Mechanical Properties of Mo Weld Joints Produced by EBW and GTAW Methods

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Abstract. The aim of the paper is to research and compare mechanical properties of molybdenum welds created by different welding methods, EBW and GTAW. It is known that Mo weld ability is poor due to high affinity to O, N and creation of brittle phases. Welds were tested by means of metallography, optical microscopy, nanoindentation, and as more suitable way of molybdenum welding is EBW method.

Keywords: Molybdenum, EBW, GTAW, Welding, Nanoindentation, Reduced Elastic Modulus, Hardness.

Introduction
Molybdenum is a refractory metal that is used for special high temperature applications such as aircraft parts, holders of tungsten filaments, anodes, heating elements of furnaces etc. One of interesting applications is vessels for high temperature furnace remelting glass and gemstones. For such an application thin Mo sheets are to be welded to create vessel of specific shape.

Materials
Molybdenum (Mo) is refractory metal, with melting point 2620 °C, Young’s modulus 320 GPa and hardness 1.5 GPa. Compared to other refractory metals it has lower density, 10.2 g/cm³ and low coefficient of thermal expansion, 4.8.10⁻⁶ m/mK. Mo has high affinity to oxygen, nitrogen, carbon. In air, over 400°C MoO₂, low melting, brittle compound and over 1100°C molybdenum nitrides are created. These compounds, i.e. carbides, oxides, nitrides, segregate at the grain boundaries and the weld metal (WM) ductility is decreases. Thus welding needs to be done in inner shielding gas of high purity (Ar, He) or at best vacuum chamber [1]. As welding technology suitable for such reactive material and small sheet thickness, EBW – Electron Beam, LBW – Laser Beam and GTAW – Gus Tungsten Arc Welding can be selected [5].

Experiment
Thin rolled pure Mo sheets of thickness 0.2 and 0.4 mm were used. Chemical composition is: sheet with thickness 0.2 mm – Mo = 97.35 %, P = 2.31 %, W = 0.34 %; sheet with thickness 0.4 mm – Mo = 97.67 %, P = 2.35 %. Microstructure of base metal (BM) is in Fig. 2, lamellar structure resulting from rolling is visible. In this research EBW and GTAW welding methods (without filler metal) are used, EBW for the 0.2 mm thick sheet and GTAW for 0.4 mm sheet.

Micromechanical properties were obtained using the nanomechanical instrument Hysitron TI 950 TriboIndenter™. On each tested area were done 16 indents in 4x4 matrix with the distance 5μm between indents. After nanoindentation, the tested area was scanned by using in-situ SPM (Scanning Probe Microscopy) with the contact force 2 μN. Size of the scanned area was 20x20 μm. The measurement methodic is according Oliver and Pharr theory [2].

Microstructure of weld joints was observed in optical microscope Carl Zeiss Axio Observer D1m. Special production process of metallographic section was used [3].
Results

Macrostructure of both welds are in Fig. 1. Weld metals (WM) of both welds are shown in Fig. 3. Both heat affected zones (HAZ) are in Fig. 4.

Both samples contain significant volume of phosphorus that is known to decrease significantly ductility in many metallic materials and had adverse effect on Mo weldability [4].

Results of nanoindentation are summarized in Tab. 1. From these values were calculated values of Young's modulus and hardness HV. Results are in Fig. 5 and Fig. 6. Fine grain recrystallization by EBW is sharply increasing Young's modulus and hardness in the WM and HAZ. For GTAW weld this increase was not so sharp. This is caused by resulting grain size. The width of HAZ_{EBW} = max 1.5 mm and HAZ_{GTAW} > 35 mm. Wider HAZ increases the risk of cracking.

<table>
<thead>
<tr>
<th>Method and Thickness</th>
<th>Position of indentation</th>
<th>Reduced modulus Er [GPa]</th>
<th>Indentation hardness H_{IT} [GPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBW (0.2 mm)</td>
<td>Weld metal (WM)</td>
<td>249.4</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>Heat affected zone (HAZ)</td>
<td>255.9</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>Base metal (BM)</td>
<td>81.7</td>
<td>3.1</td>
</tr>
<tr>
<td>GMAW (0.4 mm)</td>
<td>Weld metal (WM)</td>
<td>125.1</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>Heat affected zone (HAZ)</td>
<td>125.8</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>Base metal (BM)</td>
<td>51.1</td>
<td>2.7</td>
</tr>
</tbody>
</table>
EBW and GTAW weld microstructure differs very much in grain size and shape. In WM area of GTAW, weld is crystallizing in columnar dendrites morphology. On the other hand, EBM weld crystallizes in cellular morphology, because of much higher temperature gradient.

The resulting microstructure is determined by the amount of heat input and cooling rate (ie used welding technology). When using EBW method the amount of heat input is significantly lower (also narrower HAZ). Although in WM the grain became significantly coarse, E almost increased to the value of pure Mo. Because of fine grains in the HAZ it nears to this value more.
For GTAW method was heat effect bigger and elasticity significantly decreased. Low values of Young’s modulus in BM (for both methods) are given by production technology (rolling thin sheets together - layering). Marked anisotropy of mechanical properties is here. The thinner sheet, the bigger anisotropy.

Hardness of BM increased due to rolling. Material became brittle and was more susceptible to cracking due to irregular heating and structural changes.

**Summary**

EBW and GMAW welding of Mo sheets were done. The difference in micro, macrostructure, size of respective WM, HAZ areas is very big. Recrystallization caused by welding resulted in microstructure change and change of mechanical properties, especially considering the as rolled structure of BM. For EBW the grain size is much finer compared to GTAW. The WM, HAZ width is much smaller for EBM, thus we consider this welding method as more suitable for pure Mo welding. Although when EBW method is used, the hardness of the material significantly increased in WM and HAZ, its elasticity is almost equal to the tabular values of pure Mo.
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References