APPLICATION OF ELECTROSLAG WELDING IN HRB400 REINFORCED BAR

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HRB400 Reinforced Bar is normally called New III Grade reinforced bar mainly branded 20MnSiV, which has been keenly promoted by the Ministry of Construction these years. Such grade of rebar is characteristic by high strength, good ductility and seism resistant, for which it will substitute the former II Grade rebar for predominant applications in concrete structures.

Being reliable, easy to operate and cost-efficient, the electroslag welding, is usually applied for connection between vertically loaded rebars in on-spot casting concrete structures. As per the current norm of “Procedures for Rebar Welding and Acceptance” (JGJ18 - 96), the electroslag welding can only be applied for welding of the I and II Grades. There is no stipulation for III Grade in this norm.

In order to associate with the promotion of HRB400 rebar, the research group has done a lot of analysis on the weldability of HRB400 both theoretically and experimentally based on the present application examples in Chinese metallurgical industry, which results in feasibility of electroslag welding for HRB400 rebar.

1 Theoretical Analysis on the Weldability of HRB400

1.1 Estimated calculation

The weldability of rebar is usually estimated and calculated in terms of $C_{eq}$, carbon equivalent value as follows:

$$C_{eq} = C + \frac{Mn}{6} + \frac{(Cr + V + Mo)/5}{15} + \frac{(Cu + Ni)/15}{15}$$

Where we can see a relation that more content of C leads higher $C_{eq}$ and V content has more or less no influence to $C_{eq}$. Meanwhile, the experiences have demonstrated lower $C_{eq}$ leads better welding property.

1.2 The strengthening mechanism of HRB400 (20MnSiV)

The increase in strength of ordinary grades of hot rolled rebar is achieved by a strengthening mechanism of increasing the carbon content. For example, the strength of 20MnSi is greatly improved by increasing carbon content. However, this method is seldom used in practical engineerings due to the fact that increased $C_{eq}$ can lead great reduction in ductility, toughness and weldability.

For HRB400, by way of microalloy by adding micro content of V, the strength and toughness can be increased through a mechanism of refined grain and strengthened precipitation. The V has good combination activity with N, in form of VN compound. Under normal heating temperature, the compound can be solvable and precipitated in later processes of rolling and cooling, thus making the strength increased. Moreover, the big amount of fine grains can also prevent the grain boundary
from removing to refine the ferrite grains for increase in toughness.

The addition of micro content of V can improve the toughness of the HAZ of rebar, which is beneficial to weldability.

Due to its special strengthening mechanism, HRB400 (20MnSiV) can be improved in strength and toughness and hence the weldability by reducing C content.

2 The Physical Situation of Chinese Steel Industry

The HRB400 production has been physically improved with the technical progress in Chinese metallurgical industry. Products from domestic large-sized enterprises normally have $C_{eq}$ value of 0.50%, which is lower than the required $C_{eq}$ of HRB335 grade (0.52%) stipulated in GB1499 – 1998, and lower content of harmful elements, such as P and S, which is favorable to welding operation.

3 Experimental Results

3.1 Mechanical results

From 1997 to 2001, the research group has made four times of systematic electroslag welding experiments for a number of 1000 welding joints by using fluxes of HJ431 and YD40 – III on rebars of $\phi$18 – $\phi$32 mm, among which, 540 joints made by HJ431 in two times of experiments and 480 joints by YD40 – III in the others.

The experiments have shown, without taking into accounts of influence by human qualifications of the welding operators, the tensile strengths of the test pieces meet the demands and all the fractures happen on the parent material in form of plastic fractures. During the experimentation, a number of welding data have been analyzed and a table showing parameters under different application of fluxes has been defined, which shows executable for practical applications (See table 1, table 2).

3.2 Impact toughness test

Some U-shape notched test pieces from groups of HRB400 $\phi$25 mm, HRB400 $\phi$18 mm and HRB335 $\phi$18 mm joints have been made for tests of impact toughness under ambient temperature. The results are shown in the table 3.
### Table 3 Impact toughness test results

<table>
<thead>
<tr>
<th>Dia. of joint/mm</th>
<th>Notch position</th>
<th>Impact power</th>
<th>Ratio between averaged impact power and parent material/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRB400 025</td>
<td>Parent material</td>
<td>131 - 138</td>
<td>134</td>
</tr>
<tr>
<td></td>
<td>Welding seam</td>
<td>52 - 80</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>Heated area</td>
<td>108 - 127</td>
<td>118</td>
</tr>
<tr>
<td></td>
<td>Parent material</td>
<td>139 - 144</td>
<td>141</td>
</tr>
<tr>
<td></td>
<td>Welding seam</td>
<td>52 - 96</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>Heated area</td>
<td>109 - 138</td>
<td>117</td>
</tr>
<tr>
<td>HRB400918</td>
<td>Parent material</td>
<td>118 - 141</td>
<td>133</td>
</tr>
<tr>
<td></td>
<td>Welding seam</td>
<td>48 - 78</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>Heated area</td>
<td>96 - 130</td>
<td>115</td>
</tr>
</tbody>
</table>

The results have shown that the impact toughness of HRB400 joint is basically similar to that of HRB335 joint.

#### 3.3 Hardness test

A HRB400 025 mm joint has been chosen for making V – hardness gradient test along vertical section. The results from 48 tests show that the maximum gradient, which is 307.96, reached at positions near the welding seam and the minimum is 199.45 and average 253.49, which is smaller than 350.

In addition, tests were done for hardness comparison between HRB400 and HRB335 on both parent material and joints. The results showed the hardness of HRB400 of both parent and joint is slightly bigger than that of HRB335, without apparent trend to hardening.

#### 3.4 Metallographic test

The microstructures of the joints have been observed by metallographic tests with keen attention to the seam, melted area and overheated area both on HRB400 and HRB335 rebars. The results show no sign of abnormal structures. The grain of the HRB400 joint is apparently finer than that of HRB335 joint due to V addition.

From the test results above, we may conclude that the weldability of HRB400 is basically similar to that of HRB335, which means electroslag welding is also applicable to HRB400.

### 4 Results from Samples of Buildings

From April to September 2001, we have made statistic calculations based on electroslag–welded HRB400 joints sampled from the training building of Hunan Provincial Construction Company, the multi – floored living building of Hunan Haili Chemicals and the multi - functional building of Changsha Municipal Construction company. Test pieces are 186 pieces from 62 groups on representation of 12 000 pieces, produced by Chinese Xiangtan Steel Co. and Chengde Steel Co. . The results show good mechanical properties of HRB400 joint.

The sampling situation is as follows:

1. The chemical composition of all the parent material meet the stipulations of Hunan Provincial Norm DB43/T153 – 2001 “Quality HRB400 Hot Rolled Ribbed Rebar For Concrete”.

   \[
   C \leq 0.23 \%, \ Si \leq 0.80 \%, \ Mn \leq 1.50 \%, \ P \leq 0.035 \%, \ S \leq 0.035 \%, \ V \leq 0.08 \%, \ C_{eq} \leq 0.50 \%
   \]

2. Mechanical properties of the parent material:

   \[
   n = 62 \text{ groups}, \sigma = 621.6 \text{ MPa}, \sigma_{hmin} = 570
   \]

MPa, $\sigma_{\text{bmax}} = 695$ MPa, $\delta_s = 27.7\%$, $\delta_{\text{bmin}} = 24\%$, $\delta_{\text{bmax}} = 32\%$.

(3) Mechanical properties of the joints is shown in table 4.

Table 4 Mechanical properties of Sampling joints

<table>
<thead>
<tr>
<th>Dia. / mm</th>
<th>Quantity / pieces</th>
<th>Tensile strength / MPa</th>
<th>Features and positions of the fractures</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi 25$</td>
<td>30</td>
<td>580 - 640 / 610</td>
<td>Except one piece fractured at the welding seam, the others fractured at the parent material in form of plastic fractures</td>
</tr>
<tr>
<td>$\phi 22$</td>
<td>48</td>
<td>570 - 610 / 590</td>
<td>All fractured at the parent material in form of plastic fractures</td>
</tr>
<tr>
<td>$\phi 20$</td>
<td>42</td>
<td>570 - 615 / 590</td>
<td>All fractured at the parent material in form of plastic fractures</td>
</tr>
<tr>
<td>$\phi 18$</td>
<td>66</td>
<td>575 - 635 / 605</td>
<td>All fractured at the parent material in form of plastic fractures</td>
</tr>
</tbody>
</table>

5 Conclusions and suggestions

Through a number of tests and statistical sampling inspections, it can be concluded that electroslag welding is applicable to qualified HRB400 rebars. With an aim to ensure the welding quality, we suggest attention be paid to the following points during welding operations:

(1) diameter of the rebar to be welded

It is well known the bigger the diameter is, the more difficult the welding operation will be, hence the requirements for welding equipment and operator will be higher. Therefore much care must be taken in big-sized rebar welding operation.

(2) welding flux

The quality of the welding flux is key factor for welding quality, which should be well checked before operation. the special flux YD40 - III for electroslag welding and HJ431 used for HRB335 is recommended.

(3) welding parameters

Different flux requires different welding parameters. All parameters must be finalized after adjustment from trial welding.

(4) qualification of operator

The welding operator must be qualified and should follow relative welding procedures.

(5) quality of parent material

The parent material must be in conformity with the stipulations in related national standards and be well checked during operation.

References:
