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# Fatigue characterization and optimization of the production process of heavy-section ductile iron castings

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Proper design of heavy-section ductile iron castings requires a database nowadays absent or very poor. In this paper, it will be presented the mechanical characterization, carried out at Fonderie Ariotti S.p.A., of ductile irons with solidification time up to 20 hours.

The characteristics of the various types of cast iron can widely change varying the solidification time. It was observed that the ferritic cast iron is more suitable for the production of large thickness castings subjected to fatigue loads, because decrement in ductility and its effect on other properties is less. For these reasons, the study of high silicon ferritic cast irons will be deepened.

It has been verified that data dispersion (especially significant in heavy castings and rarely found in the literature) of ferritic cast irons is on average lower than that of the pearlitic ones, probably because of the higher ductility of the matrix.

***Keywords:*** *ductile cast iron, heavy-section, long solidification times, mechanical properties.*

## 1. Introduction

Ductile cast irons are widely used because they represent low cost ferrous alloys with high fluidity and very low shrinkage [1].

Increasing the castings size, decreases the cooling rate and consequently the internal microstructure can heavily change, with possible formation of defects and anomalous structures and decrease of the mechanical properties of the material [2]. The fatigue behavior of a ductile cast iron primarily depends on the matrix microstructure, on the presence of surface defects such as oxides, inclusions and porosity [3,4] and on the graphite nodules count and morphology [5]. In heavy-section castings, the desired spherical morphology of graphite often degenerates into different shapes, such as spiky, vermicular, exploded and chunky [6].

The substantial lack of technical data for heavy-section castings design forces the designers to oversize the dimensions to reduce any risk.
This work is aimed at obtaining a redefinition of the rules for heavy-section structural elements fatigue design in presence of defects.

## 2. Experimental procedure

### 2.1 Materials

The first tests results shown in this work are included in a larger project that involves a full characterization in terms of microstructural and mechanical properties of different types of cast irons for the production of heavy-section castings in order to establish the application areas of each of them.

The studied materials are standard ferritic ductile cast irons compared to ferritic cast irons with high silicon content and pearlitic matrix ductile irons.
The chemical composition of the first tested samples is reported in table 1.

Table 1 Chemical composition of the samples (mass%, Fe the rest).

| Sample | C | Si | Mn | Cu | Mg | Cr | P |
|---|---|---|---|---|---|---|---|
| A | 3.59 | 2.54 | 0.25 | 0.22 | 0.06 | 0.05 | 0.03 |
| B | 3.58 | 2.62 | 0.22 | 0.14 | 0.05 | 0.07 | 0.04 |
| C | 3.58 | 2.48 | 0.21 | 0.16 | 0.06 | 0.04 | 0.03 |
| D | 3.39 | 3.35 | 0.29 | 0.07 | 0.05 | 0.05 | 0.03 |

### 2.2 Techniques and methods

A direct comparison between two identical castings of the weight of 9t, one in high silicon ferritic iron with 3.4% Si and one in pearlitic cast iron with 1.0% Cu, showed nearly identical values of fatigue limit, but with a data dispersion 60% higher for the pearlitic one.

Based on these results, in order to deeply investigate the behavior of different materials with low cooling rates, an innovative production line has been then devised to reproduce the characteristics of castings of tens of tons, with different solidification times up to 20 hours, on a small scale sample in an electric furnace. The whole cooling cycle of the samples has been monitored using a thermocouple inserted in the casting .

### 2.3 Mechanical characterization

The first analysis performed was an ultrasonic control to detect any possible internal defects. Tensile and fatigue tests bars were then obtained from the castings.

Tensile tests were performed at room temperature, according to the UNI EN ISO 6892-1: 2009 and Brinell hardness was measured by using a durometer B3000J with a sphere diameter of 10 mm and an applied load of 29.4 KN.

The fatigue properties were studied by rotating bending fatigue tests, using the stair-case method according to UNI 3964/85 standard to calculate the fatigue limit with a survival probability of 50%. All tests were carried out at room temperature with a frequency of 100 Hz. The fatigue tests were stopped at sample failure or after $5 \cdot 10^6$ cycles.

Metallographic analysis were carried out on samples taken from various mechanical test bars for all the studied castings and, in some cases, also SEM (Scanning Electron Microscope) analysis of the fracture surfaces were performed to define the different fracture mechanisms.

## 3. Result and discussion

Table 2 Cooling curves and metallographic analysis results.

| Sample | Matrix | Solid. time (h) | Eutectic T(°C) | Eutectic t(h) | Nodule count (n/mm$^2$) |
|---|---|---|---|---|---|
| A | Ferritic | 3 | 1153 | 2.5 | 8 |
| B | Ferritic | 6 | 1160 | 5 | 9 |
| C | Ferritic | 20 | 1153 | 18 | 5 |
| D | Ferritic High Si | 12 | 1164 | 10 | 9 |

Table 3 Mechanical tests results.

| Sample | $R_m$ (MPa) | $R_{p0,2\%}$ (MPa) | A% | HB | $\sigma_{f,50\%}$ (MPa) |
|---|---|---|---|---|---|
| A | 329±17 | 286±3 | 3.1±1.4 | 153±4 | 145±6 |
| B | 353±8 | 298±2 | 4.2±0.8 | 165±8 | 167±18 |
| C | 249±29 | / | 0 | 162±8 | 130±17 |
| D | 347±9 | 342±6 | 0.9±0.9 | 165±8 | 157±10 |

From the results of the tests described above, it was found that cooling curves, microstructures and mechanical properties of the samples are similar to those of the heavy-section production castings already tested. The validity of the process was confirmed.

According to these results, many trials were performed to check some changes in the production process. For so long solidification times, modifications in the preconditioning and inoculation treatments (quantity and type) did not led to improvements.

## 4. Conclusions

- In heavy-section castings, the fatigue behavior of a fully ferritic matrix cast iron is better compared to an even partially pearlitic one, because of the higher ductility and the lower data dispersion.

- The first presented results confirm the similarity between the samples obtained according to the developed system and some production castings with weights of tens of tons, in terms of microstructures and mechanical properties.

- For long solidification times, all the different preconditioning and inoculation treatments tested loose any effect.

- Solidification time is critical to the mechanical properties in the centre of the castings. Microstructure and mechanical properties have been greatly improved by active cooling systems, applied and checked on castings up to 30t of weight, and actually extended at much higher weight, up to 60t.

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