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INFLUENCE OF AUSTEMPERING HEAT TREATMENT ON MECHANICAL AND CORROSION PROPERTIES OF DUCTILE IRON SAMPLES

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Mechanical properties and corrosion resistance of metals are closely related to the microstructure characteristics of the material. The paper compares the results of these two sets of properties after investigating samples of base ductile iron and heat-treated samples of the base austempered ductile iron (ADI). The basic material is perlite ferritic iron alloyed with copper and nickel. To test the corrosion rate of the base material (ductile iron) and the heat-treated samples (ADI), electrochemical techniques of potentiostatic polarization were used (the technique of Tafel curves extrapolation and the potentiodynamic polarization technique).

Key words: ductile iron, austempering heat treatment, corrosion, mechanical properties, tafel curves

INTRODUCTION

Ductile iron is an iron based alloy that contains a carbon content that exceeds its solubility in iron. The high carbon content causes the presence of pure carbon or graphite embedded in the iron matrix. In the case of ductile iron, the shape of the graphite is spheroidal or round (graphite nodules). The material is usually referred to as ductile iron, nodular cast iron or spheroidal graphite iron.

Austempered ductile iron (ADI) is a heat-treated ductile iron. ADI has many good properties such as a very favorable combination of high strength and ductility, good wear resistance and high fatigue strength. Its increased mechanical properties compared with ductile iron are related to the specific microstructure of ADI called "ausferrite" that consists of acicular ferrite (α) and high carbon (retained) austenite (γHC).

Austempering is a heat treatment process applied to ductile iron in order to improve its properties. A precondition for a successful heat treatment process is the high quality of the base ductile iron. Good quality base ductile iron means following: a minimum nodule count (higher than 120 / mm^2), a minimum nodularity of 85 % and consistent chemistry.

A high nodule count is important to minimize the segregation of the alloying elements and prevent the possibility of carbide formation. The segregation of the alloying elements and the carbide presence in the matrix can delay the start of the ausferrite transformation and decrease its rate.

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The morphology of the micro constituents (acicular ferrite and retained austenite), their volume fraction and the carbon content of the austenite depend on the applied heat treatment of ductile iron, (Figure 1) [1,2].

The heat treatment usually consists of five steps.

- Heating to the selected austenitizing temperature (AB),
- Holding at the austenitizing temperature (BC),
- Cooling (very fast) to the temperature of isothermal transformation (CD),
- Holding at the temperature of isothermal transformation (DE),
- Cooling to room temperature (EF) [5].

Many scientists have studied the influence of the above-mentioned parameters on the evolution of the microstructure and the mechanical properties of ADI. There are two isothermal temperature ranges for ADI production. Low temperature ADIs (where the temperature of the isothermal transformation: 250 °C - 330 °C) have increased hardness, high strength and low ductility. As has already been stated, ADI is a ferrous, cast

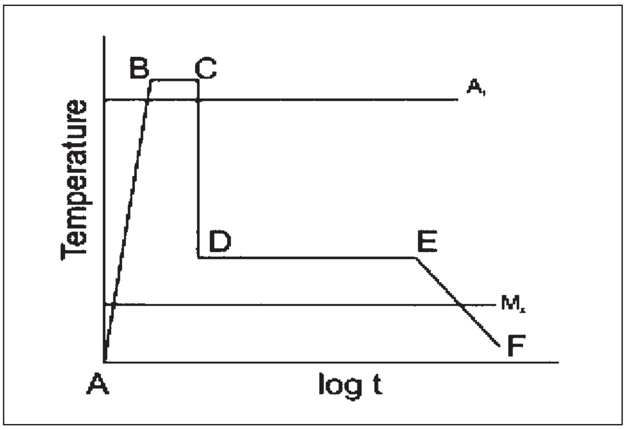

Figure 1 Heat treatment diagram [1,2]

material with a high strength-to-weight ratio and good dynamic properties. The strength decreases with the increasing temperature of isothermal transformation, while the ductility increases simultaneously. High temperatures ADIs (where the temperature of isothermal transformation: 350 °C - 420 °C) produce a typically upper ausferritic microstructure, which consists of broad blades of isolated ferrite with a high tensile toughness [3,4]. Despite these good properties, many designers are not so familiar with the savings related to using this material that can compete favorably with steel and aluminum castings, weldments and forgings.

EXPERIMENTAL PROCEDURE

The first step of the experiment was the investigation of the mechanical properties of the base ductile iron material and its corrosion behavior. The chemical composition of the ductile iron used in the experiment is given in Table 1.

Table 1 **Composition of ductile iron / wt. %**

C	Mn	Si	P	S	Cr	Ni
3,29	0,31	2,53	0,015	0,013	0,053	0,81
Cu	Mg	Mo	Ti	Sn	V	W
0,51	0,031	0,002	0,004	0,006	0,003	0,004

Ductile iron was poured into U blocks for further investigation according to EN1564:1997.

The microstructure of the investigated material was studied using optical microscopy and Scanning Electron Microscopy techniques.

For the investigation of the mechanical and ductile properties of the base material, universal machines for the tensile test and the charpy impact test were used.

To test the corrosion rate of the base material (Ductile iron) and the heat-treated samples (ADI) electrochemical techniques of potentiostatic polarization were used (the technique of Tafel curves extrapolation and the potentiodynamic polarization technique). The survey was conducted on a Potentiostat / Galvanostat, Princeton Applied Research Model 263A-2 device, using the PowerCORR® software package. The samples were treated in a 1% solution of hydrochloric acid at room temperature (20 - 22 ° C) [6, 7].

In order to obtain austempered ductile iron (ADI), the U blocks were cut into 20 x 35 x 200 mm pieces for the heat treatment process. An austenitization holding temperature of 850 °C was selected. The heat treating procedures were as follows: austenitizing at 850 °C for one hour, rapid cooling to the temperature of isothermal transformation (370 °C), holding at the temperature of isothermal transformation for 90 min in a KNO_3 salt bath and cooling to room temperature in the air (Figure 2).

After heat treatment the test specimens for the investigation of the microstructure, mechanical and ductile properties were prepared and investigated using the same procedure as for the base ductile iron.

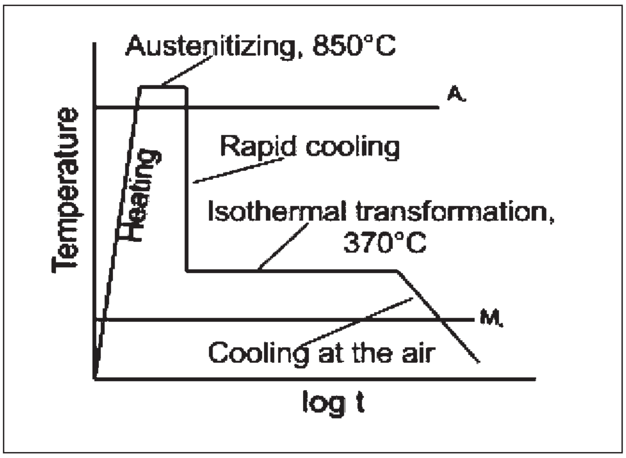

Figure 2 Heat treatment diagram of ductile iron

RESULTS AND DISCUSSION

The first step of the investigation was the characterization of the base ductile iron. The microstructure of the base ductile iron is presented in Figure 3. Analyzing the polished surface of the prepared samples, Figure 3a, it can be concluded that the microstructure consists of graphite nodules embedded into a metallic matrix. The graphite nodularity of the base material produced was higher than 85 %. The nodule count per mm^2 was higher

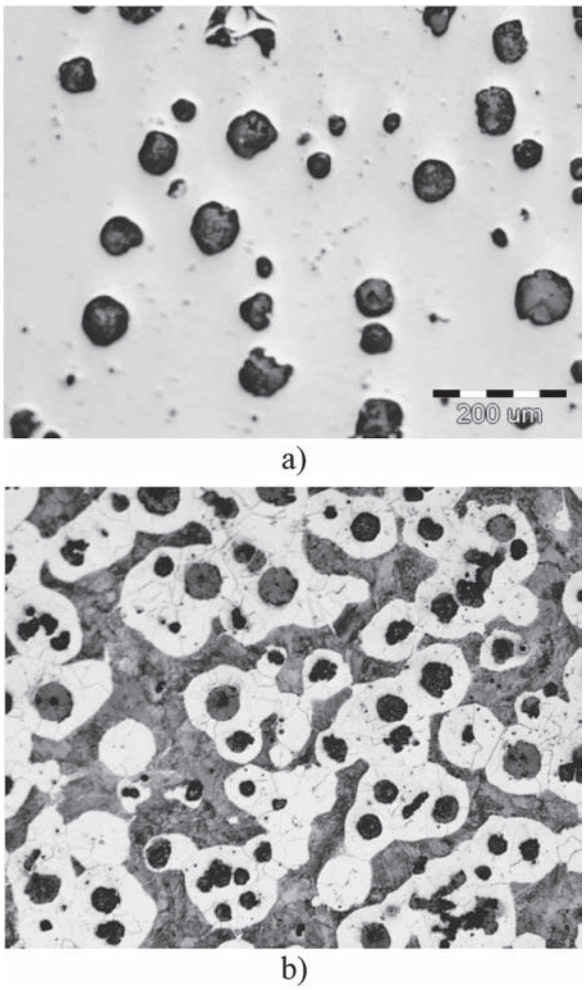

Figure 3 Microstructure of base nodular iron, a) polished 100x, b) etched, Nital, 100x

than 120. According to the high nodule count and good level of nodularity, the produced base material was suitable for heat treatment.

After nital - etching of the polished samples, a ferrite - perlite metallic matrix was observed. (with a typically Bull's eye microstructure). The perlite / ferrite ratio of the base ductile iron microstructure was 55 % / 45 %.

The average values of the three tests of mechanical and ductile properties of the base ductile iron are presented in Table 2.

Table 2 **Mechanical and ductile properties of the base ductile iron**

Order number	Yield strength $Rp_{0,2}$ / N/mm^2	Tensile strength R_m / N/mm^2	Elongation *A* / %	Reduction of area *Z* / %
1.	419	658	7,8	10
2.	426	657	7,6	10
3.	414	657	7,6	11
Average:	420	657	7,8	10

After finishing the examination of the base ductile iron according to the plan of the experiment, heat treating of the samples was conducted. The examination of the heat treated samples was finished using the same apertures and methods as in the case of base ductile iron [8].

The average values of the three tests of mechanical properties heat treated samples are presented in Table 3.

Table 3 **Mechanical and ductile properties of the heat treated samples**

Order number	Yield strength $Rp_{0,2}$ / N/mm^2	Tensile strength R_m / N/mm^2	Elongation *A* / %	Reduction of area *Z* / %
1.	770	920	10,6	9,0
2.	775	912	10,0	9,5
3.	764	914	10,9	9,1
Average	770	915	10,5	9,2

The microstructure of the heat treated samples is presented in Figure 4. From Figure 4a and Figure 4b it can be seen that the microstructure of the metallic matrix was fully ausferritic. The characteristics of the fracture surface (Figure 4c) can be considered as ductile.

Table 4 and Figure 5 present the results of tests of the corrosion rate using the technique of Tafel curve extrapolation. The results in Table 4 indicate that the basic material has a much higher corrosion current density and a slightly lower potential of open circuit in relation to the heat-treated samples.

Using a potentiodynamic polarization technique, Figure 5 also shows that the samples of the base material show more corrosion activity in a 1 % solution of hydrochloric acid. The current density at all scanned potentials is greater for the base material, Figure 6.

CONCLUSION

In summarizing the collected data after sample investigation, it is obvious that heat treatment is a very

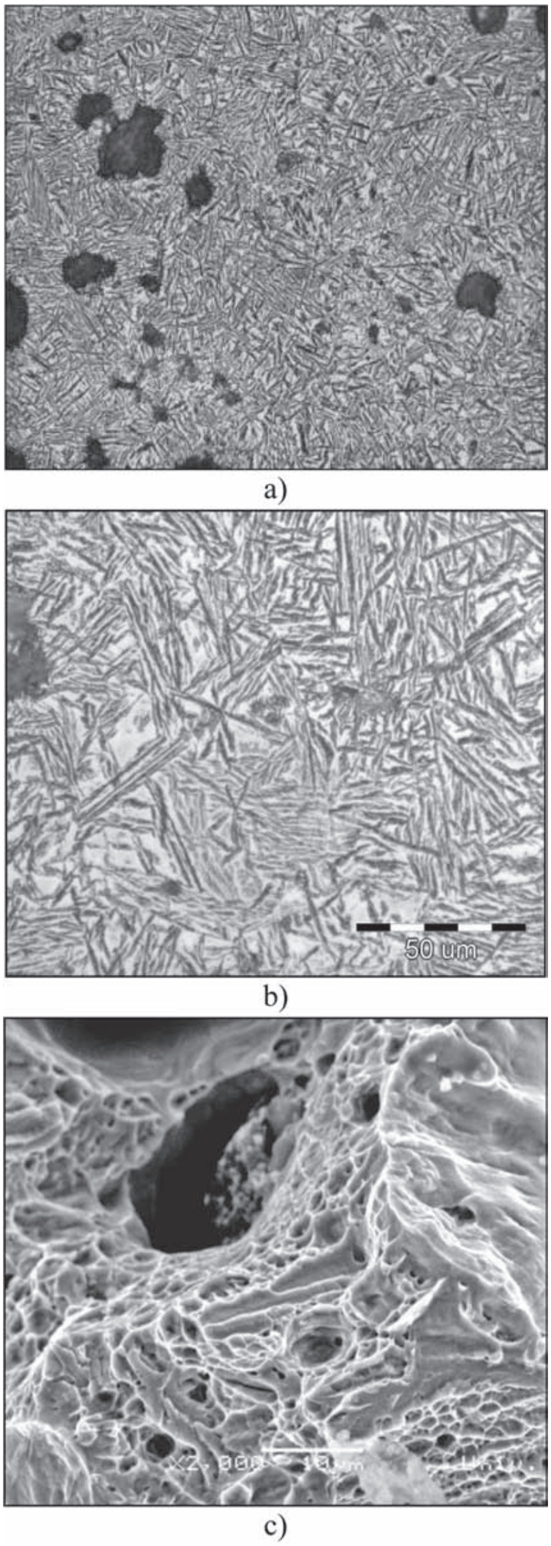

Figure 4 Heat-treated ductile iron, a) Ausfferrite microstructure, 100x, Nital etched, b) Ausfferite microstructure, 500x, Nital etched, c) Fracture surface of the heat treated samples (SEM 2000x)

Table 4 **Current density and open circuit potential of the tested samples**

Samples	Current density *i* / μAcm^{-2}	Open circuit potential *E*(i=0) / mV
Heat-treated samples (ADI)	$6,422 \cdot 10^1$	-462,114
Base material (ductile iron)	$2,648 \cdot 10^2$	-481,172

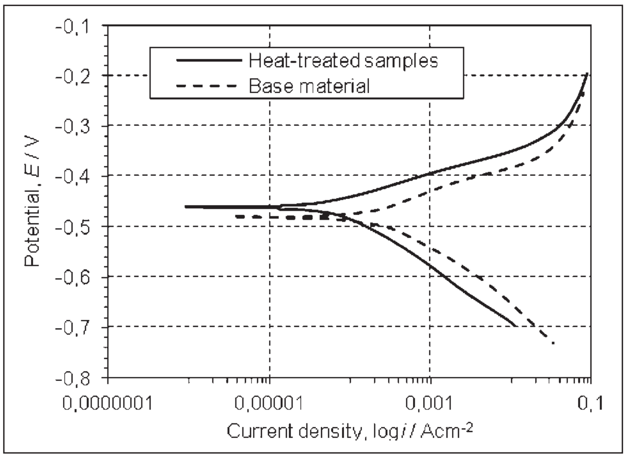

Figure 5 Tafel curves of the samples treated in 1 % HCl, for: heat-treated samples (ADI) and base material (ductile iron)

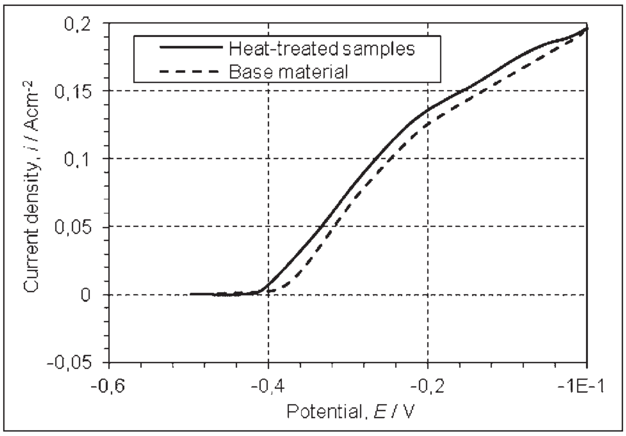

Figure 6 Anodic polarization curves of the samples treated in 1 % HCl, for: heat-treated samples (ADI) and base material (ductile iron)

powerful tool for getting material which is superior to base material. The plan of the experiment was prepared correctly and the results obtained were as expected. The microstructure of the heat treated samples was fully ausferritic, which indicates that the chosen heat treatment parameters were correct. The tensile strength of the heat treated material increased by up to 30% compared to base ductile iron, while keeping the ductile properties at the same level. According to the results from Table 4, it can be concluded that in the 1% solution of hydrochloric acid, the base material shows much more corrosion activity than the heat treated samples.

Acknowledgements

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Note: The person responsible for English language translation: Matt Whiffen, MA. The Institute of Foreign Languages, University of Montenegro, Podgorica, Montenegro