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ENRICHED I&E FUEL ELEMENTS FOR PT-IP-247-A.
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RADIOMETALLURGICAL EXAMINATION OF 1.47
ENRICHED I&E FUEL ELEMENTS FOR PT-IP-247-A. (RM-404)

by

R. Teats

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RADIOMETALLURGICAL EXAMINATION OF 1.47
ENRICHED I&E FUEL ELEMENTS FOR PT-IP-247-A. (RM-404)

INTRODUCTION

Under the conditions of PT-IP-247-A, four columns of self-supported and four columns of rib-supported I&E 1.47% enriched fuel elements were irradiated to determine their relative performance under severe operating conditions. Four of the self-supported and two of the rib-supported control elements were received for examination.

The two rib-supported control pieces, which were classified as "near failures" had received average exposures of 353 and 359 MWD/T at average specific power levels of 91 and 108 KW/ft before they were discharged because of other ruptured pieces in the tubes. The nominal specified canned fuel dimensions of the rib supported elements was 1.445" OD, .310" bore, and 7.640" long.

The first two self-supported elements were selected for examination on the basis of high weight losses sustained during irradiation, and the second two were selected to determine the effect of specific power levels on the AlSi bonding. The average specific power levels of the four self-supported elements varied from 79 to 110 KW/ft and the exposure varied from 845 MWD/T to 949 MWD/T.

The nominal canned dimensions of the self-supported elements, which were made oversize to attain high annular coolant temperatures with respect to the interior coolant channel, were 1.460" OD, .375" bore, and 7.640" long. The eight bridge rail supports were spot welded on and gave an effective rib outside diameter of 1.600". All of the components were X-8001 aluminum alloy.

SUMMARY AND CONCLUSIONS

The two control pieces had severe side hot spots from cocking in the tube. An accelerated intergranular corrosion attack on the aluminum alloy cladding had formed large cavities near the center of the hot spots. In one element the corrosion had penetrated to the AlSi and caused an incipient rupture. In the other the corrosion had penetrated through more than 50% of the canwall. The cladding had separated from the core under the hot spot areas where spheroidization of the AlSi and deterioration of the compound layer had occurred.

On the two self-supported elements with high weight losses, a thick black corrosion film had formed on the outside canwall during irradiation. A chemical cleaning treatment after discharge had removed most of the scale leaving a rough orange peel surface. The other two self-supported elements were relatively clean and showed little of this type of scaling. No accelerated corrosion had occurred on the self-supported elements.

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There was no indication of beta phase transformation or high alpha anneal found in the cores but extensive micro-cracking of the uranium had occurred in both the control and self-supported elements.

Although the bonding around the spires was largely broken, no deterioration or loss of spire wall was found.

A limited amount of AlSi spheroidization had taken place in the self-supported elements but was uniformly dispersed around the outside periphery. No areas were found where localized overheating had occurred such as in the hot spot areas of the control elements. There was no correlation found between the severity of the bond cracking or the degree of AlSi spheroidization and the power levels sustained by these elements.

DETAILS

The two control elements, which had operated at average specific power levels of 91 and 108 KW/ft had developed side hot spots, as shown in Figure I, from cocking in the tube. Near the center of the hot spots an accelerated intergranular corrosion attack had caused large cavities in the X-8001 alloy canwall. The surface temperature at the center of the hot spots probably reached 350°C where accelerated corrosion of the X-8001 alloy begins. Corrosion had penetrated to the AlSi layer of the #8 piece from tube 1764B, as shown in Figure 4, and caused an incipient rupture. Water had entered the cladding through the hot spot but the swelling near the male end had not yet ruptured the cladding. The corrosion attack had penetrated more than 50% of the canwall of the other element. Micros showing the intergranular attack on the X-8001 Al Alloy can be seen in Figures 7 and 8. Under the hot spots the cladding had pulled away from the cores and extensive spheroidization of the AlSi occurred. By comparison with results from an unpublished spheroidizing study by R. M. Peekema on unirradiated AlSi, it is estimated the maximum AlSi temperature under the hot spots exceeded 400°C. The extent of the spheroidizing can be seen in Figures 9 and 10.

A thick black corrosion film had formed on the canwall of #3 and #5 self-supported pieces from tube 1768B. When this scale was removed by a chemical treatment after discharge, a rough orange peel surface on the aluminum was exposed. By comparison, the self-supported pieces #9 from tube 1880B and #2 from 1872 B were relatively clean with little of this type of corrosion film found. There was no evidence of any accelerated corrosion of the cladding on the four self-supported elements examined.

Transverse and longitudinal sections were made in the two elements which had lost the most weight and the residual canwall and spirewall thickness measured. The canwall was thickest under the support tabs where the surface was protected from the erosive effect of the water. This can be seen in the transverse section through the support tabs as shown in Figure 11. The average residual canwall thickness near the center of element #3 was .023" with a maximum of .028" and a minimum of .020". Near the center of #5 element, the average was .029 with a maximum of .032" and a minimum of .023".

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From the longitudinal sections, the interior surfaces of the spire were examined and no significant corrosion or film accumulation was found. Light spiral scratches were still evident on the spire surfaces which was probably caused by the probe of the bond and penetration testers. The average residual spire wall thickness on both elements was .040" with a maximum of .044" and a minimum of .035" found.

The uranium cores of all six elements were examined for signs of beta phase transformation or high alpha anneal. Nothing was found in the macro structure to indicate the core temperatures were high enough to cause annealing. Even in the control pieces under the hot spots where the highest localized heating had occurred, there was no evident change in the uranium structure, as shown in Figure 3. The cooling effect of the inner spire undoubtedly kept the uranium temperature below the transformation point.

Metallographic examination of the cores revealed extensive micro cracking in the uranium. The cracking was generally in a radial direction with many of the cracks emanating from the inner bore. Examples of the micro cracking found are shown in Figures 13 and 14.

The bonding around the spires in both the control and self-supported elements was largely broken or cracked. No sign of AlSi spheroidization was seen on the spires. Radial cracks in the compound layer indicate the failure of the bonding was caused by tensile stresses induced by thermal expansion. This type of bond cracking is illustrated in Figure 15.

Because of the high specific power levels sustained by the self-supported elements in this test, a thorough micro examination was made of the canwall bonding of the four elements to determine, if possible, the future potential of the AlSi bonding process at high power levels. One element had been irradiated at an average specific power level of 79 KW/ft, two at 87-89, and one at 110 KW/ft. In all four elements, the bonding had broken away or cracked for about half of the circumference. There was only a limited degree of AlSi spheroidization found and it was not particularly associated with the broken bonding. There was no significant difference noted in the degree of AlSi spheroidization or in the severity of cracking in the four elements examined.

No obvious reasons were found during the metallographic examination that could explain why the bonding failed where it did. It is possible that some of the cracking might have occurred during the cutting operation when the metallographic samples were removed, but most of the cracking was, undoubtedly, caused by thermal cycling during irradiation. Representative micro structures of the bonding layers of the self supported elements are shown in Figures 15 through 20. Additional photomicrographs of AlSi bonding are available in the Radiometallurgy negative file.

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References:

HW-59756-C, R. E. Hall; HW-59756-E, R. E. Hall
Radiometallurgy Negative File

R. Teats

R. Teats, Engineer
Radiometallurgy Laboratory
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Neg. #13673 .80X

Neg. #13680 .80X

FIGURE 1

As-received side views of control elements showing the side hot spots. Element #9 from 1882B is on left and #8 from 1764 B, the incipient rupture is on the right.

Photograph Unclassified

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Neg. #13947

Neg. #13942

Neg. #14485

Neg. #14483 .80X

FIGURE 2

As received side views of self supported elements

Piece #	5	3	2	9
Tube#	1768 B	1768 B	1872 B	1880 B
Avg. kw/ft	89	87	79	110
MWD/T	859	859	845	949

Photograph Unclassified

Neg. #13799

2.2 X

FIGURE 3

Transverse section, cathodically etched, through hot spot of control element #8. The grain structure is unchanged under the hot spot.

Neg. #13825

2.7X

FIGURE 4

Transverse section through hot spot showing where the corrosion product had fallen out leaving the thin Alsi layer.

Photograph Unclassified

Neg. #13769

50 X

FIGURE 5

Transverse section through edge of hot spot on control element #9.

Neg. #13851

Polarized Light

50 X

FIGURE 6

Transverse section through edge of hot spot of control element #8,
showing remnant of corrosion product in cavity.

Photograph Unclassified

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Neg. #13794

Polarized Light

250 X

FIGURE 7

Transverse section through edge of hot spot cavity showing the intergranular corrosion attack.

Neg. #13859

Bright Field

300 X

FIGURE 8

Intergranular corrosion of X-8001 Al alloy at edge of hot spot cavity.

Photograph Unclassified

Neg. #13861

300 X

FIGURE 9

Neg. #13858

300 X

FIGURE 10

Spheroidized Alsip, moderate at top and severe at bottom, found under hot spot area. Note the compound layer along the edge.

Photograph Unclassified

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Neg. #14224

2.3 X

FIGURE 11

Transverse section as etched through support tabs of Piece #5, tube 1768B. Element had lost 8.66 gm during irradiation.

Neg. #14424

FIGURE 2

1.5 X

Longitudinal section through support tab at female end of Piece #5, tube 1768B.

Photograph Unclassified

Neg. #14072

300 X

FIGURE 13

Micro cracks in U at the inner bore of Piece #3, Tube #1768B.

Neg. #14289

300 X

FIGURE 14

Micro cracks in U near center of Piece #5, Tube 1768B.

Photograph Unclassified

Neg. #14759

As Polished

250X

FIGURE 15

Alsi layer along inner spire of Piece #5, Tube 1768 showing radial cracks across compound layer

Neg. #14746

As Polished

250 X

FIGURE 16

Alsi layer along the outer cladding Piece #5, Tube 1768B.

Photograph Unclassified

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Neg. #14542

As Etched
FIGURE 17

250 X

Alsi layer along outer cladding of Piece #2, Tube 1872 B.

Neg. #14543

As etched
FIGURE 18

250 X

Cracked compound layer in same transverse section as above

Photograph Unclassified

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Neg. #14723

As Polished
FIGURE 19

250 X

Alsi layer along outer cladding piece #9, Tube 1880B showing the start of crack in compound layer.

Neg. #14720

As Polished
FIGURE 20

250 X

Same transverse section as above showing a void under the compound layer probably caused by surface contamination on the uranium during canning.

Photograph Unclassified

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