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**BOND STRENGTH EVALUATION OF THE BRITTLE
BOND PROBLEM IN PRODUCTION FUEL ELEMENTS**

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J. C. Tverberg

Fuels Fabrication Development

**REACTOR AND FUELS RESEARCH
AND DEVELOPMENT OPERATION**

November 10, 1958

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BOND STRENGTH EVALUATION OF THE BRITTLE BOND PROBLEM
IN PRODUCTION FUEL ELEMENTS

INTRODUCTION

Brittle bonds and the factors controlling their formation have been of substantial concern in the production of dip canned fuel elements. Detection of brittle bonds has been by the chisel test and by metallographic examinations. At best, these are qualitative tests and do not establish the degree of brittleness. For this reason bond tensile strength analysis has been suggested. Tests have been run to determine if a change in canning variables could be detected by a change in bond strength.

SUMMARY AND CONCLUSIONS

1. Bond strengths appear to be a satisfactory criterion in gaging the tendency to form a brittle bond. A fairly large number of samples are required to establish the average bond strength and to assure that the values obtained are characteristic for the group.
2. The cap end of the fuel elements submitted for evaluation were most prone to form a brittle bond, with 68.3 per cent of the brittle failures occurring at that point.
3. Bond strengths ranged from 0 to 9230 psi. The average of all the specimens tested was 5230 psi.
4. Microgrooved cores had the highest average bond strength, 6850 psi, and displayed no brittle failures.
5. A change in the duplex bath variables indicated that an increase in bond strength was obtained when the canning basket was moved toward the horizontal, the lead temperature increased and the silicon content of the AlSi reduced slightly from the present canning conditions.

MATERIAL

One hundred fuel elements were submitted for bond strength determination. These pieces were canned at 588°C and 11.2 per cent of silicon in the Aluminum-Silicon alloy. Duplex furnace conditions were varied as in Table I.

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TABLE I

DUPLEX CANNING CONDITIONS

<u>Series</u>	<u>Number Pieces</u>	<u>Lead Cover Inches</u>	<u>Lead Temperature Degrees Centigrade</u>	<u>Basket Angle Degrees From Horizontal</u>	<u>Aluminum-Silicon Alloy Percent of Silicon</u>
1*	20	1	606	60	10.5
2	20	6	606	11	10.5
3	20	6	617	11	10.5
4	20	6	620	11	9.1
5**	5	6	615	11	10.5
6	5	6	625	11	7.5
7	5	6	620	11	8.1
8	5	6	620	11	9.4

* 306 Regular Production Control Pieces

** Microgrooved Cores

PROCEDURE

Studs were welded to the fuel element jacket with a Graham stud welder. These studs were made of 1100 aluminum as illustrated in Figure 1. The sharp tip was included to initiate the arc during welding. Three studs were welded to each fuel element approximately one inch from each end and in the center. The studs were kept in as straight a line as possible. After welding, the aluminum can wall was cut from the base of the stud as illustrated in Figure 2. These fuel elements were then placed in a Dillon Tensile Machine and a tensile load applied. Total load at time of failure and the diameter of the can wall section attached to the stud were recorded. These data were compiled and average values obtained. Many studs fell off during the initial machining and were entered on the data sheet as brittle bonds with no bond strength. Metallographic examination proved this to be the case. Microsections of representative and unusual samples were submitted for photographing.

DISCUSSION OF RESULTS

One major criticism of the tensile method of bond strength determination has been offered; a false reading may result if the stud is not aligned exactly parallel with the direction of applied force. Use of a ring clamp, Figure 3, has overcome this difficulty as the circular section allows the fuel element to automatically align itself.

Average bond strengths obtained by this method are presented in Table II. Any zero values from brittle bonds were averaged into the total, accounting for the lower values. Complete data are included in the Appendix.

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TABLE II

AVERAGE BOND STRENGTHS* AND PER CENT OF BRITTLE BONDS

Series	Cap End		Center		Base End		Average
	Bond	Per Cent	Bond	Per Cent	Bond	Per Cent	Bond
	Strength	Exhibiting	Strength	Exhibiting	Strength	Exhibiting	Strength
	Pounds Per	Brittle	Pounds Per	Brittle	Pounds Per	Brittle	Pounds Per
	Sq. In.	Bond	Sq. In.	Bond	Sq. In.	Bonds	Sq. In.
1	1720	68	6660	5	7140	5.6	5170
2	1070	80	4250	37	4850	0	3390
3	4450	26.3	5820	5	6580	0	5620
4	5000	30	5720	5	5740	1	5490
5	6430	0	7010	0	7120	0	6850
6	5760	0	5280	0	5100	0	5380
7	2050	60	4710	0	3480	40	3410
8	6750	0	6520	0	6310	0	6530

*Based on the average of all samples, including those with zero psi bond strength.

Photomicrographs were made of the following sections:

1. A tensile stud which fell off during machining and the uranium section to which the stud was attached. These are illustrated in Figure 4. A cross section of the compound layer is shown in Figure 5. These samples were taken from series 2 with a 0 psi bond strength.
2. As a comparison to photomicrography, Figure 5, a very low tensile strength section was examined and photographed as Figures 6 and 7. This section was taken from series 2 with a 900 psi bond strength.
3. A fuel element of average bond strength was sectioned. Figure 8 illustrates the compound layer and Figure 9 shows the mode of tensile failure. This sample was taken from series 8 with a 6000 psi bond strength.
4. A section of extremely high tensile strength and the tensile failure are illustrated in Figures 10 and 11. These photomicrographs were from series 4 with a tensile strength of 9230 psi.
5. The compound layer of a microgrooved core and the mode of tensile failure are illustrated in Figures 12 and 13. These were from series 5 with a 7150 psi bond strength.

Comparison of the bond strengths and photomicrographs show that in the instances of low tensile strength, Figures 5 and 6, a thick bond has formed next to the uranium indicating a brittle intermetallic compound. In the case of zero bond strength the layer is traversed by many cracks, while the 900 psi sample appears to be free of the microfractures. In both micrographs note the zones of lightly-colored aluminum-uranium diffusion extending through the darker brittle layer into the uranium.

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The normal compound layer, Figure 8, is heavily traversed with aluminum-uranium diffusion, but the brittle layer is considerably thinner than the compound layer of the brittle bond.

Compound layers of high tensile strength, Figure 9, have fewer areas of aluminum-uranium diffusion, and such a thin layer of the brittle compound that the brittle layer almost escapes detection.

Microgrooved core compound layers are interesting in that the aluminum-uranium diffusion appears to be at a maximum, but yet the brittle layer seems to be at a minimum. The mode of failure was above the zone of aluminum-uranium diffusion.

Definite conclusions were difficult to derive as to which conditions were responsible for the formation of the brittle bond. As several variables had been changed at once, it was difficult to determine which variable was directly responsible for the change in bond strength. If further samples are to be submitted for bond strength determination, the following is recommended:

1. At least ten samples should be submitted for each change in canning variables.
2. Only one variable in the canning cycle should be changed at one time.

J. C. Tverberg
Fuels Fabrication Development

JCT:lmh

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FIGURE 1 -- TENSILE WELD STUD.

FIGURE 2 -- TENSILE STUD WELDED IN PLACE AND ISOLATED FROM JACKET BY MACHINING.

FIGURE 3 -- FUEL ELEMENT CLAMP

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FIGURE 4

Brittle Fracture Showing Mode of Failure Across Compound Layer-250X

FIGURE 5

The Brittle Bond with Zero psi Bond Strength.
Lighter Colored Portions of Compound Layer are Zones
of Aluminum-Uranium Diffusion. 250X

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FIGURE 6

Compound Layer of Low Bond Strength, 900 psi. 250X

FIGURE 7

Mode of Failure of Low Bond Strength Tensile Specimen.
Failure Occurred Between Brittle Layer and AlSi. 250X

FIGURE 8

Normal Compound Layer, 6000 psi Bond Strength.
Note Gas Hole in Upper Right, and Uranium-Aluminum
Diffusion Below Brittle Layer. 250X

FIGURE 9

250X

Mode of Failure at Normal Compound Layer. Note the Material Adhering to the Uranium, indicating the Brittle Zone is Above.

FIGURE 10

250X

Compound Layer at Extremely High Tensile Strength, 9,230 psi.

FIGURE 11

250X

Mode of Failure of High Strength Compound Layer. Note the Presence of Uranium-Aluminum Diffusion Along Fracture Zone.

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FIGURE 12

250X

Compound Layer of Microgrooved Core, 7150 psi.
Note excessive Uranium-Aluminum Diffusion.

FIGURE 13

250X

Mode of Failure of Microgrooved Core.
Failure has Occurred Above the Diffusion Zone.

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APPENDIX

1. All values reported are the individual tensile specimens.
2. Values are in pounds per square inch (psi).
3. Average values include all bonds of zero psi bond strength.
4. Per cent of brittle bonds = $\frac{\text{Number of zero values}}{\text{Total number of values}} \times 100$.

SERIES 1					SERIES 2					SERIES 3				
No.	Cap	Center	Base	Average	No.	Cap	Center	Base	Average	No.	Cap	Center	Base	Average
1	7660	5630	6760		1	2700	6300	6980		1	0	6870	5540	
2	0	8100	8780		2	8650	8330	0		2	6200	2230	1920	
3	0	9000	9000		3	0	6530	7660		3	0	2800	6400	
4	6300	7660	7300		4	0	8200	8110		4	1940	6950	6840	
5	4730	4280	0		5	0	5180	900		5	0	7460	7880	
6	2700	7430	8330		6	0	3830	8110		6	0	6490	6640	
7	6760	8100	8100		7	0	0	0		7	4850	3820	6390	
8	0	lost	8200		8	0	6080	7430		8	7690	6150	4620	
9	4500	8100	lost		9	0	6980	0		9	0	0	7620	
10	0	8560	4730		10	0	0	2480		10	8200	7030	5660	
11	0	6760	lost		11	0	6760	8110		11	lost	6780	7950	
12	lost	3600	7660		12	0	0	6080		12	6050	7360	4650	
13	0	9230	9000		13	0	0	0		13	6000	7170	6980	
14	0	5860	9460		14	0	0	0		14	7170	7130	7170	
15	0	7200	7200		15	0	0	5400		15	6780	6590	8140	
16	0	7660	8330		16	0	9100	4500		16	6640	4840	7950	
17	0	4050	5630		17	0	0	6980		17	6000	7170	7170	
18	0	6760	8330		18	0	8780	8780		18	5810	6400	7170	
19	0	8560	5180		19	6080	4730	8560		19	3880	7670	7360	
20	0	0	6530		20	3950	lost	6980		20	7360	5620	7620	
AVE	1720	6660	7140	5170		1070	4250	4850	3390		2050	4710	3480	3410

% Brittle Bonds 68

5 56

80 37 25

60 0 40

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APPENDIX CONT'D.

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SERIES 4				
No.	Cap	Center	Base	Average
1	3150	1560	7030	
2	0	3320	6050	
3	0	2930	2340	
4	0	6840	3710	
5	0	0	0	
6	8560	1120	2000	
7	7200	6980	7880	
8	7200	9000	7660	
9	7880	8560	6080	
10	0	9230	8560	
11	3600	7880	4280	
12	7200	lost	8110	
13	7430	7880	7200	
14	7200	8290	7430	
15	8330	7890	7430	
16	6300	5650	0	
17	3600	5400	8560	
18	0	4050	4280	
19	8830	7200	7890	
20	8560	4950	8330	
<hr/>				
AVE	5000	5720	5740	5490
<hr/>				
% of Brittle Bond	30	5	1	

SERIES 5				
No.	Cap	Center	Base	Average
1	6450	7190	7500	
2	7150	6840	7620	
3	6450	lost	5660	
4	lost	lost	7810	
5	5660	lost	7030	
<hr/>				
AVE	6430	7010	7120	6850
<hr/>				
% of Brittle Bond	0	0	0	

SERIES 7				
No.	Cap	Center	Base	Average
1	0	6580	0	
2	4910	3900	5660	
3	0	4300	5470	
4	0	2150	6250	
5	5320	6640	0	
<hr/>				
AVE	2050	4710	3480	3410
<hr/>				
% of Brittle Bond	60	0	40	

SERIES 6				
No.	Cap	Center	Base	Average
1	5040	4850	3880	
2	7420	6200	7420	
3	6980	4650	3680	
4	2130	4070	3490	
5	7230	6640	7030	
<hr/>				
AVE	5760	5280	5100	5380
<hr/>				
% of Brittle Bond	0	0	0	

SERIES 8				
No.	Cap	Center	Base	Average
1	6000	4650	6200	
2	6590	6980	6000	
3	7560	7170	6690	
4	6980	7620	6560	
5	6640	6200	6090	
<hr/>				
AVE	6750	6520	6310	6530
<hr/>				
% of Brittle Bond	0	0	0	

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