Effect of nitrogen on structure and mechanical properties of ductile iron with small additions vanadium and niobium

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Abstract

Results of investigations of influence of small additions of vanadium (about 0.08 and 0.12 % V) and niobium (about 0.05 and 0.16% Nb) as well as nitrogen (32 - 58 ppm.) on mechanical properties and structure of ductile iron is presented. Effect of these additions on graphite diameter distribution, nodule count, and ferrite fraction is determined. It has been also shown that vanadium and niobium lead to formation of their complex carbides, while nitrogen – complex carbide-nitrides containing magnesium and silicon.

Key words: Mechanical properties; Ductile iron; Structure; Nitrides; Carbides.

1. Introduction

Ductile iron is a valuable construction material and depending on its matrix can offer wide range of utilize properties [1]. Taking into account these properties and production costs castings made of ductile iron started compete with steel goods. One of the way of improving properties of steel goods is their microalloying by the addition of vanadium, niobium, titanium and nitrogen [2]. In case of ductile iron this area is practically unknown. This is why the aim of the first stage of investigation that is analysis of small additions of vanadium, niobium and nitrogen on structure and mechanical properties of ductile iron.

2. Research Methodology

Ductile iron was obtained in an electric induction furnace of medium frequency and with 15 kg capacity. The raw materials were pig iron, steel scrap, ferrovanadium 80% and ferroniobium 80%. The metal was preheated at 1500 °C and then depending on requirements it was introduced Fe80%Mn-8%N alloy in order to increase nitrogen content in ductile iron. Rest of the investigation detail are given in work [3]. From Y-shaped castings samples for tensile tests and metallographic investigations were taken in order to estimate graphite nodule count Nv, graphite equivalent diameter dgr, ferrite f and cementite fc fractions and number of carbides NW, using quantitative analyzer Leica QWin and scanning electron microscopy JEOL with EDS system enabling determine chemical composition of phases.

3. Results

Results of influence of nitrogen, vanadium and niobium on structure indicators and mechanical properties are given in Table 1, while examples of structure are shown in Figs. 1-5. From presented results it is shown that nitrogen changes distribution character of the graphite nodule diameter. In ductile iron without nitrogen distribution of the graphite nodule diameter exhibits one maximum, while with nitrogen two maximum (Fig.1). Nitrogen significantly decreases ferrite fraction in ductile iron with...
additions of vanadium and to a small extent in ductile iron containing niobium (Table 1, Fig. 2, 3). Influence of nitrogen on nodule count and their diameter is insignificantly (Table 1).

Table 1.
Chemical composition and structure indicators and mechanical properties of cast iron

<table>
<thead>
<tr>
<th>No</th>
<th>C %</th>
<th>Si %</th>
<th>V %</th>
<th>Nb %</th>
<th>N ppm</th>
<th>N_p mm^2</th>
<th>d_m µm</th>
<th>f</th>
<th>R_m</th>
<th>R_p,0,2</th>
<th>A %</th>
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<tbody>
<tr>
<td>V1</td>
<td>3.31</td>
<td>2.05</td>
<td>0.076</td>
<td>-</td>
<td>760</td>
<td>9.3</td>
<td>67</td>
<td>455</td>
<td>297</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>V1/30</td>
<td>3.24</td>
<td>1.98</td>
<td>0.081</td>
<td>-</td>
<td>632</td>
<td>11.1</td>
<td>31</td>
<td>555</td>
<td>338</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>V1/60</td>
<td>3.20</td>
<td>2.01</td>
<td>0.075</td>
<td>-</td>
<td>48</td>
<td>9.4</td>
<td>25</td>
<td>595</td>
<td>370</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>V2</td>
<td>3.34</td>
<td>1.98</td>
<td>0.121</td>
<td>-</td>
<td>759</td>
<td>7.4</td>
<td>64</td>
<td>470</td>
<td>285</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>V2/30</td>
<td>3.25</td>
<td>2.06</td>
<td>0.129</td>
<td>-</td>
<td>847</td>
<td>9.9</td>
<td>54</td>
<td>489</td>
<td>294</td>
<td>15</td>
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<tr>
<td>V2/60</td>
<td>3.34</td>
<td>2.01</td>
<td>0.119</td>
<td>-</td>
<td>58</td>
<td>10.5</td>
<td>21</td>
<td>632</td>
<td>363</td>
<td>9</td>
<td></td>
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<tr>
<td>Nb1</td>
<td>3.51</td>
<td>1.97</td>
<td>-</td>
<td>0.052</td>
<td>809</td>
<td>8.9</td>
<td>65</td>
<td>414</td>
<td>277</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Nb1/30</td>
<td>3.58</td>
<td>2.05</td>
<td>-</td>
<td>0.064</td>
<td>32</td>
<td>10.8</td>
<td>54</td>
<td>511</td>
<td>321</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Nb2</td>
<td>3.58</td>
<td>1.99</td>
<td>-</td>
<td>0.160</td>
<td>729</td>
<td>9.5</td>
<td>68</td>
<td>445</td>
<td>304</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Nb2/30</td>
<td>3.53</td>
<td>2.10</td>
<td>-</td>
<td>0.154</td>
<td>28</td>
<td>11.4</td>
<td>62</td>
<td>485</td>
<td>315</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

R_m, R_p,0,2, A- Tensile strength, yield strength and elongation, respectively.

Microscopic examinations also show that in ductile iron structure there are presented (a few hundred per square millimeter) complex vanadium (Fig.4a) and niobium (Fig. 4b) carbides occupying 1% of metallographic section and smaller particles of complex vanadium carbide-nitrides (Fig.5a) and also niobium carbide-nitrides (Fig.5b) containing magnesium and silicon. In all samples it has been also affirmed presence of complex inclusions containing iron, silicon and magnesium. Mechanical tests (Table 1) show that increase in nitrogen content in ductile iron tensile strength R_m and yield strength R_p,0,2 increases, while elongation A decreases. It can be judged that the main reason of such changes is decreases of ferrite fraction.

It is worth to note that ductile iron from heat no.V1/30 and V1/60 meet R_m and R_p,0,2 requirements typical for ductile iron of EN-GJS-500-7 (according to PN-EN) grade, but with a higher elongation fulfilling ductile iron of EN-GJS-450-10 grade. Similarly from heats including niobium ductile iron fulfill EN-GJS-400-18, EN-GJS-450-10 and EN-GJS-500-7 grade from the viewpoint of R_m and R_p,0,2 but with higher elongation (by one class) corresponding ductile iron of EN-GJS-350-22 and EN-GJS-400-15 grade.

4. Conclusions

Additions of nitrogen in ductile iron: changes distribution of graphite nodule diameter, essentially increases pearlite fraction and also tensile strength R_m and yield strength R_p,0,2 and decreases elongation. Fraction of complex vanadium and niobium carbides is small and amounts about 1%. Nitrogen causes formation of complex carbide-nitrides, while spheroidizing-inoculation treatment formation of complex inclusions containing iron, silicon and magnesium.

Acknowledgments

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References

Fig. 1. Distributions of graphite diameter in ductile iron with vanadium, niobium and nitrogen additions
Fig. 2. Structure of ductile iron (500x, nital etched)

Fig. 3. Structure of ductile iron (500x, nital etched)

Fig. 4. Appearance of vanadium carbides (a) and niobium carbides (b)

Fig. 5. Appearance of carbon-nitrides particles in ductile iron alloyed with vanadium (a) and niobium (b) and particles of Fe-Si-Mg (c)