Intermediate Temperature Grain Boundary Embrittlement in Austenitic Filler Metals

N.E. Nissley and J.C. Lippold
Welding and Joining Metallurgy Group
The Ohio State University

Introduction

Ductility Dip Cracking (DDC) is a solid-state phenomenon that plagues a number of engineering materials, including austenitic stainless steels, Ni-base alloys, Cu-base alloys, and Ti alloys. Under the right conditions these materials exhibit a loss of ductility over a temperature range below the solidus temperature. In the weld metal it occurs preferentially along migrated grain boundaries. The mechanism for DDC is unclear and tests to determine susceptibility to DDC are often inconclusive. This presentation will examine new work completed on understanding DDC in austenitic filler metals.

Procedure

Susceptibility to DDC was evaluated using the strain-to-fracture (STF) Gleeble®-based test technique to isolate the desired testing temperatures and to evaluate the materials response to applied strain. In this study, eight experimental INCONEL® FM-52M and FM-72 Ni-base filler metal compositions have been evaluated. Optical and electron microscopy were used to evaluate the microstructure and backscatter electron diffraction was used extensively to evaluate the crystallographic orientation variation with strain.

Results and Discussion

The spot pre-weld downslope time was found to significantly affect the DDC resistance when the current downslope time was altered. Faster cooling rates resulted in finer solidification substructure, fewer metastable intragranular precipitates, and a reduced DDC susceptibility. Subsequent solutionizing and precipitation heat treatments improved the DDC resistance and were attributed to microstructure homogenization and $M_{23}C_6$ precipitation that resulted in improved grain boundary strength.

Elongated intergranular $M_{23}C_6$ precipitates that formed during the heat treatment of one alloy resulted in dynamic recrystallization during STF testing and were attributed to particle stimulated nucleation (PSN). The resulting recrystallized microstructure had a smaller grain size and $\Sigma 3$ twin boundaries (special boundaries) that were effective at blunting DDC crack propagation; both increasing the resistance to DDC.

A significant increase in DDC resistance was observed in an alloy with 4% Mo and 2.5% Nb and was attributed to the skeletal precipitate morphology whose large surface area and dense distribution were highly effective at pinning grain boundaries. The resulting tortuous boundaries mechanically locked the grains together, thereby reducing boundary sliding and cracking.

The observed DDC cracking susceptibility was compared with thermodynamic calculations and single sensor differential thermal analysis (SS-DTA) to develop a better understanding of how carbide precipitation affects grain boundary locking and the mechanism for DDC. Macroscopic grain boundary locking occurs in alloys that form intragranular precipitates at the end of solidification. The morphology and distribution of these precipitates affects their ability to pin boundaries, resulting in wavy or tortuous boundaries by limiting grain boundary migration. Microscopic grain boundary locking occurs in alloys that form intergranular solid state precipitates. The distribution, morphology, and when they form can affect their ability to improve grain boundary strength.

Conclusions

The STF test technique has been demonstrated as an effective tool in isolating testing conditions and allowing for a better understanding of the variables that affect a material's susceptibility to DDC. The use of the STF test in connection with advanced analysis techniques has expanded our knowledge of DDC in Ni-base filler metals.