CONF-801115--2

POST TEST EVALUATION OF A FIRE TESTED RAIL SPENT FUEL CASK*

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During January 1978, a 67 metric ton stainless steel-lead shielded spent fuel shipping container was exposed to a JP-4 jet fuel fire at Sandia National Laboratories. This test was intended to simulate a severe, but highly improbable, fire-associated accident condition. The shipping container used in this test was constructed in 1962. It was a double-walled, lead-shielded cylindrical vessel 3.96 m long and 1.5 m in diameter. The inner cask liner had been fabricated from two pieces of 9.4-mm-thick 304 stainless steel with one girth and one seam weld. The outer shell was manufactured from two pieces of 34.8-mm-thick 304 stainless steel while the top and bottom of the vessel were ACI type CF8 stainless steel castings. Initially, the cask utilized an auxiliary water cooling system consisting of 3.05-mm-thick-walled copper channels longitudinally welded to the outside of the cask inner cavity wall. These channels were subsequently replaced by 304 stainless steel channels when it was discovered that the original copper channels had been dissolved during the first lead pour. Additionally, copper fins were longitudinally welded to the inside of the outer shell to enhance the thermal path between the lead shielding and the outer shell.

Prior to the fire test, the cask/railcar system was subjected to a 131 km/h impact into a massive concrete barrier. The cask survived the impact without failure, suffering only minor cooling fin damage. Post-crash test inspection revealed that the outer shell of the cask had not been penetrated and that the cask had retained its internal cavity pressure.

After the crash test, the cask and railcar were moved to the fire site and placed over a specially constructed pool fire test facility. The railcar was supported by concrete pedestals located centrally in the pool, with wheel trucks under one end of the car to maintain its post impact orientation. The level of the fuel was 1.4 m below the lowest point of the cask. Flame temperatures during the fire test ranged from 1250 to 1475 K with the container showing no signs of degradation for at least 90 minutes. At about 100 minutes into the test, white smoke, indicative of lead combustion, became intermingled with the normal JP-4 fuel black-colored smoke. The fuel supply was then stopped and the fire self-extinguished at about 125 minutes. Because of the weakened condition of the concrete and metal supports and the railcar frame, the railcar toppled on its side at this point--severing all instrumentation connections. Internal thermocouples on the cask indicated, however, that complete lead melt had occurred prior to toppling (1).

Examination of the shipping container following the fire test showed that the cask inner shell, which was the containment boundary, was unperturbed. It did, however, reveal the presence of two macrofissures in the outer cask shell, Fig. 1. Both cracks had their major direction lying parallel to the longitudinal axis of the cask. Crack no. 1 was located within the seam weld fusion zone region while

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*This work sponsored U. S. Department of Energy under Contract DE-AC04-76-DP00789.
A U. S. Department of Energy Facility

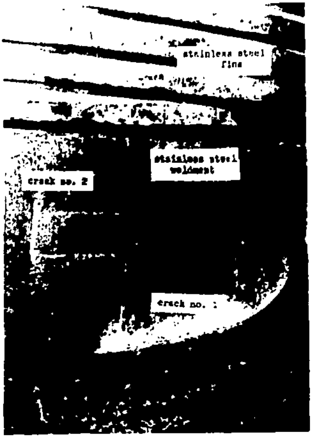


Fig. 1. Enlarged view of cask outer shell containing two macrofissures

crack no. 2 lay in the 304 stainless steel base metal. The latter crack also showed indications of lead seepage and gross plastic deformation (2).

Crack no. 1 was approximately 115 mm long and was located 12 mm from the centerline of the stainless steel seam weld. Examination of the internal surface of the outer shell indicated that the weldment had been fabricated using a backup strip. Chemical analysis of the base metal, fusion zone, and backup strip, Table 1, showed that they all met the requirements of 304 stainless steel although the higher chromium content of the weld fusion zone did suggest that 308 filler wire was used in its manufacture.

Table 1

[illegible] Spent Fuel Shipping Cask Materials

Element (Weight Percent)

[illegible]	[illegible]	[illegible]	[illegible]	Mn	[illegible]	[illegible]	[illegible]	Mo	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1.51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1.02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Observation of the fracture surface showed that crack no. 1 had initiated on the external surface of the outer cask shell and had not completely penetrated the outer shell wall, Fig. 2. Further examination also showed that the original seam weld had not resulted in full weld penetration. Typically, approximately 20 percent of the outer shell thickness had not been joined by the seam welding procedure utilized for the original cask fabrication. Metallographic sections taken normal to this crack illustrated the multipass character of the weldment. Higher magnification examination revealed the presence of numerous internal microcracks, Fig. 3. These cracks tended to lie along the austenite-δ ferrite interface, changing direction when traversing from one weld puddle to the next. Comparison with previous studies of weld cracking in austenitic stainless steels (3) suggests that these internal microcracks, and by implication crack no. 1, are hot cracks.

Fig. 2. Macroview of crack no. 1

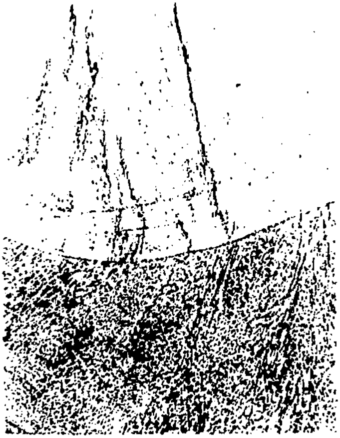


Fig. 3. Optional micrograph illustrating internal cracking in stainless steel of weld fusion zone. Magnification : 25x

Hot cracking of austenitic stainless steel weldments is generally associated with the presence of a low melting point liquid film at the austenite-δ ferrite interface. This liquid film reduces the local cohesive strength of the stainless steel weldment. Concurrent stress application then results in crack formation.

Scanning electron microscope observations support the aforementioned hypothesis that crack no. 1 was a hot crack formed in the weld fusion zone during the fire test. Elemental analysis of droplets lying on the fracture surface indicated that they contain substantial amounts of sulfur, probably in the form of complex alloy sulfides, Fig. 4. Comparing typical values for alloy sulfide melting points (1250-1475 K) (3) with measured cask temperatures suggests that these sulfides were molten under the present fire test conditions. The further requirement, an applied stress, was apparently supplied by internal pressurization of the fire-exposed spent fuel shipping cask. Indeed internal pressurization within the lead gamma shield cavity was accentuated in the present instance by a manufacturing oversight whereby passage holes from the shield cavity to appropriate expansion volumes originally provided for in the cask design were omitted during cask fabrication.

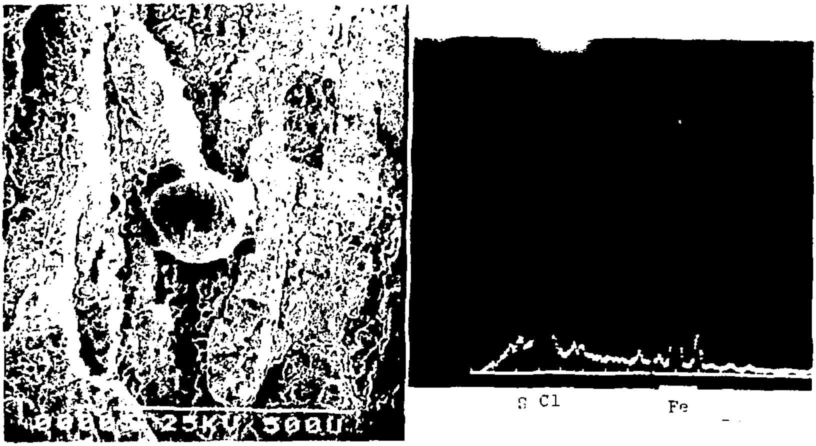


Fig. 4. (a) Scanning electron micrograph of crack no. 1 fracture surface and
(b) elemental analysis photo of droplet shown in (a)

Crack no. 2, which had penetrated the cask outer shell, was approximately 70 mm long and was located in the stainless steel base metal. Visual observations of the inside surface of the outer shell immediately behind crack no. 2 confirmed that copper fins had been welded to the outer shell. Further study indicated that many of these copper/stainless steel weldments were cracked, Fig. 5. Detailed examination of these cracks showed that they were predominantly intergranular, Fig. 6, following the austenitic stainless steel grain boundaries. Microprobe examination also showed that the cracks contained significant quantities of copper and lead and lesser amounts of aluminum and silicon, Fig. 7.

Generally, successful welding of copper to stainless steel requires that <u>low</u> heat inputs be combined with the use of a nickel filler wire (4). Microprobe examination indicated that, in the present instance, a copper base filler wire had been used to join the copper cooling fins to the cask outer shell. Further

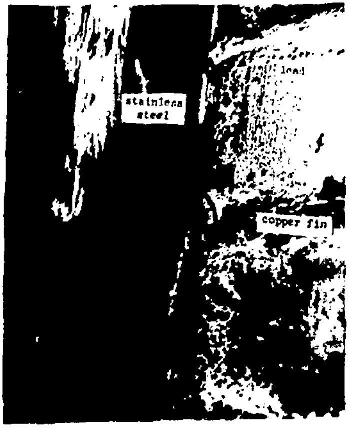


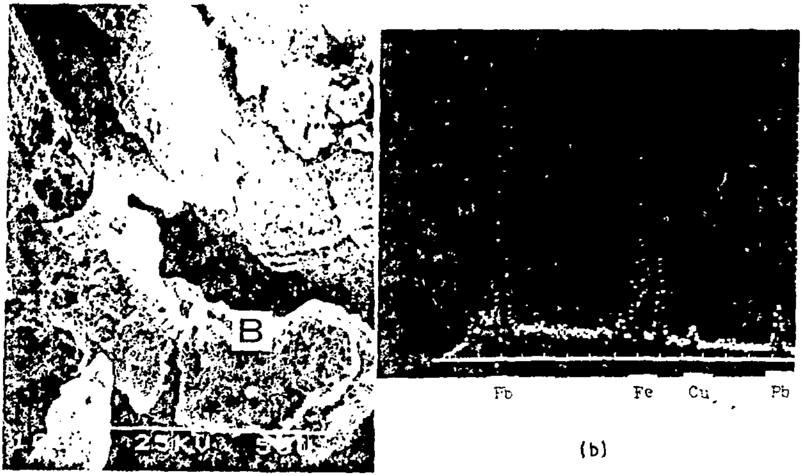
Fig. 5. Typical crack observed originating from copper-stainless steel weldment

Fig. 6. Optional micrograph illustrating intergranular character of crack in stainless steel. Magnification : 100x

analysis of droplets observed in the copper-stainless steel fusion zone indicated that they contained appreciable quantities of iron and chromium. The form of these droplets and their chemistry suggest that they were formed by a high heat input welding process which caused localized melting of the 304 stainless steel during welding.

Consideration of the above suggests that crack no. 2 originated from microcracks formed during improper welding of the copper cooling fins to the stainless steel outer shell. This assumption was supported by elemental analysis of the crack no. 2 fracture surface, Fig. 8, where copper could be detected to a depth of

Fig. 7. Identical area elemental distribution **photomicrograph of crack emanating** from 304 stainless steel/copper joint. Magnification : 100x.



(a)

(b)

Fig. 8. (a) Scanning electron micrograph of crack no. 2 fracture surface and (b) elemental analysis of region B near mid-section of crack no. 2

approximately 17 mm, i.e., 50 pct. of the outer shell wall thickness. It appears then that final crack propagation through the outer shell wall occurred during the fire-test, the driving force for this crack propagation being supplied by the internal pressurization within the lead gamma shield alluded to previously.

Summarizing, a postmortem examination of a large rail-transported spent fuel shipping cask which had been exposed to a JP-4 fuel fire revealed the presence of two macrofissures in the outer cask shell. One, a part-through crack located within the seam weld fusion zone of the outer cask shell, is typical of hot cracks found in stainless steel weldments. The other, a through-crack, was apparently initiated during the formation of a copper-stainless steel dissimilar metal joint, with crack propagation through the cask outer shell having occurred during the fire-test.

REFERENCES

1. H. R. Yoshimura, "Full Scale Simulations of Accidents on Spent-Nuclear-Fuel Shipping Systems," Proceedings of the Fifth International Symposium: Packaging and Transportation of Radioactive Materials, Las Vegas, NV, May 7-12, 1978, pp. 463-476.
2. H. J. Rack and H. R. Yoshimura, "Postmortem Metallurgical Examination of A Fire-Exposed Spent Fuel Shipping Cask," SAND79-1424, Sandia National Laboratories, Albuquerque, NM, April 1980.
3. T. G. Gooch, "Welding Metallurgy of Stainless Steel," Stainless Steel, Iron and Steel Institute Publication No. 117, Iron and Steel Institute, London, 1969, pp. 77-84.
4. H. B. Bott, "How to Weld Copper to Stainless Steel and Mild Steel," Welding Journal, 38, 236 (1959).