THE FABRICATOR *Article reprinted with permission from the November 1991 issue of The FABRICATOR.*

# Joining Dissimilar Metals

## Bimetal welding of aluminum using inertia welding

The need for joining dissimilar metals has existed for a long time and has generally been considered to be beyond the state of the art.

It is desirable when dealing with aluminum because of the limitations of some of its properties. For a variety of chemical/metallurgical reasons, aluminum has been considered unweldable to most other metals, especially those of a steel or stainless steel base.

This problem is based on the need for conventional welding processes to melt the metals together. Since not all metals melt at the same temperature, and for various other reasons, this technique does not work.

The high-quality welds between 6061-T6 aluminum and 304L stainless steel presented in this article were produced through the use of a solid-state (no melt) process called inertia welding. Welds of this material combination have been successfully produced in aerospace and commercial applications for at least 22 years.

The basic use for these weldments is on transition fittings, which are conventionally welded into various vacuum or pressure lines, and pressure vessels, including the cryogenic fuel cells on the space shuttle vehicle.

### Successfully-Welded Metal Combinations

**1.** 6061-T6 aluminum to 304L stainless steel (used on space simulators and various satellites.

**2.** 6061-T6 aluminum to 316 stainless steel.

**3.** 2219-T351 aluminum to 6061-T6 aluminum to 304L stainless steel (used on cryogenic fuel cells for the space shuttle vehicle).

**4.** 6061-T6 aluminum to 316 stainless steel.

**5.** 6061-T6 aluminum to various brass alloys.

**6.** 6061-T6 aluminum to various copper alloys.

**7.** 6061-T6 aluminum to various alloy and mild steels.

**8.** 6061-T6 aluminum to metal matrix aluminum alloys.

**9.** Metal matrix aluminum to alloy and mild steel, and stainless steels.

**10.** 6061-T6 aluminum to 6AL-4V titanium.

**11.** 6061-T6 aluminum to 304L to 6AL-4V titanium.

**12.** 6061-T6 aluminum to tungsten (not a full-strength weld).

**13.** 5083 aluminum to 6061-T6 aluminum to 304L stainless steel.

**14.** 4043 aluminum to 316 stainless steel.

**15.** 1100 aluminum to OFHC copper.

**16.** 1100 aluminum to 316 stainless steel.

**17.** 6AL-4V titanium to 316 stainless steel and 304L stainless steel.

**18.** Titanium and its alloys to other titanium alloys.

**19.** Steel and alloys steels to various stainless steels, INCONEL® alloys, and other nickel-based alloys.

**20.** Zirconium to tungsten.

**Figure 1**

**These metal combinations have been successful, meaning full strength with no leakage.**

## Joining Dissimilar Metals

Many who have been involved with designing, engineering, welding, fabricating, and the problems associated with controlling quality and costs are familiar with the frustrations of joining metals that have different properties.

Many have experienced the frustration of trying to weld various combinations using everyday welding techniques in various atmospheres and using various types of joining materials. Little or no success is the normal result because these techniques try to "melt" the two dissimilar metals together.

Dissimilar metals have different chemistries, so they have different properties, such as melting temperatures. Many of these metals are alloys or a mixture of several elements, all of which melt at different temperatures. Therefore, when accomplishing a weld, it is virtually impossible to prevent a chemical change at the moment a melt of the parent metals occurs.

The new chemistry formed as a result of the melt products produced at the time of resolidification generally leaves formations of brittle intermetallics and a generally wide heat-affected zone (HAZ) in the parent material. These combine to grossly degrade the properties of the metals involved. The results are weak or brittle welds that leak.

In the mid 1960s, a process was developed which allowed metals to be joined by a forging process that does not melt the metals. This process is called inertia/friction welding. It is a friction welding process that uses flywheel or kinetic energy for the heat source and a high-pressure system for the forge force.

Because of the high pressure, the metal, as it becomes heated by friction, is forged together with no melt product being produced, i.e., no chemical change and a very narrow HAZ.

This allows a variety of metals that have different or melt-sensitive chemistries to be joined with resulting properties that are excellent and comparable to the base metal. Because of the nature of this process, the welds are limited to being round at the weld interface.

For a general reference, a few of the metal combinations which have been successful, meaning full strength with no leakage, are shown in **Figure 1**.

In the last 18 years, many alloys of aluminum have been inertia welded to themselves and to other aluminum alloys. To date, there have not been any combinations that have not been successfully welded. These include alloys like 7075-T6 and 2024-T3, which are currently being used in production in critical applications on the B1-B, KC-135, and Black Hawk helicopter aircraft.

## The Procedure

For simplicity, one of the most common combinations, 6061-T6 aluminum to 304L stainless steel, has been selected for review in this article. This combination is frequently used as a transition joint because of the generally good weldability of each base metal, using a variety of conventional welding methods, to other base metals of similar chemistry.

This combination has been tested and approved for use by many aerospace and commercial hardware manufacturers.

The weldments are used in cryogenic, heat pipe, medical, pressure, and vacuum applications.

The specific parts for this article were taken from standard production parts held in inventory for potential sale. They consist of a ¾-inch-diameter 6061-T6 aluminum bar that is 2½ inches long and 304L stainless steel with ⅝ outer diameter (OD) and 3⁄16 inner diameter (ID) tube section and 2 inches long.

Using proprietary techniques that have been developed and perfected through extensive trial and error over the last 18 years, these parts were welded on a Model 100 inertia welder machine in open air with no special atmosphere required.

One component was held in a collet device attached to the rotatable spindle. Also attached to the spindle was a flywheel of a specific weight. The other component was held in a nonrotatable collet device on the tailstock. Both components had been specially prepared on a lathe prior to being put into the welder.

The weld cycle consisted of the spindle being accelerated to a predetermined and set speed, which is controlled electronically and stops the drive system when the set speed is reached. This allows the rotating components to be freely driven by kinetic energy alone.

At that precise time, a controlled pressure is applied axially, causing friction to occur at the weld interface. This pressure or "load" is maintained until all of the energy in the rotating mass has been consumed in the weld, thereby stopping the rotating component.

During the weld cycle, metal which was in the interface and became plastic as a result of the frictional heat was forged out of the weld. The remaining plasticized metal was hot worked together to accomplish the weld. This results in a length loss, referred to as upset.

## Obtaining High-Quality Welds

Because of the inherent repeatability of the energy input under given pressure that is extremely repeatable, upset measurement, once it has been determined for a given weld, becomes the first key factor in determining weld quality. In any given material combination, a given energy under a given load will cause a given amount of material to displace.

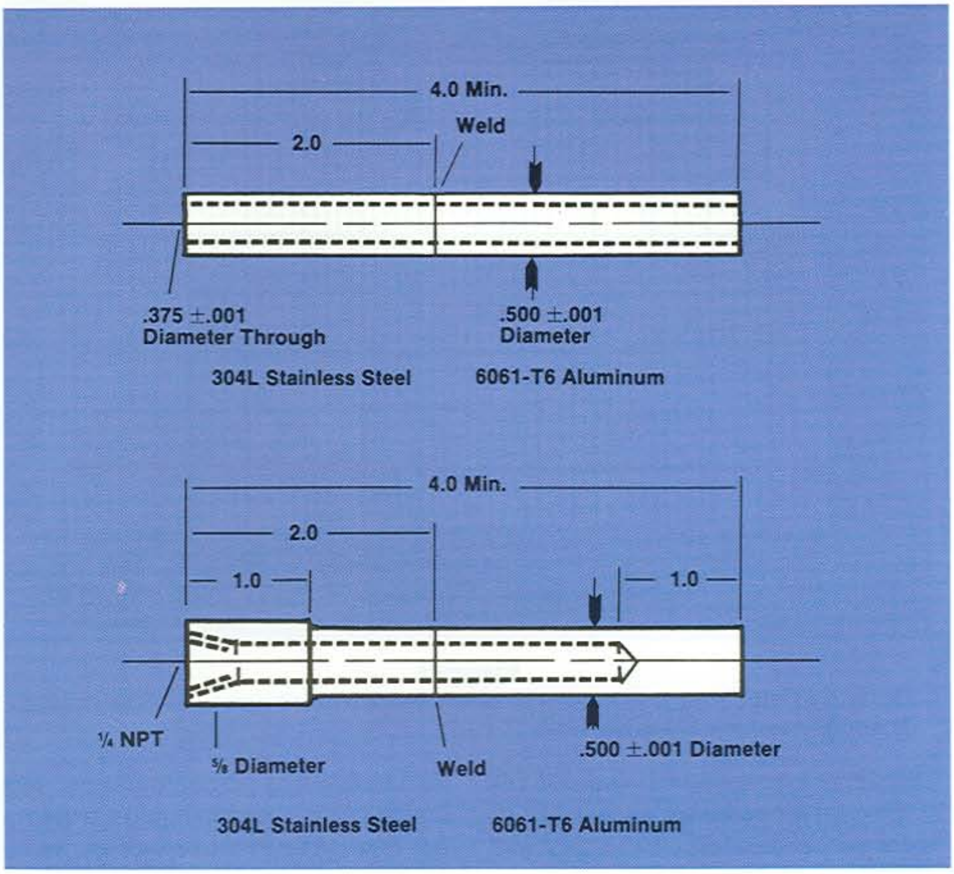



**Figure 2**
**Weldments were machined for pressure testing.**

**When accomplishing a weld between metals, it is virtually impossible to prevent a chemical change at the moment a melt of the parent metals occurs.**

Outside of the welding process itself, the following factors must be controlled to obtain high-quality welds repeatedly:

1. Parent metal that is reasonably clean metallurgically.

2. Weld interfaces that are properly prepared for surface finish and cleanliness.

3. Assurance that the parts are placed in the properly functioning inertia/friction welder without becoming contaminated.

Cleanliness, except for heavy oxides or for most bimetal combinations involving aluminum or copper, is not normally a factor when inertia/friction welds are made.

## Testing the Weld

The weldments were machined for pressure testing as shown in **Figure 2**. Test configuration #1, with a through hole, allowed for a pressure test with no end load (tensile) on the weld. Test configuration #2, with a blind hole, subjected the weld to a small tensile load. All

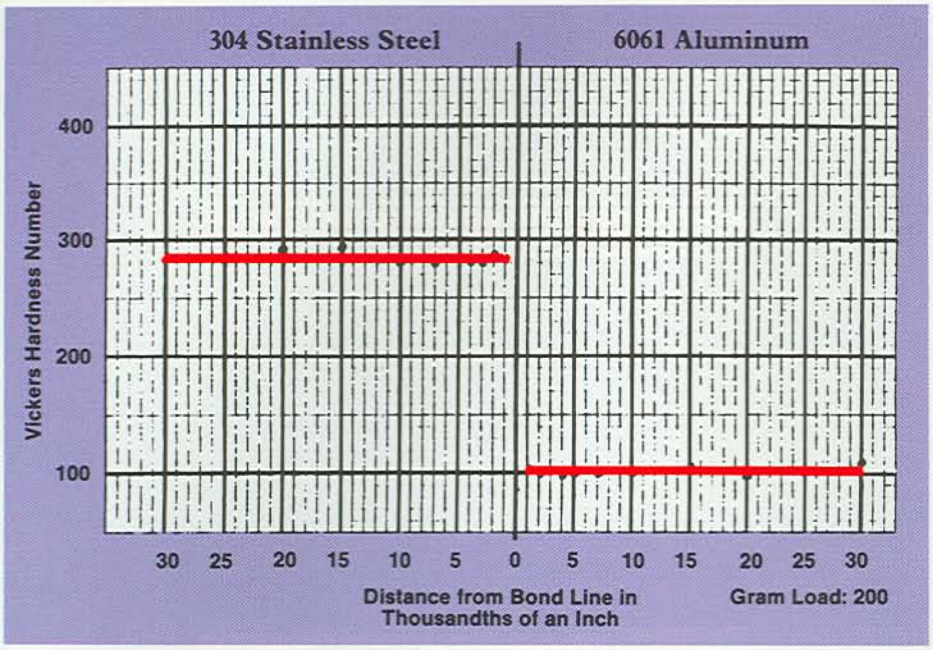



**Figure 3**
**The lack of wide HAZ is indicated by the micro/hardness survey with no change detectable under a 200-gram load.**

specimens have a .500 OD and .375 ID.

Fluorescent penetrant was not used on these parts because experience has shown that the percentage of rejects over the years was zero. However, it is one of the techniques recommended for inspection.

Another technique is thermal shock followed by a helium leak test. This is accomplished by placing weldments in a cryogenic bath, such as liquid nitrogen, a few times prior to the helium leak test.

When submitted to an hydraulic burst test, all specimens burst in the aluminum section after yielding in an area completely away from any HAZ. The failures were typical of parent metal failures and followed the direction of the grain in the parent metal. None of the splits reached the HAZ. Burst pressure ranged from 12,200 PSI to 13,000 PSI.

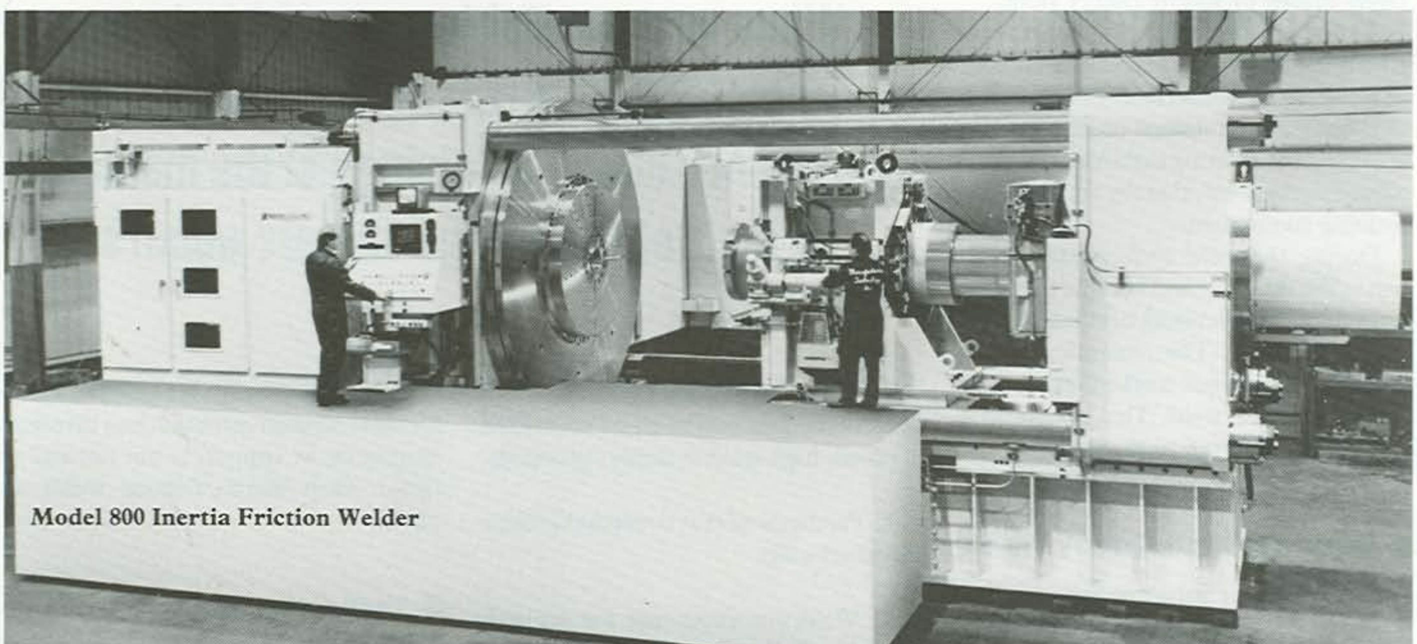
Helium leak tests were performed prior to hydraulic bursting, and the welds were found to have no evidence of leakage greater than 1.11 by $10^{-8}$ std cc/sec helium.

A photomicrograph of a cross section, when etched with a solution of light kellers and viewed at 800X, shows little or no plastic deformation in the weld zone. The lack of a wide HAZ is indicated by the micro/hardness survey with no change detectable under a 200-gram load (see **Figure 3**).

## Summary

It is possible, by using proper procedures and with proper inertia/friction welding equipment, to generate full-strength welds between 6061-T6 aluminum and 304L stainless steel on a repeatable basis. ■

*The information presented in this article was prepared by Al Wadleigh, President, Interface Welding, Carson, California. INCONEL® is a registered trademark of Inco Alloys International, Huntington, West Virginia.*



**Model 800 Inertia Friction Welder**