Microstructure and creep properties of high Cr resisting weld metal alloyed with Co

Xue WANG¹, Liang-fei ZHAN¹, Qian-gang PAN², Zhi-jun LIU¹, Hong LIU¹, Yong-shun TAO²

¹(School of Power and Mechanical Engineering, Wuhan University, Wuhan 430072, China)
²(DongFang Boiler Group Co. Ltd., Zigong 643001, China)

E-mail: wxue2003@tom.com
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Abstract: A 9% Cr ferritic steel weld metal containing 1% Co, partially substituted for nickel, was prepared by submerged arc welding (SAW) processing. The microstructure and creep properties of the weld metal were investigated. The microstructure exhibited a fully tempered martensitic structure free of δ-ferrite. The creep properties of the obtained weld metal were inferior to those of the P92 base metal at 600 and 650 °C. The values of A and n for weld metal in the Norton power law constitution at 650 °C are 1.1×10⁻¹⁰²¹ and 8.1, respectively.

Key words: 9Cr steels, Weld metal, Microstructure, Creep properties
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1 Introduction

High Cr ferritic heat resisting steels are regarded as the best potential material for ultra-supercritical (USC) power plants (Masuyama, 2001; Kern et al., 2002). In the new generation of ferritic chromium steels, tungsten has been added to improve creep rupture strength. The newly developed typical steels, ASME-P92 (9Cr-0.5Mo-1.8W-VNb), ASME-T/P911 (European E911) (X11CrMoWVNb9-1-1), and ASME-P122 (11Cr-0.4Mo-2W-CuVNb) (Bendick et al., 1999; Masuyama, 2002; Vaillant et al., 2008) grades of steels have been widely used. It is of great importance that matching filler metals are developed simultaneously to base metals (Baune et al., 2006). Tungsten is a strong ferrite-stabilising element promoting the retention of δ-ferrite in the weld metal upon rapid cooling process. The detrimental effects of δ-ferrite on impact toughness and creep rupture properties of ferritic steels are well known (Kimura et al., 2006). Therefore, weld metal development aims to eliminate retained δ-ferrite by modification of the chemical compositions of weld metal. The addition of nickel, an austenite-stabilising element, produces positive effects on the impact toughness of NF616 (P92) weld metal by suppressing the formation of δ-ferrite (Naoi et al., 1995). However, as the nickel content increases, the Ac₁ transformation temperature falls below the post-welding heat treatment (PWHT) tempering considerably (Brühl, 1989). Thus, untempered martensite will appear in the weld metal, which is also detrimental to the toughness. The addition of cobalt has almost no influence on the transformation temperatures, but can also reduce retained δ-ferrite content effectively (Letofsky, 2001; Knežević et al., 2008; Klotz et al., 2008), which is likely to solve the problem. Previous studies have investigated the microstructure and creep properties of high Cr steels weld metal alloyed with about 1% nickel (Sireesha et al., 2001; Santella et al., 2003; Yamashita and Goto, 2003). However, little has been reported with regard to those of weld metals containing Co.
In the current work, high Cr ferritic steel weld metal containing about 1% Co, partially substituted for nickel, was produced using the submerged arc welding (SAW) processing. The creep tests were performed at 600 and 650 °C to investigate the creep properties of weld metal, which was compared with those of P92 base metal.

2 Experimental

The pad weld metal was obtained by SAW using US-12CRSD filler metal and PF-200SD flux, both KOBE Steel products (Japan). The pad were made using 2.4 mm diameter wire deposited on a mild steel base 90 mm in thickness, which was built up with a minimum of 12 layers, about 37 mm in thickness. The welding conditions parameters used for preparing reducing the weld metal are given in Table 1. After completion, the pads were given a PWHT at 755 °C for 5 h. Specimens were machined from the upper layers to obtain the undiluted weld deposit.

The experiments were also conducted using P92 steel pipes with a dimension of \( \Phi 325 \text{ mm} \times 71 \text{ mm} \) produced by Vallourec & Mannesmann Tubes Industries (France and Germany), to investigate the difference in creep behaviour between the weld metal and the base metal. Heat treatment of P92 pipes is normalizing at \( (1060 \pm 20) \text{ °C} \) and tempering at \( (765 \pm 15) \text{ °C} \). The chemical composition of the obtained weld metal and the P92 base metal are shown in Table 2.

Microstructural examination on the weld metal was carried out using both optical microscopy and transmission electron microscopy (TEM). The etchant Vilella’s reagent was used to reveal the microstructure. TEM observations were carried out using thin foil specimens fetched from the weld metal. The creep round-bar specimens, with a gauge of \( \Phi 10 \text{ mm}\times100 \text{ mm} \), were exposed at 600 °C (150 MPa) and 650 °C (90, 100 and 110 MPa, respectively). Extensometers were attached to the specimen shoulders to measure the extension along the variation of time.

3 Results and discussion

3.1 Microstructure

The optical micrograph structure of the obtained weld metal is illustrated in Fig. 1. Because the pad was built up with multi-layer beads, weld metal exhibited the initial columnar grained microstructures, together with the coarse grained and fine grained microstructures formed by the weld thermal cycle of subsequent weld passes. A fully tempered martensitic structure free of \( \delta \)-ferrite was observed in each zone of weld metal. The probability of \( \delta \)-ferrite retention is a function of weld metal composition, depending on the relative amounts of ferrite and austenite stabilizers. The chromium equivalent empirical expressions (Sireesha et al., 2001) have been suggested for estimating the tendency of ferrite retention:

\[
\text{Cr}_{eq} = \%\text{Cr} + 6\%\text{Si} + 4\%\text{Mo} + 1.5\%\text{W} + 11\%\text{V} + 5\%\text{Nb} + 8\%\text{Tr} - 40\%\text{C} - 2\%\text{Mn} - 4\%\text{Ni} - 2\%\text{Co} - 30\%\text{N} - \%\text{Cu}.
\]

It has been suggested that the ferrite retention will appear in welds if \( \text{Cr}_{eq} > 10 \). \( \text{Cr}_{eq} = (8.8) \) for the tested weld metal is lower than 10. It can be seen that there is good agreement between the calculation and observation results, which indicates that the addition

<table>
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<tr>
<th>Material</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>W</th>
<th>V</th>
<th>Nb</th>
<th>Co</th>
<th>N</th>
<th>B</th>
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<tr>
<td>Filler metal</td>
<td>0.081</td>
<td>0.30</td>
<td>0.78</td>
<td>9.50</td>
<td>0.29</td>
<td>0.52</td>
<td>1.52</td>
<td>0.20</td>
<td>0.033</td>
<td>0.91</td>
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</tr>
<tr>
<td>Weld metal</td>
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<td>0.27</td>
<td>0.74</td>
<td>9.77</td>
<td>0.37</td>
<td>0.40</td>
<td>1.44</td>
<td>0.20</td>
<td>0.026</td>
<td>0.85</td>
<td>0.035</td>
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</tr>
<tr>
<td>P92 base metal</td>
<td>0.12</td>
<td>0.21</td>
<td>0.43</td>
<td>8.84</td>
<td>0.50</td>
<td>0.16</td>
<td>1.67</td>
<td>0.21</td>
<td>0.067</td>
<td>—</td>
<td>0.042</td>
<td>&lt;0.0005</td>
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