Insight into the Metallurgical Mechanism of Ductility Dip Cracking in Ni based filler metals

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Introduction

A690 is a Ni-Cr-Fe alloy with excellent resistance to general corrosion, localized corrosion and stress corrosion cracking. However, the companion filler metal for A690, EN52, has been shown by several researchers to be susceptible to ductility dip cracking (DDC), which limits its widespread use in joining applications. DDC is an intergranular form of solid state cracking that occurs upon reheating a previously deposited weld pass. Previous research presented at the April 2005 AWS conference revealed that Ni-Cr-Fe alloys similar to A690 which form MC carbides are less susceptible to DDC than those that form intergranular $M_{23}C_6$. The evolution of carbides during a typical weld reheat thermal cycle and their role in DDC is the focus of this investigation.

Technical Approach

The susceptibility to DDC was assessed via hot ductility testing. A Gleeble thermal mechanical simulator was utilized to explore the tensile response of wrought A600, A690 and as-solidified EN82H and EN52 filler metals at approximately 125°F temperature intervals along both the on-heating and on-cooling portions of a simulated weld reheat thermal cycle. JMatPro computational software program was used to guide the test program by determining the carbide solvus temperatures and generating transformation diagrams for each alloy. The test specimens were flat tensile bars machined from wrought A690 and A600 and as-solidified EN52 and EN82H weld metal. The reduction in area, energy to fracture and elongation to fracture were measured to characterize the mechanical behavior and subsequent DDC susceptibility of each alloy. The corresponding microstructural evolution was characterized by first water quenching samples at select temperatures along the weld thermal cycle to freeze in the elevated temperature microstructure. Subsequently the samples were examined using light optical microscopy (LOM), scanning electron microscopy (SEM), X-ray energy dispersive spectroscopy (EDS), and electron back scatter diffraction (EBSD).

Results/Discussion

On-heating and on-cooling hot ductility curves will be presented for all four alloys. These curves will compare the reduction in area, fracture energy and elongation at fracture for all four alloys as a function of temperature. To examine the role carbides play in DDC two different peak temperatures were used for the on-cooling hot ductility tests. The first peak temperature was 25°F below the nil strength temperature of each alloy. Samples that were water quenched from this peak temperature confirmed that this elevated temperature excursion resulted in dissolution of intergranular carbides. The second peak temperature used for the on-cooling hot ductility testing was selected based upon JMatPro calculated carbide solvus temperatures. Samples heated to a temperature below the respective high temperature carbide solvus temperature for each alloy where also tested on-cooling. The result of this work will be discussed. The effect of hold time at the ductility minimum temperature and cooling rate on DDC susceptibility with also be covered. Additionally, results from microstructural characterization at select temperatures both on-heating and on-cooling for each alloy will be presented. LOM will be used to characterize the general microstructure and measure grain size. The intergranular precipitate linear density will be quantified using a field emission gun

(FEG)-SEM and quantitative image analysis. EBSD will be used to identify the intergranular precipitates and measure the local grain boundary plastic strain accumulation in samples fractured at select temperatures along the weld thermal cycle.

Conclusions

Results to date show a strong correlation between the time and temperature for the precipitation of $M_{23}C_6$ intergranular carbides with the observation of a tensile ductility dip in alloys A690 and EN52. Unlike alloys A690 and EN52, Alloy 600 and EN82H show little ductility dip and form significantly different grain boundary microstructure. These findings indicate that semi-coherent precipitates such as $M_{23}C_6$ carbides may lead to DDC by imparting a local grain boundary stress during nucleation, while incoherent carbides such as Cr_7C_3 and NbC do not promote DDC.