Inertia Welding in Gas Transfer Systems

If you have ever thought that a lot of inertia exists at Sandia, you would be correct in this case. The Gas Transfer Systems group (org. 8243) and the Engineered Materials Dept. (org. 8724) are developing the capability to use inertia friction welding in the fabrication of reservoirs for the containment of high-pressure hydrogen isotopes. These reservoirs are part of a major engineering weapon subsystem of particular interest to the SNL/CA site, the gas transfer system (GTS).

Background

Traditionally, GTS reservoirs have been fabricated using two forged and machined hemispherical shells made of type 304L stainless steel that are fusion welded at the girth. Many successful components have been fabricated in this manner; however there is always some concern about potential defects that may occur in the solidified microstructure, as well as in the so called "heat affected zone," where the welded material becomes much weaker due to the high temperatures. While much work has gone into the development of careful welding procedures and inspection techniques, the desire to minimize these issues has led to the consideration of new processes for the fabrication of the reservoirs. Recent geometric and volumetric considerations in reservoir designs have furthered interest in a welding process that produces weld joints having a higher fraction of the base metal strength, as well as in higher strength stainless steels. Thus, the use of nitrogen-strengthened, austenitic stainless steel alloys and the inertia welding process have become the focus of recent investigations.

Sparks, red-hot molten metal, and solidification of metal (the "uncontrolled casting" process) usually come to mind when most people think of welding. Friction welding is different however; it is referred to as a solid-state welding process since it involves no molten material. Parts to be joined are typically rubbed together by spinning one of the components to generate heat from the resulting friction, while an axial force is applied to enhance cohesion. The frictional heating continues while the parts are held in intimate contact by a large, applied axial force until the metal deforms plastically and upsets. The heating and plastic deformation produce atomically clean surfaces that form a metallurgical bond as the process comes to an end and chemical diffusion occurs. Inertia welding is a specialized case of friction welding, where a lathe-like machine stores a predetermined amount of kinetic energy in a flywheel. The flywheel then transfers the energy to one of the components, which is rotated while the other is held stationary. Once a given rotational velocity is reached, the parts are thrust together and allowed to come to a stop, at which point the weld is complete. (See Figure 1.)

Advantages of Inertia Welding

Some anticipated advantages of inertia welding over typical gas tungsten arc welding (GTAW or TIG) for GTS reservoir girth welds include higher strength joints (no reinforcement or constraint is needed for strength and performance), weld microstructures closer to forged microstructures (improves compatibility with hydrogen isotopes), less sensitivity to detailed chemistry or surface preparation (due to upset and extrusion of joint), repeatable volumetric control, and process simplicity.

The process is considered to be simpler as it involves generally simpler fixtures to hold the parts, fewer processing steps, and fewer machine settings about which to be concerned (the only variables are rotational velocity, axial force, and flywheel inertia). Also, inertia welding produces joints that are metallurgically simpler. In a recent evaluation performed by the GTS group for pressure-vessel girth welds, inertia welding was ranked higher than GTA welding and electron beam welding in nine out of 11 attributes such as process control,

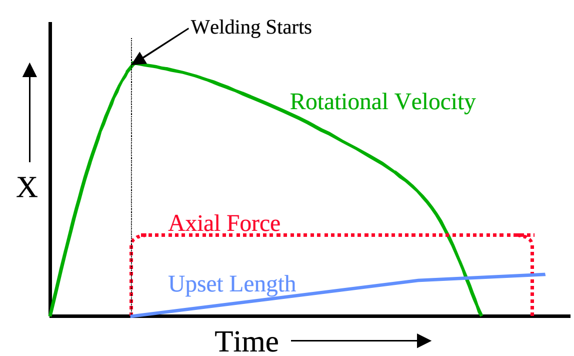

Figure 1. Inertia welding parameter characteristics

strength of joint, and product dimension optimization.

Technical Challenges

Although inertia welding has been successfully employed for many years in industry and holds great promise and potential for GTS reservoir applications, further understanding and development of the process are necessary to meet our unique performance requirements, which differ considerably from typical applications. For example, typical industrial welds are made using large upsets, with subsequent processing steps being used to finish to net-shape dimensions. However, for our applications, we will not have the luxury of subsequent machining operations to finish interior surfaces of our parts to final dimensions; therefore we must control our welding process very accurately to maintain precise volume control. This weld control is likely to take the form of a very low amount of upset, which is very atypical and hence is not well understood. For this and other reasons, a more quantitative understanding is necessary to accurately predict and understand the processing and performance of the reservoirs.

Current Work

Currently, there is a considerable amount of research being conducted to understand many of the issues surrounding the introduction of inertia welding into the fabrication of reservoirs. An understanding of the interdependence of heat generation through friction, abrasion and shear, heat dissipation, plastic deformation, and chemical diffusion is being pursued. Instrumented weld trials are being conducted to better determine those relationships. In addition to actual welds being made, experimental thermomechanical weld simulations are being performed. These experiments allow for the study of controlled thermal cycles in the steel, which produce microstructures that represent welded regions. From the welds that are being manufactured, we have begun testing to study both the basic mechanical properties as well as the hydrogen-assisted fracture properties of these unique welds.

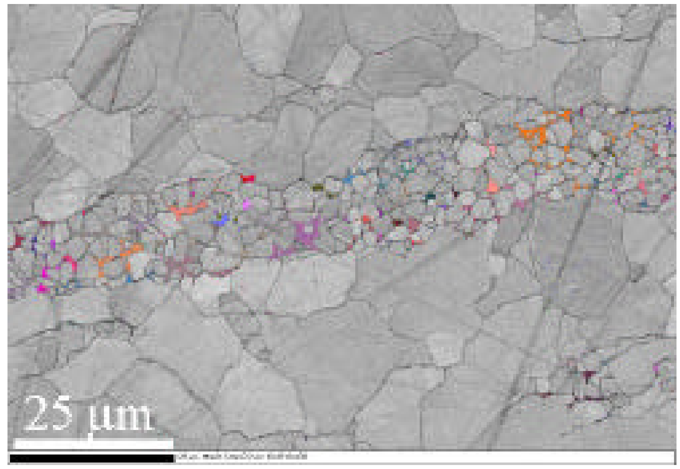

Figure 2. Typical inertia weld microstructure in 21-6-9 stainless steel (photo by Joseph R. Michael of 1822)

Microstructural analysis has also been conducted on welds made with a wide range of processing parameters. Figure 2 shows a typical weld microstructure where different crystallographic phases of the steel are observed. A very fine-grained austenite region is observed along the weld interface, mixed with some intergranular ferrite (shown in color). Given that the strength of a polycrystalline metallic material tends to be inversely related to grain size, it is thought that the presence of very fine grains along the interface is one reason that an inertia weld retains a much higher percentage of the base material strength than a fusion weld in the same material.

Future Work

Future work will include the refinement of inertia weld parameters and joint designs. Further microstructural analysis and mechanical testing, including full-up unit pressure and burst tests, will also be performed.

As the capability to use inertia welding is successfully developed, the GTS design engineers will have an improved joining tool to add to their toolbox. This will facilitate improved GTS reservoir designs, which will incorporate higher quality joints, possibly new geometries, and simpler processing conditions.

Gordon Gibbs (from left), Annette Newman, Joseph Puskar, Mikal Balmforth. Gordon received his AAfrom the College of San Mateo and joined Sandia in 1979. Annette received her AA in welding from Chabot College and joined Sandia in 1982. Joseph received his BS, MS, and Ph.D in Engineering & Science from Penn State and joined Sandia in 1998. Mikal received his BS, MS in Welding Engineering from Ohio State; MS in Materials Science & Engineering from MIT; and MS in Technology & Policy from MIT and joined Sandia in 2001.