The effect of thermal treatment on the mechanical properties of vermicular cast iron

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Received: 26.02.2010; accepted in revised form: 30.03.2010

Abstract

The work determines the effect of austempering (isothermal quenching) on the basic mechanical properties of cast iron with vermicular graphite. The cast iron has been produced in one of Polish foundries. Copper addition in the amount of about 1% has been introduced to the cast iron in order to obtain the pearlitic matrix. The mechanical properties (Rm, R0.2, A5, HB) have been determined both for the as-cast state and after austenitizing at 960°C combined with quenching at 290°C for 90 minutes, and also after austenitizing at 960°C followed by isothermal quenching at 290°C for 150 minutes. It has been found that the thermal treatment, resulting in the cast iron matrix change from the ferritic-pearlitic one to the one composed of acicular precipitates of ferrite and residual austenite, causes a distinct increase in cast iron strength; after the thermal treatment it has reached about 900÷1000 MPa. The examination has been performed using the specimens cut out of the reversed U-block test coupons of walls 25 mm thick and 50 mm high.

Keywords: Vermicular cast iron; Ausferrite cast iron; Austenitizing; Austempering; Mechanical properties.

1. Introduction

The cast iron containing vermicular graphite, commonly regarded as a material of properties intermediate between grey cast iron and nodular cast iron, becomes an object of still growing interest of design engineers. Although its mechanical properties, both strength and plastic, do not reach the level proper for various grades of nodular cast iron, nevertheless the vermicular cast iron exhibits distinctly better heat conductivity than the nodular cast iron. This conductivity is close to that demonstrated by pearlitic grey cast iron [1]. Due to these properties of vermicular graphite, this alloy is wider and widely applied where the moderate plasticity and strength are satisfactory and the high thermal conductivity is demanded. According to the author of Ref. [2], the machinability of vermicular cast iron, as well as its abrasion resistance and thermal fatigue resistance, are much better than those of nodular cast iron.

Vermicular cast iron is applied inter alia for the following types of castings:
- bodies of combustion engines of large compression ratios designed for high combustion temperatures, ingot moulds, piston rings, brake plates, exhaust manifolds, cylinder heads [1];
- gear wheels, parts of machines subjected to vibration during their work, bodies of turbochargers [2];
- moulds for glass industry [3].

The as-cast vermicular cast iron is usually characterised by either ferritic or ferritic-pearlitic matrix. For the ferritic matrix, the tensile strength achieves 330÷340 MPa, the elongation 5÷10%, and the hardness 130÷190 HB. As far as the cast iron with pearlitic matrix is concerned, these values are 400÷580 MPa, 2÷5%, and 215÷250 HB, respectively [1].
It should be noticed that producing vermicular cast iron castings is considered to be rather difficult due to the necessity of maintaining the quantity of the spheroidizing agent in the alloy at a certain strictly determined level [4].

Properties of nodular cast iron can be significantly increased by subjecting the alloy to controlled austempering process. In such a case it is necessary to introduce a proper amount of Mo, Ni, or Cu into the cast iron in order to assure the demanded hardenability. Then it is possible to quench the cast iron to the temperature at which there can proceed the isothermal transition from austenite to ‘ausferrite’ (the metal matrix being a mixture of acicular ferrite and austenite supersaturated with carbon) [1]. Several grades of austempered nodular cast iron, the so-called ADI (Austempered Ductile Iron), are covered by the American Standard ASTM 897 M-90. Such a type of cast iron is also presented in Polish Standard [5]. Tensile strength of ADI cast iron exceeds 1600 MPa, and its elongation is over 10% [1].

It seems that the possibilities of increasing the properties of nodular cast iron by austempering are already relatively well defined. However, there is a lack of accurate data concerning the influence of the considered thermal treatment on the basic properties of vermicular cast iron.

2. Authors’ examinations

The work has been aimed to determine the influence of thermal treatment comprising austenitizing and subsequent isothermal quenching on the basic mechanical properties of cast iron with vermicular graphite.

The vermicular cast iron utilized for examinations has come from one of domestic foundries. Its production has included three operations for which the master alloys produced by SKW Company, Germany, have been used. They have been, subsequently, ‘conditioning’ of the initial cast iron by means of the VL(Ce)2 master alloy, vermicularizing by means of the DENODUL 5 modifier and graphitizing modification by means of the SRF 75 master alloy. The chemical composition of the cast iron subjected to further examinations is given in Table 1.

![Graphite precipitates in as-cast vermicular cast iron](image1)

Table 1. Chemical composition of vermicular cast iron

<table>
<thead>
<tr>
<th>Content [%]</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cu</th>
<th>P</th>
<th>S</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.27</td>
<td>2.80</td>
<td>0.203</td>
<td>0.98</td>
<td>0.0515</td>
<td>0.013</td>
<td>0.016</td>
</tr>
</tbody>
</table>

The content of basic elements occurring in the alloy is similar to the usually met values for such alloys. The copper addition has been introduced in order to pearlitize the matrix and make easier the further thermal treatment.

Test coupons in the form of reversed U-blocks (the IIb type according to the Standard [6]) have been cast of the produced cast iron. Specimens intended both for metallographic examination and for the basic mechanical tests have been cut out of the test parts of the U-blocks. The diameter of the gauge length of tensile specimen has been equal to 10 mm in the case of the as-cast cast iron. Figure 1 presents the shape and the size of graphite precipitates in the as-cast vermicular cast iron, as well as the microstructure of the material.

![Microstructure of vermicular cast iron](image2)

The performed thermal treatment consisted of austenitizing and isothermal quenching in salt bath. Experiments have been performed on sixteen specimens, eight of them being taken from the ingots poured during the initial stage of test moulds pouring, another eight from the ingots cast during the final stage of pouring.

![Shape and size of graphite precipitates](image1)

Table 2. Mechanical properties of the as-cast vermicular cast iron

<table>
<thead>
<tr>
<th>Value</th>
<th>$R_m$ [MPa]</th>
<th>$R_{0.2}$ [MPa]</th>
<th>$A_5$ [%]</th>
<th>HB</th>
</tr>
</thead>
<tbody>
<tr>
<td>minimum</td>
<td>355</td>
<td>290</td>
<td>2.84</td>
<td>159</td>
</tr>
<tr>
<td>maximum</td>
<td>407</td>
<td>325</td>
<td>3.51</td>
<td>175</td>
</tr>
<tr>
<td>average</td>
<td>378</td>
<td>311</td>
<td>3.15</td>
<td>167</td>
</tr>
</tbody>
</table>

Fig. 1. Cast iron with vermicular graphite, the as-cast state: a) the shape and the size of graphite precipitates, non-etched microsection; b) microstructure, etched with Nital
carried out in one of domestic foundries on the industrial stand equipped with the resistance furnace made by ELTERMA Company and the quenching tank. Two options of the thermal treatment have been tested: the first one has comprised austenitizing at the temperature $T_\gamma=960^\circ C$ for $\tau_\gamma=90$ minutes and isothermal quenching at the temperature $T_\alpha=290^\circ C$ for $\tau_\alpha=90$ minutes; the second one has consisted in austenitizing at the temperature $T_\gamma=960^\circ C$ for $\tau_\gamma=150$ minutes and salt bath quenching at the temperature $T_\alpha=290^\circ C$ for $\tau_\alpha=150$ minutes.

Figure 2 shows the structure of vermicular cast iron subjected to austempering according both to the first and to the second option of thermal treatment.

![Figure 2. Microstructure of vermicular cast iron after heat treatment](image)

The heat treatment have been applied for the tensile specimens with 12 mm diameter of the gauge length. After the heat treatment the specimens have been machined once again to achieve the diameter of 10 mm (as it has been for the specimens made of the as-cast alloy) in order to remove the thin scale layer arisen during the annealing process from the surfaces of specimens. Four specimens have been subjected to each of the thermal treatment options. After austenitizing the specimens have been carried together from the furnace to the quenching tank in order to eliminate differences in cooling rates between the individual specimens during this operation.

The obtained values of tensile strength $R_{m\gamma}$, yield strength $R_{0.2\gamma}$, elongation $A_\gamma$, and hardness for the vermicular cast iron subjected to the thermal treatment are gathered in Table 3.

<table>
<thead>
<tr>
<th>Heat Treatment</th>
<th>Value</th>
<th>$R_{m\gamma}$ [MPa]</th>
<th>$R_{0.2\gamma}$ [MPa]</th>
<th>$A_\gamma$ [%]</th>
<th>HB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st option of heat treatment</td>
<td>minimum</td>
<td>910</td>
<td>834</td>
<td>0.2</td>
<td>354</td>
</tr>
<tr>
<td></td>
<td>maximum</td>
<td>981</td>
<td>887</td>
<td>0.8</td>
<td>451</td>
</tr>
<tr>
<td></td>
<td>average</td>
<td>941</td>
<td>855</td>
<td>0.47</td>
<td>401</td>
</tr>
<tr>
<td>2nd option of heat treatment</td>
<td>minimum</td>
<td>943</td>
<td>860</td>
<td>0.2</td>
<td>426</td>
</tr>
<tr>
<td></td>
<td>maximum</td>
<td>970</td>
<td>944</td>
<td>0.4</td>
<td>468</td>
</tr>
<tr>
<td></td>
<td>average</td>
<td>961</td>
<td>890</td>
<td>0.32</td>
<td>448</td>
</tr>
</tbody>
</table>

### 3. Conclusion

The heat treatment of vermicular cast iron which comprise austenitizing at the temperature $T_\gamma=960^\circ C$ and subsequent isothermal quenching at the temperature $T_\alpha=290^\circ C$ leads to the obtaining of structure consisting of ferrite and residual austenite. This influence to a great degree the mechanical properties of the alloy. The tensile strength of the thermally treated vermicular cast iron reaches 940-960 MPa, while the hardness of the considered cast iron after heat treatment rises to the level of 400-450 HB which is of about 230-280 units higher than for the as-cast state of vermicular cast iron.

The increase in strength properties of vermicular cast iron subjected to austempering is accompanied by the drop in its plasticity. Thus if the elongation of the cast iron in the as-cast state has been equal to about 3%, it has dropped after the heat treatment to the level of 0.3-0.5%.

The examined cast iron has been subjected to the heat treatment performed according to two options. For both of them the austenitizing and the isothermal quenching temperatures have been the same ($T_\gamma=960^\circ C$, $T_\alpha=290^\circ C$), and the both options of heat treatment have differed only in the time of maintaining the specimens in the austenitizing temperature (90 minutes for the first option, 150 minutes for the second one) and in the time of isothermal quenching (also 90 minutes and 150 minutes, respectively). Comparing the data in Table 3 one can find that the lengthening of austenitizing and isothermal quenching time does not affect significantly the individual properties of vermicular cast iron.

To summarize the obtained results it should be said that the austempering treatment, applied so far in the case of nodular cast iron, allows as well for significant improvement of a series of mechanical properties of vermicular cast iron. It can be supposed that thanks to such a treatment the cast iron with vermicular graphite would be wider
applied in the production of castings and that, perhaps, it would find also new applications.

References


