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# Effect of the Carbon Content on the Abrasive Wear Behavior in Ductile Cast Irons

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**Abstract:**

The In the present work, a comparative study is carried out to determine the resistance to abrasion of three types of cast irons. These materials are produced in the company Plant Mechanics of Santa Clara, taking for this study those of greater production, which are known as Fe 15, Fe 20 and Fe 30. A characterization of them is carried out, which includes chemical analysis, hardness measurement and structural analysis. To carry out the test, the method established in the ASTM G 65 standard known as the dry sand-rubber wheel is used. Method B of this standard is used, which has as working parameters the application of a force of 130 N, 2000 revolutions of the rubber wheel and a linear distance of 1436 meters. Finally, it is concluded that the highest resistance to abrasive wear coincides with the highest percentage of carbon and with the highest hardness of Fe 30.

**Keywords :** Abrasive wear, Cast Irons, Carbon content.

## 1. INTRODUCTION

Friction and wear are caused by multiple and complicated processes of microscopic interaction between two or more surfaces that are in mechanical contact. These interactions are the result of the materials, the geometrical and topographic characteristics of the surfaces and the general conditions under which the sliding of one surface with respect to the other occurs, such as the load, the temperature, the atmosphere, the type of contact, among others. All the mechanical, physical, chemical and geometric aspects of the surfaces in contact and the surrounding atmosphere also affect the tribological characteristics of the system. Therefore, friction and wear are not simple parameters of the materials that are available in the manuals, they are unique characteristics of the tribological system that is being analyzed [1]. The tribological tests can be performed in numerous ways. During the last years a great amount of equipment has been designed for the evaluation of wear and friction, called tribometers. The process of selecting the most appropriate test for a specific purpose is fundamental for a correct interpretation of the results [1].

Among the basic mechanisms of wear is pure abrasion, which occurs when hard particles or hard protrusions are compressed and move on a solid surface [2]. Compared with other types of wear, the analytical models developed to describe abrasion are much more reliable and understandable, which greatly facilitates the interpretation of test results.

There are numerous works in which tribological studies are carried out on cast iron. Rojas et al. [3] conducted a study in which aluminum particles are added to alloy irons to determine their influence on wear resistance. In this work abrasive wear tests are carried out, however it is not specified which method is used. Salim M., et al. [4] study the behavior before the adhesive wear of the spheroidal cast iron with different heat treatments. For wear tests, the pin on disk method was used according to the ASTM G 99 standard. In his work Kopycinski et al. [5] study the abrasive wear of cast irons with a high content of carbides, for the purpose of their use in mining equipment. The tests are carried out in a Millar machine, according to the ASTM G 75 standard. For his part Haider M. [6] performs a study in which he analyzes the effect of sliding speed, hardness and surface roughness in the coefficient of friction and wear of cast iron. For that work he uses the pin on disk method. Higuera O., et. to the. [7] study the influence of the variables time and temperature during the heat treatment of a white cast iron with a high chromium content and relate it to abrasive wear resistance. In this work, they use the dry sand-rubber wheel method according to ASTM G 65. Kotecki and Ogborn [8] carry out a work in which they study the resistance to low-stress abrasion of several cast irons, depending on the composition and hardness. They conclude that the carbon content is the main variable that determines the resistance to abrasion, while the hardness and the chromium content have the second place in importance in this property of the cast irons. They use the dry sand-rubber wheel method established in the ASTM G 65 standard. As can be seen, several methods are used for the study of abrasive wear in cast irons and all are considered valid.

In the Santa Clara Mechanical Plant several types of cast iron are produced, among which are the Fe 15, Fe 20 and Fe 30. In many cases these materials are used in the manufacture of parts that are subject to wear due to abrasion. However, a study has never been carried out to determine which of these cast irons has a greater resistance to wear, which would guarantee a better quality of the manufactured parts. It is for this reason that it is decided to begin a study that characterizes these materials from the abrasive wear resistance.

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## 2. MATERIALS AND EXPERIMENTAL PROCEDURE

To carry out the tests, the dry sand-rubber wheel method established by the ASTM G 65 standard was used [9]. This standard establishes five procedures, in this study procedure B was used, which has as working parameters the following: applied force 130 N, abrasion distance of 1436 m, which corresponds to 2000 revolutions of the rubber wheel. The test was divided into three stages, two first of 660 laps and a final of 680, to control the wear process. The machine used meets the requirements established in the standard and is shown in Fig. 1.

**Figure 1.** ASTM G-65 machine used

The weighing of the test pieces before, during and at the end of the test was carried out on a SCALTEC digital weigh scale, that has an accuracy of 0.0001 g. The specimens were made with the dimensions established in ATM G 65 and the material was obtained from different castings in the foundry of the Mechanical Plant. After the specimens were manufactured, the chemical analysis was carried out to check their composition. This operation was carried out on a Spektrometrie Opto-Electronik machine at 20X.

The three cast irons probes were also subjected to a metallographic analysis. The analysis and the images of its structure were made with a Neophot32 microscope. In the same way, the hardness probes were realized at the Rockwell C scale and measured in the BUEHLER VMT-7 hardness tester equipment.

## 3. RESULTS AND DISCUSSION

### 3.1 Characterization of materials

The average values of the different chemical elements in each cast irons are shown in table 1. The hardness values are showed in the table 2.

**Table 1.** Chemical composition of the cast iron studied

| Cast iron | C | Si | Mn | S | Cu | Cr | Mo | V | Ti | Mg | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fe 15** | 3.37 | 2.06 | 0.473 | 0.120 | 0.253 | 0.216 | 0.009 | 0.014 | 0.014 | 0.001 | 93.23 |
| **Fe 20** | 3.48 | 1.75 | 0.649 | 0.100 | 0.273 | 0.184 | 0.015 | 0.017 | 0.019 | 0.001 | 93.17 |
| **Fe 30** | 3.55 | 2.23 | 0.592 | 0.091 | 0.245 | 0.216 | 0.010 | 0.0195 | 0.038 | 0.001 | 92.61 |

**Table 2.** Hardness values of the cast iron studied

| Cast iron | HRC Hardness | Resistance (N/mm$^2$) |
|---|---|---|
| Fe 15 | 13 | 640 |
| Fe 20 | 18 | 698 |
| Fe 30 | 20 | 731 |

As a result of the metallographic analysis, it was determined that the cast iron corresponding to Fe 15 has a pearlitic matrix with the presence of laminar and nodular graphite (Fig. 2 a). The material corresponding to Fe 20 has a ferritic matrix with nodular graphite (Fig. 2b), and the material corresponding to Fe 30 has a pearlitic matrix with lamellar graphite (Fig. 2 c).

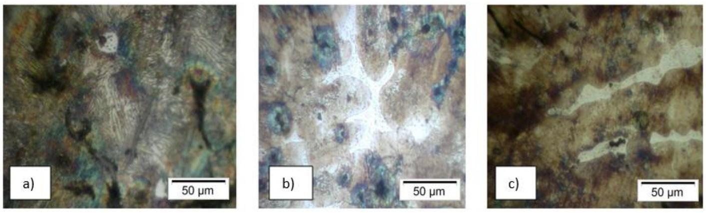


**Figure 2.** Metallographic images of the cast iron studied. a) Fe15, b) Fe20, c) Fe30

The wear tests were carried out in the three cast irons and the results of the measurements in them are showed in Table 3. In addition, the table 4 shows the losed mass obtained at partial laps numbers and the final test.

**Table 3.** Abrasive wear results of mass

| Test number | Initial mass (g) | Mass 660 laps (g) | Mass 1320 laps (g) | Final mass (g) |
|---|---|---|---|---|
| 1 | 129,6642 | 129,5179 | 129,3780 | 129,2547 |
| 2 | 130,0495 | 129,9003 | 129,7564 | 129,6180 |
| 3 | 131,0331 | 130,8572 | 130,6898 | 130,5319 |
| 4 | 129,5595 | 129,4029 | 129,2578 | 129,1159 |
| Average | 130,0766 | 129,9196 | 129,7705 | 129,6301 |
| 1 | 134,3394 | 134,2332 | 134,1334 | 134,0365 |
| 2 | 134,3915 | 134,2791 | 134,1726 | 134,0743 |
| 3 | 133,8911 | 133,7819 | 133,6732 | 133,5772 |
| 4 | 133,2817 | 133,1627 | 133,0481 | 132,9391 |
| Average | 133,9759 | 133,8642 | 133,7568 | 133,6568 |
| 1 | 134,7615 | 133,1627 | 134,5770 | 134,4909 |
| 2 | 134,5824 | 134,4899 | 134,3935 | 134,3079 |
| 3 | 135,1395 | 135,0453 | 134,9572 | 134,8712 |
| 4 | 135,2900 | 135,1938 | 135,1020 | 135,0123 |
| Average | 134,9434 | 134,4729 | 134,7574 | 134,6706 |

**Table 4.** Losed mass at partial laps and final test.

| Material | Initial mass (g) | Losed mass 660 laps (g) | Losed mass 1320 laps (g) | Losed final mass (g) |
|---|---|---|---|---|
| Fe 15 | 130,0766 | 0,1570 | 0,3061 | 0,4465 |
| Fe 20 | 133,9759 | 0,1117 | 0,2191 | 0,3191 |
| Fe 30 | 134,9434 | 0,0940 | 0,1859 | 0,2727 |

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The losed volume is calculated from the losed mass (table 4). The results are showed in fig. 3.

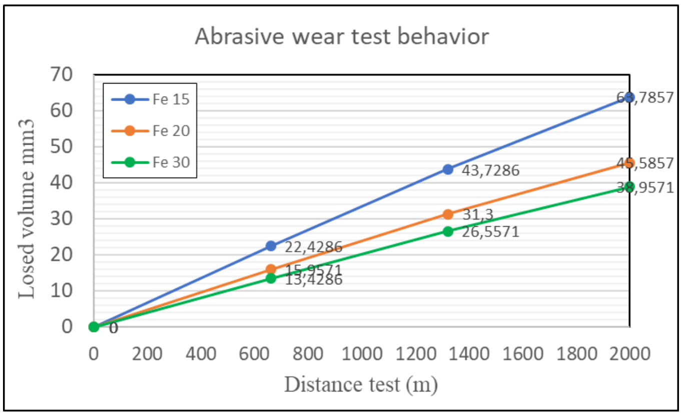


**Figure 3.** Abrasive wear behavior of the ductile cast irons.

As previously stated, it is very complicated to model the phenomena of wear, and it is difficult to follow analytical methods that resemble actual conditions in practice [10]. Consequently, the wear modeling is usually of an experimental nature, and is done by determining the wear coefficient with the Archard equation:

$$V = \frac{K \cdot L \cdot W}{H} \qquad (1)$$

Where V is the wear volume, K is the coefficient of wear, L the distance of testing, W the normal force between the surfaces and H is the hardness to the penetration. Clearing from (1) the expression is reached in order to determine the wear coefficient K.

$$K = \frac{V \cdot H}{W \cdot L} \qquad (2)$$

For the case analyzed, this coefficient will be determined at the final test distances carried out in each cast iron. The common data for test considered W = 130 N and L = 2000 m. In the table 5 are presented the factor K in each ductile cast iron studied.

**Table 5.** Coefficient of wear

| Material | Losed volume (mm3) | Hardness (N/mm2) | Coefficient of Wear |
|---|---|---|---|
| Fe 15 | 63,7857 | 640 | 0,0001571 |
| Fe 20 | 45,5857 | 698 | 0,0001224 |
| Fe 30 | 38,9571 | 731 | 0,0001095 |

As can be seen, the wear coefficient is higher in Fe 15 (lower carbon percentage) and decreases until Fe 30 (highest carbon percentage), which indicates that the cast iron with low carbon experiences the highest abrasive wear rate. This result coincides with much of the literature, which states that the higher the carbon content in the cast iron and in the steels, and the greater the hardness, the greater the resistance to abrasive wear.

## 3. CONCLUSION

When determining the wear coefficient (K) it can be seen that in the cast iron with low carbon percentage (Fe 15) was greater than in the cast iron with middle carbon percentage (Fe 20) and this in turn greater than the cast iron with the major carbon percentage of the cases studied (Fe 30). This is related to the carbon content of each, which in turn is related to the hardness of each material. This coefficient K determines that Fe 30 has a better resistance to abrasive wear than Fe 20 and this in turn is greater than Fe 15.

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