INFLUENCE OF CHARGE COMPOSITION ON MICROSTRUCTURE OF NODULAR CAST IRONS AFTER HEAT TREATMENT

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Abstract
The contribution deals with comparing of microstructure and mechanical properties of synthetic nodular cast irons with graded amount of steel scrap in a charge. Chemical composition of individual meltages was regulated alternatively by ferrosilicon (FeSi) and carburizer or metallurgical silicon carbide (SiC). The paper shows the influence of charge composition on microstructure of nodular cast irons after casting and after heat treatment (ferritizing annealing and isothermal heat treatment). The results of experiments shows that SiC additive positively influences the microstructure as well as mechanical properties of nodular cast iron, especially in specimens from the meltages with higher ratio of steel scrap in the charge. Moreover, production of synthetic nodular cast irons with SiC additive is economically advantageous.

Keywords: nodular cast iron, heat treatment, silicon carbide

1 Introduction
Nowadays it is actual from an economic point of view to deal with the possibility to substitute a part of more expensive pig iron for cheaper steel scrap in the charge of graphitic cast irons. The transition from the traditional use of pig iron (claimed to be rich in nuclei) to synthetic cast iron prepared from steel scrap (generally believed to contain only few graphitic nuclei) requires the regulation of chemical composition of melt. It is closely linked with the introduction of metallurgical silicon carbide SiC [1,2] as a siliconizing and carburizing additive (SiC additive is believed to supply the synthetic pure melts with nuclei) [3,4].

SiC additive positively influences the count of crystallisation nuclei of graphite in the cast iron melt (it increases the count of nuclei), consequently the count of graphitic nodules is increased and at the same time the susceptibility to occurrence of carbide in the structure is decreased.

The technological foundry literature describes the addition of SiC to the cast iron melt frequently as having a special pre-inoculating effect. This influence is well documented in the case of grey cast iron and has also been observed to some extent at industrial as well as at laboratory experiments in the case of nodular cast iron [5].

The paper deals with the influence of charge composition (different ratio of pig iron and steel scrap in the charge and FeSi or SiC additive) on microstructure and mechanical properties of synthetic nodular cast irons after casting and after heat treatment (ferritizing annealing and isothermal heat treatment).

2 Experimental materials and methods
Two series of five meltages of nodular cast iron were used for experiments. The resultant meltages have approximately the same chemical composition but this was achieved by different charge composition (Tab. 1). The basic charge of individual meltages was formed by different ratio of pig iron and steel scrap and for the regulation of chemical composition the additive of carburizer and silicon carbide (in meltages 1 to 5) or ferrosilicon (in meltages 6 to 10) was used. For modification FeSiMg7 modifier was used and for inoculation FeSi75 inoculant was used [6].

Two different types of heat treatment of specimens were made, namely ferritizing annealing

Table 1 Charge composition of experimental meltages

<table>
<thead>
<tr>
<th>Number of meltage</th>
<th>pig iron</th>
<th>steel scrap</th>
<th>carburizer</th>
<th>SiC90</th>
<th>FeSi75</th>
<th>modifier FeSiMg7</th>
<th>inoculant FeSi75</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>6</td>
<td>0.27</td>
<td>0.09</td>
<td>0.5</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>18</td>
<td>12</td>
<td>0.48</td>
<td>0.23</td>
<td>0.5</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>18</td>
<td>0.69</td>
<td>0.37</td>
<td>0.5</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>24</td>
<td>0.90</td>
<td>0.70</td>
<td>0.5</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>30</td>
<td>1.00</td>
<td>0.90</td>
<td>0.5</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>24</td>
<td>6</td>
<td>0.27</td>
<td>0.08</td>
<td>0.5</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>18</td>
<td>12</td>
<td>0.40</td>
<td>0.69</td>
<td>0.5</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>12</td>
<td>18</td>
<td>0.65</td>
<td>0.74</td>
<td>0.5</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>24</td>
<td>0.90</td>
<td>0.80</td>
<td>0.5</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>30</td>
<td>1.25</td>
<td>0.92</td>
<td>0.5</td>
<td>0.2</td>
<td></td>
</tr>
</tbody>
</table>
and isothermal heat treatment [7,8].

The ferritizing annealing consisted of heating to the temperature 680 °C, holding time at this temperature for 4 hours, slow cooling to the temperature 580 °C in a furnace and after-cooling to the ambient temperature in the air.

The isothermal heat treatment consisted of austenitization and following isothermal transformation (Fig. 1). The austenitization temperature was 920 °C and the holding time at this temperature was 30 minutes. The isothermal transformation of austenite was realized in AS 140 salt bath at the temperatures 380 and 250 °C and the holding time at these temperatures was 90 minutes. After-cooling to the ambient temperature was realized in the air [9-12].

The metallographic analysis of specimens of basic material (after casting) and specimens after heat treatment was made by the light metallographic microscope Neophot 32. The microstructure was evaluated by STN EN ISO 945 (STN 42 0461) and by automatical image analysis (using Lucia software) [13-16]. The tensile test was made by STN EN 10002-1 by means of the testing equipment ZDM 30 with loading range F = 0 to 50 kN. The impact bending test was made by STN EN 10045-1 by means of the Charpy hammer with nominal energy 300 J. The Brinell hardness test was made by STN EN ISO 6506-1 by means of the testing equipment CV 3000 LDB with a hardmetal ball of diameter D = 5 mm forced into specimens under the load F = 2452 N [17-19].

3 Results and discussion

3.1 Analysis of specimens after casting

From microstructural point of view all specimens of basic material (after casting) are ferrite-pearlitic nodular cast irons with different content of ferrite and pearlite in a matrix, different size of graphite and count of graphitic nodules per mm². Graphite occurs only in a perfectly-nodular and imperfectly-nodular shape in all the specimens. For comparison, Fig. 2 shows the microstructure of specimens from the meltage 3 (with SiC additive) and the meltage 8 (with FeSi additive) with the same ratio of steel scrap in the charge [20].

The results of evaluation of microstructure and mechanical properties of chosen specimens of basic material (after casting) by STN 42 0461 and

<table>
<thead>
<tr>
<th>Number of meltage</th>
<th>Microstructure</th>
<th>Mechanical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>content of ferrite [%]</td>
<td>count of graphitic nodules [mm²]</td>
</tr>
<tr>
<td>1</td>
<td>60%VI₅/6+40%V₆ – Fe80</td>
<td>61.6</td>
</tr>
<tr>
<td>3</td>
<td>80%VI₆ + 20%V₆ – Fe94</td>
<td>74.0</td>
</tr>
<tr>
<td>5</td>
<td>70%VI₅/6+30%V₆ – Fe94</td>
<td>78.0</td>
</tr>
<tr>
<td>6</td>
<td>70%VI₅/6+30%V₆ – Fe55</td>
<td>50.8</td>
</tr>
<tr>
<td>8</td>
<td>70%VI₅/6+30%V₆ – Fe80</td>
<td>65.2</td>
</tr>
<tr>
<td>10</td>
<td>70%VI₅/6+30%V₆ – Fe80</td>
<td>56.0</td>
</tr>
</tbody>
</table>

Table 2 Microstructure and mechanical properties of chosen specimens after casting

Fig. 1 Process of isothermal heat treatment in the diagram of isothermal transformation of austenite

Fig. 2 Microstructure of chosen specimens after casting – ferrite-pearlitic nodular cast irons, etched 1% Nital
Mechanical properties (tensile strength $R_{\text{m}}$, absorbed energy $K_0$ and Brinell hardness $H_B$) depend especially on the character of matrix (content of ferrite and pearlite) and also on the size and count of graphitic nodules. The mechanical properties of specimens from the meltages with SiC additive (i.e. meltages 1 to 5) are generally better than mechanical properties of specimens from the meltages with FeSi additive (i.e. meltages 6 to 10), especially in case of the specimens with higher ratio of steel scrap in the charge.

3.2 Analysis of specimens after heat treatment

From microstructural point of view the specimens after ferritizing annealing are ferritic nodular cast irons. The content of ferrite in the matrix is 98 % or more; pearlite occurs only in a few isolated cases. Graphite occurs only in a perfectly-nodular and imperfectly-nodular shape in all the specimens. The shape, size and count of graphitic nodules in the specimens after ferritizing annealing are not changed in comparison with the specimens of basic material (after casting).

For comparison, Fig. 4 shows the microstructure of specimens after ferritizing annealing from the meltage 3 (with SiC additive) and the meltage 8 (with FeSi additive) with the same ratio of steel scrap in the charge.

The content of ferrite in specimens after ferritizing annealing from the meltages with SiC additive (i.e. meltages 1 to 5) is generally higher than in specimens from the meltages with FeSi additive (i.e. meltages 6 to 10). This relates with the content of ferrite in specimens of basic material (after casting). The specimens after casting from the meltages with SiC additive have higher content of ferrite, therefore they need shorter holding time at ferritizing temperature than specimens from the meltages with FeSi additive to obtain ferritic matrix.

The specimens after isothermal heat treatment are austempered ductile irons (ADI). The matrix of ADI is created by acicular ferrite and retained austenite (this mixture is called ausferrite). Technical literature often describes this matrix as bainite [21-23].

The specimens with the temperature of isothermal transformation of austenite 380 °C have the matrix created by upper bainite and retained austenite (Fig. 5). The specimens with the temperature of isothermal transformation of austenite 250 °C have the matrix created by lower bainite and retained austenite (Fig. 6). The content of retained austenite is slightly lower in specimens from the meltages with SiC additive (i.e. meltages 1 to 5) than in specimens from the meltages with FeSi additive (i.e. meltages 6 to 10). Graphite occurs

Fig. 3 Results of quantitative evaluation of microstructure of specimens after casting

Fig. 4 Microstructure of chosen specimens after ferritizing annealing – ferritic nodular cast irons, etched 1% Nital

a) content of ferrite in the matrix

b) count of graphitic nodules

Fig. 4 Microstructure of chosen specimens after ferritizing annealing – ferritic nodular cast irons, etched 1% Nital
only in a perfectly-nodular and imperfectly-nodular shape in all the specimens. The shape, size and count of graphitic nodules in the specimens after isothermal heat treatment are not changed in comparison with the specimens of basic material (after casting).

The results of evaluation of mechanical properties of chosen specimens after heat treatment (ferritizing annealing and isothermal heat treatment) are given in Tab. 3. The hardness is generally higher in specimens from the meltages with SiC additive (i.e. meltages 1 to 5) than in specimens from the meltages with FeSi additive (i.e. meltages 6 to 10).

### 4 Conclusion

The substitution of a part of pig iron for steel scrap in the charge of nodular cast iron has a considerable economic contribution. For the regulation of chemical composition of melt it is advantageous to use metallurgical SiC additive which has been used in this work as an alternative additive instead of FeSi in meltages with a different ratio of pig iron and steel scrap in the charge.

Increasing ratio of steel scrap in the charge together with increasing amount of SiC or FeSi additive influence the microstructure as well as mechanical properties of nodular cast iron. The content of ferrite in the matrix is increased, the count of graphitic nodules per unit area is increased.

<table>
<thead>
<tr>
<th>Number of meltage</th>
<th>after ferritizing annealing</th>
<th>after isothermal heat treatment (380 °C/90 min.)</th>
<th>after isothermal heat treatment (250 °C/90 min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>matrix</td>
<td>Brinell hardness HB</td>
<td>matrix</td>
</tr>
<tr>
<td>1</td>
<td>ferrite</td>
<td>200</td>
<td>upper bainite + retained austenite</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>182</td>
<td>upper bainite + retained austenite</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>184</td>
<td>upper bainite + retained austenite</td>
</tr>
<tr>
<td>6</td>
<td>ferrite</td>
<td>169</td>
<td>upper bainite + retained austenite</td>
</tr>
<tr>
<td>8</td>
<td>(more than 98 %)</td>
<td>176</td>
<td>upper bainite + retained austenite</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>169</td>
<td>upper bainite + retained austenite</td>
</tr>
</tbody>
</table>
and the occurrence of undesirable cementite is eliminated; consequently the mechanical properties are improved. This positive influence is more significantly shown in specimens from the meltages with SiC additive.

After ferritizing annealing the specimens have ferritic matrix; pearlite occurs only in a few isolated cases, especially in specimens from the meltages with FeSi additive. Therefore it is necessary to use longer holding time at ferritizing temperature to obtain ferritic matrix.

After isothermal heat treatment the specimens have matrix created by upper or lower bainite and retained austenite. The content of retained austenite is slightly lower in specimens from the meltages with SiC additive than in specimens from the meltages with FeSi additive.

Acknowledgements

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References