Laser Welding of Dissimilar Metals: Titanium to Nickel

Metallurgical study shows why Ti to Ni joints were unsuccessful by laser welding

BY J. SERETSKY AND E. R. RYBA

Introduction

Laser welding is sometimes used to weld dissimilar metals when other methods prove unsatisfactory. A number of such cases have been reported in the literature and are listed in Table 1. However, the welding of these pairs of metals was usually done in response to a specific engineering need, and very little has been reported on the relationship between the welding variables, the properties of the weldment, and metallurgical structure. No systematic studies of laser welding of dissimilar metals have apparently been attempted yet. The present investigation was initiated with the intent of metallurgically characterizing dissimilar metal welds.

The system chosen was titanium-nickel. Welding of titanium to nickel certainly presents some difficulties. Previous studies (Ref. 1) on the ordinary welding of titanium-nickel alloys showed that titanium alloys with greater than about 2% nickel crack upon solidification. This cracking is most likely due to the formation in the weld of two brittle intermetallic compounds, Ti_2Ni (37.5 w/o Ni) and $TiNi_3$ (78 w/o Ni). A third compound, TiNi, exists in the titanium-nickel system,

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Table 1 — Laser Welding Studies of Dissimilar Metals

Metal combination [a]	Reported by
.003 Tungsten wire .020 Nickel wire	Buddenhagen (1963) (Ref. 7)
20 μ SiC fibers .005 Nickel wire	Buddenhagen (1963) (Ref. 7)
.0025 Nichrome wire .040 Silver-plated brass	Hice (1963) (Ref. 8)
.002-.005 Gold wire Silicon and Al-coated Si	Platte and Smith (1963) (Ref. 9)
.015 Copper wire .015 Tantalum wire	Jackson (1965) (Ref. 10)
.030 Stainless steel wire .025 Tantalum wire	Anderson and Jackson (1965) (Ref. 11)
.005 Tungsten wire .020 Nickel wire	Anderson and Jackson (1965) (Ref. 11)
.020 Nickel wire .025 Tantalum wire	Frick (1966) (Ref. 12)
.015 Copper wire .020 Nickel wire	Frick (1966) (Ref. 12)
.009 Phosph. bronze wire .005 Palladium wire	Orrok (1967) (Ref. 13)
.020 Nichrome wire .140 Monel rod	Orrok (1967) (Ref. 13)
.005-.025 René 41 .125 Columbium D36	Orrok (1967) (Ref. 13)
.002-.003 Copper .019 Brass	Barnov and Metashop (1968) (Ref. 14)
.002-.003 Copper .002-.030 Mild steel	Barnov and Metashop (1968) (Ref. 14)
.002-.019 Copper .031 Stainless steel	Barnov and Metashop (1968) (Ref. 14)
.025 René 41 .025 Hastalloy X	Kloepper (1970) (Ref. 15)
.031 Titanium wire .016 Gold	Benson (1970) (Ref. 16)

(a) Decimals indicate thickness, inches

but it is a ductile compound and, if formed, would not be expected to add to the brittleness of the weldment. Thus, one of the major interests in this investigation was to determine if laser welding would alter the formation of phases due to the more rapid rate of solidification of the molten material.

The phase TiNi is interesting in itself. This alloy, usually called Nitinol (Refs. 2,3), exists over the composition range 55-58 w/o Ni and is ductile, nonmagnetic, corrosion resistant, and has good low temperature toughness. In addition, it exhibits a "shape memory" effect due to a martensitic transformation, whereby, after deformation, the alloy reverts to its original shape when heated to 40-60 C. If titanium-nickel weldments which contained predominantly TiNi could be produced, they would likely have some very interesting properties.

Another interest in this investigation was to develop techniques for the characterization of the weldment structure. Electron microprobe analysis and metallographic analysis were chosen for this. Some tensile and microhardness tests were also performed.

Experimental Procedure

The metals used in this investigation were both 99+% pure and were supplied by The International Nickel Co., Reactive Metals, Inc., and Titanium Metals Corp. of America. Samples for the determination of the best welding parameters were made by welding pieces of titanium and nickel placed together in a bakelite mount. A polished surface of about 1/16 × 3/4 in. of each metal was exposed with the interface along the 3/4 in. dimension. The tensile test samples were made by butting pieces 1/16 × 1/4 × 1-1/4 in. in size together along the 1/16 × 1/4 in. face. This face was first milled to insure complete contact between the two metals. These pieces were placed in a grooved plexiglass holder for welding.

In the initial welding tests, helium was blown across the surface to be welded, but a thin oxide layer formed on the surface. Therefore, the sample assemblies were placed in a plexiglass drybox about 6 in. diam and 2 in. high, which was filled with argon during the welding. A glass disc was cemented on the drybox where the laser beam passed through it. The drybox was placed on an indexing table which moved the sample into position and varied the depth of the focal point of the optically focused laser beam in the sample. A neodymium-doped glass rod laser was used.

Optimum values of the operating parameters for the laser system were determined as follows. The focal point of the beam was first kept constant, approximately 0.030 in. below the work surface, while the beam energy was varied from 16-24 joules/pulse. Then, for 22, 24 and 30 joules/pulse, the focal point was varied from 0.010-0.050 in. below the surface of the sample. The best penetration with the least amount of metal expulsion was obtained for 30 joule pulses focused 0.025 in. below the surface and 24 joule pulses focused 0.030 in. below the surface. The pulse length was measured with an oscilloscope and found to be 15 ms.

Welds were then made under these conditions in several ways: single pulses separated some distance from each other along the interface, single overlapping pass across the butt seam on one side of the sample only, single pass of overlapping weld spots on both sides of the sample, and multiple overlapping passes on both sides of the sample. The period between each individual pulse was 1-1/2 to 2 minutes.

Weldments to be used for microstructure studies and electron microprobe analyses were mounted in Koldmount, ground and then polished in a Vibromet polishing unit. The Kroll etch was found to be the best for simultaneously displaying the structures of titanium, nickel, and their alloys.

For electron microprobe analyses, point-count readings for titanium and nickel radiations were taken at various points in the polished and etched fracture faces of a number of welds. Unfortunately, the microstructure of the samples was so fine that the results could not be interpreted in any reasonable way.

Microhardness values were measured with a Knoop indenter on a Vickers microhardness tester using a 50 g (1.76 oz) weight. Tensile tests were made with an Instron unit. The cross head speed was 0.2 in./min.

Results and Discussion

One of the initial observations in the laser welding of titanium to nickel was that there is a difference in the reflectivities of titanium and nickel. This is shown in Fig. 1, which was made with ruby laser light at a relatively low power of 9 joules/pulse. The larger portion of the "splash" is on the titanium side. At higher powers, this difference in reflectivities is not so readily apparent.

Approximately 75% of the weld spots displayed cracking, both radial, originating from the center of the weld spot, and circumferential, concentric with the center of the weld spot, as shown in Figs. 2 and 3. This cracking

Fig. 1 — A single spot weld, formed under argon atmosphere, showing the effect of the different reflectivities of titanium (top) and nickel to ruby laser light. The spot weld was made with a 9 joule pulse focused at −0.25 in. X50, reduced 29%

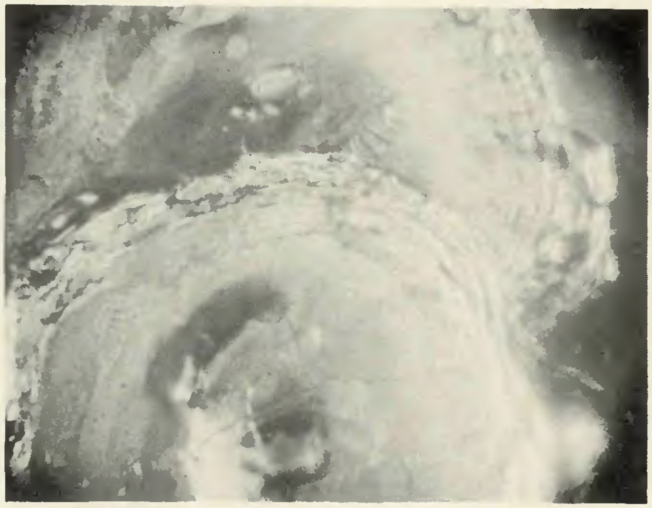

Fig. 2 — Radial cracks in weld spots. Weld spots were made with a Nd-doped glass rod laser. 24 joule pulses focused at −0.030 in. were used. X50, reduced 29%

Fig. 3 — Circumferential cracks in weld spots. Weld spots were made with a Nd-doped glass rod laser. 30 joule pulses focused at 0.025 in. were used. X50, reduced 29%

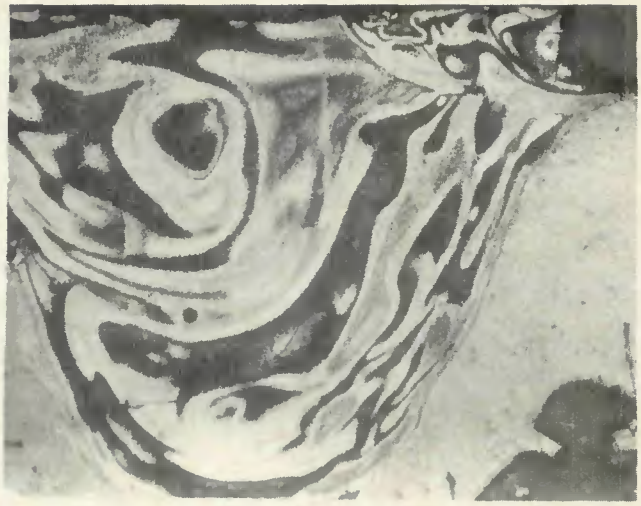

Fig. 4 — Microstructure of Ti-Ni weld showing convection swirls. Weld spot was made with a Nd-doped glass rod laser using a 24 joule pulse focused at −0.030 in. Kroll etch. X100, reduced 29%

is, of course, undesirable, and its occurrence could not be traced to any of the welding variables. It is not known if the cracking is due to the rapid quenching of the molten metal after irradiation, or to some chemical interaction between titanium and nickel. These cracks occurred with the same frequency in welds made in single passes over one side only and multiple passes over both sides of the samples.

Figure 4 shows a typical microstructure for the weldments along a plane parallel to the original titanium-nickel interface. All showed frozen convection swirls from the poorly mixed liquids of different composition in the weld spot. This structure is similar to those obtained by Unger (Ref. 4) and by Nippes, Pfluger and Slaughter (Ref. 5) in their studies of spot resistance welding of Cor-Ten to 18-8 stainless steel and monel to steel. Their evaluations of the welds led them to conclude that this is not a good weld structure. Why this occurs in titanium-nickel weldments is not known. However, since the time for melting and solidification is short, a non-equilibrium situation probably exists. This means that the equilibrium titanium-nickel phase diagram is of little assistance in the interpretation of these results. At short interaction times, there may be an apparent miscibility gap between certain compositions.

One of the welded samples was annealed at 900 C for two hours. Although some solid state diffusion took place, which altered the microstructure, it still exhibited a pronounced swirled appearance.

In an attempt to create a more gradual composition gradient from titanium to nickel in the weldment, rectangular pieces of the intermetallic compound TiNi, 1/2 × 1/16 × 0.020 in. in size, were placed between the pieces to be welded. The microstructures of these weldments, as shown in Fig. 5, were less swirled in appearance and exhibited distinct grains in some regions. However, the weldments were still cracked and, therefore, unacceptable.

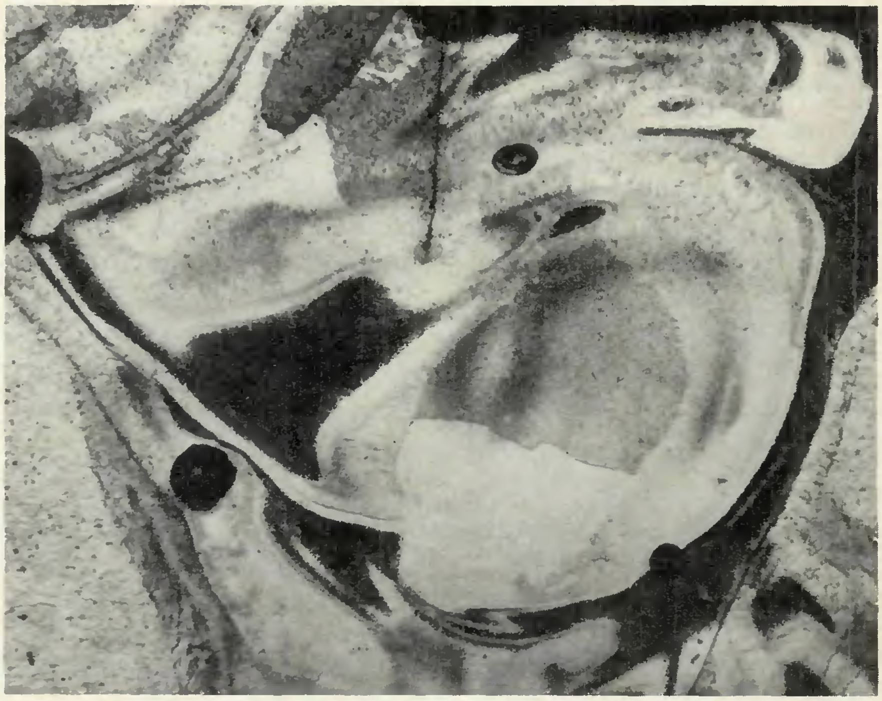

Fig. 5 — Microstructure of Ti-TiNi-Ni weld. Weld spot made with a Nd-doped glass rod laser using a 34 joule pulse focused at −0.025 in. Kroll etch. X100, not reduced

Because of the cracks in the weldments, the results of the tensile tests are not indicative of the strength of the weld material. All specimens fractured within the weld region and exhibited strengths of 10,000-18,000 psi for samples without the TiNi filler and 3,000-5,000 psi for samples with the TiNi filler. Microhardness values ranged from 250 to 750 kg/mm^2 (DPH), depending upon the region in the weldment where the test was made. Although microhardness values can be calculated from the Rockwell hardness values given by Buehler and Wiley (Ref. 6) (arc-cast TiNi: 301-309 DPH; Ti_2Ni: 561 DPH; $TiNi_3$: 338 DPH), these values were of little assistance in identifying phases in the weldment because of the fineness of the structure.

Thus, laser welding of titanium to nickel appears to be unsuccessful and results in a cracked weldment which exhibits a poor microstructure. The cracking could not be eliminated by changing the laser power or by rewelding the samples.

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"Submerged Arc Weld Hardness and Cracking in Wet Sulfide Service"

by D. J. Kotecki and D. G. Howden

This study was undertaken to determine:

(1) The causes of higher-than-normal hardness in submerged-arc welds in plain-carbon steels

(2) The levels of strength or hardness which will not be susceptible to sulfide-corrosion cracking

(3) Welding procedures which will assure that nonsusceptible welds will be produced.

Concentration is primarily on weld metal, though some consideration to the weld heat-affected zone is given. The study covered a two-year period. The first year was concerned with a macroscopic view of the weldments. In that first-year study, some inhomogeneities were observed in weldments which are not obvious in a macroscopic view of the weldment. It appeared likely that these inhomogeneities could affect the behavior of the weldment in aqueous hydrogen-sulfide service. Accordingly, their presence and effects were investigated during the second year.

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WRC Bulletin
No. 185
July 1973

"Improved Discontinuity Detection Using Computer-Aided Ultrasonic Pulse-Echo Techniques"

by J. R. Frederick and J. A. Seydel

The purpose of this project, sponsored by the Pressure Vessel Research Committee of the Welding Research Council, was to investigate means for obtaining improved characterization of the size, shape and location of subsurface discontinuities in metals. This objective was met by applying computerized data-processing techniques to the signal obtained in conventional ultrasonic pulse-echo systems. The principal benefits were improved signal-to-noise ratio and resolution.

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