The influence of austenitization temperature on the anizothermal eutectoid transformation of spheroidal cast iron

T. Szykowny, M. Trepczyńska – Lent*
Faculty of Mechanical Engineering, University of Technology and Life Sciences, Kaliskiego 7, 85-796 Bydgoszcz, Poland
* Corresponding author. E-mail address: trema@utp.edu.pl

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Abstract

In the work one can find the research of anizothermal eutectoid transformation of unalloyed austenitized spheroidal cast iron in the temperature 875 or 1000°C. By means of the metallographic method one prepared TTT diagrams. On the basis of the quantitative metallographic analysis the influence of austenitization temperature on the mechanism and kinetics of the eutectoid transformation was interpreted.

Keywords: spheroidal cast iron, eutectoid transformation, continuous TTT diagram

1. Introduction

The eutectoid transformation in the unalloyed cast iron may occur according to the stable system, that is austenite \( \rightarrow \) ferrite + graphite or metastable austenite \( \rightarrow \) pearlite. The most often the eutectoid transformation in the unalloyed spheroidal cast iron occurs according to both of the systems, which results in the ferrite and pearlite structure [1]. The mutual quantitative relation of the transformation products, the size of the ferrite grains, and the dispersion of pearlite decide about the mechanical properties of the cast iron.

Among the factors which influence the course, kinetics, and the final structure received as a result of the eutectoid transformation in the spheroidal cast iron, one may mention the chemical composition, structure properties which are the effect of the primary crystallization, heating, austenitization, and cooling conditions of the cast iron. The researches on the mentioned concepts are the essence of the works [2 – 14].

The continuous TTT diagram, connecting the location of the temperature transformation and structure with the cooling rate (the thickness of the cast wall), is a rational base for designing the normalization conditions and cast iron ferritisation annealing. The data included in the continuous TTT diagram let us predict the results of the heat treatment of the cast in practise.

The cast iron TTT diagrams are performed experimentally, the most often with the dilatometric method [11, 12, 13, 14]. Any dilatometric method lets us to observe the transformations, but the differentiation of the order, character, and mutual quantitative relations of the creating transformation products creates the problems. Very little dilatation effects accompany the before-eutectoid precipitation of carbide, in the case of the cast iron – the secondary cementite [15].

The influence of the austenitization temperature on the kinetics of the eutectoid transformation was the subject of the research included in the works [10-14, 16]. Generally it is stated that the increase of the austenitization temperature moves the continuous TTT diagram lines according to the vector of the time axis [11, 12]. In the works [13, 14] it was stated that the increase of normalization and cast iron ferritization. The data included in the continuous TTT diagram let us predict the effects of the heat treatment of the cast in practice.
The aim of the work is to determine the influence of austenitization temperature of cast iron on the anizothermal eutectoid transformation on the basis of the quantitative metallographic analysis which let us observe separately the increase of its products, as well as the before-eutectoid cementite.

2. Experimental procedure

As for the research one type of spheroidal cast iron was accepted. The cast iron was smelted in a cupola furnace and cast in the form of YII samples. The chemical, structural, and value composition of critical temperatures is presented in table 1.

Table 1. Characteristic cast iron

<table>
<thead>
<tr>
<th>Chemical composition, % mas.</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Mg</th>
<th>S'</th>
<th>Kg°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3,53</td>
<td>2,81</td>
<td>1,14</td>
<td>0,11</td>
<td>0,015</td>
<td>0,08</td>
<td>1,04</td>
<td>8,71</td>
</tr>
</tbody>
</table>

Austenitization temperature, °C

<table>
<thead>
<tr>
<th>Ac11</th>
<th>Ac12</th>
<th>Ar11</th>
<th>Ar12</th>
</tr>
</thead>
<tbody>
<tr>
<td>795</td>
<td>862</td>
<td>774</td>
<td>685</td>
</tr>
</tbody>
</table>

* the coefficient of eutectic saturation Kg°C was calculated according to Giršowić formula [17]

The cast iron in the cast state is of pearlite and ferrite structure (24,5% ferrite volume). Nodular graphite (Gf7) covers 9,7% of cast iron volume, and occurs in the quality of 107 precipitations as per 1 mm² of the microsection area.

The research samples cut from the cubic part of the YII cast were of the rings shapes of the diameter 20 mm of the thickness equal to 3 mm.

The scheme of the heat treatment is presented figure 1.

![Fig. 1. Scheme of the heat treatment, tA 875 or1000°C](image)

The heat treatment was carried out using the vertical pipe furnaces of izothermal dilatometer of Zakłady Doświadczalnego Instytutu Metalurgii Zelaza in Gliwice production. The set of 7 samples were austenitized in the high-temperature furnace in the temperature 875 or 1000°C for 0,5 h. After the austenitization the set of samples was cooled in a way which guarantees the reception of required repetitive values of cooling rate. With the very moment of achieving the required cooling time (rate v1) or the required temperature (V1), one sample of the set was cooled in water. The greatest rate v1 was achieved by means of cooling the samples in the air. The remaining rates were achieved by using the low-temperature furnace of dilatometer. The furnaces were rinsed with argon. By means of thermoelement Ni-CrNi welded with a sample which were cooled as the last one, the curve of cooling was recorded on the computer. For every cooling rate the sample was used twice. The differences between the temperature values of which the samples were cooled were 10°C.

The average values of cooling rate in the scope of temperatures 800–650°C are presented in table 2.

Table 2. The average values of cooling rate

<table>
<thead>
<tr>
<th>Austenitization temperature, °C</th>
<th>Cooling rate, °C/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>875</td>
<td>v1 10,02 v2 1,75 v3 0,54 v4 0,27 v5 0,06</td>
</tr>
<tr>
<td>1000</td>
<td>v1 9,33 v2 1,74 v3 0,50 v4 0,27 v5 0,05</td>
</tr>
</tbody>
</table>

On the axial section of samples the metallographic microsections were performed which were etched with nital. On the basis of the linear interpolation of the results of metallographic analysis the temperature values were defined, ones which correspond with the occurrence of the eutectoid transformation in the amount occurrence of austenite transformation in η=1% of ferrite or pearlite, and the occurrence of transformation in the amount of η=99%. The general transformation amount constitutes to the sum of ferrite and pearlite precipitation. The temperature values which correspond to the occurrence of the austenite transformation in η=1% and 99%, and temperatures corresponding to the austenite transformation in 1% of pearlite were plotted on the proper cooling curves. This is the way the CTPc diagrams were received.

3. Results and discussion

The content of ferrite, pearlite and general transformation stage of η in the function of cooling temperature for the selected cooling rates (V1, V2, V3) of austenitized cast iron in the temperature 875 and 1000°C are presented in the figure 2,3 and 4.

In the austenitized cast iron in the temperature 875 or 1000°C and cooled with the v1 rate the pearlite transformation occurs only, and the predominant and remaining austenite volume transforms into martensite. The precipitation of the secondary cementite in the amount 5,7% of volume is characteristic for the austenitized cast iron in the temperature 1000°C (fig. 2).

In the case of the austenitized cast iron in the temperature 1000°C and cooled with the v2 and v3 rate the pearlite transformation precedes the transformation austenite → ferrite + graphite. For the lower cooling rate (v4, v5) the eutectoid transformation starts according to the stable system, and next, it continues together with the pearlite transformation until the austenite runs out.

The austenitized cast iron cooling in the temperature 875°C with the v2 rate results in the fact that the eutectoid transformation
starts at the same time the crystallization of ferrite (in the contact with graphite) and pearlite (on the borders of the eutectic grains). During cooling with the rates lower than \( v_2 \), the eutectoid transformation starts exclusively according the stable system.

After the crystallization of some ferrite amount, the pearlite transformation starts around graphite. The remaining austenite transforms to the very end both according to the stable system and the metastable one (fig. 2, fig. 3).

In the case of the cooling rates lower than \( v_1 \), in the final effect of the eutectoid transformation, the pearlite and ferrite structure was achieved. The content of the structure elements depends on the cooling rate and the austenitization temperature. Higher rate of cooling and austenitization temperature results in higher pearlite content (fig.5).

In the figure 6 one finds the continuous TTT diagrams of the austenitized cast iron in the temperature 875 and 1000°C. The bold continuous lines correspond to the occurrence of the eutectoid transformation in the degree of \( \eta = 1 \) or 99%, whereas the dashed lines correspond to the transformation of austenite in 1% of pearlite.

The relations between the continuous TTT diagrams of the austenitized cast iron in the temperature 875 or 1000°C may be explained taking into account the initial austenite precipitation with carbon. The carbon content in austenite in the balance state corresponds to the composition in the crossing point of lines E'S' with the isotherm of the austenitization temperature. The structure of the austenitized cast iron in the temperature 875°C saturates to the content of 0.66%, whereas in the temperature 1000°C to the content 0.95%C [18]. The higher initial content of carbon in the austenitized cast iron structure in the temperature 1000°C results in the fact that during the process of cooling with the given rate, austenite is more saturated in respect to cementite than after heating in the temperature of 875°C. The very higher saturation results in the fact that for the \( v_1 \) rate high-carbon phase – cementite educes from austenite. The crystallization of the cementite network simplifies the nucleation and the increase of it around pearlite.

The lower supersaturation of austenite with carbon causes that for the initiation of the pearlite transformation higher cooling is required; this is why the temperature \( Ar_{11} - Ar_{12} \) of the austenitized cast iron in the temperature 875°C in the scope of rates higher than \( v_1 \) is lower. The secondary cementite is also absent.
temperature of 875°C. This is why the temperatures $\text{Ar}_{11}$ and $\text{Ar}_{12}$ in the structure with carbon, that is the austenitized in the higher temperature (in the cast iron of lower initial saturation of austenite with carbon) is reached quicker (in the carbon concentration in the cooled austenite. The properly low to the stable system, it is necessary to obtain the properly low metastable or stable ones (of the cooling rates higher than $v_\gamma$), which point the eutectoid transformation starts in the stable system, are higher for the austenitized cast iron in the temperature 875°C.

5. Summary

As for the researches it results that the influence of the austenitization temperature of cast iron on the location of the start and finish line of the eutectoid transformation is of different direction, depending on the extent of the cooling rate. In the area of the cooling rate, in which the eutectoid transformation starts exclusively according to the metastable system or according to the metastable or stable ones (of the cooling rates higher than $v_\gamma$), the increase of the austenitization temperature results in the increase of $\text{Ar}_{11}$ and $\text{Ar}_{12}$ temperature. In the area of cooling rate, in which the eutectoid transformation starts exclusively according to the stable system the increase of the austenitization temperature decreases the temperatures. The stated influence of the austenitization temperature on the start and end line location of the anizothermal eutectoid transformation is confirmed in the works [11,13], in which the continuous TTT diagrams were performed with the dilatometric method.

In the scope of the cooling rate, where the eutectoid transformation starts exclusively according to the stable system, the start of the pearlite transformation does not hinder the continuation of the transformation austenite $\rightarrow$ ferrite + graphite.

The results obtained in the work may be used in cast iron heat treatment practice, for example in normalization. The aim of normalization is obtaining possibly high content of pearlite. The higher content of pearlite in reference to cast iron in the cast state was received in the cooling rate scope from 0.5 to 1.75°C/s, which corresponds to the cooling rate of cast iron plates of the thickness from about 12 to 25mm [16]. The danger of the secondary cementite occurrence takes place in the case of applying high austenitization temperature and cooling temperature which corresponds to cooling a plate of the thickness smaller than 12mm in the air.

Literature