THE COMMERCIAL TRIAL – PRODUCTION OF HRB400 REINFORCED BAR WITH V – N MICROALLOYING

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Abstract: The commercial trial production of V – N microalloyed HRB400 reinforced bar in Magang is presented. The composition of the reinforced bar, the microalloying process and the relation between specification and structural property are studied. The nitrogen – enhancing and strengthening effect of the V – N alloy is analyzed.

Key Words: V – N alloy; reinforced bar; microalloying; strength

1 Preface

The II class hot rolled ribbed steel bar of 335 MPa grade produced with 20MnSi steel is still widely used in China, while high strength hot rolled ribbed bar of 400 MPa, 460 MPa and 500 MPa grade has already been generally used in overseas construction industry. With high strength, stable performance, large safety reserve, good anti-vibration, low consumption and easy handling, the high strength hot rolled ribbed bar is more suitable for the construction of super – high building, big – spanned and anti-vibration structure. Its application can bring great economic and social benefits. In order to upgrade the construction steel and catch up with the international standards for reinforced steel products, China is making great efforts to promote the application of HRB400 reinforced bar.

As the production base for construction steel in China, Ma’anshan Steel produces over 1.0 million tons of hot rolled ribbed bar annually, of which 1.6 x 10^5 tons is of HRB400 grade, and the percentage is ever increasing. Its HRB400 reinforced bar has been used in some national key projects such as Tianwan nuclear power plant, Runyang bridge and multi-story building in Guangdong province, the high quality has been confirmed by customers. In the past, the process of microalloying with ferrovanadium addition had been used in Ma’anshan Steel to produce HRB400 reinforced bar. In order to lower the cost, Ma’anshan Steel has been developing HRB400 reinforced bar using V – N microalloying, and by now it has successfully been put into batch production. The property of the product is stable and the cost is lower.

2 Commercially Trial Production of HRB400 Reinforced Bar with V – N Microalloying

2.1 The composition and required properties of HRB400 reinforced bar

The Chinese national standard GB1499 – 1998 is implemented for HRB400 reinforced bar production. The required chemical composition, mechanical behaviors and processing properties are showed in table 1. Good weldability and fatigue – resistance are also required for HRB400 reinforced bar.
Table 1 The chemical composition, mechanical behaviors and processing properties required for HRB400 reinforced bar

<table>
<thead>
<tr>
<th>Smelting composition and carbon equivalent (%)</th>
<th>Mechanical behaviors</th>
<th>Processing properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Si</td>
<td>Mn</td>
</tr>
<tr>
<td>≤0.25</td>
<td>≤0.80</td>
<td>≤1.60</td>
</tr>
</tbody>
</table>

*note: 1) $C_{eq} = C + \frac{Mn}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15}$;
2) The δb test may be left out if its qualification can be guaranteed;
3) According to GB5001-2002, $\sigma_b/\sigma_u \geq 1.25$ and $\sigma_u, measured \leq 1.30 \sigma_u, standard$ (e.g. $\sigma_u \leq 520$MPa) must be satisfied for the longitudinally effective bar in frame structure designed with anti-vibration of class 1 and 2. This should be included in the terms of agreement.

2.2 The choice of microalloying process

In order to meet the property requirements of HRB400 reinforced bar, microalloys such as V, Nb and Ti are usually added into low carbon Mn-Si steel, so the precipitation strengthening and grain size refinement by carbide and nitride can be achieved. Reinforced bar of 400MPa with steel grades 20MnSiV, 20MnSiNb and 20MnTi, recommended by Chinese national standard GB1499-1998, has been trial produced by various plants in China, mostly using V microalloying process. So the good effects of V microalloying has been generally accepted.

There are three kinds of microelement addition in steel, the addition of vanadium iron (V-Fe), the addition of vanadium slag and the addition of V-N alloy.

V-Fe addition is a traditional method. The average yield for V in the HRB400 steel produced by BOF in Ma’anshan Steel is about 90%. When vanadium slag is added, the V average yield can reach 83%, with microalloying in ladle processed by the mixture of vanadium slag and reducing agent. Though the production cost can be lowered in this way, up to now the V yield with the direct microalloying by V slag is still unstable. When V-N alloy is added, N can be steadily added while V is being added, so the precipitation of vanadium-carbonitride is enhanced and the precipitation strengthening is increased. With the effective utilization of the cheap element N, the consumption of vanadium is reduced, thus the production cost is reduced. When V-N alloy is added, the V yield is about 92% and N yield is about 65%.

In the past, V-Fe addition had been mainly used for microalloying in Ma’anshan Steel, but now it is using V-N alloy Nitrovan12 supplied by Strategic Mineral USA.

2.3 Trial production process

The primary process flow for the trial production of HRB400 reinforced bar using V-N microalloying in Ma’anshan Steel is as below: 50 tons BOF → Secondary deoxidation and alloying → Wire feeding and argon treatment → 140 billet from 6-strand caster → Ø12-Ø40 mm hot rolled ribbed bar from continuous bar mill.

In order to ensure that V-N alloy be added steadily and effectively and the good properties of the final reinforced bar products, the composition of the hot metal must be strictly controlled. In the smelting process the tapping temperature and the aim carbon content must be well controlled, and the V-N alloy should be gradually added. Wire is fed and argon treatment is done. At rolling stage suitable reheating temperature should be
set, which should be able to ensure that V be thoroughly solved in the austenite so the precipitation strengthening effect can be brought to full play, and to prevent austenite grain from over-growth when being heated.

3 Result and Analysis

3.1 The mechanical properties of the reinforced bar

The data for the properties of the trial produced HRB400 reinforced bar with V-N microalloying is showed in table 2. Comparing table 2 with table 1, it can be seen that the properties of HRB400 can meet the standard requirements very well. What's more, the performance is rather stable and the ratio of tensile to YS is comparatively high. Reinforced bar of ≥ Ø16 mm can satisfy the performance requirements for the longitudinally effective bar in frame structure designed with anti-vibration ability of class 1 and 2, i.e. $\sigma_b / \sigma_s \geq 1.25$ and $\sigma_b$ measured ≤ 1.30 $\sigma_b$ standard (e.g. $\sigma_s \leq 520$MPa). Only Ø12 mm and Ø14 mm reinforced bar does not meet the anti-vibration qualification, but reinforced bar of such small specifications is seldom used as longitudinally effective bar in anti-vibration design.

3.2 Observation of the microstructure in reinforced bar

Metallographical examinations were done on samples from the Ø20 mm HRB400 reinforced bars with V-N and V-Fe microalloying and HRB335 reinforced bar. The metallurgical microstructures are ferrite + pearlite, as showed by fig. 1. The grain size for HRB400 reinforced bar with V-N and V-Fe microalloying is No. 9 ~ 10, while for HRB335 is No. 8 ~ 8.5. Apparently the structure of HRB400 is finer than that of HRB335. The grain refinement effect of V become clear. The grain size for HRB400 with V-N microalloying is slightly finer than that with V-Fe microalloying, and the V content of the former is much lower, so the grain refinement effect of per unit of V is the strongest.

3.3 The correlation between tension test property and composition and specification

Using the test data of the commercial trial-products, the following empirical formulas have been obtained through multivariate regression analysis (the linear relationship is proved to be highly prominent):

$$\sigma_b (\text{MPa}) = 246.8 + 24.5(\% \text{C}) + 68.7(\% \text{Mn}) + 199.7(\% \text{Si}) + 623.3(\% \text{V}) - 1.03\Omega$$

![Table 2 Statistics of the properties of the HRB400 reinforced bar trial - produced with V-N microalloying](image-url)
Fig. 1 The comparison of the metallographical structures in different kinds of Ø20 mm reinforced bar.

![Metallographical structures](image)

\[
\sigma_b (\text{MPa}) = 294.2 + 46.9 (\% C) + 174.8 (\% \text{Mn}) + 23.2 (\% \text{Si}) + 1432.0 (\% \text{V}) - 0.030 (\text{mm})
\]

\[
\delta_5 (\%) = 48.9 - 2.1 (\% \text{C}) - 9.0 (\% \text{Mn}) + 4.3 (\% \text{Si}) + 41.5 (\% \text{V}) - 0.330 (\text{mm})
\]

From these formulas it can be seen that strength and elongation is enhanced when V is increased in the steel through the addition of V – N alloy. For the composition range of the trial-produced steel, \(\sigma_b\) can be raised by 6.2 MPa and \(\delta_5\) by 14.3 MPa every time V is increased by 0.01%.

3.4 The N-enhancing effect of V – N alloy

The N-enhancing behavior of V – N alloy addition in HRB400 steel can be seen in table 3. “Original N” refers to the N content in ordinary BOF steel, and in table 3 it refers to the N content in HRB335 steel (without V – N addition) produced in the same period. “Residue V” refers to the residue V content in ordinary BOF steel, and in table 3 it refers to the residue V in HRB335 steel (without V addition) produced in the same period. From table 3 it can be seen that 8.5 – 13.9 ppm (10.9 ppm on average) of N is brought into the steel by every 0.01% of V increased. According to the actual addition of Nitrovan12 for each heat, it is calculated that 6.0 – 10.9 ppm (average 7.7 ppm) is brought in by every 0.01% of Nitrovan12 addition.

3.5 Comparison of the strengthening effects of V – N alloy and V – Fe alloy

The mechanical properties of HRB400 reinforced bar with V – N and V – Fe microalloying, of similar composition, produced with the same process technique, are compared in table 4.

From table 4 it can be seen that the strength

<table>
<thead>
<tr>
<th>Item</th>
<th>Total N( ppm)</th>
<th>Original N( ppm)</th>
<th>N( ppm) increased</th>
<th>Total V( %)</th>
<th>Residue V( %) increased</th>
<th>V( %) increased by 0.01% V</th>
<th>N( ppm) increased by 0.01% V – N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max.</td>
<td>105.6</td>
<td>41.7</td>
<td>63.9</td>
<td>0.054</td>
<td>0.012</td>
<td>0.048</td>
<td>13.9</td>
</tr>
<tr>
<td>Min.</td>
<td>64.0</td>
<td>35.5</td>
<td>27.6</td>
<td>0.036</td>
<td>0.006</td>
<td>0.028</td>
<td>8.5</td>
</tr>
<tr>
<td>Ave.</td>
<td>75.7</td>
<td>37.5</td>
<td>38.3</td>
<td>0.043</td>
<td>0.008</td>
<td>0.035</td>
<td>10.9</td>
</tr>
</tbody>
</table>
of V - N microalloyed reinforced bar is much higher than that of V - Fe microalloyed, without sacrificing the elongation. When V - N microalloyed reinforced bar is compared with V - Fe microalloyed, with all the specifications in table 4 taken into account, it can be calculated using the data in the table that \( \sigma_a \) is increased by 25 - 50MPa (38MPa for average), and \( \delta_a \) is increased by 17 - 52MPa (42MPa for average).

4 Conclusion

(1) The process technique used by Ma’anshan Steel to produce the microalloyed HRB400 reinforced bar is stable and reliable. The HRB400 reinforced bar trial - produced with V - N microalloying not only can meet the quality requirements, but also has stable properties and high ratio of tensile to YS.

(2) The metallographical structure of the V - N microalloyed HRB400 reinforced bar is clearly finer than that of the HRB335 without V, and slightly finer than that of the V - Fe microalloyed HRB400 with a higher V content.

(3) The strengthening effect of V in the V - N microalloyed HRB400 is remarkable. With every 0.01% of V increased, \( \sigma_a \) can be enhanced by about 6.2MPa, \( \delta_a \) about 14.3MPa.

(4) Under the production conditions of Ma’anshan Steel, 8.5 - 13.9ppm (10.9ppm on the average) of N is brought into the V - N microalloyed HRB400 steel by every 0.01% of V increased, and 6.0 - 10.9ppm (average 7.7ppm) is brought in by every 0.01% of Nitrovan12 added.

(5) When composition is basically the same and V content is 0.05% - 0.06%, the strength of the V - N microalloyed HRB400 reinforced bar is remarkably higher than that of the V - Fe microalloyed steel, without lowering the elongation. \( \sigma_a \) is increased by 25 - 50MPa (38MPa for average), and \( \delta_a \) is increased by 17 - 52MPa (42MPa for average).

(6) In the future, hot – rolled ribbed bar of 460MPa and 500MPa grade will be trial – produced using V – N microalloying process, to meet the demand of international and domestic market. The influence of the rolling process parameters on the properties of V – N microalloyed steel will be further studied, and the strengthening mechanism of the steel under the production conditions will be analyzed, so as to optimize process parameters and bring the V – saving potential into full play.

<table>
<thead>
<tr>
<th>Spec. mm</th>
<th>Alloy Add.</th>
<th>Rolling No.</th>
<th>Composition (heat analysis %)</th>
<th>Mechanical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>C</td>
<td>Si</td>
</tr>
<tr>
<td>Ø16</td>
<td>V - N</td>
<td>10859</td>
<td>0.20</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>V - Fe</td>
<td>08096</td>
<td>0.21</td>
<td>0.56</td>
</tr>
<tr>
<td>Ø20</td>
<td>V - N</td>
<td>11616</td>
<td>0.21</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>V - Fe</td>
<td>04900</td>
<td>0.21</td>
<td>0.43</td>
</tr>
<tr>
<td>Ø25</td>
<td>V - N</td>
<td>11121</td>
<td>0.23</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>V - Fe</td>
<td>06054</td>
<td>0.22</td>
<td>0.54</td>
</tr>
<tr>
<td>Ø32</td>
<td>V - N</td>
<td>11520</td>
<td>0.21</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>V - Fe</td>
<td>02200</td>
<td>0.22</td>
<td>0.43</td>
</tr>
</tbody>
</table>