CONF

DETECTION AND SIZING OF UNDERB/EAD CRACKS
USING ULTRASONIC NONDESTRUCTIVE EXAMINATION

J. D. SCARBROUGH
W. M. WIERZBICKI

DPSPU--82-30-11

DE83 012205

Paper for presentation at the Golden Gate Metals and Welding Conference, February 9-11, San Francisco, Ca.

Material previously discussed at Miamisburg, Ohio, November 17-18, 1981 in meeting with other DOE contractors.

This paper was prepared in connection with work under Contract DE-AC09-76SC00001 with the U. S. Department of Energy. By acceptance of this paper, the publisher and/or recipient acknowledges the U. S. Government's right to retain a nonexclusive royalty-free license in and to any copyright covering this paper, along with the right to reproduce and to authorize others to reproduce all or any part of the copyrighted paper.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

EAB

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DETECTION AND SIZING OF UNDERBEAD CRACKS
USING ULTRASONIC NONDESTRUCTIVE EXAMINATION

ABSTRACT

Ultrasonic nondestructive examination (NDE) will detect three mil deep underbead cracks in welds joining thin walled iridium hemishells. A correlation was developed to relate the amplitude of the signal reflected from the crack with crack wall area. The observed cracks occur in the weld underbead in the arc taper area during encapsulation of $^{238}\text{PuO}_2$ pellets for thermoelectric generators used in deep space exploration.

INTRODUCTION

The Plutonium Fuel Form (PuFF) facility working for the Office of Space Nuclear Projects, U. S. Department of Energy, is dedicated to the production of General Purpose Heat Sources (GPHS) for use in radioisotopic thermoelectric generators for projects Galileo and the International Solar Polar Mission space probes. A critical process step in PuFF is the encapsulation of the $^{238}\text{PuO}_2$ pellets in two iridium containment cups by gas tungsten arc welding at the equator (figure 1). Due to intrinsic properties of the iridium alloy, approximately one in five equatorial welds crack in the arc taper area of the underbead. These cracks are not visible on the external surface of the weld and, if left undetected, could compromise the containment of the $^{238}\text{PuO}_2$ heat sources (fueled clads) in the unlikely event of an aborted launch or re-entry into the earth's atmosphere.

An ultrasonic nondestructive examination (NDE) method and instrument were developed by Marvin Tarpley, Savannah River Plant, to reject grossly cracked welds from the PuFF process. This study was undertaken to verify the reliability of the NDE instrument and method and to determine if the instrument could be used to estimate the size of weld defects.

SUMMARY

The NDE method and instrument were found to be a reliable means of detecting underbead cracks in the equatorial welds. A significant correlation was found between the NDE reflected signal amplitude and the surface area of the underbead crack wall. The correlation was drawn from ultrasonic inspection and destructive analysis of twenty-three fueled clads.

Not only is the method useful in detecting and sizing underbead cracks, it is being used to detect common weld defects such as lack of penetration. This NDE inspection permits the elimination of grossly cracked or otherwise inferior welds and thus greatly enhances the safe use of radioisotopic generators.

DISCUSSION

Sample and Defect Geometry

The primary defects of interest are small underbead cracks in the equatorial welds joining the two thin walled (0.025") iridium hemishells. The inner weld bead width is approximately 0.050". The diameter of the iridium hemishells is 1.74". The cracks occur after the butt joint is completely sealed and the weld current is slowly decreased. This causes the weld puddle penetration to drop from full penetration to a no-melting state over a 0.8" - 1.0" length of weld. This overlap region of the weld is characterized by a trough of molten material on top of a once welded solidified base (Figure 2). The grain boundaries of the solidified base are weakened during melting of the trough by the melting of a "eutectic-like" film, possibly high in thorium. These weakened boundaries

then separate due to the thermal and solidification stresses associated with welding (Figure 3). Due to the intergranular nature of the cracks they are found in three orientations or combinations of these orientations along the grain growth directions dictated by the weld solidification (Figure 4).

Theory

The NDE instrument uses a single KB-Aerotech gamma series transducer containing a lead zirconate piezoelectric crystal generating a 5 MHz ultrasonic shear wave. This immersion technique uses a pulse echo mode controlled by a reflectoscope gated in the proper time frame to eliminate erroneous signals from the base metal. The transducer positioning is shown in Figure 5 with the 31 degree critical angle for Lamb waves in iridium.

McMaster (1) states that the area of the reflector is proportional to the response of the transducer under two given conditions. First, the area of the reflector must be less than the cross sectional area of the sound beam. Second, the length of the reflector must be larger than two wavelengths of the ultrasound. These two conditions are satisfied in this application, therefore, transducer response should be proportional to crack wall area.

Probe Orientation and Standardization

To duplicate crack size and orientation for instrument development, slots 0.003", 0.006", and 0.012" deep were machined in the weld underbead of standard iridium capsules both parallel with and at a 60 degree angle to the weld direction. Slots parallel to the weld direction were 0.050" long and slots at the 60 degree angle were 0.025" long.

Two instruments were developed. One instrument, Model 1, had a single probe designed to detect cracks primarily parallel to the weld direction. A second instrument, Model 2, had three probes to enhance crack detection in the three known orientations. All three probes were fixed in a single cluster without the capability for individual probe movement.

Standardization of Model 1 was achieved by optimizing the reflected signal from the 0.003" slot parallel to the weld direction. The signal was optimized by physically moving the probe with respect to the capsule. Once the signal was optimized, it was electronically adjusted to represent ten divisions on the reflectoscope. Standardization of the Model 2 probes was achieved in a similar manner. The centerline probe and the upper transverse probe were optimized as a unit on one 0.003" slot parallel to the weld direction and one 0.003" slot at 60 degrees to the weld direction. Standardizing two probes at once lead to some compromise of the signal level of both probes. The lower transverse probe was standarized independently of the other two probes. Once the instrument was standardized, inspection of individual fueled clads could proceed. ✓

Sample Inspection

Twenty-three fueled clads were inspected and later destructively analyzed. Of these fueled clads, nine were inspected by both instruments, eleven were inspected by Model 1 and three were inspected by Model 2. The results of these inspections are listed in Table 1.

After ultrasonic inspection, the fueled clads were destructively analyzed. The fueled clads were sectioned in a manner that would not further damage the weld and the internal bead was inspected at 30X magnification. Next, a dye penetrant inspection was performed to highlight the cracked areas with fluorescent dye.* Crack lengths were measured and the crack locations were marked for metallographic sectioning. Several metallographic sections were taken to give crack depth along the crack length (Figure 6). With the length and depth measurements, an approximate crack wall area could be determined for each crack (Table 1).

Signal Amplitude to Detect Size Correlation

Signals from the cracks can be differentiated from signals from incomplete by penetrated butt welds (Figure 7). The ability to detect cracks and differentiate them from other weld defects yields a highly reliable inspection technique.

Using a linear regression technique, correlations were drawn between the crack area and the amplitude of the reflected signal for all probe arrangements tested. Correlation coefficients ranged from -0.18 for the lower transverse probe of Model 2 to 0.93 for the single probe of Model 1. The Model 1 correlation is plotted with statistical confidence intervals in Figure 8. It is, therefore, shown that the single probe of Model 1 is able to detect a crack in any of the three possible orientation.

At 97.5% confidence, an NDE signal of four represents a defect larger than 150 square mils. Such a crack is typically three or four mils deep and 40 to 50 mils long. The cross-sectional area of the ultrasound beam is approximately 3,500 square mils. This type defect clearly meets the criteria of McMaster (1) discussed above.

CONCLUSIONS

The single probe Model 1 instrument was found to be reliable in detecting cracks having a crack wall area as small as 150 mils (2). Not only are the cracks detected, but they can be sized to permit accepting capsules with defects that have been shown to have no detrimental impact on the safety of the radioisotopic generators.

To date, over 350 fueled clads have been inspected using this technique. This technique has greatly increased the margin of safety associated with the use of radioisotopic thermoelectric generators for deep space exploration.

REFERENCES

1. Banks, B., Oldfield, G. E., Rawding, H.; Ultrasonic Flow Detection In Metals; Pentice-Hall Inc., N.J., 1962.
 2. Krautkramer, J., Krautkramer, H.; Ultrasonic Testing of Materials; Springer-Verleg, NY, 1969.
 3. McMaster, Robert C.; Nondestructive Testing Handbook; Ronald Press Co., New York, NY, 1959.
 4. International Critical Tables Vol V., McGraw-Hill Publishing Co., New York, NY, 1929.
-
- (1) McMaster, Robert C.; Nondestructive Testing Handbook; Ronald Press Co., New York, NY, 1959, p. 45-18, 19.

TABLE 1

NDE RESPONSE AND CRACK AREA DATA

<u>SAMPLE</u>		<u>MODEL</u> <u>1</u>	<u>CENTER</u>	<u>UPPER</u>	<u>LOWER</u>	<u>CRACK</u> <u>AREA (MILS²)</u>
FC	51	5.0	NT	NT	NT	0
	52	5.5	6.0	5.3	7.3	100
	53	1.0	0.0	0.0	0.0	50
	81	8.0	NT	NT	NT	180
	87	0.0	NT	NT	NT	50
	88	7.0	NT	NT	NT	225
	92	7.5	5.5	6.0	0.0	125
	99	7.0	5.0	0.0	0.0	100
	108	8.0	5.5	8.5	0.0	250
	109	13.0	5.0	0.0	0.0	760
	111	14.0	11.0	6.0	0.0	510
	113	3.0	0.0	0.0	0.0	45
	117	3.5	0.0	0.0	0.0	0
	134	NT	11.5	11.0	0.0	2000
	137	NT	0.0	11.0	0.0	850
	138	NT	0.0	9.0	0.0	250
	160	17.4	NT	NT	NT	680
	FC 376	19.4	NT	NT	NT	820
	LS 155	2.0	NT	NT	NT	0
	157	0.0	NT	NT	NT	0
	162	4.1	NT	NT	NT	0
	163	2.8	NT	NT	NT	0
LS	164	0.2	NT	NT	NT	0

NT = Not Tested

Mag. 2X

Neg. EE 4030-F

FIGURE 1. Fueled clad produced in 235-F PuFF Facility.

Ir FIGURE 2
Is WELD CONFIGURATION DURING CRACKING

g

Separated
Grain
Boundary

100X

EE 5788-F

FIGURE 3. Crack Configuration in Ir Weld.
(Longitudinal Section)

Weld Direction

1 - Upper transverse

2 - Center line

3 - Lower transverse

Weld Direction - \

PuFF Weld 67

FIGURE 4. Crack Orientation in Ir welds.
(interior surface)

Figure ⁵~~4~~ Transducer Capsule Alignment

100X

First Grind
(no crack)

EE 5476-F

100X

Second Grind

EE 5482-F

100X

Third Grind
Etched

EF 5490-F

100X

Third Grind
(unetched)

EE 5488-F

FIGURE 6. Crack shape and size as determined by metallography.

FIGURE 7: COMPARISON OF SIGNALS FROM A WELD CRACK (LEFT)
AND LACK OF PENETRATION (RIGHT)

Figure 8. Crack Wall Area vs. NDE Response