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SUBJECT: Corrosion in the Oak Ridge Research Reactor Core-Cooling System

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FROM: P. D. Neumann

SUMMARY

Corrosion specimens of the five major aluminum alloys used in the construction of the Oak Ridge Research Reactor have been exposed to the high-purity primary cooling water in the ORR core and in the external portion of the primary cooling loop to determine their corrosion rates under actual operating conditions. These alloys, 1100, 3003, 5052, 5154, and 6061, exhibited average corrosion rates of less than 2.6 mpy during the first 500-hr test period and less than 0.5 mpy for a 4032-hr test. Only very superficial pitting was observed, and no case of intergranular corrosion was found.

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Corrosion in the Oak Ridge Research Reactor Core-Cooling System

INTRODUCTION

The Oak Ridge Research Reactor is an MTR-type reactor constructed almost entirely of aluminum alloys. The aluminum-clad fuel elements and aluminum core assembly are enclosed in an aluminum tank through which high-purity water is circulated. This water is then pumped through aluminum-alloy finned-tube radiators which exhaust the reactor heat to the atmosphere. The core tank is submerged in a large pool of high-purity water which serves as shielding and in which some heat is generated. This heat is removed by circulating the water through a conventional heat exchanger-cooling tower system.¹

An extensive corrosion testing program is being conducted in the ORR to measure the corrosion rates of the various alloys used in the construction of the ORR under service conditions. A knowledge of the corrosion rates of the various alloys should allow estimates to be made of the probable service life of the various components. It is the purpose of this report to present the data that have been obtained to date in the core system which includes the core and the external piping. Other reports to be written will present the data obtained in the pool and pool-cooling system.

Only four aluminum alloys were used in fabricating the major components. The core tank is constructed of 5052-F and 5154-F alloys, and the top cover is constructed of 6061-T6. Large-diameter pipelines (up to 36 in. OD) are of 5154-F, while small-diameter piping is of 6061-T6. The fuel elements are clad with 1100-H14 alloy. Other alloys present in small amounts are 3003-H14 and 6063-T6. Table 1 presents the compositions of the alloys, and Table 2 gives the temper designations. The alloys that have been tested include types 1100, 3003, 5052, 5154, and 6061 aluminum.

EXPERIMENTAL

Core Specimens. The core coupons and holder are shown in Fig. 1. They were designed to fit into the isotope irradiation assembly shown in Fig. 2 in place of the isotope cans. The assembly occupies a core position during operation of the reactor.

The two-piece coupon holders were 13/32 in. in diameter and 2 3/8 in. long and were machined from 6061-T6 aluminum plate. They were assembled with aluminum rivets. The specimens were machined from 0.064-in.-thick sheet of the various alloys. The guide rods shown on the bottom of the specimen holder were made from 5052-O aluminum wire and were bent to form a cone to hold the specimen holder off the bottom of the isotope bucket to facilitate the flow

¹P. D. Neumann, Secondary-Side Water Treatment for Corrosion Control in Aluminum Heat Exchangers: Practices and Results at the Oak Ridge Research Reactor, ORNL CF-59-8-50 (Aug. 12, 1959).

Table 1. Composition of Aluminum Alloys²

Former designation:	2S	3S	52S	54S	61S
Aluminum association designation:	1100	3003	5052	5154	6061
Al (min.)	99.00	Remainder	Remainder	Remainder	Remainder
Si	1.0*	0.6	0.45*	0.45*	0.40-0.80
Fe		0.7			0.7
Cu	0.20	0.20	0.10	0.10	0.15-0.40
Mn	0.05	1.0-1.5	0.10	0.10	0.15
Mg			2.2-2.8	3.1-3.9	0.8-1.2
Cr			0.15-0.35	0.15-0.35	0.15-0.35
Zn	0.10	0.10	0.10	0.20	0.25
Ti				0.20	0.15
Other	0.15	0.15	0.15	0.15	0.15

* Iron plus silicon.

Table 2. Temper Designations of Corrosion Coupons²

Designation		Treatment
Former	Aluminum Association	
2S 1/2H	1100-H14	Strain-hardened halfway between full anneal and full hardness.
3S 1/2H	3003-H14	
52S	5052-F	As fabricated.
54S	5154-F	
52S-0	5052-0	Annealed at 650°F to produce a fully softened condition.
61S-T	6061-T6	Solution annealed at 970°F and quenched. Aged 6 to 10 hr at 350°F.

²ALCOA Aluminum Handbook, pp 8-11, Aluminum Company of America, Pittsburgh, Pa., 1956.

Plate 3096-1

a. ORR Corrosion Test Coupons in Coupon Holder

Plate 4355

b. Completely Assembled Corrosion Test Assembly

Fig. 1. Corrosion Specimens and Holder
Exposed in ORR Core Assembly

Photo 41741

Fig. 2. ORR Isotope Irradiation Assembly
(Corrosion specimen holders are placed in the cylindrical
buckets in place of some of the isotope cans.)

of cooling water through the holder. The cooling water flows over the holders at an estimated velocity of 8 to 12 fps.

Pipeline Specimens. Specimens for corrosion testing outside the core tank were cut from 0.0625-in. sheet and machined to 1.00 in. x 2.50 in. A stainless steel mounting bar was designed and fabricated to hold two coupons on each of the ten stainless steel studs. Teflon insulators were used to separate the aluminum coupons from the stainless steel. Teflon could be used since these holders were used only in low-intensity radiation. In this case the location was downstream from the decay tanks in the core outlet piping. Figure 3 shows one section of such a mounting bar with two corrosion coupons in place. Provisions were made so that several mounting bars could be connected in series to provide additional test coupons at each location. Two such mounting bars with 30 samples were installed in the body of the strainer in the 24-in. cooling-water exit pipe in the core-cooling loop.

Preparation of Specimens. After being machined, the specimens were marked with stamping dies and then pickled in a solution containing 58 ml of concentrated sulfuric acid and 30 g of chromium trioxide per liter of solution. The specimens were continuously agitated for 20 min in this solution at 70°C. They were then washed thoroughly in demineralized water, dried at 120°C, cooled, and weighed. After assembly in the holders, all parts were degreased in alcohol and acetone.

Exposure Conditions. The ORR operates on a 4-week cycle in which three weeks of operations are followed by approximately one week of down time. The first full-length operating cycle started July 20, 1958. Sixteen complete corrosion coupon holders, each containing four specimens, were exposed in this cycle. Eight holders were removed at the end of the first cycle and replaced with eight new ones. (The other eight holders have been in test since July 20, 1958.) During the 500 hr of reactor operation in this cycle, the reactor accumulated 7582.4 Mw-hr of operation. The group of eight holders inserted in cycle 2 were removed and replaced with new ones after cycle 6, corresponding to a total time of 4032 hr in the reactor of which 2318 hr were at power. Total power accumulation for this period was 45,563 Mw-hr. At power, the core inlet and outlet temperatures were 124°F (51°C) and 132°F (56°C), respectively. Maximum design outlet temperature is 135°F (58°C).

The circulating water in the core-cooling loop is purified continuously by ion exchange. A bypass stream from the main loop is passed through a purification system consisting of a cation exchanger followed by an anion exchanger and a mixed-bed demineralizer. The effluent from this system runs at a pH near 7 and 1 to 1.5×10^6 ohm-cm resistivity.

Examination and Evaluation. The coupon holders as removed from the reactor core were sufficiently radioactive that they could not be examined directly. After three months' dry storage in a lead carrier, this activity had decayed to a level where the assemblies could be examined without

Photo 49141

Fig. 3. A Single Section of an Out-of-Pile Corrosion Coupon
Bracket Showing One Coupon in Place on Each Side

shielding. The pipeline coupons were only slightly radioactive as removed from the strainer body. The maximum reading of any one coupon was 5 mr/hr on contact after a distilled-water rinse.

All coupons were removed from their holders and degreased, weighed, and examined under the microscope. They were then given a defilming treatment of 45 min in a solution containing 35 ml of concentrated phosphoric acid and 20 g of chromium trioxide per liter of solution at 80°C, washed in demineralized water, and dried. Finally the specimens were reweighed and examined again under the microscope. Selected specimens showing defects were examined metallographically.

RESULTS AND CONCLUSIONS

Core Assemblies. Corrosion data for the 32 coupons exposed in the ORR core for 500 hr in cycle 1 (beginning July 20, 1958) are shown in Table 3. Note that the observed rates vary from an undetectable rate to 2.6 mpy for one of the 6061-T6 coupons. Although the data show considerable scatter, there is an indication that the corrosion rates increased with increasing amounts of alloy constituents.

The corrosion rates observed for 32 coupons which were exposed in cycles 2 through 6 for 4032 hr are shown in Table 4. The average corrosion rates for this period are lower than rates observed during the first 500-hr period.

Figures 4 through 6 are photographs of some typical test specimens taken before and after testing. Some light staining of the surface and slight crevice corrosion where the coupons contacted the holders can be seen in the photographs. This crevice corrosion was visible only as a darker stain on the coupon surface and pitting of the same magnitude as seen on the remaining surface. What appeared to be several deep pits were seen under a microscope at 15X. Subsequent metallographic examination of these specimens revealed that many of the apparently serious defects observed were, in reality, lightly attacked surfaces of mechanical defects which could be easily identified by the deformation in the surrounding microstructures. Such a defect is shown in Fig. 7. No evidence of intergranular corrosion was found in any of the coupons examined.

Figures 8 through 10 are photomicrographs of some typical surfaces as found by metallographic examination. No evidences of serious localized corrosion were found; neither were the average corrosion rates indicative of excessive generalized attack. The specimens exposed for 4700 hr were very similar in the appearance of their surfaces.

Pipeline Samples. The first coupons were started in test May 20, 1959. Two coupons of each alloy were removed from the strainer position after 720 hr of exposure. Two more were removed after 4700 hr. Corrosion data

Table 3. Corrosion of Aluminum Alloys in the ORR Core

Exposure time: 500 hr
Accumulated power: 7582.4 Mw-hr

Alloy	Specimen Number	Weight Loss (mg/cm ²)	Corrosion Rate (mpy)	Remarks
1100	14A1	0	0	Mostly light corrosion with a few shallow pits and a few grooves
	14A2	0.1	0.2	
	20A1	0.6	1.6	
	22A1	0.1	0.2	
	22A2	0	0	
	28A1	0.5	1.3	
3003	14B3	0.6	1.6	Light, general corrosion with very little evidence of localized attack
	14B4	0.7	1.8	
	20B2	0.6	1.6	
	22B3	0.1	0.2	
	22B4	0.6	1.6	
	28B2	0.6	1.6	
5052	15C1	0.7	1.7	Moderate, general corrosion with considerable number of pits and grooves
	15C2	0.9	2.4	
	18C1	0.8	2.0	
	18C2	0.9	2.3	
	20C3	0.8	2.1	
	23C1	0.7	1.8	
	23C2	0.5	1.2	
	26C1	0.7	1.7	
	26C2	0.1	0.2	
	28C3	0.6	1.8	
5154	15D3	0.9	2.4	Moderate, general corrosion with considerable number of pits and grooves
	15D4	0.9	2.3	
	20D4	0.7	1.8	
	23D3	0.6	1.6	
	23D4	0.3	0.7	
	28D4	0.7	1.8	
6061	18E3	0.9	2.4	Moderate, general corrosion; some grooving and dense, shallow pitting
	18E4	1.0	2.6	
	26E3	ND	ND	
	26E4	ND	ND	

ND = No data

Table 4. Corrosion of Aluminum Alloys in the ORR Core
(second group)

Exposure time: 4032 hr
Time at power: 2312 hr
Accumulated power: 45,563 Mw-hr

Alloy	Specimen Number	Weight Loss (mg/cm ²)	Corrosion Rate (mpy)	Remarks
1100	30A1	0.3	0.1	Mostly light corrosion with some light to moderate etching.
	30A2	0.4	0.1	
	46A1	0.4	0.1	
	46A2	0.1	<0.1	
	50A1	0.1	<0.1	
	51A1	WG	WG	
3003	30B3	0.4	0.1	Very light corrosion. Some light crevice attack in the clamped area.
	30B4	0.3	0.1	
	46B3	0.0	0.0	
	46B4	0.0	0.0	
	50B2	0.0	0.0	
	51B2	WG	WG	
5052	31C1	0.2	<0.1	Mostly light, general corrosion. Scattered, shallow pits and moderate etching, shallow craters.
	31C2	0.2	<0.1	
	47C1	0.3	0.1	
	47C2	0.2	<0.1	
	48C1	0.2	<0.1	
	48C2	0.4	0.1	
	49C1	0.1	<0.1	
	49C2	0.2	<0.1	
	50C3	WG	WG	
5154	51C3	0.7	0.2	Light corrosion with some etching and crevice attack in the clamped area.
	31D3	WG	WG	
	31D4	0.3	0.1	
	47D3	0.5	0.2	
	47D4	0.4	0.1	
	50D4	1.0	0.3	
6061	51D4	0.2	<0.1	Light corrosion. Staining and light crevice attack on edges.
	48E3	1.2	0.4	
	48E4	0.3	0.1	
	49E3	0.1	<0.1	
	49E4	0.0	0.0	

WG = Weight gain

Plate 3096-1

1100

3003

a. Aluminum alloys 1100 and 3003 as machined.

Plate 4147-2

1100

3003

b. Coupons shown in (a) after 500 hr in test.

Fig. 4. Test No. AD-14

Plate 3097-2

5052

5154

a. Aluminum alloys 5052 and 5154 as machined.

Plate 4148-2

5052

5154

b. Coupons shown in (a) after 500 hr in test.

Fig. 5. Test No. AD-15

Plate 4000-2

5052

6061

a. Aluminum alloys 5052 and 6061 as machined.

Plate 4149-2

5052

6061

b. Coupons shown in (a) after 500 hr in test.

Fig. 6. Test No. AD-18

T-17025

Fig. 7. Photomicrograph of Mechanical Defect in 1100 Alloy Showing Moderate to Light General Corrosion on the Surfaces (Note the deformed microstructure all around the "pit.")

T-17019

Fig. 8. Photomicrograph of Shallow Pits Found in 1100 Alloy in an Undeformed Area

T-17023

Fig. 9. Photomicrograph of 6061 Alloy Showing Shallow Pitting

T-17022

Fig. 10. Photomicrograph of Shallow Pits Found in 5052 Alloy

for these coupons are shown in Table 5. The behavior of these coupons was very similar to that found in the core and elsewhere¹ in the reactor cooling system; i.e., the corrosion rates were low and decreased with increasing exposure time. Slight staining of the surface was observed which was only partially removed by defilming. No evidence of pitting or severe localized corrosion was seen. Very light crevice corrosion was observed in a few coupons where water leaked in between the coupon and the Teflon insulation.

Table 5. Corrosion Rates of Aluminum Alloys in
ORR Core-Cooling Water
(samples located at strainer in 24-in. exit line)

Alloy	Corrosion Rate			
	720 hr		4700 hr	
	(mg/cm ²)	(mpy)	(mg/cm ²)	(mpy)
1100	0.5	0.8	0.7	0.2
3003	0.5	0.8	0.7	0.2
5052	0.4	0.6	0.9	0.3
5154	0.4	0.6	0.8	0.2
6061	0.4	0.6	0.9	0.2

Figures 11 through 13 are representative photographs showing typical coupons exposed in the strainer. The variations in shades of grey visible in the photographs resulted from differences in surface texture and reflectance. The dark areas are not stains but areas of low reflectance caused by surface roughening.

CONCLUSIONS

Although the corrosion data obtained to date are too few to allow an estimation of the service lives of the various components of the ORR core system, it appears that corrosion is not severe and that long service can be expected from the components so long as water quality is maintained at the present level or higher.

¹P. D. Neumann, Secondary-Side Water Treatment for Corrosion Control in Aluminum Heat Exchangers: Practices and Results at the Oak Ridge Research Reactor, ORNL-CF-59-8-50 (Aug. 12, 1959).

4256-1

Fig. 11. Five Aluminum Alloys As Removed from Strainer in the
ORR Core-Cooling System After 720 hr in Test
(Magnification 1X)

4294

Fig. 12. Same Five Coupons Shown in Fig. 11 After Defilming
(Magnification 1X)

4232

Fig. 13. Five Aluminum Alloys After 4700 hr in Strainer in
ORR Core Cooling System, Defilmed
(Magnification 1X)

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