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HOT DIE SIZE PROCESS VARIABLES UPON GRAIN
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INTERIM REPORT ON THE EFFECT OF
HOT DIE SIZE PROCESS VARIABLES UPON
GRAIN GROWTH IN ALUMINUM ALLOY 8001 CLADDING

Issued by

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INTERIM REPORT ON THE EFFECT OF
HOT DIE SIZE PROCESS VARIABLES UPON
GRAIN GROWTH IN ALUMINUM ALLOY 8001 CLADDING

INTRODUCTION

Three hot die size (HDS) fuel elements charged for the HDS equivalency test, PT-IP-781-A, failed during irradiation (August, 1965) as a result of severe ledge and groove corrosion. Examination of comparison pieces revealed that ledge and groove corrosion was the most severe at the top of the downstream end of the downstream ten pieces as positioned in the process tube. In the case of HDS fuel, the downstream end is the top or cap end of the piece as it is fabricated. It was speculated that ledge and groove corrosion could be an interaction between the HDS fuel assembly process and reactor operation. For this reason, studies were initiated to determine the effect of HDS process variables upon ledge and groove corrosion in out-of-reactor tests (1,2). This report summarizes the results of testing to determine the effect process variables have upon grain size and hardness of the aluminum cladding.

SUMMARY

Initial tests to determine the effect of HDS process parameters upon aluminum large grain growth have been completed. Large grain growth on 8001 aluminum alloy clad HDS fuels was reduced by each of the following: 1) lower sizing reduction ratio, 2) lower end bonding temperature, and 3) tubing components. Combining the three conditions had a cumulative effect; i.e., use of two or more of the combinations further reduced the amount of grain growth. Grain growth at the cap end of impact extruded cans was slightly lower for the high sizing reduction than for the low sizing reduction test material. The difference was only slight and was not considered significant.

Chemical analysis of cladding from HDS fuel elements indicates that there is no significant pickup of copper, carbon, or other constituents during processing.

Process Specifications have been changed to provide a lower end bonding temperature and tubing components are being utilized. Reduction ratio will remain unchanged in that if it were lowered significantly, cumulative component tolerances would produce a reduction ratio below, the specified minimum. Other tests are being conducted to lower end bonding temperature even further.

DISCUSSION

Initial testing for the purpose of detecting differences between HDS and AlSi brazed fuels indicated the following differences in the aluminum alloy 8001 cladding (3):

1. Large grain formation near the ends of HDS fuels.
2. Reduction in hardness in large grain areas of HDS Fuel.
3. Possible carbon or copper pickup during processing of HDS fuel. (Later discovered to be an error in measuring technique.)

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DISCUSSION (Cont.)

Procedures

A test was designed to evaluate the effect varying process parameters have upon these differences. In addition, chemical analysis was obtained for as-received components, as-sized cladding, and end bonded cladding to determine what constituents, if any, were picked up during processing. The test design was as follows:

	Test Piece No.			
	High Reduction Ratio		Low Reduction Ratio	
	High EB Temp	Low EB Temp	High EB Temp	Low EB Temp
Sizing Lub Removed	1 thru 5	6 thru 10	11 thru 15	16 thru 20
Sizing Lub Not Removed	21 thru 25	26 thru 30	31 thru 35	36 thru 40

The replicate of this test employed tubing components.

Parameters varied on this particular test included high (normal) vs low reduction ratio at sizing (45% vs 25%) and high vs low end interface temperatures (580 C vs 545 C) at end bonding. Heating times on the end bonding press to attain this temperature were as listed below: All fuels were processed without AlSi wafers.

	Heating Time	Total Time	Control Temperature
"High" Temperature	1:45	2:45	750 C
"Low" Temperature	1:10	2:30	750 C

Both destructive and nondestructive tests were used in the evaluation of this material. These tests included grain size measurement, cladding hardness measurement, weld inspection, bond strength, chemical analysis, and bond testing with UE-1 and UT-14 testers. Evaluation tests or steps are discussed individually under separate headings.

IMPACTS

Large Grain Formation

Two methods were used to evaluate the extent of grain growth down the lateral surface after grain etching the 8001 alloy jacket. Grain size was used as one criteria but did not indicate any difference between the various parameters. However, it can be concluded from this data that the cap end had the larger grains (.025 - .050 inch) while the base had medium to fine grains (.010 - .025 inch and .005 - .010 inch, respectively).

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Large Grain Formation (Cont.)

The second evaluation included length measurement of the large grain growth area from the end of the fuel, Figure 1 and 2. Four measurements were taken on each end of the fuels and averaged for a sample size of eight pieces. The following is a summary of the results expressed as inches of large grain formation from the fuel end:

	<u>End Bond Temperature</u>			
	<u>High (580 C)</u>		<u>Low (545 C)</u>	
	<u>Cap</u>	<u>Base</u>	<u>Cap</u>	<u>Base</u>
High Reduction (45%)	1.326 in.	1.443 in.	1.117 in.	1.334 in.
Low Reduction (25%)	1.321 in.	1.276 in.	1.165 in.	1.169 in.

Because sample size was relatively small, over-all effects of sizing reduction ratio and end bond temperature were determined by combining as follows:

Sizing Reduction Ratio

	<u>Cap</u>	<u>Base</u>
High Reduction (45%)	1.221 in.	1.389 in.
Low Reduction (25%)	1.243 in.	1.223 in.

End Bonding Temperature

High End Bond T. (580 C)	1.324 in.	1.360 in.
Low End Bond T. (545 C)	1.141 in.	1.252 in.

Low end bonding temperature produced less grain growth. The only significant difference in reduction ratio is that the base has less grain growth at low reduction ratio. The cap is virtually unchanged. Figure 3 shows the as-sized fuel. Note the elongated grains from sizing. Large grains however, do not appear until after end bonding. Figure 4 shows the difference from end bonding temperatures. See Appendix A.

Cladding Hardness Measurements

Cladding hardness measurement values showed little difference, if any, between the various parameters of the test. Hardness patterns did, however, follow the grain growth patterns on the ends of the fuel, i.e. the larger the grains (cap end) the lower the hardness and hardness started to decrease at the point of visible grain growth. As sized fuel had a uniform hardness throughout it's length with a decrease in hardness near the ends only after end bonding. Minimum hardnesses (16 - 18 R_{15T}) were higher than initial test material (12 - 14 R_{15T}). See Appendix B.

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FIGURE 1
LENGTH OF GRAIN GROWTH REGION FROM CAP & BASE
HIGH REDUCTION RATIO

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FIGURE 2
LENGTH OF GRAIN GROWTH REGION FROM CAP & BASE
LOW REDUCTION RATIO

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Figure 3

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AS-SIZED HDS FUEL

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Figure 4

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END BONDED HDS FUEL

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Weld Inspection

There was no observable difference in weld quality for fuels produced under the various parameters of the test.

Bond Strength

Bond strength data indicates quality bonds in all fuels produced in this test. Measurements were taken on each flat end, one half inch from each end, one inch from each end and at the center. Bond strength values are listed below.

	AVERAGE BOND STRENGTH VALUES						Base
	Cap	1/2 Inch	1 Inch	Center	1 Inch	1/2 Inch	
High End Bond Temp.	490	824	720	754	647	863	696
Low End Bond Temp.	422	576	661	659	693	804	594
High Reduction Ratio	479	746	801	801	730	874	646
Low Reduction Ratio	433	654	580	607	610	793	640

There is no significant difference in bond quality as related to the variables of this test other than that produced as a result of reduction ratio. Both of these bond strengths, however, are well above specified minimums. See Appendix C.

Chemical Analysis

Samples of as-received components, as-sized cladding, and cladding samples after end bonding were all analyzed for copper and carbon. Analysis of test material showed that neither copper, carbon, nor any other materials were picked up in significant amounts on the aluminum cladding during processing.

Bond Testing

All material produced on this test passed the UE-1 and UT-14 bond testers. No significant difference in the material, as compared to normal production material, was observed.

TUBING

A replicate of this test was produced using tube cladding components. The first half of the test was lost as a result of lubricant removal prior to end bonding. This resulted in cleaning solution penetration of the cap-can closure area. (Tubing was assembled by crimping and flaring.)

DISCUSSION (Cont.)**DECLASSIFIED**Large Grain Formation - Tube Cladding

The length of large grain formation expressed as inches from the end of tube clad HDS fuel is shown in the following tables:

	<u>End Bond Temperature</u>			
	<u>High (580 C)</u>		<u>Low (545 C)</u>	
	<u>Cap</u>	<u>Base</u>	<u>Cap</u>	<u>Base</u>
High Reduction (45%)	1.136 in.	1.273 in.	0.958 in.	1.151 in.
Low Reduction (25%)	1.160 in.	1.196 in.	0.816 in.	1.074 in.

As in the case of impact components, low end bonding temperatures had the greatest effect upon grain growth formation. Over-all effects of sizing reduction ratio and end bond temperature upon aluminum grain formation in tube clad fuel are shown below:

	<u>Sizing Reduction Ratio</u>	
	<u>Cap</u>	<u>Base</u>
High Reduction (45%)	1.047 in.	1.212 in.
Low Reduction (25%)	0.988 in.	1.135 in.

	<u>End Bonding Temperature</u>	
	<u>Cap</u>	<u>Base</u>
High End Bond T (580 C)	1.148 in.	1.235 in.
Low End Bond T (545 C)	0.887 in.	1.113 in.

Grain growth formation was less for tube clad than for impact clad HDS fuel. All sizing reduction and end bond test data for each of the impact and tube clad tests are combined to show the relative effect of using the two types of components on HDS fuel. Length of grain growth expressed as inches from the end for impact and tube clad HDS fuel are listed below:

	<u>Fuel Cladding Type</u>	
	<u>Cap</u>	<u>Base</u>
Impact	1.232 in.	1.306 in.
Tubing	1.018 in.	1.174 in.

Cladding Hardness Measurements

In general, the minimum hardness of tube clad fuels was slightly higher than for impact cladding, i.e., minimum was 18 - 20 R_{15T}. The only significant difference in hardness patterns was that the high reduction ratio as-sized fuel, had reduced hardness on the ends. (Similar pattern as fuels that are end-bonded). See Appendix D.

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CONCLUSIONS

Three processing variables have a measurable affect on cladding grain growth in the manufacture of HDS fuels. Although this influence is measurable it does not eliminate the grain growth observed on the ends of HDS fuels. As has been shown in this test sizing along does not produce grain growth, however, the lower the reduction ratio at sizing the lower the resultant grain growth after end bonding. This is as a result of the lesser degree of cold work (residual stresses) remaining in the cladding as a result of the lower reduction ratio.

End bonding results in grain growth (stress relieving) as the ends are heated to bonding temperature. Therefore it is reasonable to assume (test data verifies) that lower temperatures will produce a lesser degree of grain growth. Cladding hardness, being a function of grain size, also confirms this assumption.

Tubing components also reduce grain growth because of the different residual stress produced during fabrication of the components. Grain growth also varies between different vendor's components. (Figure 5) Again the history of residual stress is the important factor. For this test the impacts were Bridgeport and tubing Alcoa.

RECOMMENDATIONS

Sizing reduction ratio is as low as is practical at this time to prevent cumulative component tolerances from producing fuel below the specified minimum. Therefore cladding reduction ratio should not be reduced. Manufacturing process specifications have been changed to reflect the reduced end bonding temperature. Further studies are recommended, with some in progress, to further reduce the end bonding temperature. Tubing components are authorized by the process specifications and are being employed in the manufacturing of HDS fuels.

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2. RL-REA-2690, "Hot Die Size Process Development Work - Ledge and Groove Corrosion", C. A. Strand, October 25, 1965.
3. "Interim Report No. 2 - Investigation of Hot Die Size Fuel Behavior with Respect to Ledge and Groove Corrosion" - Rough Draft, G. F. Jacky October 4, 1965.

Engineer, Mfg. Process Development

GM Schweikhardt:dgm

APPENDIX A

IMPACTS

GRAIN GROWTH MEASUREMENT

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Values given for fuel at cap and base are averages of four measurements @ 90°, from flat face end.

	Fuel No.	Cap Base		Cap Base		Cap Base	
		Cap	Base	Cap	Base	Cap	Base
<div>High Reduction Ratio</div> <div>High E.B. Temperature</div>	2	1.297	1.375				
	3	1.375	1.500	1.301	1.441		
	4	1.312	1.406				
	5	1.219	1.484			1.326	1.443
	22	1.297	1.359				
	23	1.344	1.422	1.351	1.445		
	24	1.390	1.484				
	25	1.375	1.516				
High Reduction Ratio						1.221	1.384
<div>High Reduction Ratio</div> <div>Low E.B. Temperature</div>	7	.938	1.406				
	8	1.031	1.203	1.074	1.328		
	9	1.188	1.359				
	10	1.141	1.344			1.117	1.334
	27	1.125	1.437				
	28	1.219	1.328	1.160	1.340		
	29	1.172	1.297				
	30	1.123	1.297				
High E.B. Temp.						1.324	1.360
Low E.B. Temp.						1.141	1.252
<div>Low Reduction Ratio</div> <div>High E.B. Temperature</div>	12	1.438	1.422				
	13	1.266	1.141	1.332	1.231		
	14	1.294	1.234				
	15	1.328	1.125			1.321	1.276
	32	1.234	1.315				
	33	1.344	1.328	1.309	1.320		
	34	1.297	1.234				
	35	1.359	1.344				
Low Reduction Ratio						1.243	1.223
<div>Low Reduction Ratio</div> <div>Low E.B. Temperature</div>	17	1.141	1.101				
	18	1.203	1.125	1.153	1.162		
	19	1.094	1.187				
	20	1.174	1.234			1.165	1.169
	36	1.266	1.219				
	37	1.109	1.171	1.176	1.176		
	38	1.156	1.172				
	39	1.171	1.141				

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APPENDIX B

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APPENDIX B

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APPENDIX B

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APPENDIX C

Impacts

Bond Strength Measurement

Values given at each location on each fuel is the average of two measurements at that point @ 180° from one another

Fuel No.	A	B	C	D	E	F	G	A	B	C	D	E	F	G
4 ²	650	938	888	838	738	838	663	Cap						Base
5 ³	575	650	763	838	663	825	788	597	888	810	832	685	869	691
24 ²²	375	888	775	850	438	725	625							
25 ²³	788	1075	813	800	900	1088	688							
High Reduction Ratio								479	746	801	801	730	874	646
9 ⁷	413	863	863	788	788	713	588							
10 ⁸	300	663	713	588	625	850	613	360	604	791	779	775	878	600
29 ²⁷	375	838	738	863	713	1050	600							
30 ²⁹	350	1050	850	875	975	900								
High EB Temp.								490	824	720	754	641	863	696
Low EB Temp.								422	576	661	659	693	804	594
14 ¹²	325	588	513	700	550	788	800							
15 ¹³	388	625	513	538	538	688	688	382	760	629	675	609	857	691
34 ²²	488	800	763	788	738	900	625							
35 ³³	325	1025	725			1050	650							
Low Reduction Ratio								433	654	580	607	610	793	640
19 ¹⁷	450	588	475	625	613	688	663							
20 ¹⁸		550	675	500	688	813	625	483	547	531	538	610	729	588
36 ³⁷	400	450	475	463	638	650	563							

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APPENDIX D

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