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Metallurgical, Mechanical and Electrochemical Behavior Study of the Lamellar Gray Cast Iron Treated with Vanadium

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This study is concerned with the research and development in the field of materials science, leading to the industrial applications especially for the development of materials by moulding process. The purpose of this study was to determine the influence of vanadium on microstructural, mechanical and electrochemical properties of gray cast iron with lamellar graphite EN-FGL250. We investigated the effect of adding element (vanadium), during the casting of the metal in the mould, in a powder form having a particle size of 0.5 mm with the amounts of 1%, 3% and 5% in weight percent on microstructural and mechanical properties of gray cast iron with lamellar graphite. The originality of this work is the addition of the vanadium powder during the last stage of cooling of the melted gray cast iron EN-FGL250. These additions have a significant impact on the solidification phenomenon since the deposited vanadium powder into the sand moulds creates the new sites of nucleation and absorbs a lot of heat leading to the fast cooling. From the experimental results, we can confirm that the cooling rate directly affects the microstructural, mechanical and electrochemical behavior of the cast gray iron treated with vanadium. As result, it was observed that there is a slight decrease of the elasticity modulus of the work pieces, and a reduction of the maximum tensile resistance R_{m}. Finally, the addition of vanadium considerably reduces the corrosion current of gray cast iron treated with vanadium.

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1. Introduction

The diversity in the applications of iron alloys is primarily due to the role played by the adding elements used as interstitial or substitutional to form the different solid solutions. This is one of the first challenges facing the metallurgist researcher to define the importance that plays each adding element that may have a synergistic or opposite influence, depending on their contents but especially for further use in the development of iron alloys.

Indeed, the presence of flakes in lamellar gray cast iron reduces the strength of the material and acts as cracking agents that cause the mechanical failures. This morphology of graphite leads to the brittleness of gray cast iron.

In this material, the cracks tend to propagate along the flakes, turning into gray the surface of fractured lamellar gray cast iron. In addition, our objective in this study will be focused on improving the mechanical and chemical properties of gray cast iron EN-GJL250 (industrial cast iron).

We aim at studying the influence of the addition of vanadium at different contents 1%, 3% and 5% in the form of a powder grain size of 0.5 mm on the microstructural and mechanical behavior of gray cast iron with flake graphite EN-GJL250.

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2. Experimental

We have used the permanent model (wood pattern) for achieving the imprint of mould during the casting process. The specimens for the tensile tests are obtained by the sand casting in the foundry El Harrach (ALFEL) following the French standard norm AFNOR NF A32-101 [1].

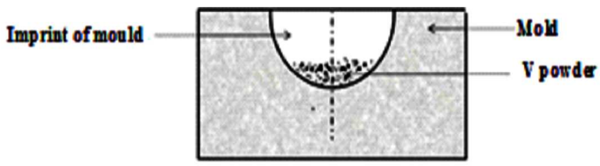

Fig. 1. The mould used for the casting process.

For this purpose, we have done the following steps:

- The confection of silico-clay sand molds for casting;
- The preparation of vanadium powders;
- The necessary amount of deposition of powders inside the mold (Fig. 1);
- The preparation of the charge, melting and casting in the treated mold.

The elaborated samples are observed by an optical microscope (Zeiss) equipped with a camera connected to a computer. The samples are also characterized by the tensile tests using a machine (INSTRON HDX 1000) with an applied load up to 50 kN on the test pieces prepared by molding. The potentiodynamic experiments are conducted through a three-electrode cell connected to PARSTAT 4000 system. A saturated calomel electrode SCE was used as a reference to measure the potential across the electrochemical interface and a carbon sheet as counter electrode. The sweep rate was taken as 1 mV s^{-1}. The electrochemical results are automatically collected and analyzed with VersaStudio software.

3. Results and discussion

The morphology of the as-cast pig iron is observed by an optical microscope shown in Fig. 2. The resultant microstructure is typical for the conventional gray cast irons in comparison with other studies [2–8].

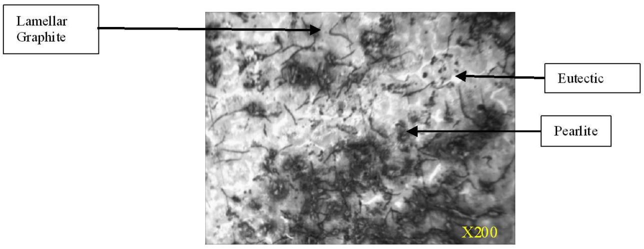

Fig. 2. Optical micrograph of the as-cast pig iron.

Indeed, the appearance of three predominant structures that characterize the gray cast iron with lamellar graphite is highlighted by our observations, these are:

- Graphite appears as lamella;
- Pearlite characterized by a dark contrast in the matrix of gray cast iron with lamellar graphite;
- The phosphorous eutectic having a bright contrast is located inside the pearlitic matrix.

We have performed the tensile tests on the gray cast iron (EN-GJL250). Figure 3 gives the evolution of tensile stress as a function of tensile strain for the gray cast iron.

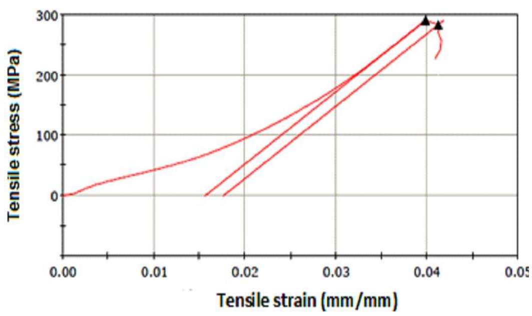

Fig. 3. Tensile curve of the test specimen of pig iron cast EN-GJL250.

The as-cast pig iron presents an elastic behavior with a value of the conventional yield strength tensile strength about 283 MPa and the tensile strength reached a value of 290 MPa. These results are comparable with those given in Ref. [3]. Therefore, the cast iron EN-GJL250 is characterized by a brittle fracture.

We have done a qualitative comparison regarding the microstructure of the gray cast iron treated with vanadium at different contents. Figure 4 shows a series of optical micrographs of the cast iron treated with vanadium for increasing contents.

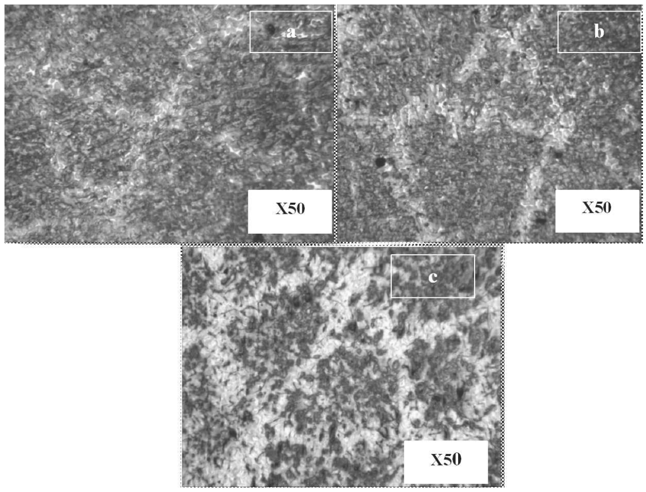

Fig. 4. Optical micrographs of cast iron treated with vanadium having a mean particle size of 0.5 mm: (a) 1% V, (b) 3% V, (c) 5% V.

With the change in the content of the adding vanadium in the elaborated cast iron, we can conclude:

- The fineness of cast iron increases with the proportion of the adding vanadium.
- The presence of the phosphorous eutectic at the grain boundaries is pronounced with increasing vanadium content. The distribution of the phosphorous eutectic varies considerably with the cooling rate of the gray cast iron [2].

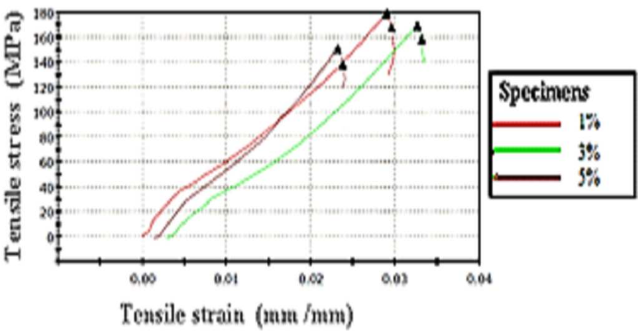

Fig. 5. Tensile curves of samples treated with vanadium.

The results of the tensile tests are shown in Fig. 5 for the treated gray cast iron with vanadium. It can be noted that the values of tensile stress are decreased with increasing vanadium content.

Figure 5 show that the behavior of the treated samples is not the same as a function of the vanadium content. Table I gathers the values of conventional yield strength, tensile stress and tensile strain at failure depending on the vanadium content in the treated gray cast iron. All the values of $R_{e0.2}$ and R_m are decreased when the vanadium content is increased.

TABLE I

Values of the yield strength and tensile strength of gray cast iron depending on the vanadium content.

Samples	$R_{e0.2}$ [MPa]	Tensile stress R_m [MPa]	Tensile strain at rupture [mm/mm]
cast iron	283.50	290.88	0.040
1% V	167.97	179.09	0.029
3% V	158.41	169.32	0.030
5% V	138.21	150.99	0.022

Figure 6 gives the variation of yield and tensile strength depending on the vanadium content in the treated gray cast irons. It can be noticed a drop in the tensile strength for 5% of vanadium. This fact can be likely explained by the presence of phosphorus eutectic that causes a brittleness of the treated gray cast iron [3, 7].

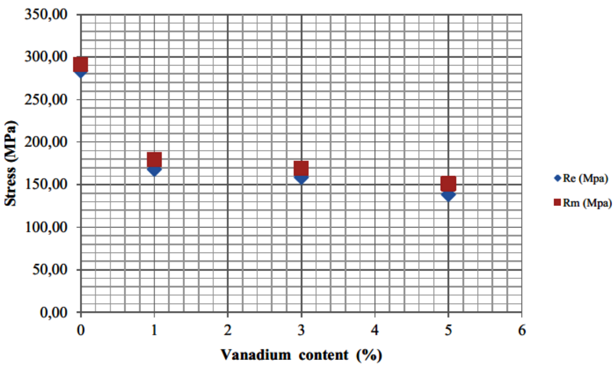

Fig. 6. Evolution of mechanical properties of treated gray cast iron with different vanadium contents.

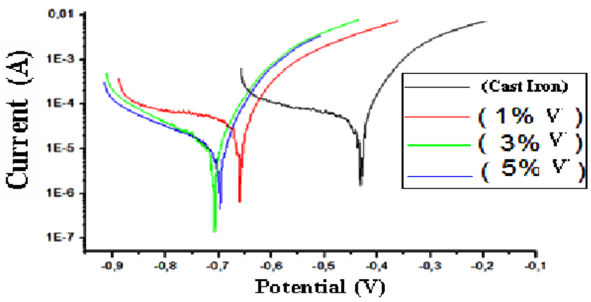

Fig. 7. Polarization curves of the as-cast pig iron and the gray cast iron treated with vanadium using the NaCl solution (3.5 M).

Figure 7 shows the polarization curves of the as-cast pig iron and the gray cast iron treated with vanadium using the NaCl solution (3.5 M). It is seen the corrosion behavior of treated gray cast iron depends on the vanadium element. A best value of corrosion resistance is observed for a content of vanadium of 5%. The corrosion parameters are determined from the exploitation of the Tafel curves using the Versa Studio software. The main results are summarized in Table II.

TABLE II

Parameters of the electrochemical corrosion of the samples with 1% V, 3% V and 5% V using the NaCl medium (3.5 M).

E_{ch}	I_{cor} [μA]	E $(I = 0)$ [mV]	B_c [mV]	B_a [mV]	R_p [Ω]
EN-GJL250	47.51	–431.10	466.05	49.19	125.89
1% V	12.07	–706.61	177.63	48.98	228.63
3% V	60.43	–658.95	2.27	77.15	192.16
5% V	12.64	–697.86	245.40	49.33	274.92

We have found the following results from Table II:

1. The value of the corrosion potential of samples 1% V, 3% V and 5% V is shifted towards negative values.

2. The corrosion current of the sample at 3% V has a high value of the corrosion current.

3. The increase in the content of vanadium has considerably reduced the value of corrosion current.

4. The polarization resistance has a maximum value for the sample treated with 5% of vanadium.

4. Conclusion

This study is concerned with the study of the gray cast iron treated with vanadium element using the sand moulding process.

The following concluding point can be drawn as follows:

- The fineness of the microstructure of the treated gray cast iron increases with the vanadium content.
- Segregation of the phosphorous eutectic occurs at the grain boundaries of pearlite.
- The addition of 1% vanadium decreases the maximum tensile strength of about 100 MPa and the yield strength of 120 MPa in comparison with the as-cast pig iron.
- The value of the corrosion potential of samples treated with vanadium is shifted towards negative values compared with those measured for the as-cast pig iron (GJL250).

- The increase in the vanadium content considerably reduces the corrosion current.
- The polarization resistance increases with an increase in the vanadium content.

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