Laser deposition of refractory high-entropy alloy NbMoTaW

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Introduction

- High entropy alloys (HEAs) are systems with four or more principle elements of 5-35 atomic % composition each
- Only became a focus of research in 2004
- Potential for superior properties compared to traditional alloys – could be applied to novel applications
- Laser deposition is a fast, cheap way to enhance a part

Objectives

- Develop parameters for successful laser deposition of NbMoTaW
- Employ characterization and properties testing techniques to determine how the HEA compares to common industry alloys

Methods

- Two substrates were chosen:
  - A36 steel and pure nickel
  - An equimolar mixture of Nb, Mo, Ta, and W powders was made and shaken by hand for 30 minutes
- Three beads were deposited on a nickel plate to provide contrast
- Laser power was selected as the first parameter to be developed
- Five beads of varying wattages were deposited on the A-36 steel
- After a visual analysis, 110W and 140W were determined to be the best beads
- Five more deposits were made between 110W and 155W

Wattage of A-36 Steel Depositions (W)

<table>
<thead>
<tr>
<th>Sample</th>
<th>50</th>
<th>80</th>
<th>110</th>
<th>140</th>
<th>171</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 2</td>
<td>110</td>
<td>121</td>
<td>133</td>
<td>144</td>
<td>155</td>
</tr>
</tbody>
</table>

- The samples were subjected to hardness testing, optical microscopy and scanning electron microscope (SEM) analysis to check for defects and determine depth of penetration, percent dilution, mixing quality, and hardness.

Results

- Penetration depth may display a slight upward trend
- Percent dilution shows no statistically significant correlation
- Qualitatively, the penetration depth was promising
  
  \[
  \%\text{ Dilution} = \frac{\text{Base Area}}{\text{Base Area} + \text{Bead Area}} \times 100
  \]

- Energy dispersive x-ray spectroscopy were used to do characterize the elemental distribution (left).
- Composition maps were made of each area (right). The transition from substrate to diffusion zone is gradual, which would lead to a more stable deposition. The mixture is largely homogeneous with the exception of a slight segregation ring between tantalum and molybdenum.
- Additionally, backscattering was used to look for intermetallics, which often form angular phases. None were detected.
- The nodules caused a tungsten deficiency in the well-mixed zones. Consequently, no equimolar regions were found.

Conclusions

- Sufficient penetration depth was achieved
- Pure metal deposits suggest powder did not fully melt
- Decreased beam focus could lead to a rounder interface
- Hardness and modulus results suggest industrial viability

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