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Mechanical and Microstructural Characterization of a Hadfield Cast Iron Subjected to Wear Regimes

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Research Article

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ABSTRACT

In this paper a manganese steel alloy, Hadfield type, manufactured at the Empresa Mecánica del Níquel, was analyzed due to the frequency of breakage, which occurs when placed under erosive media, in an aqueous environment. Three cast samples (one without having worked, in any process, and two that had given up their useful life), of which 3 each were replicated, hardness and optical microscopy tests were carried out, in order to know their microstructural behavior and the presence of hard structures that evidenced the performance of some hardening treatment. The results show that there is no coincidence, in some elements, with the norms established for the alloy, the presence of a matrix with an austenitic-ferritic structure, very soft, with an average hardness that did not exceed HRC 20, was confirmed, elements that constitute the cause of the aforementioned premature breakage of parts made of this material.

Keywords: Breakdowns; Wear; Microstructural behaviour; Hardening treatment; Matrix

INTRODUCTION

The quality of products made of metal depends on the surface condition and deterioration due to continuous use. Taking into account such deterioration in engineering practice is of relevant importance, as it is often the main factor limiting the life and performance of machine components. Wear, as a process, leads to the loss of capacity, unintentional, resulting from the use or the environment where the part is being exploited; it can be considered, essentially, as a phenomenon that affects the surface and is one of the most destructive conditions to which the materials are exposed, so it requires studies related to the resistance to this phenomenon and, especially the interaction between the bodies and their gradual loss of mass [1].

There is no general rule that is valid for the behavior of all manifestations of wear [2], it affects the parts with a variety of conditions, such as type and mode of load, speed, quantity and type of lubricant, temperature, hardness, surface finish, relative speeds of the mating elements, presence of foreign materials and chemical nature of the medium.

Just as the characteristics vary in each application, so do the corresponding manifestations of this phenomenon, generally due to the combination of one or more elemental forms. The small particles resulting from the scraping, caused by the friction at the same time favor the consequences of the phenomenon. It is not always easy to deduce the type of deterioration that has occurred [3].

That in most applications, wear can rarely be completely avoided even with the best lubrication. It is common practice to use, jointly, a hard and a relatively soft material, where the latter is used for the purpose of replacement, more frequently, and this being an economical variant. Breakage due to wear of parts generates considerable losses of materials, resources, time and requires a large amount of resources for their repair, with the consequent effect on production, as well as on the manufacture or acquisition of new parts. If we add to these factors the tendency to increase the working speeds, we have enough elements to understand why the increase of the useful life of the working parts of the machine elements has become a basic problem in the engineering practice in the last years [4].

The working parts of machinery have particularities in terms of their use, such as relatively short working periods and long storage time. The dimensions and properties of the materials vary in these parts, due to oxidation processes, corrosion and possibilities of permanent deformations, sometimes as a result of the action of the weight of the elements themselves, especially when they have considerable dimensions [5].

The objective of this work is to mechanically and microstructurally characterize a Hadfield cast iron of national production subjected to wear regimes in the mining industry.

MATERIALS AND METHODS

Manufactured parts material

The alloys of the material studied are used in the laterite ore processing industries. The chemical composition of the samples was determined as shown in Table 1, in order to rule out possible variations, so that this is not the element that influences the premature wear experienced by the parts. Hadfield steel, according to Standard A 128, combines high strength and ductility with high work hardening capacity and, usually, good wear resistance for the manufacture of parts subjected to high working conditions [6].

Table 1. Standard chemical composition of ASTM A 128: SISA steels.

Material	% C	% Mn	% Cr	% Fe
Gx 120 MnCr 12.2	1.00–1.40	10.00–14.00	2.00	Rest

Mechanical preparation of specimens: The preparation and cleaning operations were carried out in a specific sequence. In order to obtain flat surfaces with the least possible deformation, the specimens were cleaned over the entire surface and sectioned on a CM 260 type cutting machine (Echo RD brand). Three samples were taken, two from damaged parts and one from unplaced parts in operation (Figure 1), including those with the highest durability, which made it possible to compare the behavior of the material in both cases.

Figure 1. Samples of the alloys virgin alloy and worked alloys.

The specimens were cut (Figures 2a and 2b), with the use of a cutting disc, with abundant cooling to avoid heating due to friction effect, because the temperature produced can alter the structure, at least on the surface obtained [7] .

Figure 2. a) Virgin alloy; b) Samples of the alloys removed from service.

Preparation of samples for microstructural observation: Prior to the roughing and polishing operations, it was necessary to encapsulate the samples (Figures 3 and 4), for better handling of the samples and then its were marked for their subsequent identification, so as to allow working with them without the appearance of unwanted surfaces that distort the image under the microscope. This procedure was carried out by means of a machine designed for this purpose (Echo RD, type MP 350 A). Black phenolic resin was used, with a melting temperature of 150ºC-170ºC, with a permanence of 6 min-8 min, then they were cooled in the mold.

Figure 3. Encapsulated samples of the virgin alloy.

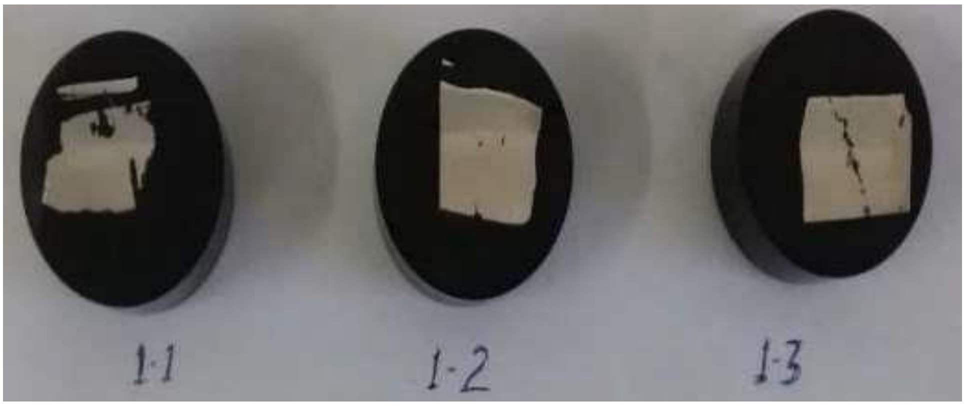


Figure 4. Encapsulated samples of the alloys out of service.

Roughing and polishing: Once the samples were placed in the phenolic container, they were roughed, which, roughly speaking, consisted of first obtaining a flat and semi-polished surface, using machine tools and abrasive papers. Polishing was carried out, guaranteeing a variation of the grain size from the coarsest to the finest.

Coarse and fine sanding: Sanding was carried out with abrasive papers, from 120 to 1200 grit. In the coarse, the angles that could cause the breakage of the emery paper or cloth during polishing were rounded. The first stages were carried out with 120 and 240 grit, respectively, to obtain a flat surface, free of distortion or traces produced by the cut and also to ensure that all the sanding marks follow the same direction, guaranteeing 900 from each other. In the fine sanding, the process began with 320 grit sandpaper, passing through 600, 800 and finally 1200. Each time the sandpaper was changed, it was rotated 90º, in order to erase the traces of the previous ones. They were polished, using felt discs and an alumina solution. Finally, they were washed with distilled water and dried with filter paper.

Attack of the samples for microscopic examination

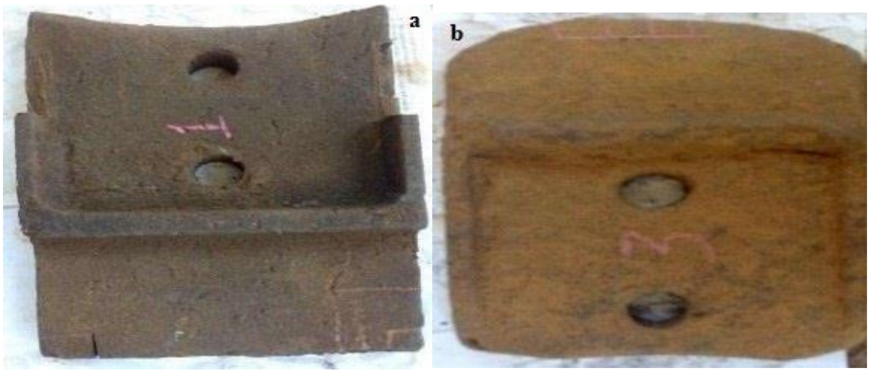
The chemical attack was carried out with the objective of highlighting the structure obtained after polishing. Nital at 4%, recommended by ASM Handbook, was used. This substance darkens the pearlite and gives contrast between its colonies, thus revealing its borders, in addition to highlighting the difference between ferrite and martensite and increasing the speed of the etching. To carry out the same, immersion is used for about 15 seconds. Once attacked, they are cleaned again with distilled water, immersed in ethyl alcohol for a few seconds and finally dried, which removes impurities and moisture [8].

Hardness determination: For the hardness measurement, the surfaces of the samples to be measured were cleaned and polished. The measurements were made with a Vickers hardness tester, for which a load of 100 kgf/mm^2 (10.19 MPa) was used on the analyzed material, the aforementioned hardness tester has a diamond-tipped indenter, which makes it possible to make an imprint at a certain depth and thus know its hardness, the measurements were replicated 3 times each, separated at a distance of 1 cm, this allowed calculating the average values of the same.

It is necessary to check the hardness of the samples and compare it with the hardness that the material should have, according to the design requirements (HRC 55-60), with this it will be possible to determine if the analyzed alloy has the necessary resistance to withstand the conditions to which it is exposed. As explained above, the procedure described above was applied.

Microstructural characterization: The microstructural analysis consisted of the observation of samples of the unused and decommissioned casting material. This will be used to establish the behavior of the casting, as well as its phases and grain size, in the areas that are directly in contact with the erosive materials and those that are not, in order to determine the causes that provoke wear in the parts manufactured with this material. Figures 5a and 5b shows the parts to be analyzed, with the areas from which they were cut for their preparation and subsequent analysis.

Figure 5. Sampling area, a) Blank part; b) Part taken out of service.



Determination of grain size in the microstructure

The crystals of metals generally have small dimensions. Metallic objects consist of a very large number of them. The microstructures were obtained under the Echo RD microscope, photos were taken with a camera for all the alloys analyzed, and the predominant sizes of the grains were measured using a computer program, which gives a measure of the hardness of the material and of the microconstituents present.

Phase transformations in the hadfield type alloy

Phase transformations, in high manganese alloys, generally result from heat treatments[8,9] because the untreated material presents, as a consequence of the recrystallization annealing it has undergone after the casting process, a structure formed by equiaxial grains of α phase with a hardness lower than HRC 20. It is observed how the formation of the original β phase occurs with an acicular grain type growth. It will be observed, in the micrograph, after quenching, the needles will be transformed into an almost single plate of martensite.

RESULTS AND DISCUSSION

Chemical composition of the specimens

The chemical composition of sample 1 in Table 2 shows that the carbon content is below that of Hadfield steel, according to the standards (between 1 and 1.40), the manganese content is within the range of the standard composition and the Cr content is lower than the 2% established for the same. A low molybdenum content was also obtained, which can influence the hardness of the steel.

Table 2. Chemical composition of sample 1, mass %.

% C	% Si	% Mn	% Cr	% Mo	% Fe
0.934	0.094	12.97	0.034	0.188	Balance

In the case of sample 2, the percentages of carbon and manganese are within the range of ASTM A 128 steel, while chromium, as in sample 1, is below the standard alloy, as is the percentage of carbon and chromium in sample 3, while manganese is within the defined range (Tables 3 and 4).

Table 3. Chemical composition of sample 2, % by mass.

% C	% Si	% Mn	% Cr	% Mo	% Ni	% Fe
0.989	0.686	12.100	0.075	0.001	0.134	Balance

Table 4. Chemical composition of sample 3, by % mass.

% C	% Si	% Mn	% Cr	% Mo	% Ni	% Fe
0.549	0.726	11.200	0.085	0.003	0.154	Balance

It is observed that the percentage of manganese obtained in the specimens, for the three samples, is within the range (10%-14%), established for the ASTM A 128 alloy, however, the chromium content is very low, so it can be said that the material used for the production of these pieces lacks the necessary content for Hadfield type steel.

Determination of the hardness of the samples

As shown in Table 5, for the unworked samples, the hardness did not exceed HRC 28, which shows that there is no presence of structures capable of withstanding wear when subjected to erosive environments. The average hardness of the material of the specimens removed from the process was HRC<20, which is too low a value recommended to face the severe wear conditions to which the parts are subjected.

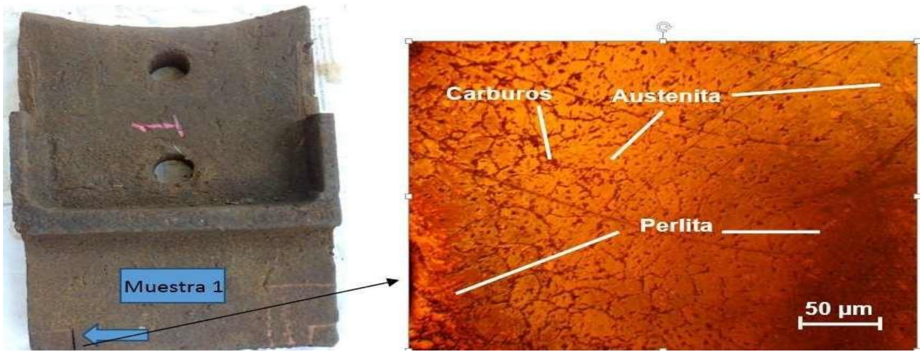
The average hardness of the alloy, for none of the cases, both the unworked samples and those withdrawn from the process, was higher than HRC 20, too low a value, which does not comply with what is recommended to face the severe wear conditions to which the parts are subjected, which should have, according to the design requirements, hardnesses between HRC 55-60, so that the failure of these parts will occur in a relatively short exploitation time.

Table 5. Hardness of hadfield steel for the samples taken.

Samples	Replication	Hardness (HRC)	Average hardness (HRC)
1	1.1	<20	<20
	1.2	21.7	
	1.3	<20	
	1.4	<20	
2	2.1	25.7	<20
	2.2	<20	
	2.3	<20	
3	3.1	<20	<20
	3.2	<20	
	3.3	<20	
	3.4	25.2	

Microstructure of the virgin samples: The casting of manganese steel of the Hadfield type, unworked and unworked (Figure 6), is one with a chemical composition of 1.4% carbon and approximately 13% manganese, as established by ASTM A 128.

Figure 6. Microstructure of the sample of the unaffected piece.



The microstructure is based on an austenitic matrix, which has precipitated carbide compounds and small pearlite colonies, which is the result of the rejection of carbon by the austenite during cooling. These carbides have nucleated at the grain boundaries and in the interdendritic areas within the austenite grains. They do not have a massive character and presumably are of the MxC type, exposed [10].

Characterization of the parts subjected to wear: The microstructures observed correspond to an alloy after removal from service and worked under the conditions of friction abrasion. They are preceded by an austenitic matrix, the ferritic phase and the presence of carbides, presumably of the MxC type, typical in these raw cast alloys and by the cooling temperature during their obtaining, results similar to those obtained [11].

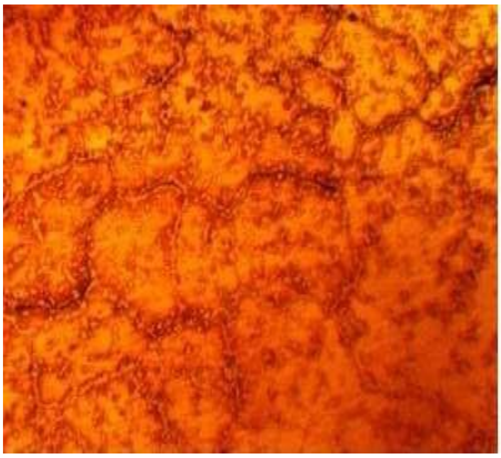
In austenitic manganese steel, by cold working, the austenite tends to transform, on the surface, because of friction. The alloy is exposed to the combined phenomena of abrasion and friction. Regardless of the microconstituents observed in sample 3, the carbides are located at the grain boundaries of the austenite and the massive presence of a ferritic structure. As in sample 2, which is less perceptible to the formation of this phase, however, in sample 3, there is an area of greater occupation of ferrite, which may be associated to the fact that in this portion of the alloy, there is greater contact with the mineral to be processed, thus bringing the occurrence of the change from one phase to another.

When the temperature is below 950ºC, the secondary phase MxC precipitates, which coexists with austenite until about 400ºC. Above 680ºC, the solid solution α appears. The work hardening of Hadfield steel decreases at temperatures above and below the dynamic strain aging range. At low temperature, <-25ºC or at higher rates and higher temperatures, the carbon atoms are immobile, both in the dislocation cores and in the lattice so that no anchoring occurs [12].

In none of the samples the presence of martensite was evidenced as a result of any heat treatment that guarantees the appearance of martensite, a fact reinforced by the hardness tests that also did not show values above HRC 27 (obtained for only one sample), in all cases the average hardness was below HRC 20.

Determination of grain size: The grain size was determined for the alloy that was not put into operation and for the two samples taken after its useful life had expired. For 1, unused, it was carried out taking into account the area (Figure 7), the number of fields and the calibration developed. The grain size (Table 6) were 1 μm and an average of 2 μm large dimensions for a heat-treated matrix.

Figure 7. Area identified to determine grain size (sample 1).



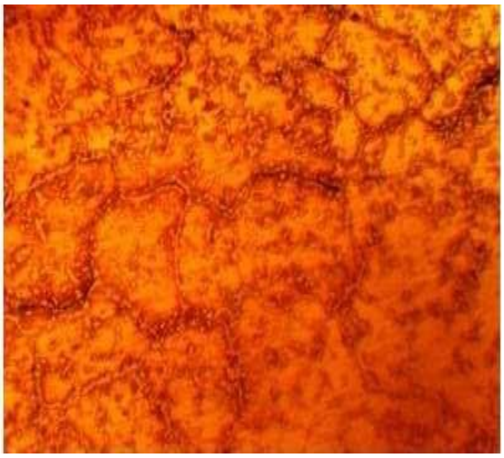


Table 6. Grain size of sample 1.

ASTM standard	AVG grain size
E 112	2

The results obtained then show the lack of the latter in the entire volume of the material and the absence of the martensitic phase in the microstructure, as an element that guarantees the hardness required for the type of alloy, as also expressed [13].

Grain sizes for the alloys withdrawn from the process

The grain sizes for samples 2 and 3, withdrawn from the process, were carried out in a similar way to that worked (Figure 8). The average dimensions obtained were larger than the unworked one (3 μm), excessively large for a matrix that should have hardness higher than HRC 50, the lack of a martensitic structure, as a result of a heat treatment (Table 7).

Figure 8. Area identified to determine grain size (sample 2 and 3), a. Sample 2, b. Sample 3.

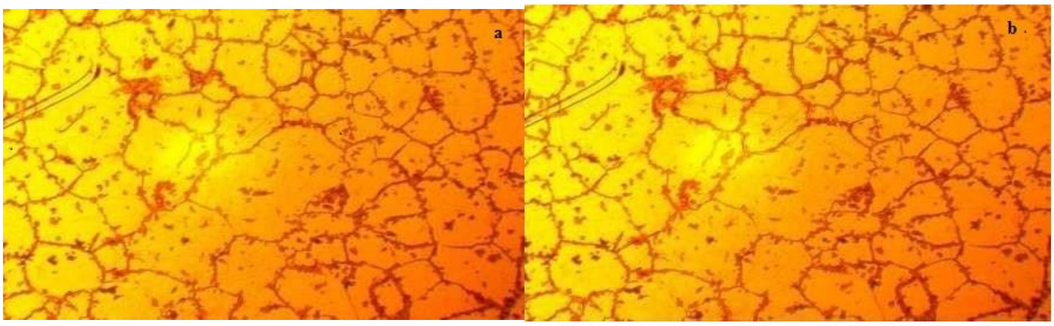


Table 7. Grain size of sample 2.

ASTM standard	AVG grain size
E 112	3

CONCLUSION

The main cause of premature wear of the alloys used in the manufacture of trowels removers for washing lateritic ores is identified as the presence of a microstructure based on low strength microconstituents. The Hadfield steel alloys studied lack martensitic structure, with excessively large grain sizes, evidencing the absence of quenching treatment to cope with the wear conditions to which its are subjected.

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