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Development of Graded Transition Joints for Avoiding Dissimilar Metal Weld Failures

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Introduction
Dissimilar Metal Welds (DMWs) are used in many applications but are susceptible to premature failure below the expected creep life. These failures can cost up to $1,000,000 per day in repair costs and lost revenue in power plant applications. When the DMW is aged, carbon diffuses across the weld interface from the ferritic to austenitic material. This creates a soft, carbon denuded zone in the ferritic steel, and a hard, carbon enriched zone in the austenitic steel. It is because of carbon diffusion and the formation of carbides that DMWs are susceptible to premature failure in service.

A proposed solution is a joint whose composition changes gradually from ferrous to austenitic to slow carbon diffusion during aging. As such, a similar weld replace one dissimilar weld. The purpose of the following microhardness tests is to understand the change in hardness values due to aging of Graded Transition Joints (GTJs) and DMWs. This research proposes that the GTJ will exhibit less severe changes in hardness with increased aging than the DMW, as carbon diffusion will be limited.

Experimental
- DMW: Grade 22 welded to 347H with IN82 filler metal
- GTJ: Fabricated using gas tungsten arc welding (GTAW) with dual wire feeders, composition was adjusted by 2% dilution starting at 7% 347H across 46 mm until 100% 347H.
- Aging: 500, 1000, 2000 hrs at 460 °C
- 100 g microhardness trace with 125 μm spacing: DMW and GTJ
- 5 g microhardness trace with 25 μm spacing: DMW
- Perpendicular and steep-angle traces

Results
Figure 4. GTAW set up with dual wire feeders for GTJ fabrication. One wire feeds ferritic GR22 while the other feeds austenitic 347H, varying the composition from 100% GR22 to 100% 347H. Fabricating a graded joint with varying composition allows for gradual changes in microstructure and properties.

Figure 5. DICTRA calculations to determine a suitable grade length for the GTJ. Carbon diffusion at 465 °C between 0 and 20 years was simulated for a 1 mm grade and a 20 mm grade. The 1 mm grade shows significant carbon diffusion across the joint after minimal aging at 465 °C, while the 20 mm grade shows little carbon diffusion after 20 years of aging. Creating a 20 mm grade suggests minimal carbon diffusion after significant aging.

Figure 6. Hardness trace on DMW samples with a 5 g load spaced 25 μm apart at a steep angle across the fusion line. After aging the DMW for 1000 hrs, there is a steep increase in hardness across the fusion line due to carbon diffusion from the ferritic to austenitic steel. The compositional gradient occurs across a length on the order of microns, allowing easier carbon diffusion.

Figure 7. Hardness traces on DMW samples taken at a 5 g load spaced 25 μm apart at a steep angle across the fusion line for as welded, 500 hrs, 1000 hrs, and 2000 hrs aging conditions. The decrease in hardness of the ferrous metal is due to the diffusion of carbon into the austenitic metal. The hardness increases in the austenitic region from carbide formation. As aging increases, the softened region becomes larger, suggesting continuous carbon diffusion at elevated temperatures.

Figure 8. Hardness traces on GTJ samples taken at a 100 g load spaced 125 μm apart across the graded region for as welded, 500 hrs, 1000 hrs, and 2000 hrs aging conditions. The hardness initially rises due to solid solution strengthening with additions of Ni and Cr, then decreases as martensite tempering with aging. Aging past 500 hrs has little influence on the hardness values. The lack of the softened zone suggests resistance to premature failure due to large concentration gradients and carbon diffusion at elevated temperatures.

Conclusions
- Carbon diffusion from aging causes decreases in hardness in the ferrous region and increases in hardness in the austenitic region, leading to premature failure of DMW
- Lack of compositional gradient in the GTJ limits carbon diffusion and reduces drastic changes in hardness values
- Aging continuously alters the hardness of DMWs, but further aging does not alter GTJs
- No local softening in the GTJ

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References

Future Work:
- Age samples for 4000 hrs – investigate further carbon diffusion
- Finer spaced hardness traces – identify minute changes in hardness
- Tensile test with digital image correlation – record localized strain rate in samples
- Tensile test at room and elevated temperatures – investigate effect of heat on strength

Figure 1. Mounted DMW sample etched in oxalic acid using electrolysis.

Figure 2. Mounted GTJ sample polished through 0.3 μm.

Figure 3. Schematic of the graded transition joint’s composition.