α and carbides), Figure 4. Refinement lost is confirmed by the larger interdendritic spacing, Table 5.

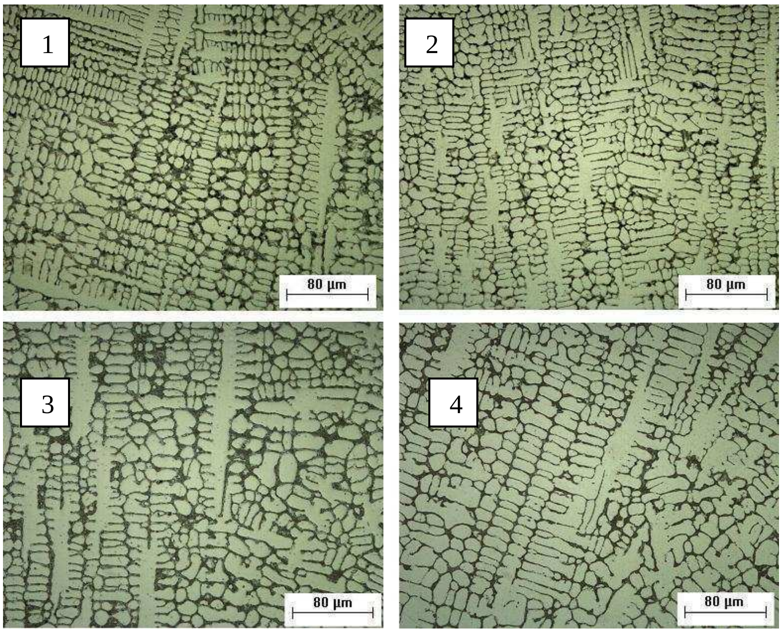


Figure 4. Stellite 6 microstructure
(1) 120A without PH – (2) 150A without PH – (3) 120A with PH – (4) 150A with PH

Abrasive wear test results with samples produced on experiment 3 and 4 (Table 5) were not utilized because they overcame nitriding layer thickness. Besides, as coating processed without pre heating did not showed cracks, pre heating was eliminated. Analyzing experiment 1 and 2 results (Table 5), both without pre heating, experiment 1 (120A) sample was chosen as it presented lower dilution and perfect metallurgical bonding between coating and base material.

3.3. Abrasive Wear Test

Results of AISI P20 as recived, nitriding and PTA coated specimen abrasive wear tests are shown on Table 6. It can be noticed that rising abrasive flow from 30 to 323g/min increase samples volume loss. This same trend is observed rising load, from 500 to 1000gf. Results are according to the observed by Ribeiro (2004), who tested Fe-Cr-C coatings deposited on ASTM A-36.

Table 6. Abrasive wear test results of AISI P20

Experiment	Abrasive flow (g/min)	Load (g)	AISI P20 volume loss (mm³)		
			As recieved	Nitriding	PTA coated**
1	30 (-)	500 (-)	5,5032	2,0573	3,2952
2	30 (-)	1000 (+)	5,5987	2,7452	3,7590
3	323 (+)	1000 (+)	16,5605	(10,7006)*	9,7590
4	323 (+)	500 (-)	14,3631	(8,8599)*	8,1928

* Wear test overcame nitriding layer.
**PTA deposition parameters: 120A without PH

Factorial experiment procedures have to be utilized when more than one factor influence results, as occurs with abrasive wear tests. Therefore, for each complete attempt with experiment replications, all possible factors levels combinations are investigated. The influence of abrasive flow (A) and load (B) factors, chosen from abrasive tests, are shown on Pareto's graphic, Figure 5. Vertical line , 2,78 de Standardized Effect, outpoints, for 95% confidence level, the limit in which analyzed parameter will be significant for testing. In this case it will influence material volume loss (Montgomery and Runger, 2003).

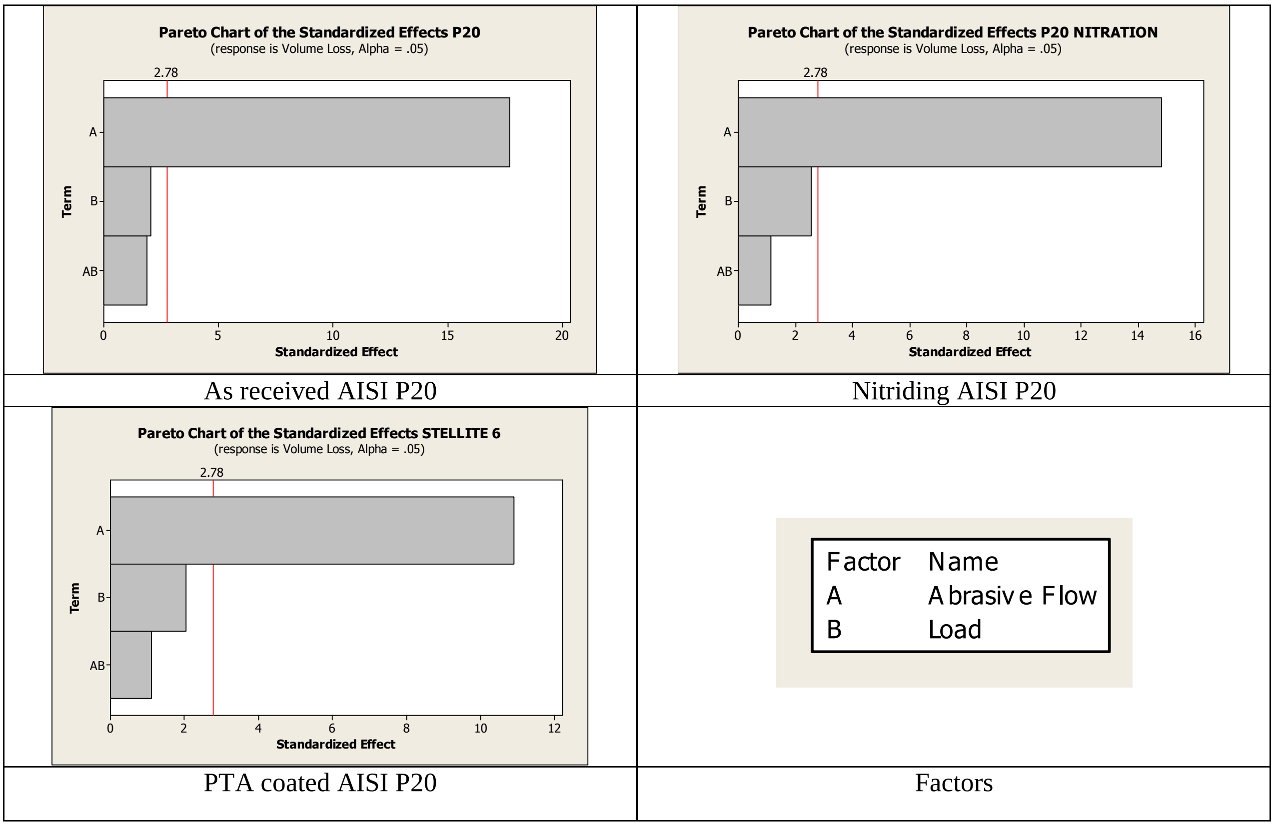


Figure 5. Abrasive flow and load influence on as received AISI P20 steel

Within the two analyzed parameters, abrasive flow and applied load, the former showed a more significant volume loss. This is in accordance with tool steel wear tests results obtained by Silva and Mello (2005), which points out the abrasive flow as the major influence of samples volume loss compared to applied load. This behavior is explained by sequential indentations (scratches) caused by abrasive particles, facilitating mass loss.

3.4 Materials abrasive wear tests comparison

The aim of this work is comparing as received, nitriding and PTA coated abrasive wear resistance, Figure 6. For all tested conditions, nitriding exhibited the lower material volume loss and therefore, better abrasive wear resistance. In his studies, Suzuki (2007) also observed the superior wears resistance of AISI H13 nitriding steel compared to the same material in the as received condition.

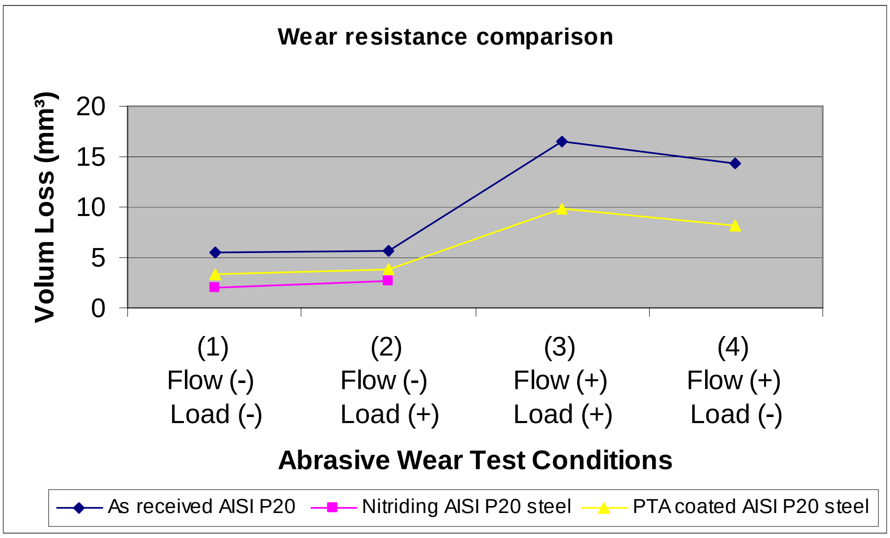


Figure 6. Wear resistance comparison (materials)

As the more critical condition, that is, exhibiting the higher volume loss, could not be used because specimen was worn beyond nitriding layer, the chosen condition was the one presenting the higher volume loss for nitriding layer (condition 2 – Abrasive flow 30 g/min and 1000gf load), Figure 7.

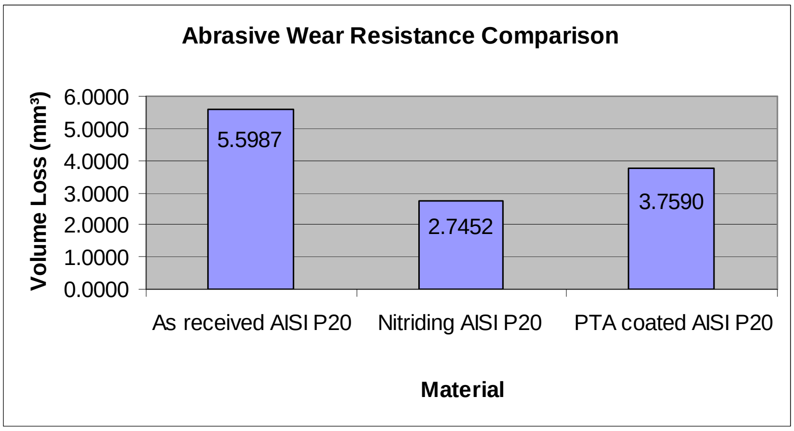


Figure 7. Abrasive wear resistance for materials in critical condition (30g/min abrasive flow and 1000gf load)

PTA coated specimen showed an abrasive wear performance 33% superior than AISI P20 steel in as received condition being nitriding sample performance even superior, 51%. This behavior can be associated to the higher hardness of nitriding surface, about 64HRC, compared to Stellite6 (120A without PH condition), 43HRC, that impacts directly on specimens volume loss. Ribeiro (2004) e Milani et al (2010) also observed the same correlation between hardness and wear resistance. Welded specimen exhibiting lower hardness due to higher dilution levels showed higher material volume loss during abrasive wear tests.

Altough nitriding samples exhibited the best abrasive wear resistance results, PTA coatings showed to be an alternative to improve abrasive wear resistance of AISI P20 injection molds life.

4. CONCLUSION

For tested conditions, it can be concluded that:

- Hardfacing of a cobalt based superalloy on the AISI P20 steel improved abrasive wear resistance of substrate, even without pre heating procedures (no cracks on welded coating);
- Pre heating procedures and rising electric current during PTA deposition leads to increasing dilution levels and less refined microstructure, having a hardness loss as a consequence;
- For as received, nitriding and PTA coated AISI P20 steel, abrasive flow has a major influence on abrasive wear tests compared to applied load;
- Abrasive wear resistance was improved in about 51% for nitriding AISI P20 steel and 33% for AISI P20 PTA cobalt superalloy (Stellite 6) coated.

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