C. Process Results and Microstructural Evolution of Inertia Arc Cladding Friction Welded Austenitic Stainless Steels: Initial Studies

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Introduction

Austenitic stainless steels (γ-SSs) are widely used in chemical processing and petroleum refining applications due to their corrosion resistance in many environments. Inertia friction welding (IFW) is a solid-state joining process that can be used for welding pipes and tubes. The thermo-mechanical cycle experienced during IFW of some γ-SSs can lead to the formation of the BCC ferrite phase along the bondline. The presence of ferrite along the bondline can create concern regarding the subsequent mechanical and corrosion properties of the weldment. For example, ferrite has low toughness at cryogenic temperatures and can aid in the formation of undesirable σ phase during high temperature service leading to a loss of ductility. The goal of this work was to examine process results and to rationalize microstructural evolution for inertia friction welding of three austenitic stainless steels.

Technical Approach

Three stainless steels were chosen for this study: 310, 304 and 255. The 310 and 304 alloys are austenitic stainless steels, while the 255 alloy is classified as a duplex (~50% austenite and ~50% ferrite) alloy. The three alloys were chosen based upon their propensity for forming ferrite at elevated temperatures (ie. based on [Cr/Ni]eq). Five inertia friction welds were produced on 1" OD tube samples (1/8" wall thickness) of each alloy using an MTI model 90 machine with the parameters shown in Table 1. All welds used the same initial energy of approximately 15.3 kJ. Welds were made at three levels of forge pressure and three combinations of I (moment of inertia) and RPM to give the same initial energy. The RPM, pressure and displacement were measured versus time for each weld, and the RPM and I were used to calculate the torque as a function of time for each weld. Following welding, samples were sectioned and polished to the maximum tube diameter to allow determination of the width and shape of the region along the bondline containing ferrite. Pseudo binary sections of the pertinent phase diagrams were determined with Thermocalc software. Results of acoustic monitoring and high-speed video on the same sets of welds are discussed in a companion presentation.

Results and Discussion

The amount of upset decreased with increasing RPM (for the same initial energy) consistent with achieving a more adiabatic heating condition along the bondline and increased with increasing forge pressure. The greatest amount of upset for a given set of conditions always occurred in the 255 alloy and the least in the 310 alloy. The upset appeared to scale with (Cr/Ni)eq with greater upset for alloys with greater anticipated volumes of ferrite during welding. The torque at the first torque peak, steady state region and the second torque peak increased with increasing pressure. The relationship between upset and torque values and the thermophysical properties and flow stress (at welding temperatures and strain rates) for each alloy will be discussed.

For all alloys, a region of refined grains was observed along the bondline presumably as a result of recrystallization. The 310 alloy contained no ferrite in the bondline region, while the 304 alloy showed a narrow band containing remnant ferrite along the bondline and the 255 alloy had a wider band. Consistent with steeper thermal gradients at higher pressures and the phase diagrams, the width and shape of the ferrite containing regions in the 304 and 255 alloys were narrower with higher pressures. The 310 alloy also exhibited a sensitized region in the outer HDAZ. The 255 alloy contained sigma phase in the outer HDAZ, and evidence for recrystallization of the austenite in this alloy was seen in the outer HDAZ.

Conclusions

Results of the initial work completed so far suggests that microstructural evolution (in terms of ferrite formation and remnant volume of ferrite) in inertia friction welds on these stainless steels can be rationalized with the pertinent pseudobinary phase diagrams assuming that welding occurs in the temperature range of 1100° to 1200° C. More work is needed to unambiguously clarify microstructural evolution.

Table 1 – Inertia Welding Parameters

	Moment of Inertia	**Forge pressure**	**RPM**
Nominal	1.56 lb ft^2 (6.57×10^{-2} kgm^2)	15,821 psi (109.04 Mpa)	6435 RPM
Low Pressure	1.56 lb ft^2 (6.57×10^{-2} kgm^2)	10,942 psi (75.41 Mpa)	6435 RPM
High Pressure	1.56 lb ft^2 (6.57×10^{-2} kgm^2)	20,553 psi (141.63 Mpa)	6435 RPM
High RPM	0.69 lb ft^2 (2.91×10^{-2} kgm^2)	15,821 psi (109.04 Mpa)	9680 RPM
Low RPM	3.32 lb ft^2 (1.40×10^{-1} kgm^2)	15,821 psi (109.04 Mpa)	4410 RPM