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CLOSURE FOR ZIRCALOY-2 CLAD FUEL ELEMENTS

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REPORT ON THE PROJECTION WELDED BRAZED
CLOSURE FOR ZIRCALOY-2 CLAD FUEL ELEMENTS

by

P. A. Ard
W. I. Steinkamp

Fuels Fabrication Development
Reactor & Fuels Research & Development
HANFORD LABORATORIES

May 15, 1961

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REPORT ON THE PROJECTION WELDED BRAZED
CLOSURE FOR ZIRCALOY-2 CLAD FUEL ELEMENTS

Introduction

The projection welded brazed closure is being studied as a possible alternate method of closing coextruded Zircaloy-2 clad uranium fuel elements for the NPR. This closure consists essentially of projection welding the Zircaloy-2 cap to the element cladding followed by a fast resistance heating of the cap and exposed uranium face under pressure to braze the cap to the uranium face. The work to date has been entirely on 0.593 inch OD rods and 1.050 inch OD by 0.500 inch ID tubular elements.

This closure has the advantage that the entire closure is completed in less than 5 seconds on one machine and consequently the element is at a temperature which would be detrimental to the Zircaloy-2 cladding and uranium bond for a very short time. The amount of uranium removed for this closure is reduced by a factor of 10 over conventional braze closure methods with a substantial savings in uranium and acid milling time. A braze material which is not toxic can be used to bond the cap to the uranium.

Conclusions

The projection welded brazed closure developed on 0.593 inch OD Zircaloy-2 clad uranium rods has withstood long term hot water and steam autoclave tests without any indication of excessive corrosion in the projection weld zone between the closure cap and the cladding. The projection weld appears to be easily reproducible and of adequate integrity under the proper welding conditions. The cap can be completely bonded to the uranium surface with a number of braze materials of which a copper plate seems to be the best from the bond quality standpoint.

This closure appears feasible on tubular elements as indicated from the closures made on 1.050 inch OD by 0.500 inch ID elements. However, the resistance welding equipment was not of adequate capacity to fully evaluate the closure concept at optimum welding conditions.

Welding Preparation

The Zircaloy-2 clad coextruded elements are prepared for closure by first facing the ends of the element and recessing the uranium 0.025 inch by acid milling to provide a cladding projection for the initial projection weld. The uranium surface is given a bright etch with concentrated nitric acid just prior to the assembly for welding.

The Zircaloy-2 closure caps are the same diameter as the element with projections machined on the cap to match the projecting element cladding. The caps are degreased and washed with acetone prior to use.

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The braze material can be plated on the face of the closure cap which contacts the uranium or the material can be placed in the recess over the uranium as a thin shim or powder.

The element and cap are assembled and clamped in the welding collet. A restraining ring of Zircaloy, and in the case of tubular elements a restraining plug, are placed in position to prevent the welds from bulging. Figure 1 shows the initial welding set up for the closure on tubular elements. All closures to date have been made in air, however an inert atmosphere might be desirable to prevent the formation of black Zircaloy oxide on the heated end.

Welding Conditions

Welding and brazing of all elements to date has been done on a Sciaky 3 phase 100 KVA spot welding machine. The element to be welded is placed in collet type holder which is attached to the lower electrode of the welder. The collet used is copper. The collet holder is a class two resistance welding alloy. The upper electrode used is copper with a flat face the diameter of the cap of the fuel element being welded.

A typical weld cycle might be described by the following seven steps:

1. The upper electrode is brought into contact with the element cap with a pressure of 500 lbs. for 1/2 second.
2. Electrical current begins to flow. Four and four-tenths volts are applied to the element and a maximum of 70,000 amps. This continues for .05 seconds. The heat generated at the mating surfaces causes them to fuse and weld during approximately the first .025 second of current flow. At that point (.025 second after the weld current has begun to flow) the clamping force is tripled. This additional force forges the walls and projections into thickened sections and brings the cap into contact with the uranium. The molten areas solidify due to the increase in thermal conductivity of the water cooled electrode and the increased contact with the more massive element.
3. Electrical current is interrupted for .1 second while the cap seats firmly on the uranium.
4. Current is again allowed to flow for .05 second. This energy is used for heating the element preparatory to brazing.
5. Current is again interrupted. This allows the heat to dissipate deeper into the element but cannot be helped because of machine limitations.
6. Current is allowed to flow for another .05 second. This completes the brazing heat input for .593 rods. (On the machine used KER tubes required two additional impulses of current to complete the braze.)

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7. Pressure is maintained for an additional two to two and one-half seconds. This provides rapid quenching and also eliminates cracking at the braze line. The complete weld and braze cycle is shown in Figure 2.

Critical points in the cycle appear to be the point at which the pressure is increased and the maintained pressure at the end of the cycle. If the forging pressure is delayed too long the projections and walls will overheat and be expelled from the weld zone. If the pressure is applied too soon welding will not take place. If pressure is not maintained after completion of the braze a crack will develop at the braze interface.

This data has been obtained on .593 rods and on .500 x 1.050 tubular elements. These appear to represent the limits and in the case of the tubular elements the extreme limits of the machine in use.

A short length of a tubular element with both ends closed can be seen in Figure 3. Figures 4 and 5 show a cross section of the closure on a tube and a rod respectively.

Projection Weld

This type of closure requires that the projection weld between the cap and the cladding be of high integrity, as this is the only barrier against the reactor coolant at the junction of the cap and the clad. Results indicate that there is substantial thickening of the cladding through the junction resulting from the forging action immediately following the projection weld. A cross-section of the closure on a 0.593 OD rod and a 1.050 OD by 0.500 ID tube is shown in Figures 6 and 7 respectively.

The projection welds on rods have been tested in both hot water (300 C water at 2200 psi for 50 hours) and steam (400 C steam at 1500 psi for 72 hours) without failure or any indication of corrosion in the weld zones. The preparation for the autoclave tests consisted of first vapor blasting and then etching the elements in a solution of 4% HF, 39% HNO₃ by volume.

The work to date on tubular elements indicates that additional power and pressure is necessary to produce the forged weld of the quality which is necessary for this type of closure. A difficulty encountered with the closure to date on tubes is shown in Figure 8. The welding pressure was not sufficient to force the cap to follow up as the projections fused, as is necessary to prevent blowing the molten Zircaloy-2 out of the weld zone. An increase of initial welding pressure would require an increase of welding power to fuse the projections, thus requiring power above that available on the 100 KVA welding machine. Results indicate that the forging pressure used was not adequate to always firmly seat the cap onto the uranium for the brazing step.

Zircaloy-2 Cap to Uranium Bond

Several materials of varying thickness have been used to aid in bonding the Zircaloy-2 cap to the uranium surface on 0.593 rods. The materials tried

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FIGURE 1

Welding Set Up for the Projection Welded Brazed Closure on Zircaloy-2
Clad Uranium Tubular Elements.

FIGURE 2

Weld and Braze Cycle

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FIGURE 3

A 4 inch long 1.050 inch O.D. by 0.500 inch I.D. Zircaloy-2 clad uranium fuel element with both ends closed by the projection welded brazed closure method. 1 X

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FIGURE 4

Cross section of projection welded brazed closure on a 1.050 inch O.D. by 0.500 inch I.D. Zircaloy-2 clad uranium tubular element. Copper plate braze material used in cap to uranium interface. 5 X

FIGURE 5

Cross section of projection welded brazed closure on 0.593 inch O.D. Zircaloy-2 clad uranium rod. Silver braze material used in cap to uranium interface. 5 X

Cross section of projection weld between Zircaloy-2 clad and cap on 1.050 inch O.D. by 0.500 I.D. tube closure. 50X

FIGURE 7

Cross section of projection weld zone between Zircaloy-2 clad and cap on 0.593 rod closure. 50 X

FIGURE 6

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FIGURE 8

Cross section of projection weld between the Zircaloy-2 clad and cap on a 1.050 inch O.D. by 0.500 inch I.D. tubular element showing effect of insufficient welding pressure. 100 X

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and the results are shown in Table I. The 100 KVA spot welder was set to produce three impulses consisting of 3 cycles each at 99% capacity of the machine. A 7 cycle delay was set between each impulse. The force is increased from 400 pounds to 1200 pounds following the first impulse which produces the initial projection weld and held for approximately 2-1/2 seconds after completion of the last impulse.

The cap appeared to completely bond in most cases with the thinner copper electroplate, the copper chemical plate and the silver solder producing the toughest bonds. The steel shim and the Zr, 4% Be, 8% Cu braze alloy seemed to produce the most brittle bond. The cap could not be bonded directly to the uranium under the same conditions without the use of the bonding materials.

Micro sections of the interfaces can be seen in Figures 9, 10, 11 and 12 and indicate considerable alloying of the bonding agents into the uranium; the depth depending upon the thickness of the initial bonding material. The steel alloyed to a considerable depth into the uranium and produced the most porous and brittle structure.

Results to date on both rods and tubes show that the cap must seat uniformly onto the uranium before the brazing cycle begins otherwise the cap will only bond to the points of initial contact. The uniform seating insures uniform current distribution and thus uniform heating of the cap. This requires that the uranium surface must be flat and both cladding projections and the uranium surface must be parallel to the welding electrode face.

A copper chemical immersion plate has been the only bonding agent used on tubular elements. A cross section of an interface is shown in Figure 13.

PAA:WIS:bo

TABLE I

COMPARISON MATERIALS USED TO BOND THE ZIRCALOY-2 CLOSURE CAP
TO THE URANIUM SURFACE IN THE PROJECTION WELDED BRAZED CLOSURE

<u>Braze Material</u>	<u>Thickness (Inches)</u>	<u>Results</u>	
		<u>Bond Integrity</u>	<u>Toughness</u>
Copper Shim	0.0015	Good	Good
Copper Electroplate	0.0005	Good	Good
Copper Chemical Immersion Plate	0.0003	Good	Good
Silver Solder Shim	0.0005	Good	Good
Silver Shim	0.0015	Good	Fair (Uranium Alloy Brittle)
Steel	0.001	Fair	Poor (Weak at Interface)
Zr, 4% Be, 8% Cu -100 Mesh Alloy	0.005	Good	Fair
No Braze Material		Spotty	Very Poor

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Zircaloy-2 Cap

0.0015 Copper Shim

0.0015 Silver Shim

FIGURE 9

Cross sections of projection welded brazed closure showing interface between Zircaloy-2 cap and uranium core using 0.0015 copper shim and 0.0015 silver shim at interface for bonding agent. 50X

Zircaloy-2 Cap

0.0005 Copper Electroplate

0.0003 Copper Immersion Plate

FIGURE 10

Cross sections of closure showing interface between cap and uranium using 0.0005 copper electroplate and 0.0003 copper immersion plate at interface for bonding agent. 50X

Zircaloy-2 Cap

-100 Mesh Zr, 4 Be, 8 Cu

FIGURE 11

0.001 Steel Shim

50X

Cross sections of closure showing interface between closure cap and uranium using 0.005 thickness of -100 mesh % Zr, % Be, % Fe W/o and 0.001 steel shim at interface for bonding agent.

Iron
Uranium
Alloy

Uranium

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Zircaloy-2 Cap

0.0005 Silver Solder Shim

FIGURE 12

Cross section of closure showing interface between closure cap and uranium using 0.0005 thickness of silver solder for bonding agent. 50X

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FIGURE 13

Cross section of interface between Zircaloy-2 cap and uranium on 1.050 O.D. by 0.500 I.D. tubular element. Copper immersion plate used as bonding agent. 500 X

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