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Wear and Mechanical Properties of Nodular Iron Modified with Copper

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***Abstract*—**In this research (using induction furnace process) nodular iron with three different percentages of copper (residual, 0.5% and 1,2%) was obtained. Chemical analysis was performed by mass spectrometry and microstructures were characterized by Optical Microscopy (ASTM E3) and Scanning Electron Microscopy (SEM). The study of mechanical behavior was carried out in a mechanical test machine (ASTM E8) and a Pin on disk tribometer (ASTM G99) was used to assess wear resistance. It is observed that the dissolution of copper in crystal lattice increases the pearlite structure improving the wear and hardness behavior, but producing a contrary effect on the energy absorption.

***Keywords*—**Ferritic and perlite structure, mechanical properties, nodular iron, wear.

I. Introduction

THE nodular iron is a material that has shown great advantages with respect to other materials (steel and gray iron) in the production of machine elements. The engineering industry, especially automobile, is a potential user of this material. As it is known, the alloying elements modify the properties of steels and castings.

Copper has been investigated as a structural modifier of nodular iron, but studies of its mechanical and tribological implications still need to be addressed for industrial use. With the aim of improving the mechanical properties of nodular iron, alloying elements (Mn, Si and Cu) are added according to their percentage of presence in order to increase their pearlite (or ferrite) structure [1].

For pearlitic iron, the percentage of Si is maintained in amounts below 2.5% and for the ferritic grade, 2.5 to 2.8%; with respect to Mn, this element is maintained between 0.4 to 0.6% in grade perlite and below 0.3% in ferritic grade [2]. Cu is pearlite phase generator [3]; in agreement with other studies, it is necessary to apply a heat treatment normalized by air cooling for one hour to obtain a pearlitic matrix, which means higher costs [4].

Where the nodular iron is alloyed with copper has a better anti-abrasion performance and less impact resistance; this element also enhances the hardenability because it stabilizes the austenite, increasing corrosion resistance against atmospheric agents and many chemical agents, especially sulfuric acid [5]. For copper additions above the apparent upper limit of 3.0 to 3.5%, this element has no additional effect on the mechanical properties of the nodular alloys. In nodular cast iron with less than 2% of copper, a pearlitic matrix 99% has been obtained with properties of tensile strength of 70 to 80 kg/mm^2, elongations of 5% to 16% and approximately 100 nodules/mm^2; copper also improves tensile strength and increases hardness [6].

Microstructural nodular iron with copper show an increase in the content of perlite in relation to its mechanical properties undergoing an increase in tensile strength as well as the fragility [7]. The ferritic nodular cast iron, whose matrix has at most 10% perlite, has high ductility, toughness, and machinability; in general terms the pearlitic foundries offer greater the tensile strength, toughness and ductility lower [8], [9].

An advantage of the addition of copper in the nodular iron is that, besides being an effective promoter of pearlite formation, it improves the mechanical properties of the alloy without subjecting it to heat treatment [10], [11]; copper also increases the hardenability and creates a barrier to the diffusion of carbon, consequently retarding the austenitizing time [12], [13]. In another report it was found that copper in nodular iron does not improve the results of impact [14]; other researchers have found that an increase in its fragility appears when adding copper values exceeding 1% [15], [16].

In order to identify their applicative advantage in industrial parts, nodular iron alloyed with different percentages of copper was produced in this research, as well as a relationship of the mechanical behavior through measurements of hardness, impact, and abrasive wear response.

II. Experimental Procedure

Nodular iron was prepared in an induction furnace, producing 4 kg of ingots; the material was cut into 1¨ diameter cylinders (10 mm thick); chemical analysis was performed by mass spectrometry. Metallographic specimens were subjected to etching in a 99-9% solution of ethanol.

Microstructures were characterized by optic microscopy (OM) and scanning electron microscopy (SEM). Pin on disk tribometer (ASTM G99) was used to assess wear resistance. The ball specimen (radius 5 mm) was alumina, with applied load 10 N, sliding speed 120 rpm, and sliding distance was 1260 m with turning radius of 10 mm.

The wear tests were carried out at room temperature, without lubrication and relative humidity was approximately 70%.

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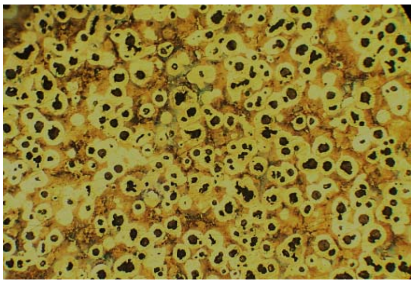
III. Results and Discussion

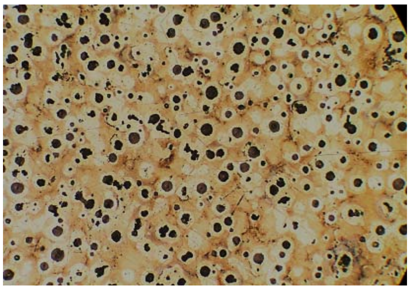
In order to produce the nodular structure, Col-Roll scrap metal and ferro-silicon are used; the melt is inoculated with a small amount of magnesium, and prior desulfurization, nodular iron with three different concentrations of copper is obtained, as shown in Table I.

TABLE I
CHEMICAL COMPOSITION OF NODULAR IRON

%Fe	%Cu	%C	%Si	%P	%Mn	%S
93.51	0.00	3.63	2.23	0.061	0.031	0.089
93.01	0.51	3.63	2.22	0.060	0.031	0.090
92.5	1.19	3.63	2.24	0.060	0.032	0.089



(a) Nodular iron without Cu



(b) Nodular iron with 0.5 % Cu

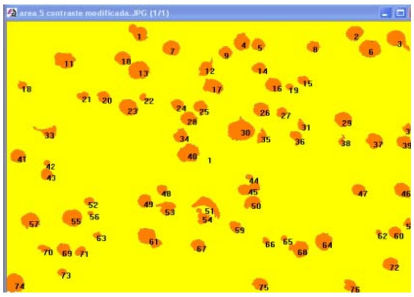
(c) Nodular iron with 1.2 % Cu

Fig. 1 Metallographic structure (200X). Graphite nodules (black dots), ferrite (light area) and pearlite (dark area) to each copper concentration: (a) without Cu, (b) 0.5 Cu, (c) 1.2 Cu

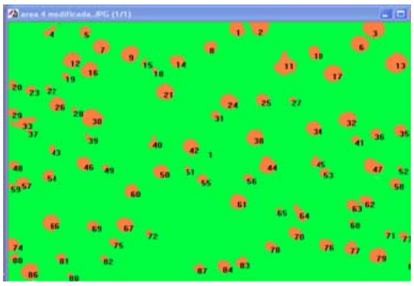
The percentage of carbon is within the optimal range (3.4 to 3.85%), since above that range there would be danger of graphite flotation (especially in heavy sections) and an increase of expansion during solidification would lead to embrittlement, particularly in processes that are made with soft sand molds.

Below this range, frailties because of lack of carbon may also occur. Silicon also is within a preferred range (2 to 2.8%), since lower levels of silicon leads to a high ductility but with carbides in thin sections. A high level of silicon accelerates annealing and helps prevent carbides in thin sections.

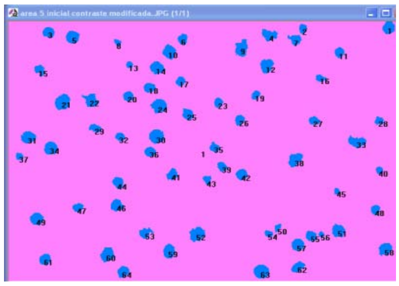
The metallographic observation shows homogeneous iron with graphite nodules and well grouped in all specimens; ferritic areas for nodular iron without copper (Fig. 1 (a)) and pearlite areas similar for both alloyed cast (Figs. 1 (b) and (c)) are observed; these pearlite zones for alloyed cast are more abundant than pearlitic zones of unalloyed casting.



(a) Nodular iron without Cu



(b) Nodular iron with 0.5 % Cu



(c) Nodular iron with 1.2 % Cu

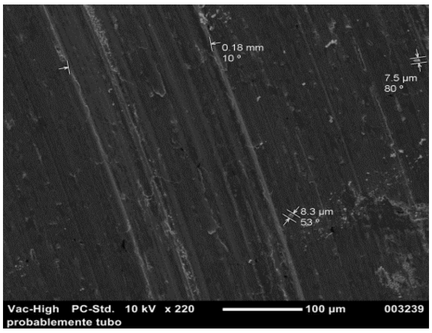
Fig. 2 Nodular images of each copper concentration: (a) without Cu, (b) 0.5 Cu, (c) 1.2 Cu

When the image processing technique known as mathematical morphology is used, a uniform granulometry throughout the area of the matrix is observed (Figs. 1 (a), 2 (b), and 1 (c)); nodule density for each specimen is summarized in Table II, with an increase in the number of nodes for alloyed specimens.

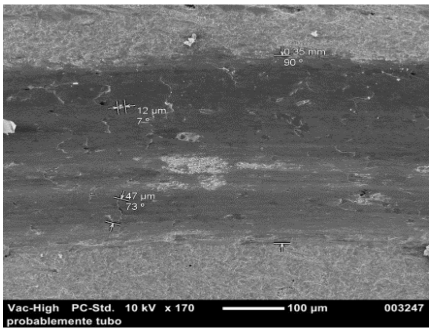
TABLE II
NUMBER OF NODULES FOR EACH CONCENTRATION OF COPPER IN THE NODULAR IRON

%Cu	#Nodules/mm^2
0	102
0.5	121
1.2	118

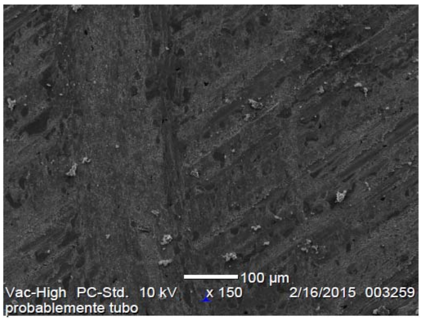
In the SEM images strongly pronounced grooves were found for the specimen without copper (Fig. 3 (a)) and moderately pronounced grooves for the specimen with 0.5% copper are observed (Fig. 3 (b)). For the specimen with the 1.2% copper (Fig. 3 (c)) wear effect is not clearly observed. The dissolution of copper in crystal lattice enables greater wear resistance.



(a) without Cu



(b) 0.5 % Cu



(c) 1.2 % Cu

Fig. 3 SEM images for each concentration of copper in the nodular iron: (a) without Cu, (b) 0.5 Cu, (c) 1.2 Cu

In relation to the wear of the specimens, an advantageous result is observed for nodular copper smelters (Table III).

TABLE III
MASS LOSS FOR NODULAR IRON ACCORDING TO THE PERCENTAGE OF COPPER IN THE ALLOY

%Cu	Mass loss (mg)
0.0	9.0
0.5	1.6
1.2	0.2

Table IV shows the results of Charpy impact test at room temperature (300 K) and 358 K; the copper addition produces a hardness increase while that in both temperature situations a toughness decrease are produced.

TABLE IV
ENERGY ABSORPTION VALUES AT TEMPERATURES OF 300 AND 358 K, AND BRINELL HARDNESS

% Cu	Energy (J) 300 K	Energy (J) 358 K	Brinell Hardness
0.0	6.0	7.25	229.57
0.50	5.25	6.25	269.14
1.2	2.75	4.25	295.71

IV. CONCLUSIONS

Copper in the range up 0.5 in the nodular iron increases the density of nodules per cm^2 and in the range up to 1.2% increases the pearlite phase causing an improvement in the wear behavior, increasing the hardness and decreasing the energy absorption.

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