Predicting ADI mechanical properties

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Abstract

Ductile cast iron was quench-hardened with the isothermal transformation according to two alternatives. The first treatment alternative consisted in the austenitizing process at temperature $t_a = 830$, $860$ and $900$°C and annealing at temperature $t_p = 400$, $350$ and $300$°C in a period of time up to 240 min. The second treatment alternative consisted in dual-stage austenitizing. The material was annealed in temperature of $t_p = 950$°C and cooled to temperature $t_a = 900$, $860$ and $830$°C. The isothermal transformation was performed in the same conditions as in the first alternative.

The cast iron was ferritizingly annealed before the isothermal quench-hardening. The cast iron matrix after the annealing was ferritic. Metallographic cubic specimens with the size about of 10 mm were quench-hardened with the isothermal transformation. Matrix microstructure, austenite percentage and Vicker’s hardness were determined using the specimens. Hardness test results were used to determine, on the base of material coefficients, tensile strength $R_m$, yield strength $R_{p0.2}$ and deformation $A_5$. Tests showed that heat treatment according to two alternatives of the quench hardening led to obtain ADI cast iron with accordance to PN–EN 1564 : 2000 grade: EN–GJS–800–8, EN–GJS–1000–5, EN–GJS–1200–2. Only ausferritic cast iron was assumed as a base of qualification.

Keywords: Austenitizing, Isothermal transformation, Properties

1. Introduction

Relations describing influence of hardness on steel strength and plasticity have been known for a very long time. Descriptions are based on mathematical formulas but they are only connected with only one technological state.

Producing castings from ADI cast iron, there is applied quench hardening with the isothermal transformation in order to create high-carbon austenite and ferrite saturated with carbon in the matrix. Such a constant of microstructure is called ausferrite, and the process of the isothermal transformation of precooled austenite is called ausferritising [4-6].

The matrix microstructure consisting of austenite and ferrite is important in the ADI high-grade cast iron technology [1-3].

In the cast iron quench hardening operation the austenitizing process, consisting in heating to temperature higher than $A_{c1}$, has to homogenize the metal matrix and enrich austenite with carbon. During heating of the cast iron to austenite carbon atoms, coming from emissions of graphite, diffuse. The metal matrix austenitising process and the role of graphite in its carbonizing were presented in the paper [7].

Austenitizing usually takes places in range of $815 \pm 950$°C. The effect of austenitising depends on the chemical composition of the matrix, the input structure of cast iron before quench hardening, emissions of graphite, temperature and time of warming, and on homogeneity of elements in eutectic grains also and growth of grains.

Investigations on ADI cast iron are mainly concentrated on the ausferrite transformation [3, 8, 9]. It is very rational attitude because microstructure of the metal matrix has the main influence on formation of high strength, good plasticity and impact strength of the cast iron.
The investigation aimed at predicting of strength and plasticity of ADI ductile cast iron on the base of its hardness tests. Whereas obtained test results in comparison with experimental tests results performed in source works might be an essential piece of engineering processes during material designs.

2. Material, program and methodology of investigations

The investigated ductile cast iron was smelted in a hot blow industrial acid cupola. The spheroidization of cast iron was performed by the ML5 magnesium-alloy by means of the rod method in a reservoir of the cupola. The cast iron was cast to moist sand forms. The casts had the YII ingot shape according to (PN - EN 1563:2000). The cast ductile iron was classified to species EN - GJS-500-7 basing on the static tensile test. The cast iron was characterized by the ferrite - pearlite (10 % pearlite) structure of the matrix and the correct nodular graphite form (11,5 % graphite on surface, 112 precipitations/ mm² of the micro section).

The chemical composition and properties of the plain cast ductile iron are presented in the table 1.

Table 1.
The chemical composition and mechanical properties in ductile iron

<table>
<thead>
<tr>
<th>Component</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>%, mas.</td>
<td>3.65</td>
<td>2.59</td>
<td>0.18</td>
<td>0.052</td>
<td>0.014</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Mechanical properties

<table>
<thead>
<tr>
<th>( R_m ), MPa</th>
<th>( A_s ), %</th>
<th>H, HV10</th>
<th>KCG, J/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>507</td>
<td>12.1</td>
<td>156</td>
<td>106</td>
</tr>
</tbody>
</table>

Lower cuboidal parts of YII specimens were ferritizingly annealed according to the scheme presented in the paper [17]. Next the ingots were cut into three flat bars. Keeping the sequence of the position of the cut from the ingot flat bars they were marked and cut into 54 specimens with dimensions of 10x10x10 mm.

Metallographic specimens were quench-hardened with the isothermal transformation according to schemes presented in fig. 1 and 2. One specimen was prepared for the each alternative treatment.

In order to evaluate the microstructure micro sections were done on heat treated specimens. That test was a base for qualification. Consequently to predict chosen mechanical properties quench hardened specimens with the isothermal transformation in time \( \tau_{pi} = 8 \div 120 \) min were used because the matrix of cast iron consisted of ausferrite.

The hardness test was performed with the usage of the HPO 250 durometer with loading 294 N. The results of Vicker’s hardness were exchanged by means of comparison tables into Brinell’s one.

For the purpose of diagrams’ plotting and determination of the mathematical relationships, among HB hardness and \( R_m, R_{p0,2} \) and \( A_s \), there were used material coefficients calculated on the base of the PN-EN 1564:2000 standard.
3. The results of investigations and their analysis

The results of investigations of hardness as function of time of isothermal precooling are showed on the figures 3 - 8.

Fig. 3. The influence of ausferritizing time on hardness of the hardened cast iron according to the alternative I form temperature $t_y = 830^\circ\text{C}$ and at temperature $t_{pc}$: a) 300, b) 350 and c) 400$^\circ\text{C}$

Fig. 5. The influence of ausferritizing time on hardness of the hardened cast iron according to the alternative I form temperature $t_y = 860^\circ\text{C}$ and at temperature $t_{pc}$: a) 300, b) 350 and c) 400$^\circ\text{C}$

Fig. 4. The influence of ausferritizing time on hardness of the hardened cast iron according to the alternative II form temperature $t_y = 950^\circ\text{C}$ and at temperature $t_{pc}$: a) 300, b) 350 and c) 400$^\circ\text{C}$

Fig. 6. The influence of ausferritizing time on hardness of the hardened cast iron according to the alternative II form temperature $t_y = 950^\circ\text{C}$ and at temperature $t_{pc}$: a) 300, b) 350 and c) 400$^\circ\text{C}$
From diagrams 4-7 it can be unequivocally stated that gradual austenitizing (treatment alternative II) essentially influences hardness of cast iron. Hardness of specimens quench hardened according the the alternative II is bigger then heat treated according to the alternative I.

Basing on material coefficients (1), (2) and (3) the values of tensile strength $R_m$, yield strength $R_{p0.2}$ and deformation $A_5$ were calculated. Values of material coefficients were determined on the base of minimum values of $R_m$, $R_{p0.2}$ and $A_5$ of ADI cast iron included in the PN-EN 1564 : 2000 standard.

$$m = \frac{H}{R_m}$$

(1)

$$p = \frac{R_{p0.2}}{R_m}$$

(2)

$$q = \frac{A_5}{H} \cdot 100\%$$

(3)

where:
- $H$ - hardness [HB],
- $R_m$ - tensile strength [Mpa],
- $R_{p0.2}$ - yield strength [Mpa],
- $A_5$ - deformation [%].

The values of mechanical properties result direct from the temperature $t_{pi}$, so for predicting were assumed material coefficients which are presented in the table 2.

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Isothermal transformation temperature, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>300</td>
</tr>
<tr>
<td>$m$</td>
<td>0,271</td>
</tr>
<tr>
<td>$p$</td>
<td>0,786</td>
</tr>
<tr>
<td>$q$</td>
<td>0,263</td>
</tr>
</tbody>
</table>

Results of tensile strength $R_m$, yield strength $R_{p0.2}$ and deformation $A_5$ for individual conditions of quench hardening according to alternatives I and II were presented in fig. 9-14.
Fig. 9. The influence of ausferritizing time on $R_{p0.2}$, $R_m$ and $A_5$ of quench hardened cast iron according to the alternative I form temperature $t_f = 830^\circ C$

Fig. 10. The influence of ausferritizing time on $R_{p0.2}$, $R_m$ and $A_5$ of quench hardened cast iron according to the alternative II form temperature $t_f = 950^\circ C$; $t_f = 830^\circ C$
Fig. 11. The influence of ausferritizing time on $R_{p0.2}$, $R_m$, and $A_{05}$ of quench hardened cast iron according to the alternative I form temperature $t_f = 860^\circ C$.

Fig. 12. The influence of ausferritizing time on $R_{p0.2}$, $R_m$, and $A_{05}$ of quench hardened cast iron according to the alternative II form temperature $t_f = 950^\circ C$ and $t_f = 860^\circ C$. 

- $300^\circ C$, ▲ $350^\circ C$, ■ $400^\circ C$
Fig. 13. The influence of ausferritizing time on $R_{p0.2}$, $R_m$, and $A_5$ of quench hardened cast iron according to the alternative I form temperature $t_f = 900°C$.

Fig. 14. The influence of ausferritizing time on $R_{p0.2}$, $R_m$, and $A_5$ of quench hardened cast iron according to the alternative II form temperature $t_f = 950°C$ and $t_y = 900°C$. 
4. Conclusions

Quench hardening with the isothermal transformation, according to alternatives I and II, was evaluated on the base of prediction of chosen mechanical properties of ADI. Parameters of heat treatment were attributed to suitable cast iron grades (table 3).

Table 3.
ADI grades classified with accordance to PN-EN 1564 after quench hardening according to alternatives I and II

<table>
<thead>
<tr>
<th>Temp. $t_{ph} ^{\circ}$C</th>
<th>Time $\tau_{ph}$ min</th>
<th>Heat treatment Alternative I</th>
<th>Heat treatment Alternative II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>350</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>•</td>
<td>•</td>
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<td></td>
<td>15</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>300</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- EN – GJS – 800 – 8,  
- EN – GJS – 1000 – 5,
- EN – GJS – 1200 – 2,  
- EN – GJS – 1400 – 1

From the table 3 results that high-strength grades (1200, 1400 MPa) can be obtained by quench hardening according to the alternative II 300, 350°C, Grades (800, 1000 MPa) – in temperature 400°C. Isothermal quench hardening according to the alternative I would let to obtain ADI cast iron – all grades, only after austenitizing in temperature 900°C.

Experimental investigations to verify the predicted mechanical properties will be continued.

Acknowledgements

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References