BDX-613-936

JOINING MAGNETIC ALLOY
49Fe-49Co-2V TO 304L
STAINLESS STEEL

Technological Spinoff Report

D. M. Jarboc, Project Leader

August 1973

MASTER

Prepared for the
United States Atomic Energy Commission
Under Contract Number AT(29-1)-613 USAEC

**Kansas City
Division**

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Project Leader:
D. M. Jarboe
Department 814

Technological Spinoff Report

Technical Communications

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BDX-613-936, UNCLASSIFIED Technological Spinoff Report, August 1973

Prepared by D. M. Jarboe, D/814

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SUMMARY

Electron beam welds joining 304L stainless steel hubs to 49Fe-49Co-2V alloy rotors in a switch assembly were consistently found to contain severe cracks. Development of a process to vacuum furnace braze these materials was undertaken to eliminate the problem.

Wettability tests were made using braze filler alloys that melted below the $\alpha \rightarrow \alpha + \gamma$ phase transformation temperature of 49Fe-49Co-2V alloy to avoid any degradation of magnetic properties caused by the formation of a martensitic phase during cooling. The ability of these braze alloys to wet the 49Fe-49Co-2V alloy was poor.

Other wettability tests were made using oxygen-free copper as the braze filler metal; excellent wetting on both base metals resulted. Because the melting point of copper is above the critical transformation temperature, a post-brazing heat treatment was devised to allow the $\gamma + \alpha \rightarrow \alpha$ transformation to be completed before cooling and thus avoid the formation of a martensitic phase.

Twenty sample parts were brazed to determine joint strength and the effectiveness of the post-brazing heat treatment. The average failure load was 2500 pounds (11120 N) which is well above the required strength of 135 pounds (600 N). The average failure load of electron-beam welded joints was only 100 pounds (445 N) which was unacceptable. The parts were metallographically inspected to determine if any martensitic phase was present. The microstructure of the 49Fe-49Co-2V alloy was found to consist of equiaxed α grains without the martensitic phase. Subsequent torque tests of the unit using brazed parts showed no loss in magnetic torque, indicating the magnetic properties had not been degraded by the brazing process.

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DISCUSSION

SCOPE AND PURPOSE

Attempts to electron beam weld 49Fe-49Co-2V magnetic alloy to stainless steel in the manufacture of a switch assembly have proved unsatisfactory because of severe cracking of the weld nugget. This report covers the development of a brazing process by which these materials can be reliably joined.

ACTIVITY

Definition of Electron Beam Welding Problem

Attempts were made to electron beam weld a 304L stainless steel hub into a rotor made of the 49Fe-49Co-2V alloy. This assembly is shown in Figure 1.

Figure 1. Hub-Rotor Assembly of Output Switch, 3X

Metallographic inspection of the electron beam pulse welds revealed that 75 percent of the weld nuggets were severely cracked. The fracture mode was consistently intergranular indicating that hot cracking was occurring during solidification of the molten weld nugget. A typical cracked weld is shown in Figure 2.

Attention was directed toward developing a vacuum furnace brazing process as a possible solution to the welding problem. Brazing with a low melting braze filler metal would eliminate the problem of hot cracking because melting of the 49Fe-49Co-2V alloy would not be required.

Design Requirements

Three basic points were considered while developing a method of brazing the 304L stainless steel hub into the 49Fe-49Co-2V alloy rotor. First, the hub was designed to fit inside the rotor with a maximum of 0.004-inch (0.1 mm) interference to maintain concentricity. In general, brazing two materials requires a small gap into which the braze filler material can flow. Changing the design to allow a gap would require special fixturing or machining. Second, the 49Fe-49Co-2V alloy was selected because of its high magnetic saturation induction and permeability. Degradation of these properties as a result of a brazing process could not be allowed. Third, the joint had to be capable of withstanding a shearing force of 135 pounds (600 N).

Metallurgy of the 49Fe-49Co-2V Alloy

Figure 3 shows the vertical section of the Fe-Co-V ternary equilibrium phase diagram which joins the vanadium apex with the midpoint of the Fe-Co composition edge.¹ At a concentration of 2 percent vanadium three equilibrium phases can exist: γ (face-centered cubic), α (body-centered cubic), and α' (ordered FeCo). Above 960°C only the γ phase exists in equilibrium. Upon cooling the γ phase transforms to the body centered cubic phase α with the transformation complete at 900°C. In addition, below 725°C the α phase undergoes an ordering reaction producing the ordered α' phase. Rapid cooling from the $\alpha + \gamma$ or the γ range can result in the formation of a metastable martensitic phase (α'') at room temperature.

The magnetic properties of this alloy are very structure sensitive. The best magnetic properties are obtained when the alloy is in the α' ordered phase. A slight reduction in saturation induction is found when the matrix is composed of the α phase. The presence of the α'' is considered undesirable because its extremely fine acicular structure degrades the structure sensitive magnetic properties.

In developing a brazing process for this alloy, it was desirable to hold the brazing temperature under 900°C to prevent any γ phase formation. If the brazing temperature exceeded 900°C, a post brazing heat treatment would be required to convert any γ phase formed during brazing into the α phase before

¹C. W. Chen, "Soft Magnetic Materials," Journal of Applied Physics, Supplement to Volume 32, No. 3, March 1964.

Figure 2. Electron Beam Pulse Weld Joining 304L Stainless Steel to the 49Fe-49Co-2V Alloy Showing Intergranular Cracking of the Weld Nugget, 120X

cooling to room temperature. This would be necessary to prevent the undesirable martensitic phase α' from forming. Annealing at a temperature just below the transformation temperature of 900°C for several hours should ensure complete $\gamma \rightarrow \alpha$ phase transformation and result in the formation of ordered α' phase upon cooling to room temperature.

The desirable microstructure as shown in Figure 4 consists entirely of equiaxed α' grains. Figure 5 illustrates the result of cooling to room temperature before the $\alpha + \gamma \rightarrow \alpha$ reaction is complete. The microstructure consists of a complex mixture of the α' (dark regions) and α (white regions) phases.

Braze Filler Alloys

A low temperature brazing process was evaluated. Four alloys were selected for testing which possessed melting points below 900°C : Silcoro 75 (75 Au-20Cu-5Ag), Incuro 60 (60Au-37Cu-3In), Palcusil 10 (58Ag-32Cu-10Pd), and Palcusil 15 (65Ag-20Cu-15Pd). Wetting tests were run on both stainless steel and the 49Fe-49Co-2V alloy using the four braze alloys. The tests were run in a vacuum furnace at an approximate pressure of 50 microtorr (6.67 mPa). None of the braze filler alloys were found to satisfactorily wet either the 304L or the 49Fe-49Co-2V alloy.

Figure 3. Vertical Section of Fe-Co-V Phase Diagram With Fe:Co = 1:1 (From American Journal of Applied Physics, Volume 32, by permission of Dr. C. W. Chen)

Figure 4. Microstructure of As-Received Annealed 49Fe-49Co-2V Alloy With Matrix Composed of Equiaxed α'' Grains, 200X

Figure 5. Microstructure of 49Fe-49Co-2V Alloy Heated to 1130°C and Cooled With Complex Matrix Structure of α'' Dark Regions and α' White Regions, 200X

Attention was then directed toward finding a braze material that would wet 304L stainless and 49Fe-49Co-2V alloy regardless of its melting temperature. Wettability tests made with oxygen-free copper showed that copper would wet both alloys readily. Copper also had excellent flow properties permitting it to flow into small gaps which are present as surface irregularities in joints with interference fits (hub to rotor assembly). Copper has a melting temperature of 1083°C which is above the critical transformation temperature; therefore, a post-braze anneal would be required to stabilize the magnetic properties of the 49Fe-49Co-2V alloy.

Brazed Assemblies

Twenty hub-rotor assemblies were vacuum furnace brazed to evaluate the process. The parts were given a heat treatment after brazing to restore the magnetic properties of the 49Fe-49Co-2V alloys. The vacuum brazing heat treatment cycle is shown in Figure 6. Examination of the assemblies after brazing revealed excellent flow through of the copper in the joint. The joint strength was measured on 16 assemblies by pushing the hub out of the rotor. The average strength was 2500 pounds (11120 N). This was 25 times the typical joint strength of 100 pounds (445 N) produced by electron beam welding.

The effectiveness of the post-brazing heat treatment in restoring magnetic properties to the 49Fe-49Co-2V alloy was evaluated in two ways. First, the microstructure of brazed rotors were examined for signs of the martensitic phase or any other variation from the normal annealed material. In all cases, the microstructure of the brazed rotor consisted of equiaxed grains of the α' phase with no evidence of the martensitic phase. Figure 7 illustrates the 49Fe-49Co-2V microstructure of a brazed hub-rotor assembly after heat treatment.

Secondly, two units with brazed hub-rotor assemblies were torque tested. No decrease in magnetic torque was found. In fact, there was a small increase noted. This indicated that the magnetic properties of the 49Fe-49Co-2V alloy had not deteriorated.

The effect of the post-brazing heat treatment on the strength of the 49Fe-49Co-2V alloy was determined by conducting microhardness tests. The mean Knoop hardness numbers for as-received and brazed material were 246 and 250 respectively. This suggested that the strength of the 49Fe-49Co-2V alloy had not been reduced by the high temperature involved in the brazing process.

Dimensional stability of the 49Fe-49Co-2V alloy was not a problem because of the ability of the brazed hub-rotor assemblies to successfully function in the units.

Figure 6. Vacuum Brazing and Post Brazing Heat Treatment Cycle

Figure 7. Microstructure of 49Fe-49Co-2V Alloy After Typical Brazing and Post-Brazing Heat Treatment; Matrix Consists of Equiaxed α' Grains, 200X

ACCOMPLISHMENTS

A vacuum furnace brazing process was developed for joining 49Fe-49Co-2V magnetic alloy to 304L stainless steel using oxygen-free copper as the braze filler metal. The process proved effective in eliminating the cracking problem associated with electron beam welding of the hub to rotor assembly on the switch assembly. Joining strengths were increased 20 times without any apparent degradation in magnetic properties.

FUTURE WORK

Work is proceeding to eliminate welding problems related to the switch assembly in which the 49Fe-49Co-2V alloy is joined to materials other than 304L stainless steel. The methods of joining which will be studied are laser welding, laser brazing, electron beam welding, and electron beam brazing.

BDX-613-936

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August 1973

Bendix Corporation
Kansas City, Missouri

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Project Leader:
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Department 814

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Prepared by D. M. Jarboe

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FUTURE WORK

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