§1. Effects of Post-weld Heat Treatment
Conditions on Hardness, Microstructures
and Impact Properties of Vanadium Alloys

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Welding is a key technology for the low-activation
vanadium alloys to realize a large component for fusion
reactors. Gas-tungsten-arc (GTA) weld joints produced from
NIFS-HEAT-1, a Japanese reference V-4Cr-4Ti alloy with
low oxygen level, exhibited better impact properties than
similar weld joints produced from the US large heat. The
results indicated that the impact property significantly
improved by reducing solute oxygen content in the weld
metal. Post-weld heat treatment (PWHT) is known to
improve the impact property of the weld joint. Systematic
study of hardness and microstructural evolution with the
heat treatment is necessary to investigate mechanism of the
PWHT effect. The purpose of this study is to estimate
PWHT effects on hardness, microstructure and impact
property for the mechanistic understanding.

Gas-tungsten-arc weld joints were made from the
V-4Cr-4Ti alloy products, which were designated as
NIFS-HEAT-1 (NH1), HP and US832665 (US) by 6-pass
welds. Impurity levels of the weld joints are shown in Table
1. Oxygen level in weld metal varied with combination of
the plate and the filler wire. All the weld joints were
contaminated with hydrogen during GTA welding. PWHT
was made at 473-1273 K for 1 hour. As shown in Table 1,
oxygen concentration was reduced from 58 wppm to 1
wppm by PWHT at 673 K. Distribution of Vickers hardness
around weld metal was measured with the load of 500 gf for
30 sec. Transmission electron microscopy (TEM) was
conducted at the center of weld metal. Charpy impact test
with 1/3 size specimens (3.3 x 3.3 x 25.4 mm) was
performed after PWHT at 673, 1073 and 1173 K. The
V-notch on the Charpy specimens was 30 degree in
included angle and 0.66 mm in depth.

Table 1 Impurity levels of gas-tungsten-arc weld joints
of V-4Cr-4Ti alloys (wppm).

<table>
<thead>
<tr>
<th>Plate</th>
<th>Weld metal</th>
<th>Base metal</th>
<th>Note</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>C</td>
<td>N</td>
<td>O</td>
</tr>
<tr>
<td>NH1</td>
<td>70</td>
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<td>135</td>
<td>59</td>
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<tr>
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<td></td>
<td></td>
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</tr>
<tr>
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<td>108</td>
<td>198</td>
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<tr>
<td>US/</td>
<td>73</td>
<td>355</td>
<td>43</td>
</tr>
<tr>
<td>US</td>
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</tbody>
</table>

*1 As-welded, *2 After PWHT at 673 K for 1 hr

Figure 1 shows change in hardness of the weld metal
and the base metal of the weld joints after PWHT at various
temperature for 1 hour. Hardness level of NH1 plates and
US plates before welds is indicated by a dark zone. Both the
weld metal and the base metal was hardened by GTA
welding. The hardening of the base metal by GTA welding
occurred in all the weld joints at any place examined. After
PWHT at 673 K both the weld metal and the base metal
were softened. Hardness of the base metal recovered to the
level before welding. From the TEM results, the precipitates
observed before welds were dissolved by the welding.
Therefore interstitial impurities, such as carbon, nitrogen
and oxygen, were expected to be released into matrix and to
cause solid solution hardening of the weld metal. On the
contrary, no significant change in microstructure was
observed by the PWHT at 673 K. The hardness recovery of
both the weld metal and the base metal is considered to
correspond to the release of hydrogen as shown in Table 1.

The weld metal exhibited hardening again after
PWHT at 973 or 1073 K. After the peak, the weld metal was
recovered in hardness to the level before welding by PWHT
at 1173-1273 K. The hardness of the weld metal increased
with increasing oxygen level. From the TEM results in NH1/
NH1 welds, a close correlation was found between the
hardness peak and appearance of the fine precipitates at
1073 K. This suggests precipitation dispersion hardening
around the hardness peak.

The hydrogen degassing and the softening by PWHT
at 673 K did not change Charpy impact property, while the
precipitation hardening by PWHT at 1073 K induced
embrittlement. Ductile-embrittle transition temperature after
PWHT at 1073 K was 277 K, which was much higher than
188 K obtained at as-welded condition. No improvement of
impact property by PWHT is expected at NIFS-HEAT. On the
other hand, precipitation behavior during long-time aging and
irradiation is expected to determine the performance of
V-4Cr-4Ti weld joints, and remains to be studied.

Fig. 1 Change in hardness of the weld metal (WM) and the
base metal (BM) after PWHT at various temperatures for 1
hour.