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MECHANICAL BEHAVIOR OF
TYPE 304 STAINLESS STEEL IN
COPPER-CONTAMINATED SODIUM
IN THE RANGE 950 TO 1300°F

AEC Research and Development Report

ATOMICS INTERNATIONAL

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Printed in the United States of America
Available from

Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151

Price: Printed Copy \$3.00; Microfiche \$0.65

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By

D. F. ATKINS

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CONTRACT: AT(04-3)-701
ISSUED: APRIL 1, 1969

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ACKNOWLEDGMENT

The author is indebted to Messrs. M. G. Metcalf and L. V. Custer for the laboratory testing work. Appreciation is also expressed to Mr. W. T. Lee for analysis of data and helpful discussions during the course of this work. The Naval Research Laboratory supplied the impact specimens and provided valuable assistance on impact tests and structural studies.

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ABSTRACT

Biaxial stress-rupture tests on Type 304 stainless steel tubing were performed in static sodium retorts at 950, 1100, and 1300°F. Pure copper tabs were immersed in the sodium to provide a copper-saturated condition throughout the test duration. Results were compared with identical tests in copper-free sodium. Charpy impact specimens, exposed to the sodium-copper environment during the stress rupture tests, were subsequently tested at -75°C (-103°F).

It was found that the presence of copper in sodium did not influence the stress rupture behavior and impact strength of 304 stainless steel at temperatures up to 1300°F. Although testing at 1300°F did not exceed 1200 hours, microstructural examinations indicated that much longer exposures could be tolerated. No serious penetration of copper into the stainless steel was observed. Copper dissolved in sodium was found to deposit on the stainless steel in the isothermal region of the 950°F static sodium test, but at 1100 and 1300°F, copper deposits occurred only in regions where the sodium bath was slightly cooler. No copper was found in the sodium vapor regions of the retorts.

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I. BACKGROUND

Following the contamination of EBR-II primary sodium with copper,⁽¹⁾ Atomics International was asked to perform a series of specific tests to assess the effects of the copper on the mechanical behavior of 304 stainless steel thin wall tubing. Many of the EBR-II components are made of this or the closely related 304L alloy. Retorts of the type used in the program of biaxial stress-rupture testing in pure sodium were assembled to test both copper plated and non-plated tube specimens in copper-saturated sodium. In addition to twelve stress-rupture specimens, the retorts contained four copper plated 304 stainless steel Charpy impact specimens and two pure copper corrosion tabs.

The initial testing was performed in 950°F sodium, and the preliminary results were reported at a review meeting at Argonne National Laboratory in June 1967. Following this meeting, a second retort test was authorized for similar tests in 1100°F sodium. The results of these two tests were reported⁽²⁾ in a letter in December 1967. In February 1968, a third retort was requested to obtain information to support the EBR-II reactor operation criteria. This retort, identical to the previous 1100°F test, was operated at a sodium temperature of 1300°F. The details, experimental results, and evaluation of the stress rupture tests, impact tests and copper corrosion observations at the three test temperatures follow.

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Figure 1. 12-Pin Biaxial Cladding Test Retort

II. EXPERIMENTAL PROCEDURES

The stress-rupture specimens used in this study were made from 304 stainless steel tubing (0.010-in. wall by 0.295-in. OD) used in the current LMFBR Cladding Program. The tubing was from a well-characterized⁽³⁾ heat and contained 10 to 15% cold work. The chemistry on this heat is given in Table I. The specimen design is identical to that used in the LMFBR Program.⁽⁴⁾ On some of the specimens, a copper plating was applied to the OD surfaces. Two plating thicknesses were chosen: 0.0002 ± 0.0001 in. and 0.0006 ± 0.0001 in.

TABLE I
CHEMICAL ANALYSIS OF TYPE 304 STAINLESS STEEL STRESS
RUPTURE SPECIMENS - HEAT NO. 20013

Element	C	Ni	Cr	Mn	Si	Mo	Cu	P	S	Co	B	W
wt %	0.06	9.30	18.66	1.50	0.30	0.22	0.20	<0.03	<0.03	<0.10	5 ppm	750 ppm

Tests were conducted in static sodium retorts containing approximately 450 cc of sodium. These retorts, designed and used in the LMFBR Cladding Program,^(4,5) test twelve specimens simultaneously. The details of the retort are depicted in Figure 1. Each tubular specimen, about 4 in. long, is internally pressurized with high purity helium gas so as to provide the desired hoop stress on the thin-walled tubing. Three special sampling tubes extend into the sodium bath to permit extraction of sodium samples without interrupting the test. A small tube, connected to each specimen, extends up through the welded retort bulkhead to permit pressurization of the specimen. Figure 2 shows the cluster of twelve specimens assembled for testing. Four of these specimens have a thin (0.0006 in.) electroplate of pure copper on the OD surfaces. During testing, two non-plated and one copper-plated specimen were stressed at the same level.

In addition to the stress-rupture specimens, the sodium retorts contained four Charpy impact specimens and two pure copper corrosion tabs (Figure 3). The Charpy specimens, of the standard Vee-notch design, were prepared from annealed 304 stainless steel plate by the Naval Research Laboratory. Figure 4 shows the specimen positions with respect to the plate. The copper corrosion

Figure 2. Biaxial Stress Rupture.
Specimens — Before Test

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Figure 3. Charpy Impact Specimens
and Pure Copper Corrosion
Tabs Before Test

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304 SS Solution Annealed at 1900°F

Figure 4. Cutting Diagram - Charpy Impact Specimens

Figure 5. Final Assembly of Twelve-Pin Biaxial Cladding Test Retort

tabs served a dual purpose. Primarily, they were included to provide a continuous source of copper to the sodium bath. Also, by accurately weighing the tabs before and after sodium exposure, some insight was gained into the effect of sodium temperature on copper solubility and transport.

The retorts were loaded directly from a high purity sodium loop which is operated to provide characterized "system quality" sodium.⁽⁶⁾ The oxygen content of the sodium was less than 10 ppm and the carbon content was controlled to about 15 ppm. Figure 5 shows a test retort after sodium loading. The gauges indicate individual specimen pressures. The gauges are not used for actual specimen pressure measurement but only to indicate a specimen failure. Rupture of a specimen is denoted by a drop in the gauge reading with a concurrent rise in pressure of the cover gas above the sodium bath.

Strain measurements were obtained by taking accurate profilometer measurements on the OD of the specimens both before and after test. The change in diameter represented the total strain absorbed by the specimens at failure.

After sodium loading, the retorts were equilibrated at the desired test temperature and then the specimens were internally pressurized to produce the intended hoop stresses. The temperature was controlled to $\pm 2^{\circ}\text{F}$ over the entire specimen length during testing.

TABLE II
EFFECT OF Cu-PLATING ON STRESS-RUPTURE PROPERTIES OF
REF. 304 SS (10 to 15% COLD-WORKED) IN
950°F Cu-SATURATED Na

Sample No.	Copper Plating Thickness (in.)	Stress (psi)		Rupture Time (hr)	Diametral Strain (%)	Strain Rate (%/hr)
		Original*	Final			
C4-1	0.0006	55,000	55,000	Discontinued	0.50	-
-2	0.0002	55,000	55,000	Discontinued	0.50	-
-3	0.0006	55,000	55,000	Discontinued	0.60	-
-4	0.0002	47,000	61,200	1905	0.64	3.36×10^{-4}
-5	0.0002	47,000	61,200	1265	0.64	5.06×10^{-4}
4-49	0	42,000	61,200	1040	0.87	8.40×10^{-4}
C4-6	0.0006	42,000	65,000	1665	1.54	9.25×10^{-4}
-7	0.0006	42,000	65,000	1510	Explosive rupture	-
4-50	0	47,000	65,000	32	0.87	2.72×10^{-2}
C4-9	0.0002	40,000	70,000	714	1.18	1.65×10^{-3}
-10	0.0002	40,000	70,000	375	0.91	2.43×10^{-3}
-8	0.0006	40,000	0	Control spec.	0	-

*Tested for about 500 hr at these values before increasing stress levels.

TABLE III
SODIUM SAMPLING DURING RETORT TESTS

Test (°F)	Sample No.	Elapsed Time at Temperature (hr)	Chemical Analysis (ppm)	
			O ₂	Cu
950	5-1	72	2.2	25
	5-2	1344	15.0	*
	5-3	3672	*	40
1100	12-1	72	11.6	75
	12-2	264	10.4	40
	12-3	672	*	28
1300	24-1	246	*	*
	24-2	1200	13	208

*Samples lost during chemical analysis.

III. RESULTS

A. STRESS RUPTURE TESTS

1. 950°F Test

This test contained ten copper-plated specimens and two unplated control specimens. After temperature equilibration at 950°F, the stress-rupture specimens were pressurized with helium to provide four different stress levels (40,000, 42,000, 47,000, and 55,000 psi hoop). Selection of appropriate stress levels to obtain ruptures over 100 to 1000 hours was difficult since there were no previous stress-rupture curves on this material (10 to 15% cold work). Literature data for annealed material were used, but the stress levels chosen were too modest. After 500 hours of test with no ruptures, the stress levels were increased. The higher stress levels and results of the test are given in Table II. Three of the specimens, stressed at 55,000 psi hoop stress, accumulated over 3500 hours without rupture. Since it was estimated that the specimens would not rupture for another 2000 hours, the test was stopped so that the ruptured specimens, impact samples and copper corrosion tabs could be examined. The stress-rupture results are plotted in Figure 6.

Sodium samples were taken during testing, and the results of the analyses are listed in Table III. The oxygen level in the 950°F test averaged 9 ± 2 ppm. This is typical of the oxygen levels encountered in high purity sodium on the LMFBFR cladding tests. Copper analysis, obtained on two of these samples by spectrographic techniques, gave 25 and 40 ppm after 72 and 3674 hours, respectively. The solubility limit for copper in sodium at 950°F has been reported as 40 ppm.⁽⁷⁾

Upon opening the retort, it was found that a thin layer of copper had deposited on all stainless steel surfaces which were in direct contact with the copper-saturated sodium. This condition is shown in Figure 7. The two non-plated control samples are at the front and possess a thin copper layer. No copper deposition was observed in regions of the retort exposed to sodium vapor. The change in sodium level due to sampling is reflected by the amount of copper deposited on the stainless steel pressure tubes.

Figure 6. Biaxial Stress Rupture of 304 SS Tubing
(10 to 15% Cold-Work) in Copper-
Contaminated Sodium

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Figure 7. Stress Rupture Specimens After Test in 950°F Sodium
(Note light copper plate on the two non-plated control specimens
in foreground.)

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Strain values, obtained from accurate profilometer measurements of the tubular specimen diameter before and after test, are given in Table II.

2. 1100°F Test

This test contained four copper-plated (0.0006-in.) specimens and eight non-plated specimens. Helium was used to apply four stress levels such that ruptures would occur over the range of 100 to 1000 hours. In this case, an 1100°F stress-rupture curve was available for the same tubing material in high purity sodium. This curve was used to select the stress levels for the copper test.

The test results are listed in Table IV and plotted in Figure 6. The data show that, at 1100°F, the presence of copper in the sodium does not influence the 1000-hour stress rupture life of the 304 stainless steel cladding. The copper-plated specimen data appear to produce a slightly steeper slope of the stress-rupture curve, but the points could fall within a normal scatter band. Based on the low scatter observed in other tests of the material in pure sodium, it seems that this behavior of the copper-plated specimens is real. One or two data points at longer rupture times would remove the uncertainty, but further tests were not scheduled. The 950°F test shows a similar behavior, but in this case only two non-plated specimens were in the retort.

Three sodium samples were taken during the test and the results are listed in Table III. The average oxygen content was 11 ± 2 ppm, which is typical of that observed on high purity sodium tests. Spectrographic analysis for copper in sodium indicated 75 and 40 ppm for the first two samples. The third sample, analyzed by wet chemistry techniques, was 28 ppm. All three values are below the reported solubility limit of 120 ppm⁽⁷⁾ at 1100°F. The differences in copper values cannot be explained, since there was an adequate supply of copper from the pure copper corrosion tabs. The apparent decrease in copper content with time suggests that the copper tabs ceased to supply copper to the sodium and the copper content in the sodium decreased with time as the copper plated out on the stainless steel components.

As the sodium was drained from the retort, it was observed to possess a brilliant copper color. When the retort was opened, all specimens were initially coated with a thin layer of copper — which rapidly oxidized after several

TABLE IV
EFFECT OF Cu-PLATING ON STRESS-RUPTURE PROPERTIES OF
REFERENCE 304 SS (10 TO 15% COLD-WORKED)
IN 1100°F Cu-SATURATED Na

Sample Number	Cu-Thickness (in.)	Stress (psi)	Rupture Time (hr)	Diametral Strain (%)	Strain Rate (%/hr)
4-124	0.0006	42,000	584	1.08	1.85×10^{-3}
C4-12	0	42,000	656	Explosive Rupture	-
4-113	0	42,000	632	Explosive Rupture	-
4-125	0.0006	46,000	347	1.31	3.77×10^{-3}
4-114	0	46,000	380	Collapsed	-
4-115	0	46,000	424	Explosive Rupture	-
4-126	0.0006	50,000	249	1.85	7.43×10^{-3}
4-116	0	50,000	138	0.84	6.09×10^{-3}
4-117	0	50,000	153	1.21	7.91×10^{-3}
4-127	0.0006	55,000	168	Explosive Rupture	-
4-118	0	55,000	68	Collapsed	-
4-119	0	55,000	80	Explosive Rupture	-

seconds exposure to air. Stable copper deposits were found on the stainless steel retort and pressure tubing in the upper regions of the retort (where the temperature was somewhat cooler). This is in contrast to the 950°F test where copper plating was observed on all stainless steel surfaces which were in direct contact with the sodium bath. No deposition occurred above the sodium-cover gas interface. Figure 8 shows the condition of the specimens after test. Visual examination of the specimens revealed that six specimens failed by explosive type ruptures. Two specimens containing small crack-type ruptures has collapsed — presumably due to the shock wave produced by the explosive-type ruptures. The explosive rupture and occasional collapse of tubing has been observed on other tests in high purity sodium at temperatures of 1100°F and lower.

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Figure 8. 1100°F Stress Rupture Specimens After Test

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Figure 9. 1300°F Stress Rupture Specimens After Test

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Diametral strain measurements were taken on those specimens which did not rupture explosively or collapse. The average maximum strain at rupture is reported in Table IV.

3. 1300°F Test

Stress-rupture tests on four copper-plated 304 stainless steel specimens and eight non-plated specimens were conducted in 1300°F sodium (copper saturated). Two of the copper plated specimens had a 0.0006-in. layer of copper plate, while the other two specimens had a 0.0002-in. copper layer. Four stress levels were applied to the specimens (3 specimens at each stress level) to produce ruptures over the range of 100 to 1000 hours. The stress-rupture results are listed in Table V and plotted in Figure 6. Again, it was found that the presence of copper-saturated sodium and the copper plating did not alter the stress-rupture characteristics of the 304 stainless steel at 1300°F.

TABLE V
STRESS RUPTURE PROPERTIES OF 10 TO 15% COLD-WORKED
304 STAINLESS STEEL IN 1300°F
Cu-CONTAMINATED SODIUM

Specimen Number	Cu-Thickness (in.)	Hoop Stress (psi)	Rupture Time (hr)	Maximum Diametral Strain (%)	Strain-Rate (%/hr)
4-211	0	12,000	1186	3.93	3.31×10^{-3}
4-212	0	12,000	1186	4.20	3.54×10^{-3}
4-206	0.0002	12,000	1175	4.30	3.66×10^{-3}
4-213	0	15,000	715	4.04	5.65×10^{-3}
4-214	0	15,000	705	3.60	5.11×10^{-3}
4-207	0.0002	15,000	681	3.76	5.52×10^{-3}
4-215	0	20,000	298	4.27	1.43×10^{-2}
4-216	0	20,000	280	3.87	1.38×10^{-2}
4-208	0.0006	20,000	280	4.20	1.50×10^{-2}
4-217	0	25,000	106	4.87	4.59×10^{-2}
4-218	0	25,000	121	3.50	2.89×10^{-2}
4-209	0.0006	25,000	121	4.30	3.55×10^{-2}

On opening the retort after sodium draining, all specimens had a light copper color which disappeared after a few minutes exposure to air. Copper plating did remain on the pressure tubing above the specimens and in spotty areas on those specimens which were originally copper plated; as observed on the lower temperature tests, no plating occurred on stainless steel parts exposed only to the sodium vapor. Figure 9 is a photograph of the 1300°F stress-rupture specimens.

Two sodium samples were taken during the test and are listed in Table III. One of the samples was contaminated during handling in the analytical laboratory. The second sample, taken at the completion of the stress-rupture testing, contained 13 ppm oxygen. The copper content of the sodium was 208 ppm. This value is somewhat lower than the values reported on solubility studies⁽⁴⁾ but is within the 95% confidence band for such data.

4. Metallography

Metallographic examination of the 1300, 1100, and 950°F specimens showed the ruptures to be intergranular, typical of those observed in high purity sodium. In the as-polished condition, no distinct penetration of copper into the stainless steel was observed. Figures 10b, 10c, and 10d show cross sections through copper-plated specimens after test at 950, 1100, and 1300°F. These are compared with a similar specimen shown before testing (Figure 10a). It is apparent from comparison of these photomicrographs that temperature strongly influences the corrosion rate of copper by sodium. When the specimens were etched, there appeared to be a very slight reaction zone at the stainless steel-copper interface. The width of the zone was about 0.00005 in., and did not appear to be influenced by temperature.

B. IMPACT TESTS

Charpy V notch impact specimens, prepared by the Naval Research Laboratory from annealed 304 stainless steel plate, were exposed to the copper-saturated sodium. Each retort contained four specimens. In the 950°F retort, each impact specimen was copper-plated (0.0006-in.). Figure 3 shows the specimens before test, and Figure 11 reveals the condition after test. The 1100 and 1300°F tests contained two plated and two non-plated specimens.

a. Before Test

b. 950°F - 3700 hr

c. 1100°F - 670 hr

d. 1300°F - 1200 hr

Figure 10. Effect of Sodium Exposure on Copper-Plated 304 Stainless Steel Stress Rupture Specimens. (Original thickness of copper plate was 0.0006 in.) Transverse Sections, Unetched

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Figure 11. Impact Specimens and Corrosion Tabs After Test
in 950°F Sodium

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TABLE VI
IMPACT-STRENGTH OF 304 SS CHARPY V-NOTCH SPECIMENS
(Impact Test Temperature: $-75 \pm 3^{\circ}\text{C}$)

Specimen Condition	Specimen Number	Cu-Thickness (in.)	Impact Strength (ft-lb)	Average Impact Strength (ft-lb)
As Received Annealed 304 SS No Sodium Exposure	K7-1	0	125	127
	K7-3	0	124	
	K7-4	0	120	
	K7-72	0	140*	
Cu-Plated Annealed 304 SS No Sodium Exposure	K7-10	0.0006	124	123
	K7-12	0.0002	122	
	K7-13	0.0002	115	
	K7-14	0.0002	131	
Annealed 304 SS Exposed to 950°F Na	K7-17	0.0006	102	108
	K7-18	0.0006	100	
	K7-19	0.0006	115	
	K7-20	0.0006	117	
Annealed 304 SS Exposed to 1100°F Na	K7-6	0	82	
	K7-7	0	81	
	K7-9	0.0006	84	
	K7-11	0.0006	78	
Annealed 304 SS Exposed to 1300°F Na	K7-8	0	40*	39*
	K7-74	0	39*	
	K7-16	0.6	40*	
	K7-73	0.6	35*	

*Specimens tested at Naval Research Laboratory

The impact strengths of the 12 exposed specimens and eight unexposed specimens are given in Table VI. The specimens exposed to 950 and 1100°F sodium were tested according to ASTM recommended practice E-23 at $-75 \pm 3^\circ\text{C}$ by an outside laboratory (Metallurgical Service Labs, Santa Fe Springs, California). The impact strength of the unexposed specimens is within the range of values reported in the literature for annealed 304 stainless steel. The reduction in impact strength on the exposed specimens is most probably due to thermal aging effects since metallographic examination did not indicate any copper penetration. Since the specimens exposed at 950°F for 3700 hours exhibited a higher impact strength than those exposed to 1100°F for 670 hours, the temperature seems to be the dominant factor in reducing the impact strength.

The 1300°F exposed specimens were impact tested by the Naval Research Laboratory. Their studies included rather detailed structural examination by optical metallography, heat treatment, and electron microprobe analysis. They concluded that the loss in impact strength was not due to copper diffusion along grain boundaries, but rather to carbide precipitation (sensitization) as a result of the thermal exposure.

C. COPPER CORROSION

In each retort, two accurately weighted pure copper tabs were inserted so as to be completely immersed in the sodium bath. Figure 3 shows these tabs just prior to final retort assembly. Figure 11 shows the same tabs after 3700 hours in 950°F sodium. One of the tabs was 99.999 copper while the other (smaller in size) was O.F.H.C.* copper. In the 1100 and 1300°F tests, both tabs were 99.999 copper.

The copper tabs in the 950°F test experienced an average loss of 5.4%, whereas at 1100°F the average loss was 5.5% in about one-sixth the exposure time. In the 1300°F test, a 25% weight loss occurred in about 1200 hours. This demonstrates, in a qualitative manner, the increase in corrosion at the higher temperature. One hesitates to assign a more quantitative significance to the data since the total copper inventory was not the same in each retort. The 950°F test contained more copper plated specimens, which could have

*Oxygen-free high conductivity grade copper.

influenced the amount lost from the copper tabs. Perhaps the most quantitative comparison exists between the 1100 and the 1300°F test. In this case, the copper plated stress-rupture specimens were essentially equivalent. The major variable (besides temperature) was the total exposure time in sodium at temperature. On this basis, the copper corrosion is about 5 times greater at 1300°F than at 1100°F. It is conjectured that the loss would have been greater in flowing sodium conditions with thermal gradients in the system. Table VII shows the data obtained from the copper tabs. No significant difference was noted between the corrosion rate of O. F. H. C. and 99.999 copper.

Pitting-type corrosion was observed on the copper tabs, with no significant evidence of grain boundary penetration. The nature of the attack is also evident in the photomicrographs of the copper-plated stress-rupture specimens, shown in Figure 10.

TABLE VII
COPPER TAB CORROSION DATA

<u>I. Exposure to 950°F Sodium for 3700 Hours</u>		
A. O. F. H. C. Copper	Weight before	1.3963 gm
	Weight after	<u>1.2873 gm</u>
		0.1090
B. 99.999 Copper	Weight before	1.6109 gm
	Weight after	<u>1.5232 gm</u>
		0.0877
<u>II. Exposure to 1100°F Sodium for 670 Hours</u>		
A. 99.999 Copper	Weight before	3.6590 gm
	Weight after	<u>3.4420 gm</u>
		0.2120
B. 99.999 Copper	Weight before	3.6620 gm
	Weight after	<u>3.4685 gm</u>
		0.1935
<u>III. Exposure to 1300°F Sodium for 1200 Hours</u>		
A. 99.999 Copper	Weight before	5.0860 gm
	Weight after	<u>3.8090 gm</u>
		1.2770
B. 99.999 Copper	Weight before	6.0320 gm
	Weight after	<u>4.5348 gm</u>
		1.4972

IV. DISCUSSION OF RESULTS

The most applicable work which was found in the literature concerning the compatibility of stainless steel with copper was that of Hume, Cope, and Hall.^(8,9) In these studies, solid diffusion couples were heat treated at various temperatures for times up to 10,000 hours. For 316L stainless steel, the maximum copper penetration after 10,000 hours at 600°C (1112°F) was only 3 microns (0.12 mil). At 700°C (1292°F) the maximum penetration of copper along grain boundaries was 14 microns (0.55 mil).

While this work suggests that there is very little problem with copper penetration into stainless steel at the temperatures of interest, there was concern that, with the copper dissolved in the sodium, the reaction of copper with stainless steel might be enhanced. The sodium would certainly remove any oxide surface film on the stainless steel which could be a potential diffusion barrier. Also, the copper atoms in the sodium would be more mobile and available for diffusion.

Some of the specimens in each test contained a thin copper plate (0.0002 to 0.0006-in.) to simulate a possible reactor condition where copper would plate out on components. Initial stress-rupture tests seemed to indicate that the copper plating reduced the creep rate. Such behavior of thin metallic films has been observed^(10,11) with other systems. However, as more data became available in the present tests, it became apparent that the rupture strength or creep behavior was not altered by the presence of the copper plating.

In Figure 6, the 1100°F stress-rupture curve was generated from data obtained in high purity sodium. The data points from the present study lie superimposed on this curve. Data at 950 and 1300°F in high purity sodium are not available. However, from the position of the data points in relation to the high purity sodium curves at 1200 and 1400°F, it is concluded that the copper contamination has not altered the stress-rupture properties.

Additional evidence that copper is not affecting the creep properties is supplied by a comparison of the average maximum diametral strain rates, as shown in Figure 12. Excellent agreement in strain-rate behavior between copper-plated specimens, unplated specimens, and a series of specimens

which were tested in copper-free high purity sodium was observed at 1100°F. At the other two temperatures, there is no discernable difference between the copper-plated and the non-plated specimens.

Figure 12. Strain-Rate Behavior of 304 SS Tubing (10 to 15% Cold-Work) in Copper-Contaminated Sodium

V. CONCLUSIONS

Based on the experimental studies in a copper-saturated sodium environment, the following conclusions can be made:

- 1) The presence of copper in sodium does not influence the stress-rupture strength, creep rate, or impact strength of 304 stainless steel at temperatures up to 1300°F. Although testing at this temperature did not exceed 1200 hours, microstructural examinations indicated that considerably longer exposures could be tolerated.
- 2) No serious penetration of copper into the stainless steel was observed.
- 3) The application of a thin copper plate to some of the specimens prior to test did not change the rupture strength or creep rate.
- 4) Pure copper corrosion tabs in the static sodium experienced weight losses, due to dissolution of the copper into the sodium, which reflected a strong influence of temperature. An accurate quantitative evaluation was not possible because of differences in copper inventory among the retorts.
- 5) The work revealed a potential problem of copper deposits forming in the cooler regions of the sodium system. In a reactor, where there is a large ΔT in the sodium system, copper could deposit and inhibit flow, valve, or instrument operation.

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