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### MICROSTRUCTURAL ANALYSIS AND HARDNESS OF WELDS OVERLAY OF FECRMO ALLOYS

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**Abstract.** *This paper aims to analyze a weld overlay of FeCrMo alloys welded by the processes of GAS METAL ARC WELDING (GMAW) and GAS METAL ARC WELDING-COLD WIRE (GMAW-CW) with different percentages of cold wire (CW), with 0, 10, 20, 30, 40 e 50% of CW. Aiming to verify the microstructure formed, its respective hardness and the behavior in wear condition when submitted to ITAC (Impact test and abrasion combined) which is a test that simulates the impact and abrasion combined (similar to conditions of wear suffered by coating the SAG mills). To evaluate the weight loss suffered by each type of coating under the same conditions, each CP was weighed on a precision scale before and after the test. The result showed that the microstructure formed in this situation was perlitic, having hardness directly proportional to the amount of CW introduced, these results occurred because the CW contained 6.5% in mass of Chromo, what favored the increase of the strength of this coating. However, the weight loss was not linear, and the best sample was the CP with 0% of CW.*

**Keywords:** GMAW, GMAW-CW, Hardness, microstructure, ITAC.

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#### 1. INTRODUCTION

The semi-autogenous grinding (SAG) is the step where material suffers comminution in a rotary mill with feed material, plus an additional means of grinding. In this type of grinding is used a small amount of steel balls, 3 - 20% of the mill volume is added to the mill to facilitate fragmentation of a tougher grinding fraction which tends to remain a long time in the mill or return sorter as current load.

The ore movement and the grinding media together during the milling process submit the coating mills to impact and abrasion conditions, which reduces the coating life and increase the need for maintenance. Thus, we developed different types of coating welds by GMAW and GMAW -CW processes that were submitted to the Impact Test and Abrasion Combined in specific equipment for this type test called ITAC.

Analyses were made comparing the microstructure, microhardness and wear to develop improved coatings for SAG.

#### 2. BACKGROUND AND THEORETICAL CONCEPTS

At first, the coating of a mill was meant only to serve as a protection against wear, but over the years different coating systems mill passed through many stages of development.

A few decades ago, the concept of using the coating is intended to not only protect the cylinder against wear, but also reduce the slip Grinder load inside the housing and to provide appropriate paths, according to Valadão and Araujo, 2007.

According to Luz et al, 2010, the coatings are made of different metal alloys, rubber and rarely ceramic or quartzite for very special uses. Various forms of coatings are produced, in the type of mill (balls or bars) including size, material processing, operating speed, etc.

Steel coatings represent the majority of coating materials used in the world, taking into account the current consumption. It appears that the steel is successfully used either in dry applications, or wet to be a very versatile material.

Oliveira apud Bergeman, 2009, reports that usually the metal- semi- autogenous mills is produced with low alloy steels containing chromium (Cr) and molybdenum (Mo) (chrome moly steels). He also reports that the Cr -Mo type steels have good resistance to impact and abrasion.

The information about coating cited by Bergeman served as the basis for the development of this research as regards the pursuit of new alloys for applications in semi- autogenous mill liners.

## 2.1 Hard Coatings Resistant Wear

The main characteristic of this type of coating is its high hardness produced by welding application of a hard and wear-resistant layer on the workpiece surface subjected to this phenomenon and can be applied to new parts, and recovery by use of worn parts.

According to the Metals Handbook, the hard coating materials are classified into five major groups as can be seen in the Tab.1, considering the alloying elements content (other than iron). In general, the wear resistance and the cost increase with the group number. The choice of a particular alloy depends on the application and the type of welding used.

Table 1: Classification of materials for hard coating.

The total content of alloying elements %	Major alloying elements
Ferrous materials low-alloy 1A 2 a 6 1B 6 a 12	Cr, Mo, Mn Cr, Mo, Mn
Ferrous materials high alloyed 2A 12 a 15 2B 12 a 25 2C 12 a 25 2D 30 a 37 3A 25 a 50 3B 25 a 50 3C 25 a 50	Cr, Mo Mo, Cr Mn, Ni Mn, Cr, Ni Cr, Ni, Mo Cr, Mo Co, Cr
Nickel based alloys and cobalt based 4A 50 a 100 4B 50 a 100 4C 50 a 100	Co, Cr, W Ni, Cr, Mo Cr, Ni, Mo
carbides 5 75 a 96	WC WC or in combination with other carbides such as TiC and TaC , always in a metal matrix

## 2.2 Coating Welding

The welding coating consists of depositing a welding consumable more noble than metal base, aimed at specific applications such as higher hardness, wear resistance or corrosion protection of the base metal which is not resistant as the material of the coating.

Direct deposition of metal coating weld on the base metal is only possible when the two metals are diluted other. This is the case, for example, the deposition of any carbon steel on stainless steel or alloy steels. When the two metals are not diluted, the problem can be solved by deposition of an intermediate layer of a third metal which is compatible with both.

The weld deposition may be done by submerged arc welding (with wire or tape electrode) or by welding with protective inert gas (MIG, for example) or by projection with plasma.

Depending on the process, the coating thickness can range from 4 to 7 mm, the penetration in the base metal 1 to 1.5 mm and dilution from 10 to 20%.

### 2.3 Welding Processes

The MIG / MAG or GMAW (Gas Metal Arc Welding ) welding process arc is based on the formation of an electric arc between the workpiece and a massive naked electrode consumable with continuous feed. The protection of the arc and the weld region from contamination by the atmosphere is made by a gas or gas mixture supplied with adequate pressure and flow rate, Fig. 1a.

Studies of GMAW welding with additional cold wire (not energized), called GMAW -CW (Gas Metal Arc Welding- Cold Wire), has emerged as a variant of the GMAW welding process double wire. Since the beginning of its development (2005), the Welding Laboratory of UFPA, has been studying the operational feasibility, economic and metallurgical welding with addition of cold wire for welding coating and filling bevels.

The proposal of GMAW-CW welding is to be a technical and economic alternative to conventional GMAW welding. This new version uses only a conventional (constant voltage source) with an extra head for feeding cold wire connected to welding torch (SÁBIO, 2007) as can be seen in Fig. 1b compared with GMAW in Fig. 1a .

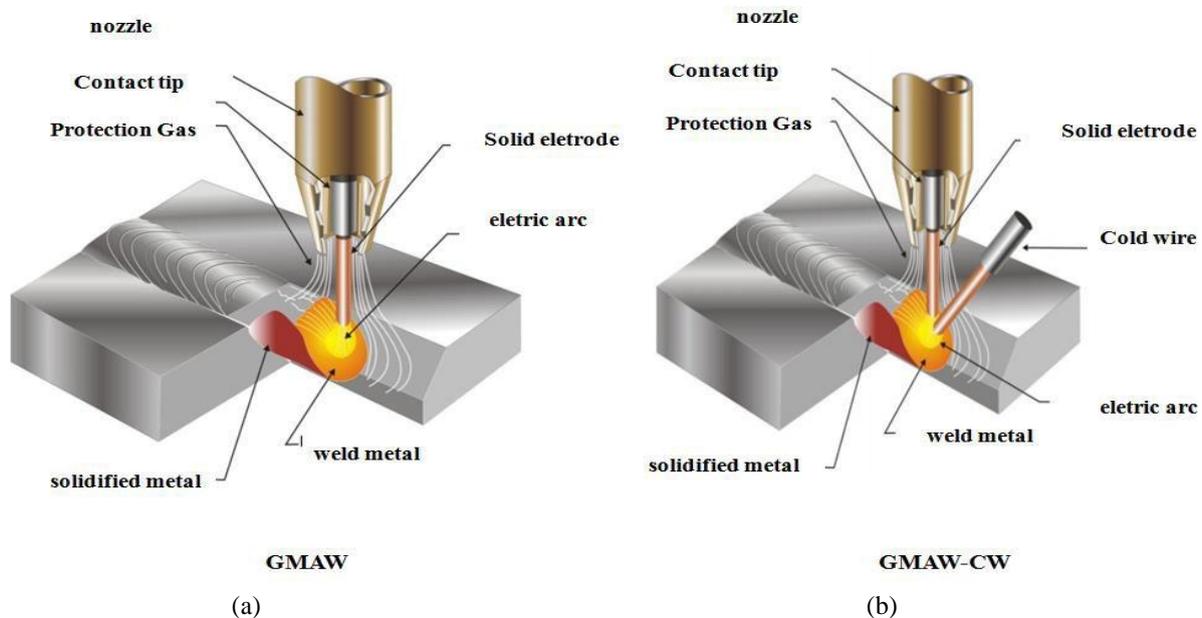


Figure 1. Schematic drawing of GMAW processes (a) and GMAW -CW (b).

### 2.4 Impact Test and Abrasion Combined (TIAC)

In many fields of industry, the abrasion and erosion processes are dominant in equipment and these mechanisms reduce the service life of expensive machines. Resistance to abrasion and / or impact, and the ability to withstand other complex mechanical actions are often necessary.

In order to quantify specific material properties such as resistance mechanisms, various test methods are in use. Wilson and Hawk (1999), reported an abrasion test that was developed in the Albany Research Center (ARC). This test is a modification of the initial design bond, the bond test uses just one test sample and ARC uses three, allowing more possibilities for analysis.

As the name implies, the purpose of this machine is to simulate the wear that occurs by two mechanisms, impact and abrasion which occur in the samples used in the assay. Both the ASTM G65 and ASTM B611 has the disadvantage that they do not simulate impact tool wear.

The test, Fig. 2, consists of a rotating wheel with three blades that sample are located on a rotating drum. The drum and the wheel turn in the counterclockwise direction during the tests at approximately 45 and 620 rpm respectively. Before you start, the cylinder is filled with 0.6 kg of abrasive material that interacts with the samples during testing. The drum is coated with rubber to allow elevation of the abrasive material until gravity overcomes the friction forces to occur and the coating material drops on the blades. Another advantage with the rubber lining is the reduction of noise during rehearsals.

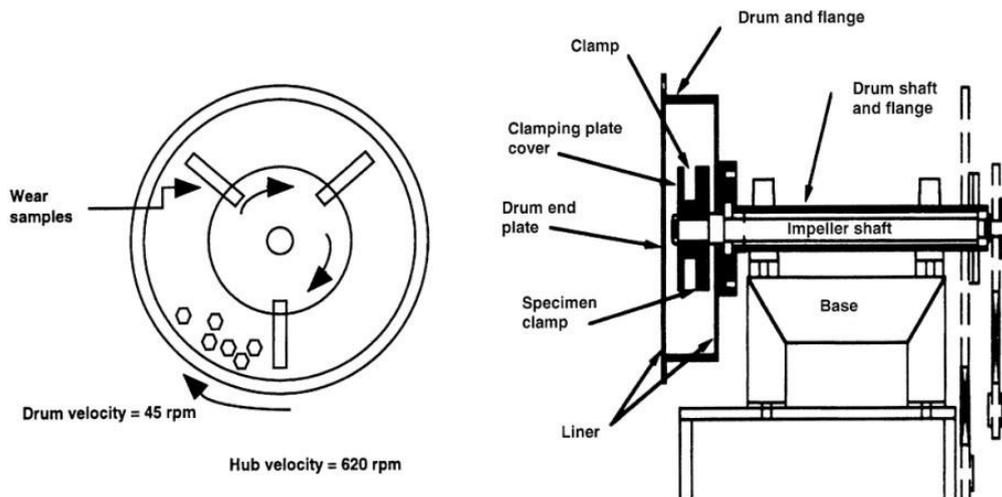


Figure 1. Schematic drawing of an impact test developed by abrasion ARC

The Metallic Materials Characterization Laboratory (LCAM) used a device that uses the same operating principles of the equipment developed by ARC, aiming to simulate in the laboratory the conditions of impact and abrasion that the SAG mill liners are subjected when in service.

### 3. EXPERIMENTALPROCEDURE

The type of the hard coating used was 1A (FeCrMoMn alloys). Four specimens were made in the 80x30mm dimensions, in which coating welds were performed using the GMAW -CW process in five passes. For Fig. 3, the regions 1, 2, 3, 4 and 7 were discarded; the region 5 was used for the realization of the chemical analyze and as a sample for TIAC; the 6 was for the metallographic and micro hardness analysis.

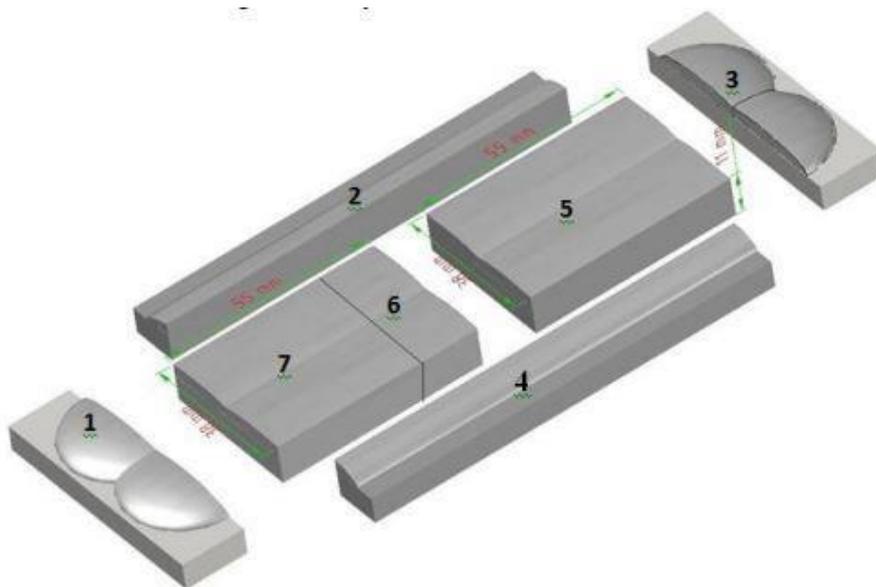


Figure 3. Illustration of the samples welded.

In one of the specimens, the cold wire was not added during welding, while the other specimens were added with 10, 20, 30, 40 and 50% of cold wire, as shown in the flowchart below Fig. 4.

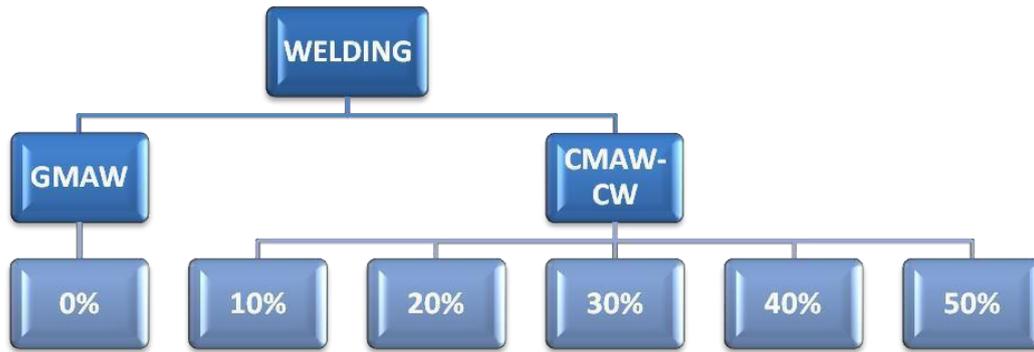


Figure 4. Flowchart diagram of the samples.

### 3.1 Microstructural and Hardness Analysis

To reveal the microstructure resulting from the welding process was used Nital's 2% attack by immersion 3s ( $\pm 2s$ ) depending on the cold-wire ratio. The disclosed microstructures were visualized by light microscopy in increments of 50, 100, 200, 500 and 1000 times. The indentations were performed on three lines with a distance of 0.5 mm between each point, totaling 30 indentations per sample.

### 3.2 Impact Test and Abrasion Combined (ITAC)

To carry out the wear test were used 2.4 kg of bauxite dry crushed and sieved, bystanders in 12.4 mm sieve and retained on the 9.4 mm. This amount was divided into four parts each 600g.

The choice of abrasive was due its natural features, it has an irregular geometric shape, with many sharp edges in their units.

The test was conducted in 1 hour, which is divided into four times of 15min. To each test of 15min were used 600g of bauxite at the end of each quarter hour of the equipment stopped running, the gravel was removed completely, the pieces were washed, weighed in the balance and subsequently placed back into the machine for performing a new test cycle with other 600g of bauxite. This cycle was repeated until the end of the one hour test. The ITAC is observed in Figure 5.



Figure 5. Provision of equipment used for testing. ITAC and the control panel (a).

## 4. RESULTS AND DISCUSSION

#### 4.1 Microstructure result

The microstructures are shown in Fig 6, showing equiaxed ferrite, acicular ferrite, Bainite, and chrome inclusions.

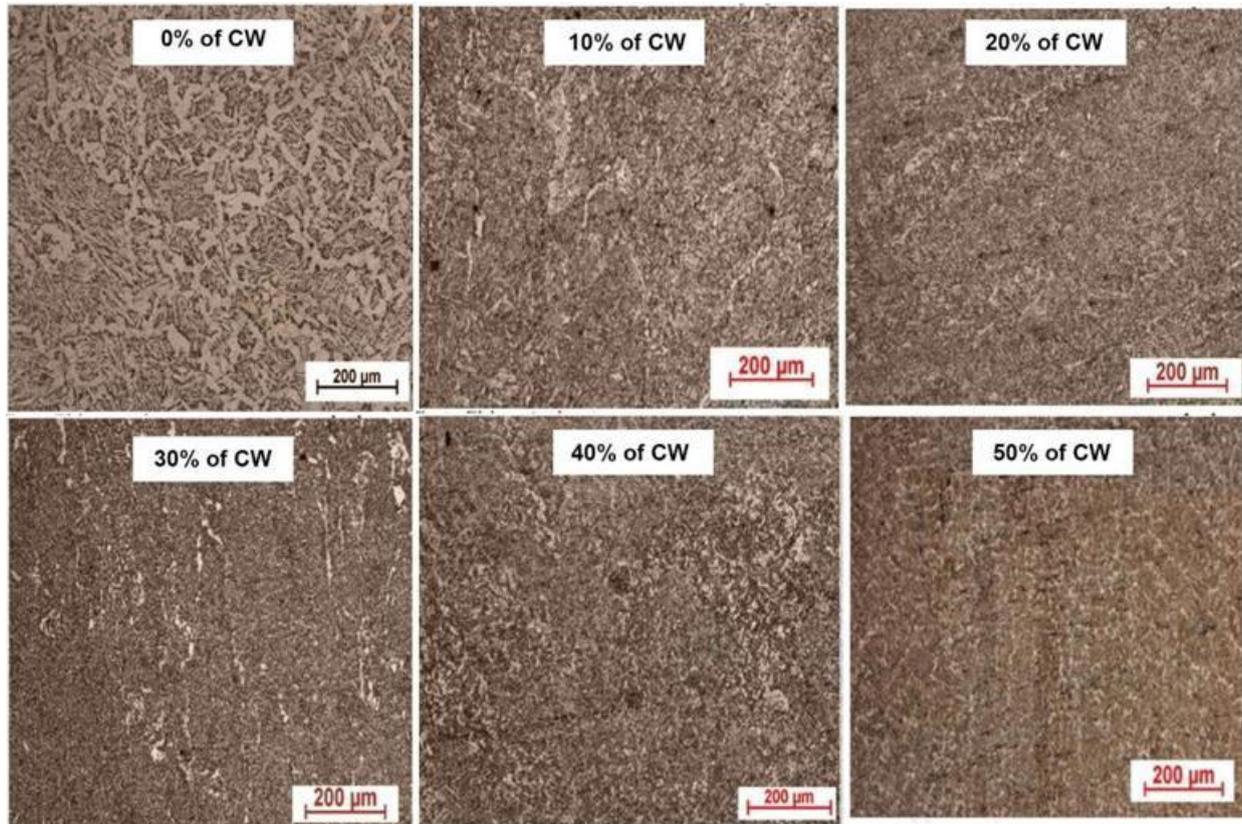


Figure 6. Microstructure of the samples (surface). Magnification 100x and attack by immersion in Nital 3s.

#### 4.2 Hardness result

The hardness results obtained for each sample are consistent with the expected, since the hardness gradually increased with increasing cold wire content, starting with 200 HV on average for welding condition without CW until 355HV for the sample with 50% of CW. The increase in hardness may be associated with the cold wire percentage that gave the refinement of acicular ferrite and the increasing of the bainitic matrix. This behavior is shown in Fig 7.

#### 4.3 ITAC test results

The specimen tested under the same conditions of impact and abrasion in ITAC presented different results in relation to wear. As it shown in Fig 7 is possible to observe that the samples tested presented a non-linear behavior, because the variation of weight among the different types of coatings do not reduces with the test time on ITAC. This behavior supports the idea held by Kirchgaßner (2008), confirmed by Neto (2015) that during ITAC there increase of the weight loss with the increasing hardness of the test surface.

## weight loss x % of CW x Microhardness

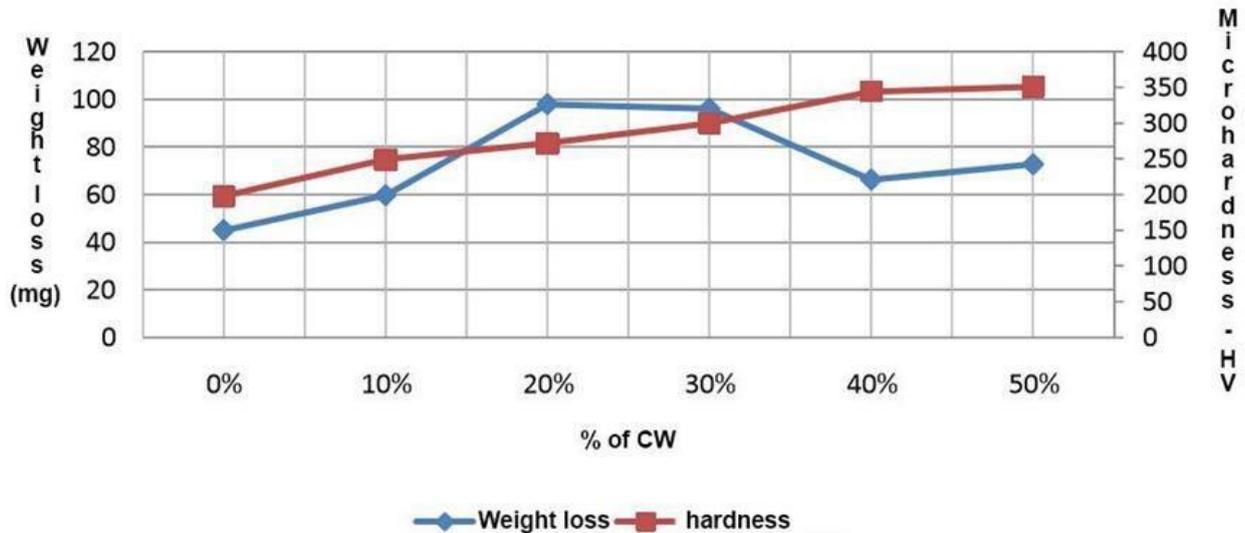


Figure 7. Behavior of the weight loss in relation with the hardness.

### 5. CONCLUSIONS

The gradual increase of cold wire made the equiaxed ferrite and the acicular ferrite disappear. Moreover, it was formed light regions that may be accumulation of Cr inclusions, it is happened because de cold wire has more Cr than the energized wire.

The microhardness increased with cold wire percentage increase, so it can be conclude that for the analyzed situation the addition of a cold-wire with a higher content of alloying elements, especially Cr, pushed up the hardness of the coatings.

The coatings mass loss observed during tests in ITAC implies that the cold wire percentage addition in GMAW-CW does not offered improved wear resistance compared with the GMAW under the same test conditions. As we can see in the Fig 7 the behavior was not linear.

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### 7. RESPONSIBILITY NOTICE

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