Comparison of achieved parameters results of high-strength ductile cast iron by different way of heat treatment

Š. Eperješi*, J. Malik, I. Vasková, É. Eperješi, D. Fecko
Technická univerzita v Košiciach, Letná 9, 04001 Košice, tel. 055 6023140, *Corresponding author. E-mail address: stefan.eperjesi2@tuke.sk
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Abstract

Because of assecuration of requirements for commercial production of ductile cast iron castings were provided the tests of heat treatment of these castings for achieving the desired strength, hardness and ductility. High-strength cast iron can be assured by heat treatment - isothermal refinement or hardening with tempering. Achieved results shown the way of realization this kind of heat treatment and its utilization in practical conditions.

Keywords: Ductile cast iron; Heat treatment

1. Introduction

Castings from ductile cast iron also nowadays are greatly utilized with ferritic, ferritic-pearlitic or pearlitic matrix. The ways of heat treatment of this cast irons more over half century can utilize the beneficial shape of graphite also for higher strength of matrix (martensitic, bainitic or sorbitic matrix).

Nowadays are on the high level revised the methods of through-hardened ductile cast iron. According to requirements for achieving of given parameters of the casting for its purpose of utilization, it can be received according to the cooling medium requested matrix, which gives us the prescribed parameters.

The advantage of ductile cast irons is the possibility of heat treatment by isothermal breakdown to bainite, or by hardening to martensite, or with another treatment to sorbite. By heat treatment we can highly change the structure of metal matrix and their related mechanical properties. Shape and the way of graphite distribution are not changed by the impact of heat treatment, or they change very little. Among most used ways of heat treatment of ductile cast iron belong annealing, refinement and surface hardening.

Under the conception of annealing we describe such ways of heat treatment, which are connected with precrystallization of matrix during heating with another cooling, by which non-steady phases are created. Mostly, two ways are used - hardening with tempering, or isothermal hardening for upper or lower bainite.

2. Experimental part

Isothermal hardening is a two-level process consisting of austentitzation by temperature cca 900°C and consecutive cooling to the temperature of isothermal holding (cca 230 - 400°C). The choice of temperature and isothermal holding time depends on chemical composition of cast iron and initial structural composition of castings matrix. This can be goodly shown from transformation diagram IRA LGG (Fig. 1) [1]. With austempering
hardening in higher temperature area (380 - 400°C) we receive the bainitic structure with residual austenite with high strength and good ductility. With breaking-off in lower temperature area (250 - 350°C) the velocity of bainite precipitation is higher and we receive the finer structure with higher strength, but lower ductility.

![Diagram IRA of non-alloyed ductile cast iron](image1)

**Fig. 1.** Transformation diagram IRA of non-alloyed ductile cast iron with the content of 2.52% Si [1]

1. Austempering in higher temperature area (400 - 380°C)
2. Austempering in lower temperature area (250 - 350°C)

A lot of commercial castings from ductile cast iron is produced with the requirement of hardening into the oil with consequent tempering. With this way we achieve sorbitic matrix with higher strength and hardness, but lower ductility.

For approval of association and comparison of requested properties of commercial casting production (tensile strength min 700 MPa, As - min 1.5%, hardness 260 - 310 HB, hardening and tempering) were executed the below described options of heat treatment of initial castings material - ductile cast iron with ferritic-pearlitic structure after cast:

1. Austempering (austenitization 920°C, holding 60 min, isothermal change, salt AS-140 320°C, holding 60 min, water wash)
2. Hardening and tempering (austenitization 920°C, holding 60 min, hardening in oil 80°C, tempering in furnace 570°C, holding 60 min, cooling in furnace)
3. Hardening and tempering (austenitization 920°C, holding 60 min, hardening in water 40 - 60°C, tempering in furnace 570°C, holding 60 min, cooling in furnace).

<table>
<thead>
<tr>
<th>Heat treatment</th>
<th>UTS [MPa]</th>
<th>HB</th>
<th>As</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1144</td>
<td>295</td>
<td>3,3</td>
<td>bainit, resid., A</td>
</tr>
<tr>
<td>2</td>
<td>898</td>
<td>306</td>
<td>2,1</td>
<td>sorbite</td>
</tr>
<tr>
<td>3</td>
<td>936</td>
<td>313</td>
<td>1,8</td>
<td>sorbite</td>
</tr>
<tr>
<td>Cast phase</td>
<td>583</td>
<td>225</td>
<td>6,4</td>
<td>ferritic-pearlitic</td>
</tr>
</tbody>
</table>

Table 2. Achieved results of requested properties according to the way of heat treatment

Microstructures after heat treatment are shown on Fig. 2, 3, 4 and 5.

![Bainitic structure 500x](image2)

**Fig. 2.** Bainitic structure 500x

![Cast structure ferritic-pearlitic 300x](image3)

**Fig. 3.** Cast structure ferritic-pearlitic 300x

<table>
<thead>
<tr>
<th>Cast phase</th>
<th>UTS [MPa]</th>
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<th>As</th>
<th>Structure</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>583</td>
<td>225</td>
<td>6,4</td>
<td>ferritic-pearlitic</td>
</tr>
</tbody>
</table>

Table 1. Chemical composition of casting material

<table>
<thead>
<tr>
<th>Chem. composition</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Cu</th>
<th>P</th>
<th>S</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>wt. %</td>
<td>3,17</td>
<td>0,18</td>
<td>2,91</td>
<td>0,14</td>
<td>0,25</td>
<td>0,039</td>
<td>0,008</td>
<td>0,026</td>
</tr>
</tbody>
</table>

Table 1. Chemical composition of casting material
3. Conclusions

The results of heat treatment of hardening into salts show the creation of final bainitic matrix in the casting and attributable values of strength, harness and ductility. Basic chemical composition is in the prescribed values of carbon content for the wall thickness of given casting cca 30 mm (cca 3,7% C) (2).

Content of Mn is also in norm, under 0,2%, whereas by higher contents it can segregate along the grain borders, which belongs the holding time of isothermal change and the creation of martensite along the grain borders, what causes the decrease of strength, ductility and hardness of cast iron. The content of Si is suggested to 2,4% for wall thicknesses from 25 mm. The higher contents can cause the occurrence of graphite ball fluctuation and also the creation of free ferrite in isothermal treated cast iron, what must be prevented. On Fig. 2 is the occurrence of this parts observable.

In higher cooling velocities (hardening into water or oil) it is possible to inhibit the change of austenite to ferrite. As a consequence of intense cooling, the bigger part of austenite is changed to hardened accurate structure - martensite, with the same satiation of C and with the same chemical composition as initial austenite. High britteness of martensitic matrix is needed to modify by yielding with heating to temperatures under Ac1. By this, the hardness is lowered, strength and ductility is commonly increases. For hardening of ductile cast iron beneficially affects the alloying elements as Mn, Cr, Cu, Mo - they increase it.

By tempering over 540 °C the secondary graphite can be created during the break-off of martensite, which is very slightly distributed in basic matrix [2]. Because of its occurrence the strength is increased about 10-15%, but the ductility decreases. The increase of strength is evident also from received results by castings hardened into water and oil and subsequently tempered by temperature 570°C.

The tests of heat treatment by isothermal refinement into salt, hardening and tempering with hardening medium as oil and water shown, that required parameters can be assured with all the described ways. For series production was advised the option No 2, hardening into oil and tempering by reason of realization possibilities and decreasing the risk of possible scratches creation by hardening to water. Hardening to the salt desired cooperation and costs for this kind of heat treatment were considerably higher (although it provides best results).

References