Investigation of the Hardening Response of Precipitation Hardened Stainless Steel 17-4 During Multi-Pass Welding

Allison Fraser, Robert Hamlin, John DuPont

Lehigh University and Defense Logistics Agency

Problem Statement

PH 17-4 is a candidate alloy for armor plating in military combat vehicles due to its high strength via copper precipitates. However, high temperatures experienced during welding result in the dissolution of the strengthening precipitates (Figure 1), requiring a post weld heat treatment to restore the strength. Post weld heat treatments are expensive and cannot be applied when welding on a large scale or when making a repair in the field. Therefore, controlled weld metal deposition during multi-pass welding in situ will be investigated as a means to restore the strength lost from primary weld thermal cycles to eliminate the need for a post weld heat treatment (Figures 2 and 3).

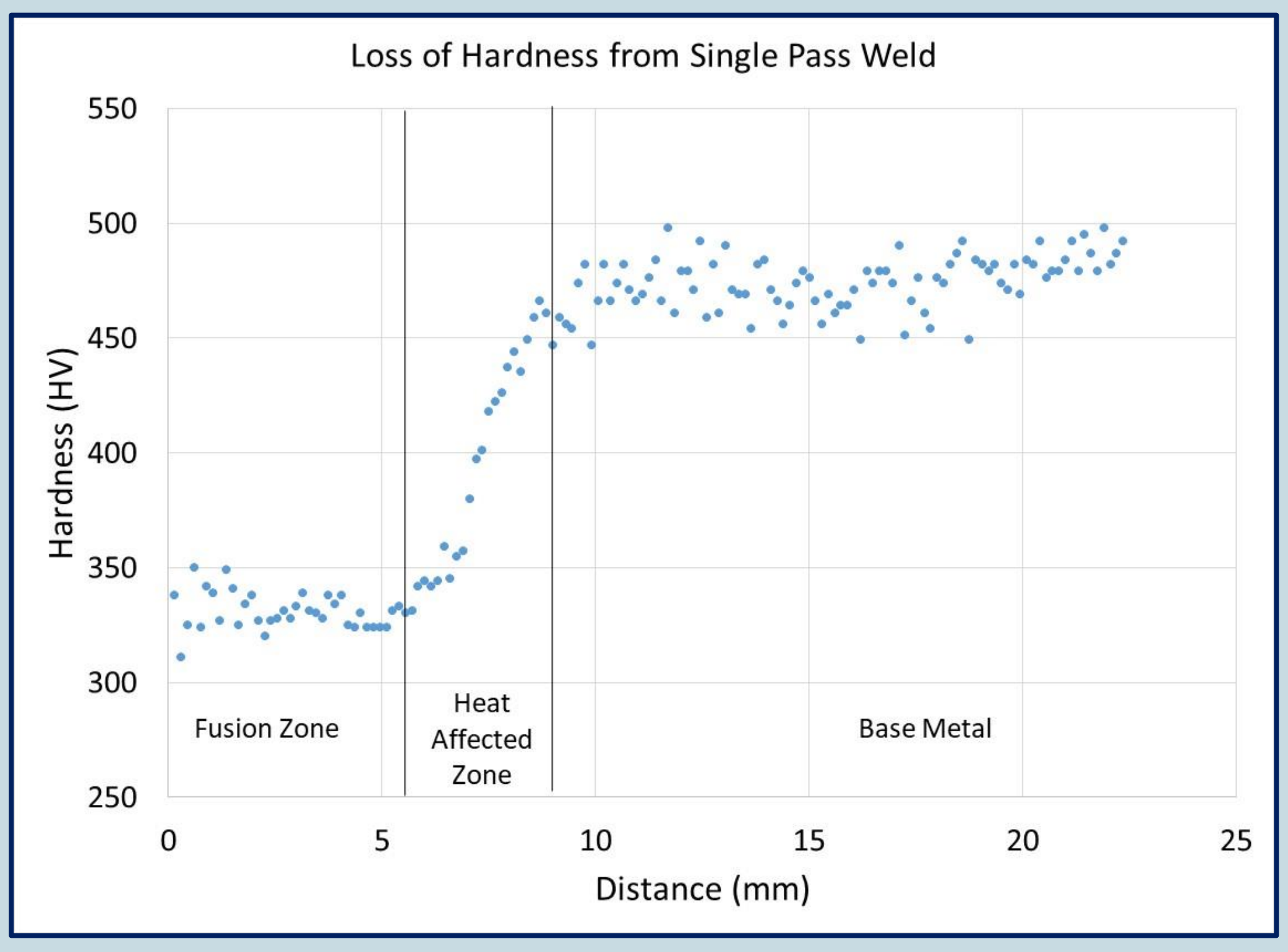

Figure 1. Microhardness trace across a single pass weld, showing the loss of hardness in the fusion zone.

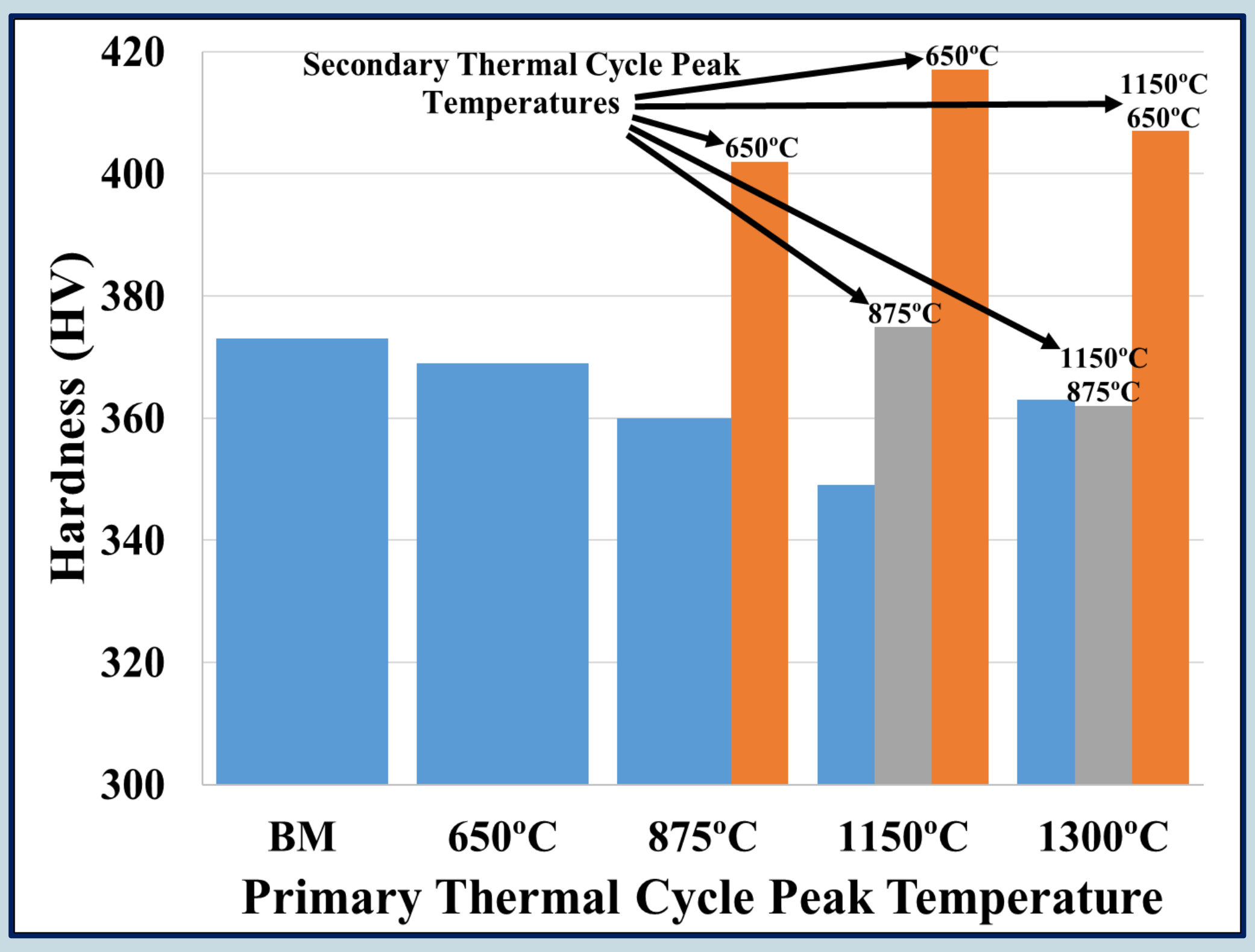

Figure 2. GLEEBLE simulation for a heat input of 2000 J/mm indicating the hardness can be restored through the use of secondary thermal cycles to promote precipitation.

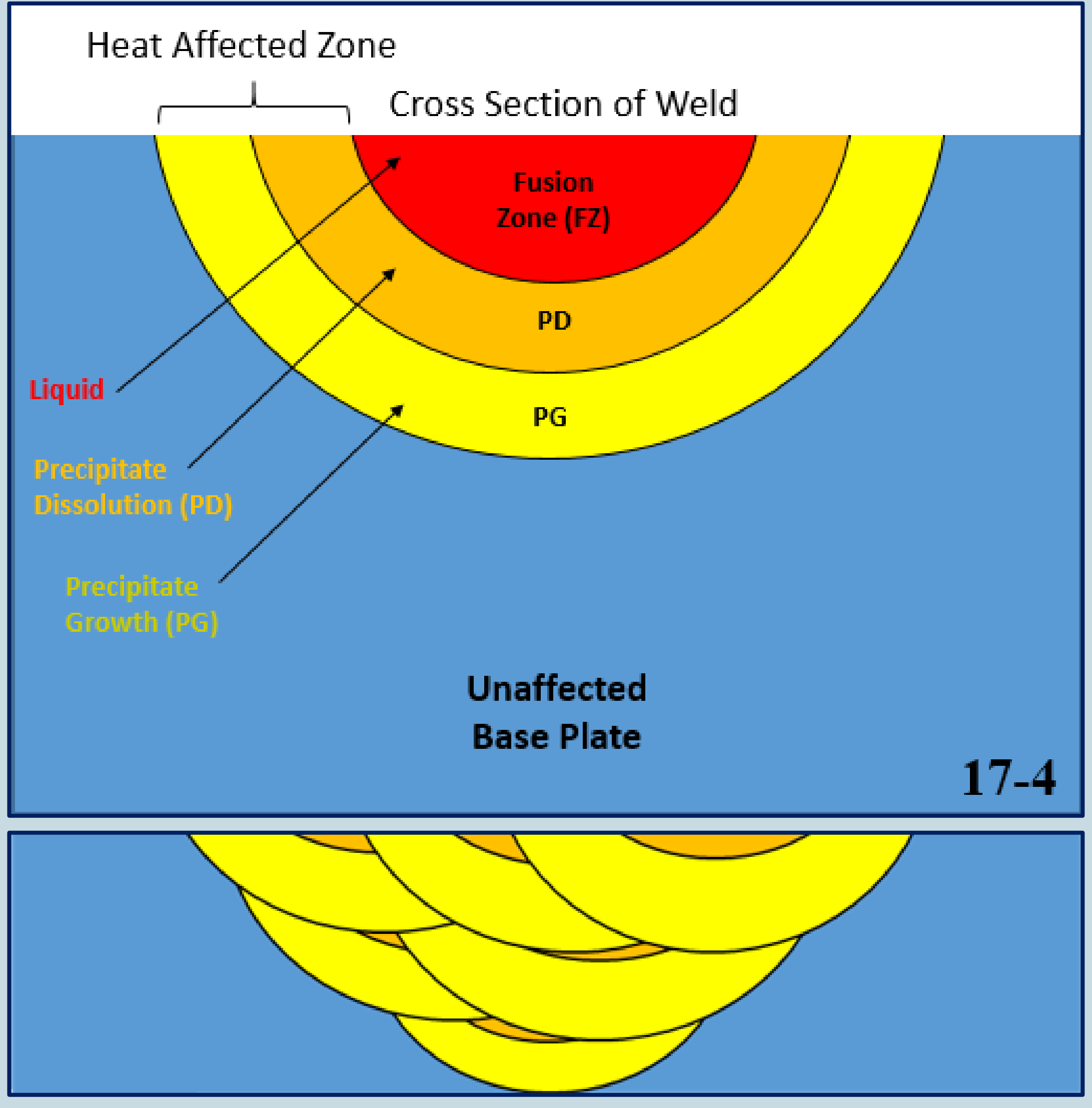

Figure 2. Schematics depicting weld cross section with precipitate dissolution & growth regions and how weld multi-passes can be strategically placed to produce a weld consisting entirely of precipitate growth region, optimizing the strength of the overall weld.

Method

- Dual pass gas tungsten arc welds were made using three heat inputs and three target overlaps
    - 1000, 2000, and 3000 J/mm
    - 25%, 50%, and 75% overlap
- Microhardness mapping was performed over a portion of the fusion zone, heat affected zone, and base metal of each weld (Figure 3)
    - 100 g load
    - 150 μm spacing between indents

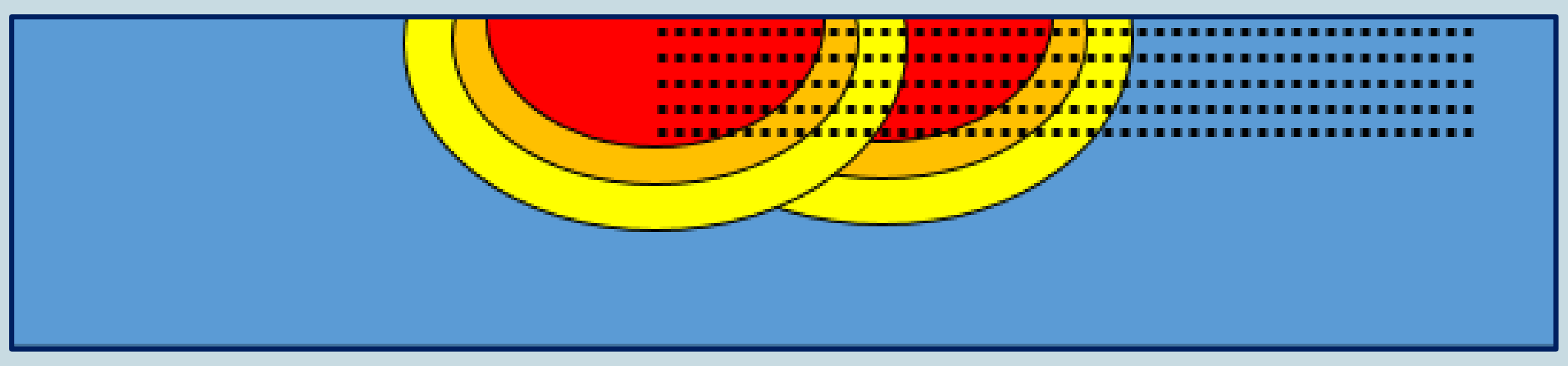

Figure 3. Schematic depicting the placement of the microhardness mapping, measuring the hardness of the fusion and heat affected zones of the two weld passes as well as the unaffected base plate for comparison.

Results

Microhardness mapping was performed for the three heat inputs at each target overlap, with the maps shown in Figures 4 through 6.

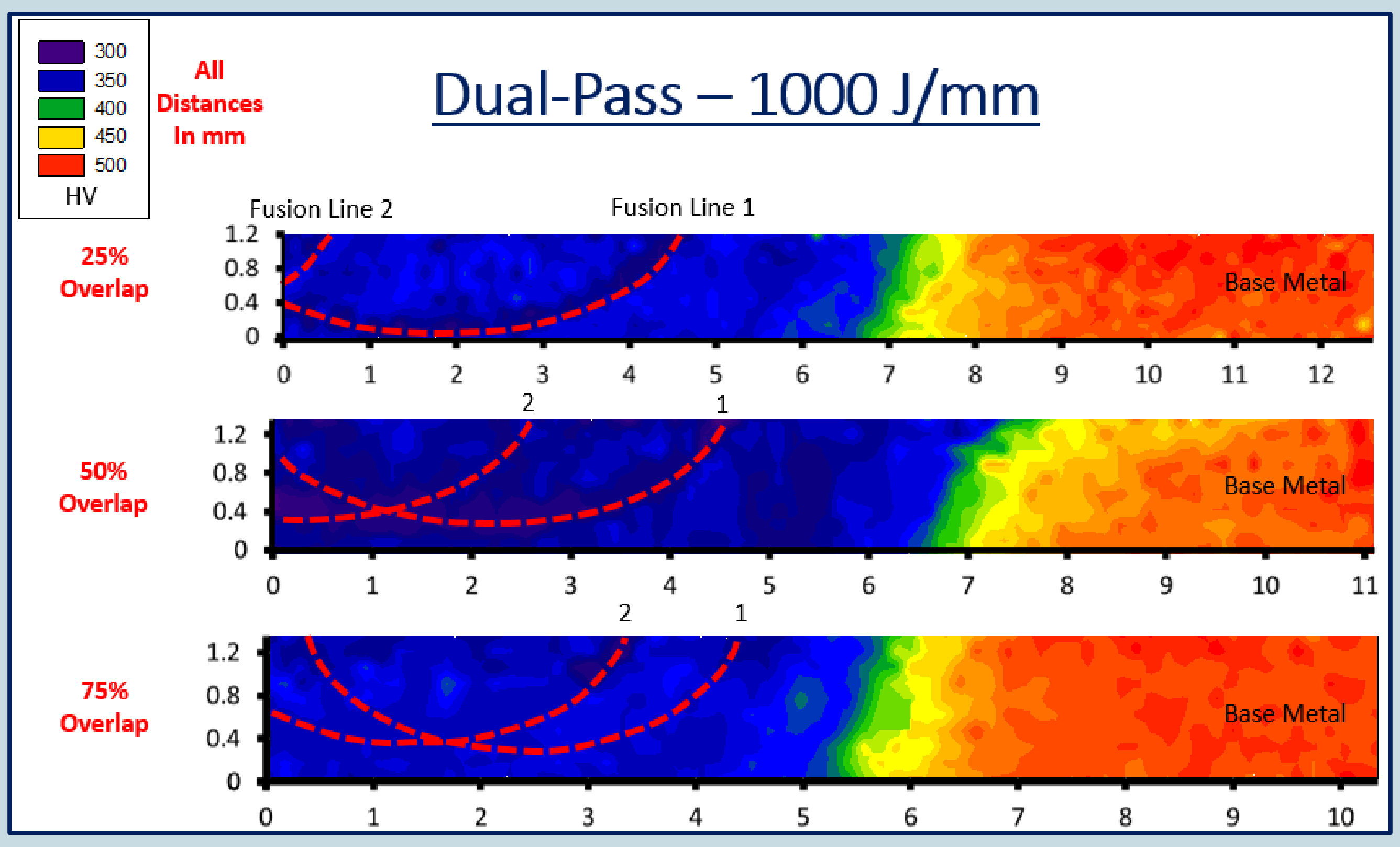

Figure 4. Microhardness mapping for target overlaps at a heat input of 1000 J/mm. The fusion zone of the primary weld pass does not show significant rehardening after the secondary weld pass in all three overlaps, indicating this heat input is not enough to allow for adequate precipitate growth.

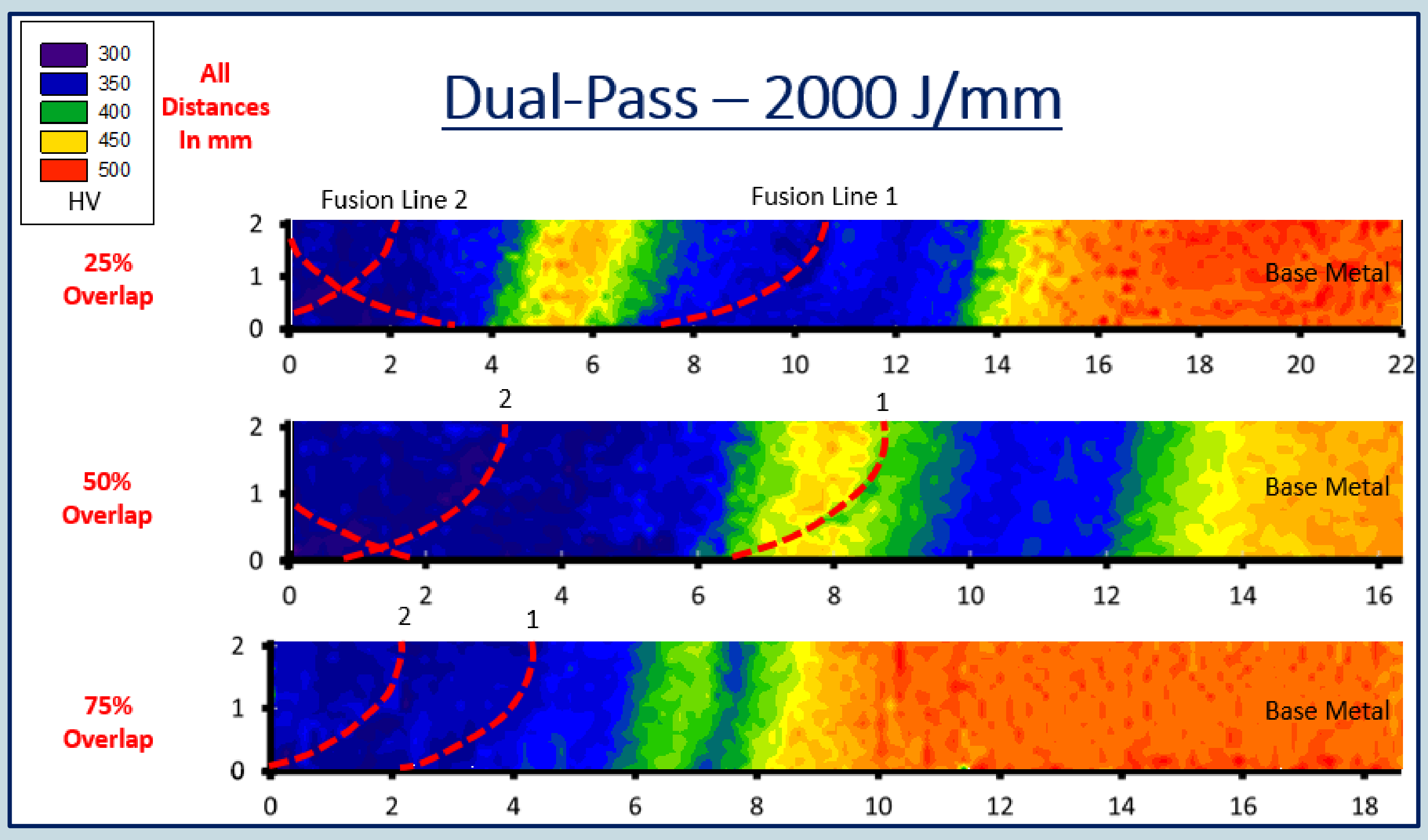

Figure 5. Microhardness mapping for target overlaps at a heat input of 2000 J/mm. Significant rehardening is observed in the fusion zone of the primary weld pass (~425 HV) to values comparable to the base metal (450 HV). An overlap of 75% may result in softening in the primary precipitate growth region, so an overlap less than 75% would be desired.

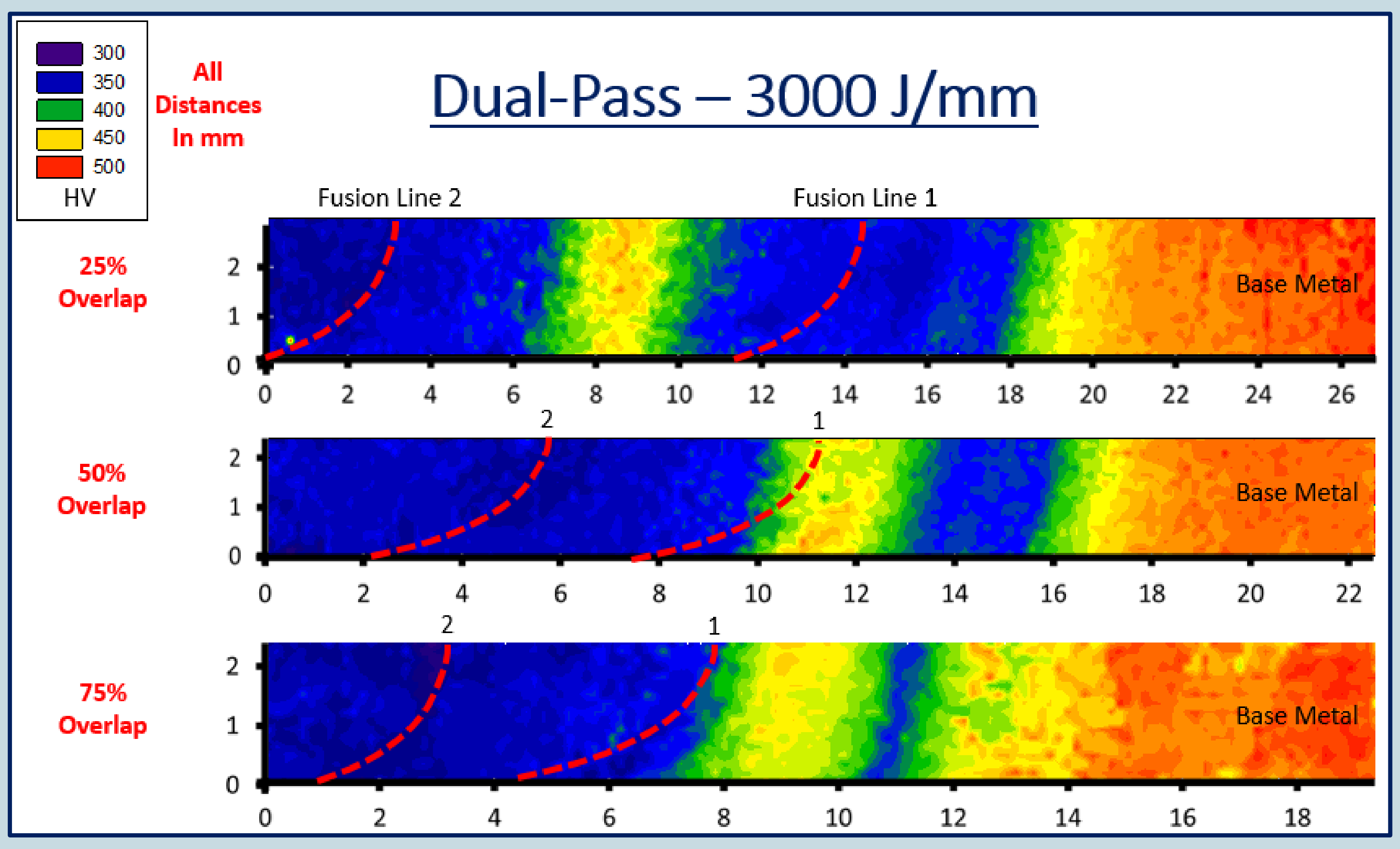

Figure 6. Microhardness mapping for target overlaps at a heat input of 3000 J/mm. Significant rehardening is observed in the fusion zone of the primary weld pass (400-425 HV) to values comparable to the base metal (450 HV).

Discussion

- At a heat input of 1000 J/mm, no significant rehardening is observed in the primary fusion zone at any target heat input, indicating that this heat input does not allow for significant precipitate growth.
- At heat inputs of 2000 J/mm and 3000 J/mm, significant rehardening is observed at each overlap.
- The overlap percentage can be manipulated to reduce the size of the softened region between the precipitate growth region of the primary weld pass to the precipitate growth region of the secondary weld pass.
- An ideal overlap occurs between 50 – 75% to avoid softening of the primary precipitate growth region due to the effects of the secondary weld pass.

Conclusions and Future Work

- Strength can be regained in the weld region through the controlled affect of secondary weld thermal cycles on the primary weld path
- Microhardness mapping of dual-pass gas tungsten arch welds indicate that higher heat inputs and overlap between 50 – 75% will provide optimal hardening of the primary weld pass

- Perform hardness mapping of dual-pass gas tungsten arc welds for 13-8+ Mo to determine optimal steel for this application
- Fabricate welds of 17-4 using filler metal to compare mechanical properties to gas tungsten arc weld fabrication method

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