Laser deposition of refractory high-entropy alloy NbMoTaW

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Introduction

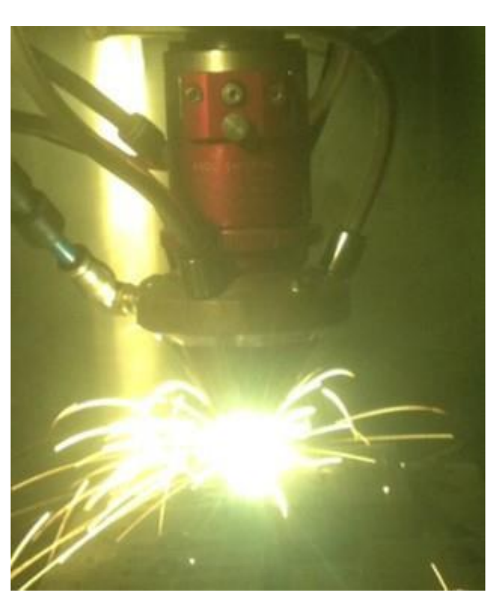
- High entropy alloys (HEAs) are systems with four or more principle elements of 5-35 atomic % composition each
- Only became a focus of research in 2004
- Potential for superior properties compared to traditional alloys – could be applied to novel applications
- Laser deposition is a fast, cheap way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



Laser deposition

- After a visual analysis, 110W and 140W were determined to be the best beads
- Five more deposits were made between 110W and 155W

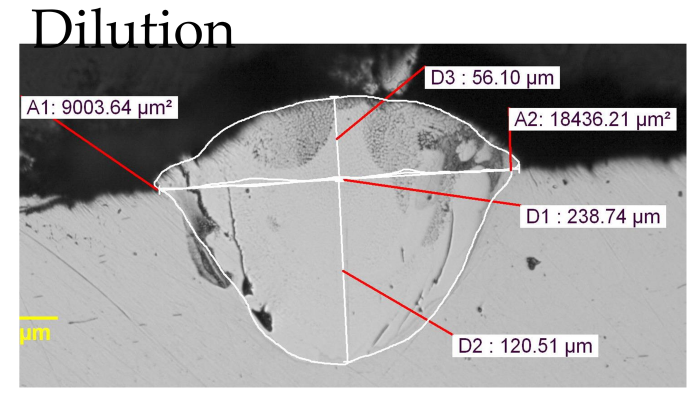
Wattage of A-36 Steel Depositions (W)

Sample 1	50	80	110	140	171
Sample 2	110	121	133	144	155

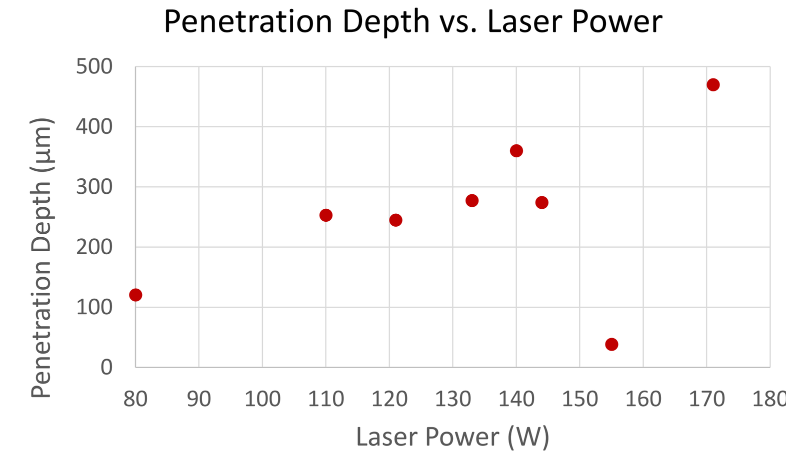
- The samples were subjected to hardness testing, optical microscopy and scanning electron microscope (SEM) analysis to check for defects and determine depth of penetration, percent dilution, mixing quality, and hardness.

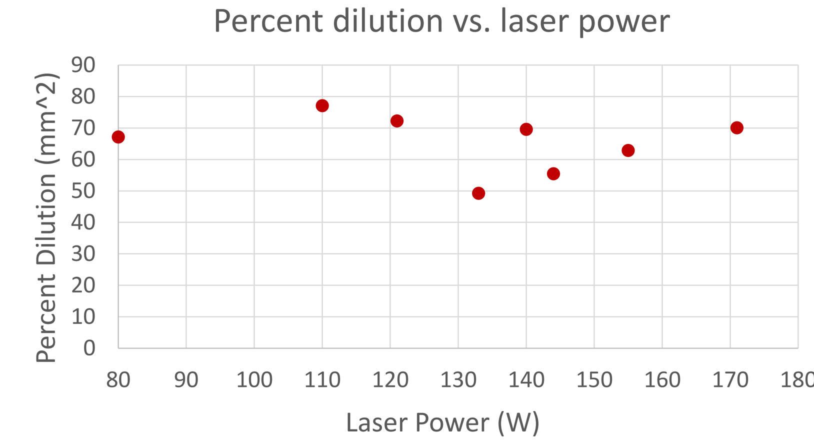
Results

Penetration Depth and Percent Dilution



80 W



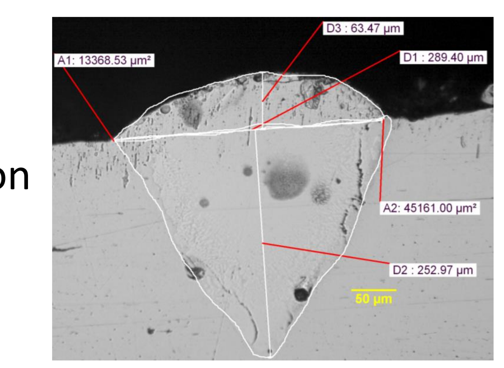


When correlated to laser power:

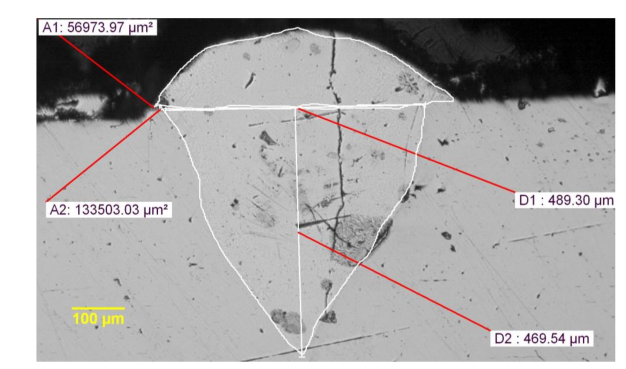
- Penetration depth may display a slight upward trend
- Percent dilution shows no statistically significant correlation

Qualitatively, the penetration depth was promising

$$\% \, Dilution = \frac{Base\ Area}{Base\ Area + Bead\ Area} * 100$$



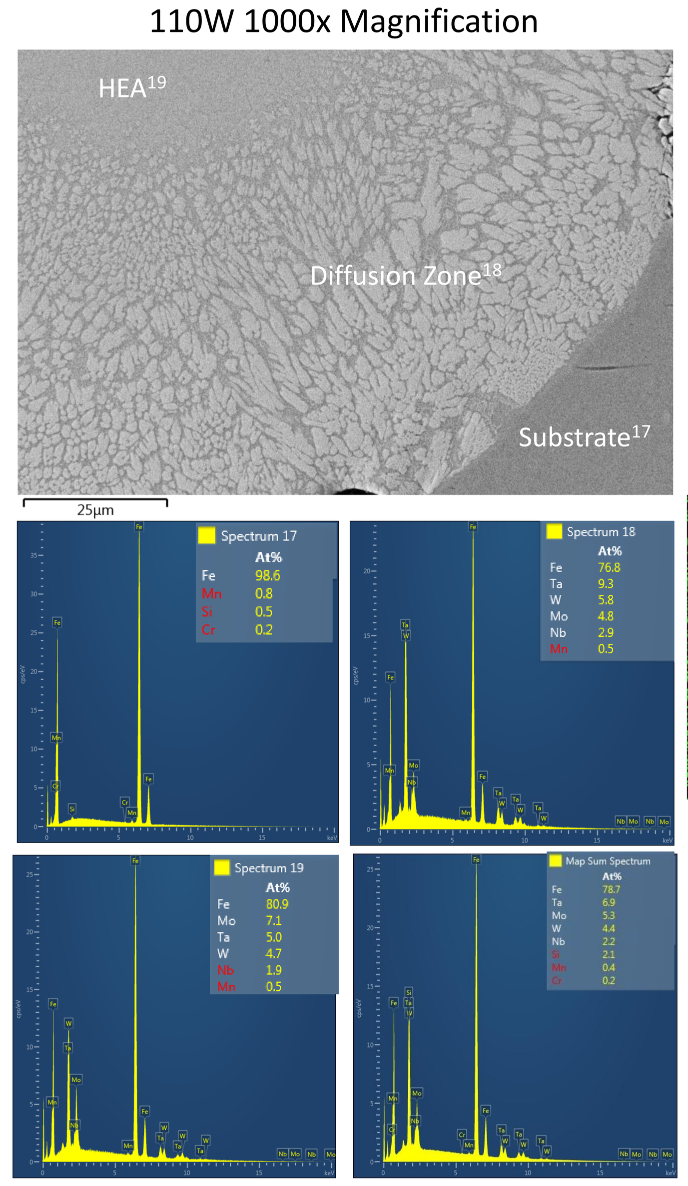
110 W

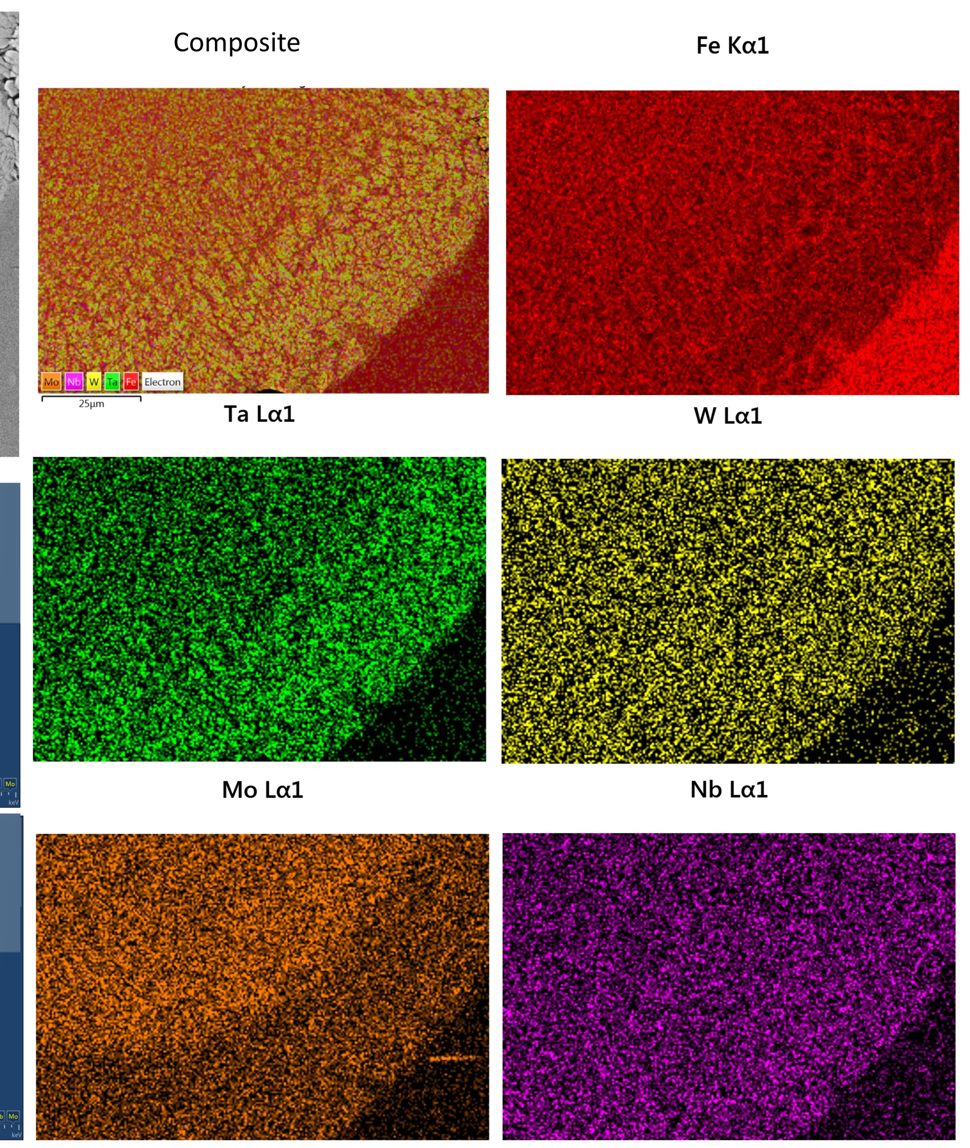


171 W

SEM Composition Analysis

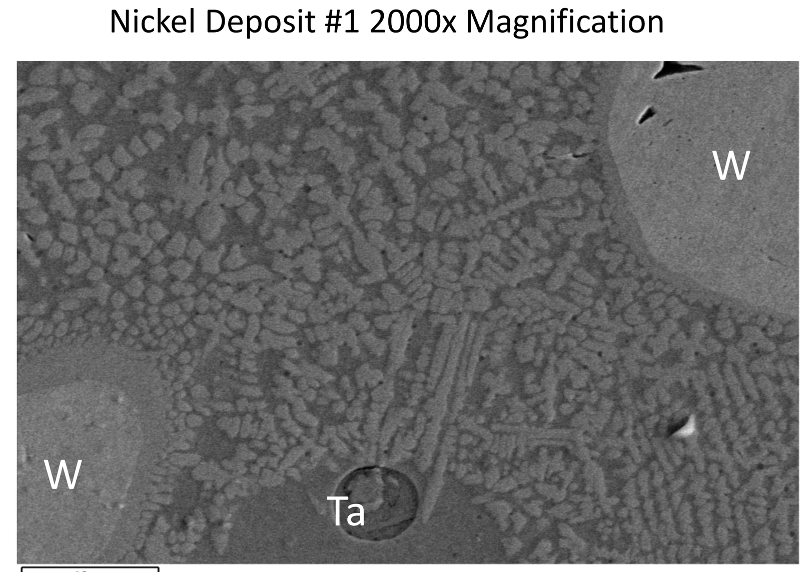
110W 1000x Magnification





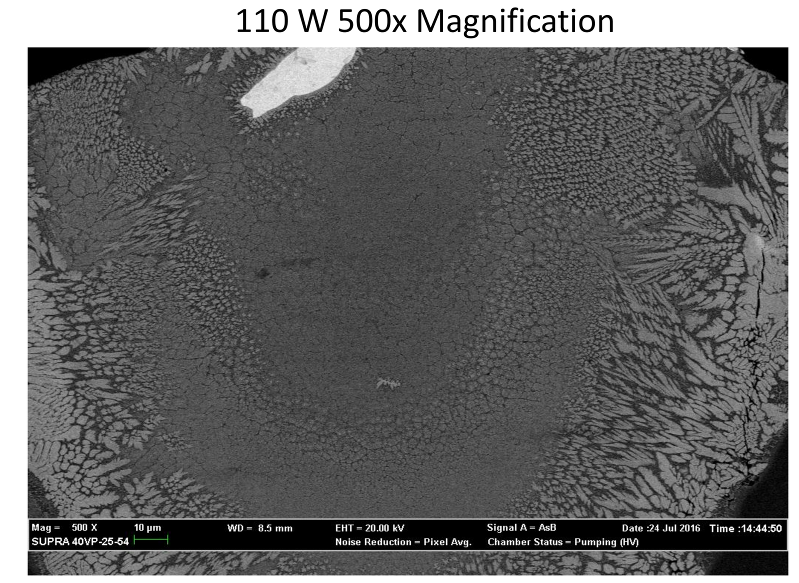
- Energy dispersive x-ray spectroscopy were used to do characterize the elemental distribution (left).
- Composition maps were made of each area (right). The transition from substrate to diffusion zone is gradual, which will lead to a more stable deposition. The mixture is largely homogeneous with the 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.

Nickel Deposit #1 2000x Magnification



Nodules of pure tungsten regularly formed in the deposits. Tantalum and molybdenum nodules were also found occasionally.

110 W 500x Magnification

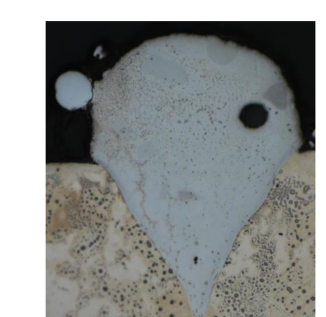


The nodules caused a tungsten deficiency in the well-mixed zones. Consequently, no equimolar regions were found.

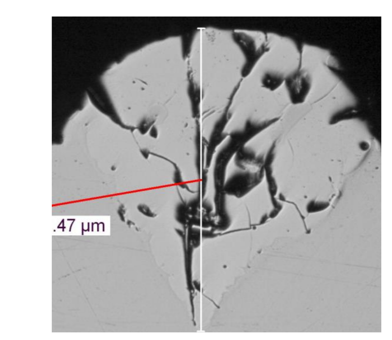
Results Cont.

Optical Microscopy

- Severe cracking in deposits made on steel
- Only minor cracks in deposits made on nickel possibly due to greater diffusivity and ductility in the nickel's FCC matrix
- The penetration areas are angular instead of rounded, which results in a smaller interface area and decreased stability of the deposit



Nickel Deposit #2 20x Magnification



133W 10x Magnification

Hardness Testing

Nanoindentation was performed on 110, 121, and 133 W to determine the hardness and modulus of elasticity. Microindentation was used to find the hardness of the nickel deposits. The substrate values have been included for comparison.*

Hardness and Elastic Modulus Values of Deposits and Substrates

Material	Hardness (HV)	Modulus (GPa)
110 W Deposit**	1509	262
121 W Deposit	931	245
133 W Deposit	992	239
Nickel Deposit	766	-------------------
Nickel*	194	205
A36 Steel*	148	200

**The values for the 100 W deposit are believed to be an error possibly caused by accidentally testing one of the segregated nodules instead of the more homogeneous material.

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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