State-of-the-art Joining Methods for Nitinol Shape-memory Alloy

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Introduction

Nitinol, a nickel-titanium alloy invented by the Naval Ordinance Laboratory, is the most prevalent of the shape-memory alloys (SMAs) used in industry. Its near-binary composition provides corrosion resistance, super-elasticity, and shape-memory properties unachievable with other metal alloys.

Joining Nitinol for Industry Applications

The use of nitinol in manufacturing often requires joining of two nitinol components, or joining of nitinol to a dissimilar metal. Nitinol-to-nitinol joints can be soldered, brazed, or welded. Regardless of the technique selected, process temperatures must be minimized to avoid detrimentally affecting shape-memory behavior, corrosion resistance, and super-elasticity.

The same is true when brazing or soldering nitinol to dissimilar metals. While fusion-based processes such as laser welding or gas tungsten arc welding can also be used, the formation of brittle Fe-Ti intermetallic compounds presents a significant challenge when welding nitinol to stainless steel and many other metals. In addition, these processes require adequate gas shielding during welding and subsequent cooling to avoid the embrittlement which occurs when titanium is exposed to the atmosphere at elevated temperature. Solid-state processes such as resistance welding and percussion welding present another viable alternative. Regardless of the welding process used, shape-memory behavior will almost certainly be affected in the weld area. This effect can be quantified through mechanical testing and metallurgical analysis of the weld and heat affected zone (HAZ).

Case Study

Nitinol is commonly joined to 304L or 316L stainless steel for guidewire-type devices used in surgical applications, or for mechanical actuators. Shape-memory actuators have a number of advantages over hydraulic actuators including efficient movement, high force, and reduced weight. EWI was asked to produce nitinol/stainless-steel torque tubes as demonstrator articles for a research partner's program focused on reducing the number of hydraulic actuators on aircraft wing and rudder control surfaces. The process used to create these torque tubes was a macro-scale version of a welding technique developed and patented by EWI over a decade ago for joining nitinol to stainless steel.

The objectives of this program were to develop a welding process to join nitinol to stainless steel in a tube-to-tube joint configuration. EWI's research partner obtained nitinol plate and used electrical-discharge machining (EDM) to remove 0.375-in. diameter tubes from it. By specifying the position of the machined tubes within the plate, their shape-memory behavior was oriented in the longitudinal direction, causing them to twist about their center axis upon heating and return to their original orientation upon cooling. 304L stainless-steel tubing of the same diameter was cut to length.

Following EWI's patented material-preparation and welding techniques, consumable nickel inserts were then designed to provide the proper proportions of nickel and iron in the weld. The addition of nickel into the fusion zone prevents the formation of the brittle Fe-Ti intermetallic upon solidification. Refractory metals such as vanadium can also be used as an insert to provide a metallurgical barrier between the nitinol and stainless-steel components; however, this approach is typically reserved for critical applications since vanadium is more expensive and challenging to machine. By comparison, the nickel insert is easily CNC-machined in large quantities.

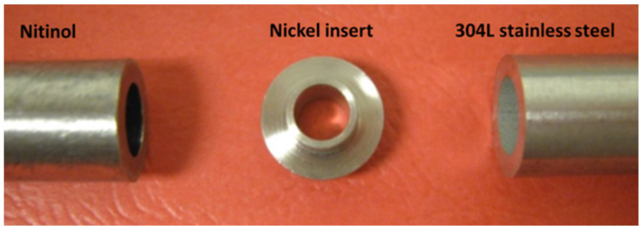

Figure 1: Unassembled components of the tube-to-tube joint between nitinol and 304L stainless steel

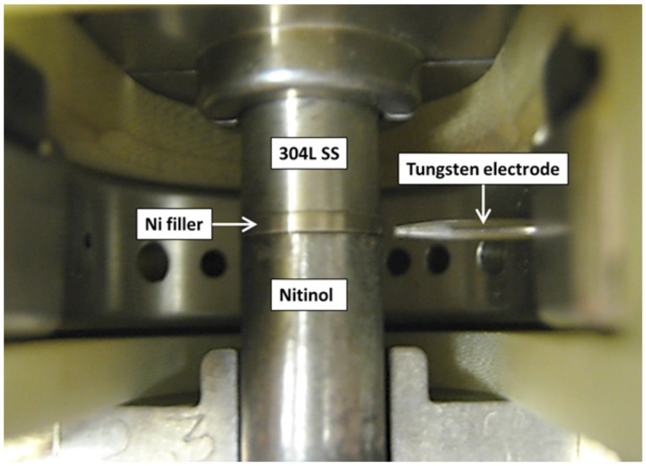

Figure 2: Image of the inside of the orbital weld head, showing the assembled components of the tube-to-tube joint

Figure 1 shows the unassembled components of the weld joint. Figure 2 provides an image of the inside of the welding head, with the tubes and insert assembled and positioned relative to the tungsten electrode.

An image of a completed joint in the as-welded condition is provided in Figure 3. Gas shielding was sufficient to allow the molten metal to flow and mix easily, and the nickel insert was fully consumed by the fusion zone of the weld.

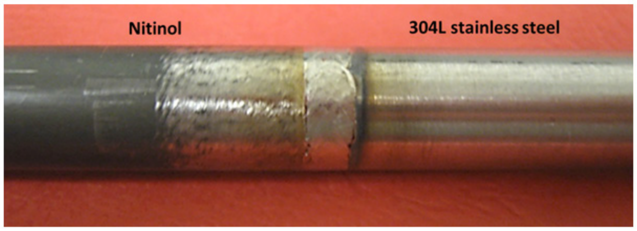

Figure 3: Completed tube-to-tube weld joining nitinol stainless steel

Six identical tube assemblies were then welded and tested by EWI's research partner in their laboratory. Torque strength was measured through several thousand thermal cycles, and repeatability of position-at-temperature was excellent, demonstrating the feasibility of this manufacturing approach.

Conclusion

Nitinol is an advanced material with many varied applications, including medical devices, batteries, and actuators for aircraft and satellites. While several joining methods can be used for assembly, proper selection and application depends on joint design, strength requirements, biocompatibility considerations, and operating-temperature requirements.

__Tim Frech__ is a Senior Engineer in EWI's Ultrasonics group. His expertise lies in microwelding, ultrasonic metal welding, ultrasonic soldering, wire bonding, and resistance welding. Tim is also experienced in plastics joining, laser welding, and helium leak detection.