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

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Abstract
Results of investigations of influence of small additions of vanadium (up to 0,15 % V) and niobium (up to 0,04% Nb) on structure of ductile iron is presented in this work. Effect of these additions on distribution of graphite nodule diameter, nodule count, fraction and carbide count have been determined. Investigations of effect of small additions of vanadium and niobium on mechanical properties taking into account tensile strength, yield strength and elongation have also been made.

Key words: Mechanical properties; Ductile iron; Structure; Vanadium carbide; Niobium carbide.

1. Introduction
Ductile iron is valuable construction materials and depending on its matrix (ferritic, ferritic-pearlitic, pearlitic, martensitic and ausferritic) offer wide range of mechanical properties simultaneously exhibits good wear resistance and damping capacity [1]. Taking into account these properties and production costs, in many cases castings made of ductile iron can be a substitute for more expensive steel forging. From foundry practice result that in many cases production of ductile iron with ferritic matrix ensure fulfill requirements concerning tensile strength and elongation but not always requirements concerning yield strength are fulfilled.
Investigations allowing state whether the foregoing problem can be resolved by means of small additions of vanadium and niobium are the aim of our work.

2. 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 poured into sand mould to get normalized Y-shaped castings. Spheroidizing and inoculation process was made in gating system using Fe-Si-5%Mg alloy, and Foundrsil inoculant containing 0,5 % Ce in amounts 1,0 % and 0,8 % with relation to bath weight, respectively. From castings samples with measurement diameter of 8 mm for mechanical testing were taken. Strength indicators of obtained ductile iron were: tensile strength $R_m$, yield strength $R_{0,2}$ and elongation $A$, which were determined using testing machine of INSTRON type. After mechanical testing from tips of mechanical samples it has been cut samples for metallographic examinations in order to estimate: pearlite, graphite $f_g$ and carbides $f_w$ fractions, graphite nodules diameter $d_{gr}$, nodules count $N_g$ and carbides count $N_w$ using quantitative image analyzer Leica QWin and scanning electron microscope JEOL with EDS system.

3. Results
Results of influence of vanadium and niobium on structure and mechanical properties of ductile iron are summarised in Tables 1-4 and shown in Figs. 1-5. Effect of small additions of vanadium and niobium on type of matrix is in principle negligible small
Because pearlite fraction is in the range of 3-7%. Effect of additions of vanadium and niobium on distribution of graphite nodule diameter is shown in Figs. 3 and 5. One can notice that contrary to vanadium, niobium increases nodule count with small diameters. From investigations result that as vanadium and niobium in ductile iron increases number of their carbides $N_w$ and fraction $f_w$ also increases (Table 2 and 4). Accordingly increases tensile strength $R_m$ and yield strength $R_{0,2}$ while elongation $A$ decreases (Table 1 and 3 and Fig. 1).

Table 1. Chemical composition and mechanical properties

<table>
<thead>
<tr>
<th>Heat no.</th>
<th>C %</th>
<th>Si %</th>
<th>V %</th>
<th>$R_m$ MPa</th>
<th>$R_{0,2}$ MPa</th>
<th>A %</th>
</tr>
</thead>
<tbody>
<tr>
<td>w1</td>
<td>3.56</td>
<td>2.00</td>
<td>0.01</td>
<td>420</td>
<td>262</td>
<td>23</td>
</tr>
<tr>
<td>w2</td>
<td>3.62</td>
<td>1.98</td>
<td>0.02</td>
<td>424</td>
<td>271</td>
<td>21</td>
</tr>
<tr>
<td>w3</td>
<td>3.63</td>
<td>2.03</td>
<td>0.02</td>
<td>421</td>
<td>275</td>
<td>22</td>
</tr>
<tr>
<td>w4</td>
<td>3.77</td>
<td>2.22</td>
<td>0.04</td>
<td>443</td>
<td>292</td>
<td>20</td>
</tr>
<tr>
<td>w5</td>
<td>3.24</td>
<td>1.98</td>
<td>0.08</td>
<td>455</td>
<td>297</td>
<td>20</td>
</tr>
<tr>
<td>w6</td>
<td>3.45</td>
<td>2.02</td>
<td>0.12</td>
<td>470</td>
<td>285</td>
<td>17</td>
</tr>
<tr>
<td>w7</td>
<td>3.45</td>
<td>2.09</td>
<td>0.15</td>
<td>499</td>
<td>310</td>
<td>17</td>
</tr>
</tbody>
</table>

Mn = 0.01 %, S = 0.005-0.01 %; Mg = 0.040 – 0.043 %

![Graph](image)

Fig. 1. Influence of vanadium and niobium on mechanical properties of ductile iron

Table 2. Structure indicators of ductile iron

<table>
<thead>
<tr>
<th>Heat no.</th>
<th>$N_v$ mm$^{-2}$</th>
<th>$f_g$ %</th>
<th>$d_v$ µm</th>
<th>$N_w$</th>
<th>$f_w$</th>
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<tr>
<td>W1</td>
<td>851</td>
<td>5.6</td>
<td>7.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>W2</td>
<td>949</td>
<td>5.7</td>
<td>6.8</td>
<td>186</td>
<td>0.03</td>
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<tr>
<td>W3</td>
<td>1079</td>
<td>7.1</td>
<td>7.4</td>
<td>173</td>
<td>0.02</td>
</tr>
<tr>
<td>W4</td>
<td>939</td>
<td>5.9</td>
<td>6.9</td>
<td>260</td>
<td>0.02</td>
</tr>
<tr>
<td>W5</td>
<td>759</td>
<td>6.4</td>
<td>8.2</td>
<td>586</td>
<td>0.09</td>
</tr>
<tr>
<td>W6</td>
<td>933</td>
<td>7.3</td>
<td>8.2</td>
<td>1645</td>
<td>0.33</td>
</tr>
<tr>
<td>W7</td>
<td>902</td>
<td>6.0</td>
<td>7.4</td>
<td>1563</td>
<td>0.37</td>
</tr>
</tbody>
</table>
Table 3.
Chemical composition and mechanical properties

<table>
<thead>
<tr>
<th>Heat no.</th>
<th>C, %</th>
<th>Si, %</th>
<th>Nb, %</th>
<th>R_m, MPa</th>
<th>R_m, Mpa</th>
<th>A, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb1</td>
<td>3.75</td>
<td>1.92</td>
<td>0.003</td>
<td>402</td>
<td>267</td>
<td>25</td>
</tr>
<tr>
<td>Nb2</td>
<td>3.63</td>
<td>2.06</td>
<td>0.007</td>
<td>416</td>
<td>267</td>
<td>23</td>
</tr>
<tr>
<td>Nb3</td>
<td>3.71</td>
<td>2.02</td>
<td>0.016</td>
<td>418</td>
<td>268</td>
<td>21</td>
</tr>
<tr>
<td>Nb4</td>
<td>3.70</td>
<td>2.04</td>
<td>0.021</td>
<td>416</td>
<td>269</td>
<td>23</td>
</tr>
<tr>
<td>Nb5</td>
<td>3.63</td>
<td>2.10</td>
<td>0.038</td>
<td>426</td>
<td>272</td>
<td>23</td>
</tr>
</tbody>
</table>

Mn = 0.01 %; S = 0.005-0.01 %; Mg = 0.040-0.045%

Fig. 2. Appearance of matrix (a) and vanadium carbides (b)

Fig. 3. Distributions of graphite nodule diameter in ductile iron with vanadium additions

Fig. 4. Appearance of matrix (a) and niobium carbides (b)
Analyzing influence of vanadium on mechanical properties of ductile iron (Table 1) it can be state that addition of 0.15 % V increases tensile strength $R_m$ by about 15 % and in a bit higher degree ($\approx 18$ %) yield strength $R_{0.2}$ but simultaneously in even higher degree ($\approx 26$ %) decreases elongation. Similar trend of niobium influence on mechanical properties is revealed (Table 3).

### 4. Conclusions

Small additions of vanadium and niobium in ductile iron increases its tensile strength $R_m$ and yield strength $R_{0.2}$ but simultaneously in even higher degree decreases its elongation $\Delta$.

### Acknowledgments

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### References