THE EFFECT OF THE SOFTENING ANNEALING AND OF NORMLIZING ON THE CAVITATION EROSION RESISTANCE OF NODULAR CAST IRON FGN 400-15

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Abstract

This paper analyzes, by comparison, the cavitation erosion resistance of the samples treated through softening annealing at 710 ± 10 °C with the purpose of partial spheroidization of pearlite and decomposition of free cementite traces from the microstructure, respectively the samples treated through normalizing at 860 ± 10 °C with the purpose of the pearlite proportion increasing and the cavitation erosion resistance improving. Cavitation tests were conducted on a vibrating device with piezo-ceramic crystals, following standard rules ASTM G32-2010.

The microstructure characterization of the heat treated and eroded by cavitation was made by optic microscopy, and scan electronic microscopy.

The obtained results show an improvement of cavitation erosion resistance after the application of the heat treatment for normalizing as a follow-up of the structure finishing and growing of the pearlite proportion in the base matrix.

Keywords: Heat treatment, cavitation erosion, microstructure, nodular cast iron

1. INTRODUCTION

Nodular cast irons are a family of materials that through the possibility of directing the microscopic and the fine structure provides a wide range of mechanical and technological properties. The main feature of all types of nodular cast iron is bound to the more or less spherical shape of the graphite. As a result of this shape, the crack propagation is prevented and creates premises to obtain satisfactory characteristics of ductility and toughness [1, 2, 3].

Nodular graphite, whose surface in a given volume is minimal, affects to a lesser extent the metal matrix of the cast iron compared with lamellar graphite. Thus, it allows the use of 60 to 80 % of the tensile strength and of 30 to 50 % of elongation and reduction in area of the base metal mass. Also, the ratio Rm / HB = 0.26 -0.36 is much higher than cast iron with lamellar graphite, and $Rp_{0.2}$ / Rm ≈ 0.7 is higher than the cast steel parts [4].These features are critical to the quality and exploitation of nodular cast iron. The mechanical properties depend on the nature of the base metal mass and the amount of the graphite present in the microstructure. They are intended for the manufacture of cylinder heads and crankshafts of automobile engines, press traverses, brake shoes, rolling mill cylinders and pumps and valves working in corrosive environments.

Due to high resistance to wear and good anti-friction properties, they are used in the implementation of some components of the machine tools, presses and forging machines. However, for severe operating conditions, performance and reliability may be limited due to various forms of wear which mainly include cavitation erosion [5-8]. Applying of heat treatment, alongside the use of high energy sources like plasma, laser and electron beam, etc. [9, 10] can provide solutions to improve the cavitation erosion resistance.

This paper is focused on the cavitation behavior of ferrito-pearlitic nodular cast iron, subjected to some heat treatments which cause morphological changes of the structural matrix.

2. EXPERIMENTAL PROCEDURE

Cylindrical samples Φ 25 x 40 mm were made from cast-iron bars FGN 400-15, which have been subjected to softening annealing heat treatment (710 °C / 30 min./ oven), either the normalizing heat treatment (860 °C / 30 min./air). Subsequently, these samples were prepared for cavitation tests and microstructural studies. Cavitation tests were carried out on an ultrasound apparatus, in accordance with ASTM Standard G32- 2010 [7] (frequency vibrations = 20000 ± 1% Hz, double amplitude of vibration = 50 µm, distilled water temperature = 22 ± 1 °C, power = 500 W). The total duration of the test of each sample was 165 minutes, which is divided into 12 periods (one of 5 minutes, one of 10 minutes, and the next 10 periods of 15 minutes).

At the end of each test, the sample was cleaned in acetone, dried with air jet and weighed with an analytical balance with 10^{-5} g sensitivity. For microstructural analysis have been used conventional metallographic techniques and scanning electron microscopy.

3. EVALAUTION OF EXPERIMENTAL RESULTS

Based on the mass loss recorded at the end of each period, was calculated the mean depth erosion MDE and their speeds MDER using relationships [3]:

- for the cumulative mean depth erosion, after each intermediary period “i”

$$\mathrm{MDE_i} = \frac{4 \cdot m_i}{\rho \cdot \pi \cdot d_p^2} \quad [\mathrm{mm}] \qquad (1)$$

- for the mean depth erosion rate, after period “i”

$$\mathrm{MDER_i} = \Delta \mathrm{MDE_i} / \Delta t_i \ [\mathrm{mm / min}] \qquad (2)$$

where:

i - represents the testing period,

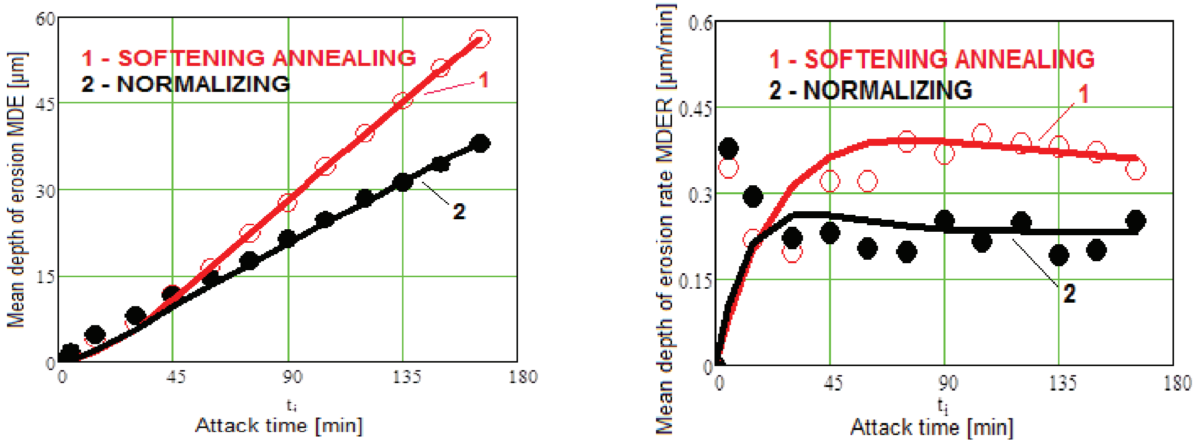
m_i - is the cumulative mass lost during the period i <grams>,

ρ - cast iron density <gram / mm^3>,

Δt_i - the cavitation exposure in the period “i” (first period of 5 minutes, second 10 minutes and the rest 15 minutes),

d_p - specimen diameter (d_{pc}= 15.8 mm),

ΔMDE$_i$ - mean depth erosion generated by cavitation in the Δt_i period.



-a- -b-

Figure 1 Specific cavitation curves: a - average penetration depth variation of erosion with the duration of cavitation; b - average penetration rate of erosion with the duration of cavitation

Softening Annealing:

MDEmax = 56.167 µm
MDER1Mmax = 0.392 µm / min.
MDER1Ms = 0.36 µm / min.

Normalizing:

MDEmax = 38.111 µm
MDER1Mmax = 0.26 µm / min.
MDER1Ms = 0.231 µm / min.
MDEmax -softening annealing / MDEmax_normalizing = 1.47
MDER1Mmax - softening annealing / MDER1Max - normalizing = 1.51
MDER1Ms - softening annealing / MDER1Ms - normalizing = 1.56

From these graphics it appears that the dispersion points from the normalized samples are essentially the same, given the dynamic and complex way of doing material damage under micro jet impact and shock waves, developed when cavitation bubbles implode.

MDER(t) evolution of approximating the curve data points, with the realization of a maximum and decrease asymptotic, to a stable value, in both cases, is specific to materials who improve their resistance to cavitation by various heat treatment techniques, due to changes in the structure and mechanical properties.

The normalizing heat treatment ensures a better resistance for vibrating cavitation, manifested since 45 min. when erosion rate MDER drops to a stable value (about 0.231 µm / min.), opposed to softening annealing heat treatment where the erosion rate drops to a stable value (0.36 µm / min) only after 90 min. of cavitation erosion. Also, normalizing heat treatment ensures an increase of resistance of about 1.47 times after the maximum cumulative mean depth of erosion (MDE(t)), respectively about 1.56 times after the parameter values for speed stabilizes (MDER).

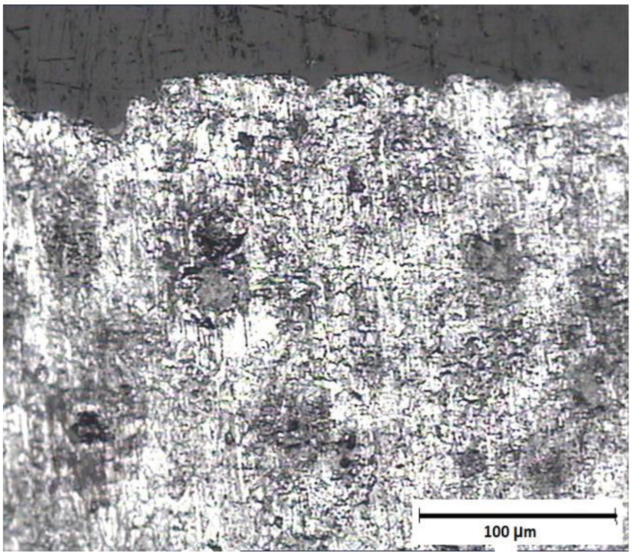


Figure 2 Normalization microstructure of a section through the cavity surface

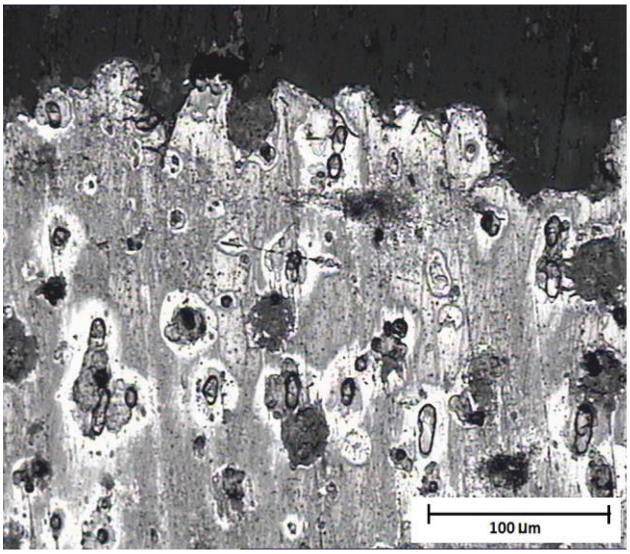


Figure 3 Softening annealing microstructure of a section through the cavity surface

These differences in cavitation behavior are justified by complete phasic recrystallization caused by normalization heat treatment with consequences on the finishing crystalline grains and pearlite matrix (**Figure 2**). Instead, softening annealing heat treatment manifests by decomposition of trace amounts of graphite and cementite in ferrite and by partial spheroidization of pearlite, both phenomena followed by a decrease in hardness (**Figure 3**). Typical surface topographies for the differently heat treated samples are shown in **Figures 4, 5** and **6.**

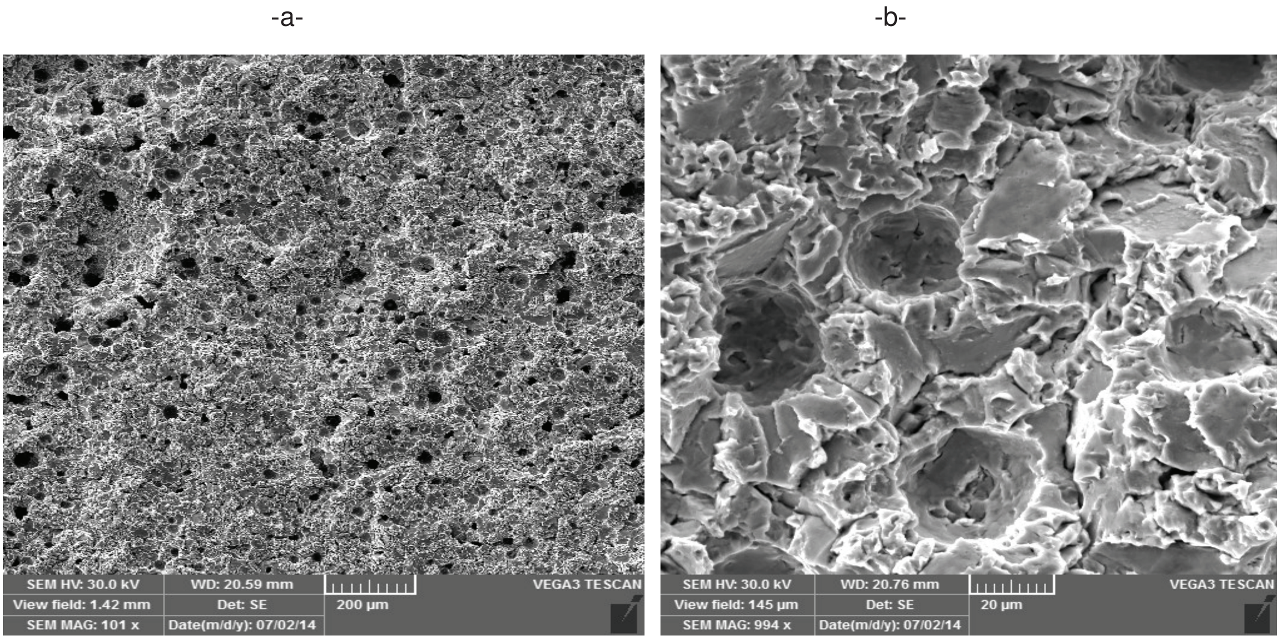


Figure 4 SEM image of the samples subjected to softening annealing treatment:
a - x 100; b - x 1000

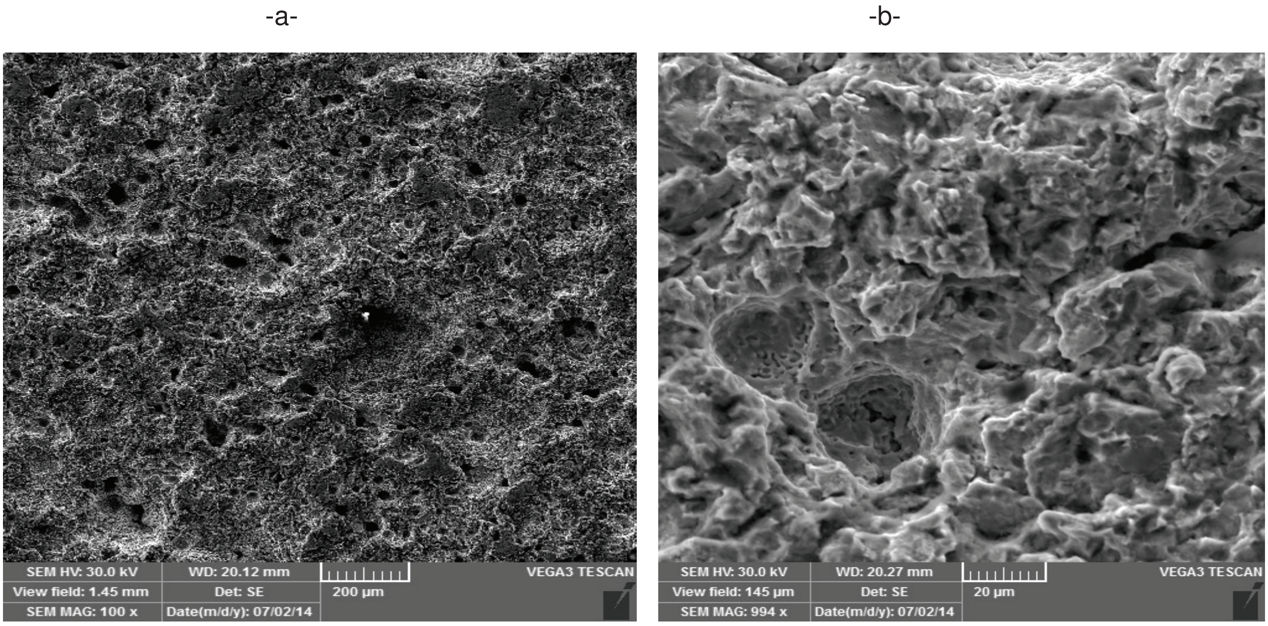


Figure 5 SEM image of the samples subjected to normalizing treatment:
a - x 100; b - x 1000

At the end of the cavitation test (after 165 min.) in the material portion where nodular graphite have been removed can notice the presence of a number of pinches (**Figure 6a**) that through coalescence caused the formation of deep micro-craters (**Figure 6b**). Also, near the bordering area of nodular graphite, intense deformation of the ferrite is occurring (**Figure 6a**), with the material degradation caused by micro jets.

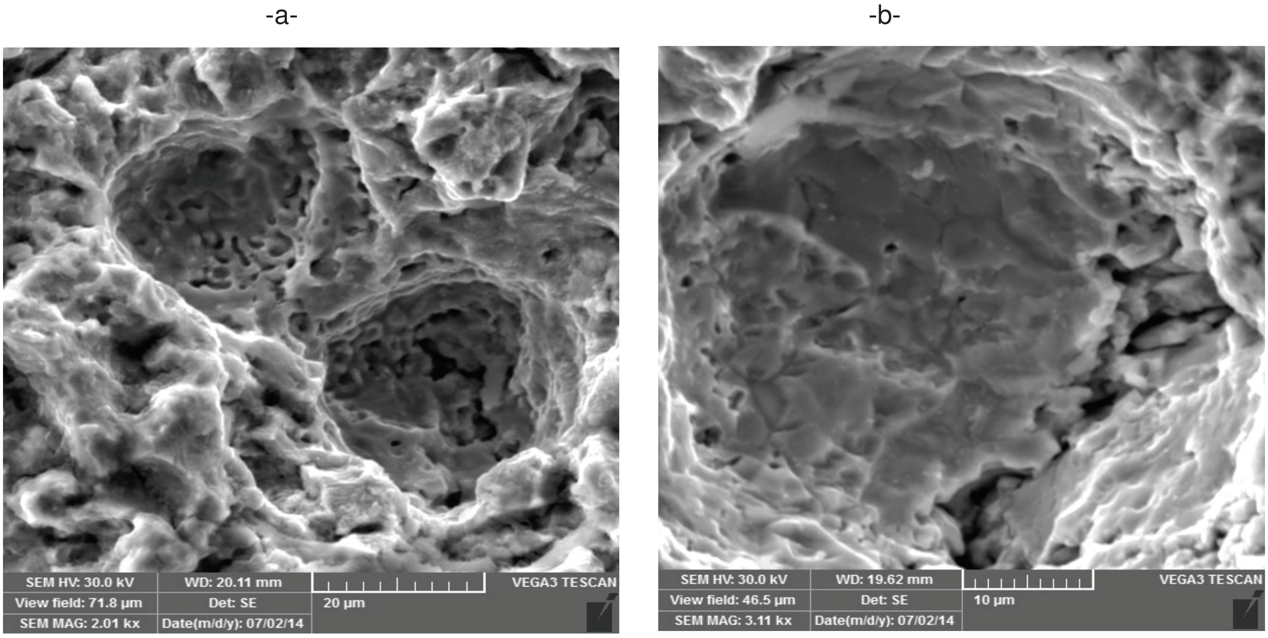


Figure 6 SEM image with the former areas of graphite nodules:
a - x 2000; b - x 3100

4. CONCLUSION

Compared to softening annealing, normalizing heat treatment ensure an increase of resistance of about 1.47 times after the maximum cumulative mean depth of erosion MDE(t), respectively about 1.56 times after the parameter values for speed stabilizes MDER.

Tested surface topographies shows that the initiation of the cavitation erosion takes place on the ferrite-graphite interface and by increasing the duration of attack it produces a partial fragmentation and expulsion of graphite nodules.

Increasing the proportion of pearlite in the microstructure after applying the normalization justifies the improvement of the resistance to cavitation whereas this structural constituent has higher mechanical strength, will oppose to surface deformation.

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