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Fabrication of Modified 9 Cr-1 Mo Steel Test Article for Exposure in Sodium Components Test Loop at Energy Technology Engineering Center

V. K. Sikka
G. M. Goodwin
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OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A03 Microfiche A01

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ORNL-6034
Distribution
Category UC-79h,
-k, -r
Task OR-1.7
"Advanced Alloy
Technology"

METALS AND CERAMICS DIVISION

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V. K. Sikka, G. M. Goodwin, J. F. King, and K. V. Cook

Date Published: April 1984

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY
under Contract No. W-7405-eng-26

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V. K. Sikka, G. M. Goodwin, J. F. King, and K. V. Cook

ABSTRACT

The fabrication, inspection, shipment, and mechanical properties of a modified 9 Cr-1 Mo steel test article for exposure in the Sodium Components Test Loop (SCTL) at the Energy Technology Engineering Center (ETEC) are described. The test article delivered consisted of modified 9 Cr-1 Mo steel pipe 232 mm in diameter by 12.7-mm wall by 610 mm long. This pipe was safe ended with type 304L stainless steel spool pieces 152 mm long on each end. The joint between modified 9 Cr-1 Mo and type 304L was made with ERNiCr-3 filler wire. The entire test article was postweld heat treated 1 h at 732°C and ultrasonically inspected before use. Radiography was used to inspect the welds between modified 9 Cr-1 Mo and type 304L stainless steel. The test article was delivered to ETEC on schedule on October 4, 1982. After delivery of the test article, we fabricated an additional piece of the same dimensions by the same procedure for archive purposes, mechanical property testing, and comparison with the actual test article after test. A part of this archive piece also provided a nondestructive examination standard for in-service inspection for ETEC. The archive specimen has already been subjected to tensile and creep testing, microstructual evaluation, and thermal aging for 2000 h at 510°C. The test article has completed a year of operation in the SCTL. We expect to remove this pipe after three years of operation for testing and examination.

INTRODUCTION

We were informed on September 23, 1982, that a test section of modified 9 Cr-1 Mo steel pipe could be incorporated into the Sodium Components Test Loop (SCTL) at the Energy Technology Engineering Center (ETEC) if a spool piece of appropriate dimensions with stainless steel safe ends could be prepared and delivered to ETEC by the morning of

*Work performed under DOE/BTP AF 15 40 10 3, OR-1.7, Advanced Alloy Technology.

October 4, 1982. An overall length of about 0.9 m with ends prepared to standard bevel at hand was desired. Descriptions of the fabrication, inspection, shipment, and mechanical properties of the test article follow.

FABRICATION OF THE TEST ARTICLE

The SCTL piping is nominally 254-mm-diam schedule 40 type 304H stainless steel. Large-diameter modified 9 Cr-1 Mo pipe was available in 245-mm-OD by 25-mm-wall extruded product from Electralloy heat 10148. The chemical analysis of this heat is given in Table 1. Note that all elements of this heat were within the specified range for modified 9 Cr-1 Mo steel. Two 254- by 203-mm schedule 40 type 304H stainless steel reducers were also available at ETEC. It appeared that the matchup could be made with 203-mm-diam schedule 80 type 316 pipe spool pieces from the reference heat. Accordingly, a 610-mm length of the 9 Cr-1 Mo pipe and two 152-mm lengths of type 316 pipe were severed, and machining was begun.

The modified 9 Cr-1 Mo pipe was normalized and tempered. The normalizing treatment consisted of holding the pipe at 1040°C for 1 h and air cooling to room temperature. Tempering was at 760°C for 1 h, followed by air cooling to room temperature. Figure 1 shows the pipe air cooling from the normalizing temperature to room temperature.

Machining of the as-extruded 9 Cr-1 Mo pipe required the removal of more material from the inside than had been anticipated. As a result, the matchup to 203-mm schedule 80 dimensions of type 316 stainless steel was lost. As an alternative, 245-mm-diam rod stock of type 304L stainless steel heat 696626 was obtained from the ORNL stores and machined to the appropriate dimensions. It was an Armco heat sold to ORNL through Associated Steel Company of Houston. The vendor and check analyses of the type 304L bar stock are given in Table 1. Note that, although the carbon content of this heat is only 0.029 wt %, its nitrogen content is quite high (0.055 wt %). The combined effect of carbon and nitrogen is expected to make this heat of type 304L comparable in properties to type 304H stainless steel. This point will become clearer when the mechanical properties are compared in a later section of this report. Finished dimensions of modified 9 Cr-1 Mo and type 304L pipe are shown in Fig. 2.

Table 1. Chemical analysis of modified 9 Cr-1 Mo pipe (Electralloy heat 10148) and type 304 stainless steel safe ends (heat 696626) used in the fabrication of Energy Technology Engineering Center test article

Element	Content (wt %)			
	9 Cr-1 Mo specification	Heat 10148[a]	Heat 696626	
			Vendor	Check[a]
Carbon	0.08–0.12	0.091	0.022	0.029
Manganese	0.30–0.60	0.49	1.57	1.59
Phosphorus	0.020 Maximum	0.018	0.027	0.027
Sulfur	0.010 Maximum	0.007	0.012	0.014
Silicon	0.20–0.50	0.35	0.73	0.76
Nickel	0.40 Maximum	0.16	9.02	9.14
Chromium	8.00–9.50	9.34	18.54	18.79
Molybdenum	0.85–1.05	0.99	0.25	0.24
Vanadium	0.18–0.25	0.21		0.06
Niobium	0.06–0.25	0.061		0.02
Titanium		0.004		<0.01
Cobalt		0.025		0.11
Copper		0.07	0.48	0.50
Aluminum	0.04 Maximum	0.001		<0.01
Boron		<0.001		<0.001
Tungsten		0.01		
Arsenic		0.002		
Tin		0.003		
Zirconium		0.001		
Nitrogen	0.03–0.07	0.037	0.054	0.055
Oxygen		0.006		

[a]Chemical analysis conducted at Combustion Engineering, Inc., Chattanooga, Tenn.

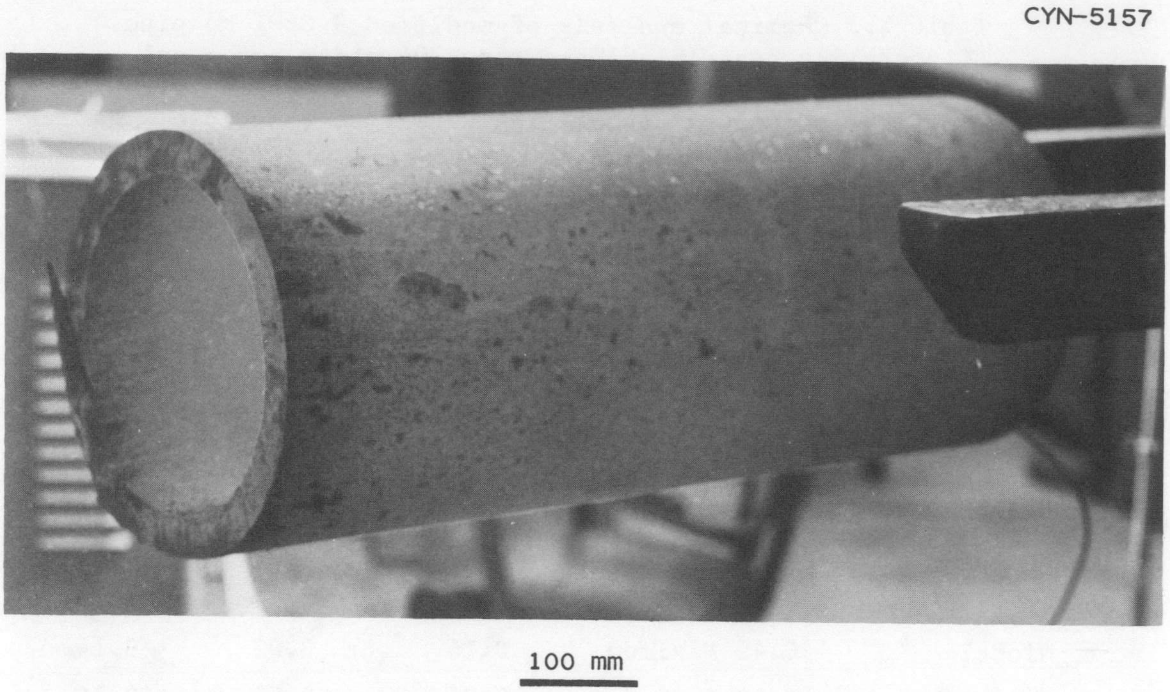


Fig. 1. Modified 9 Cr-1 Mo pipe air cooling from normalizing temperature of 1040°C to room temperature. The pipe dimensions were 245-mm OD by 25-mm wall by 610-mm length.

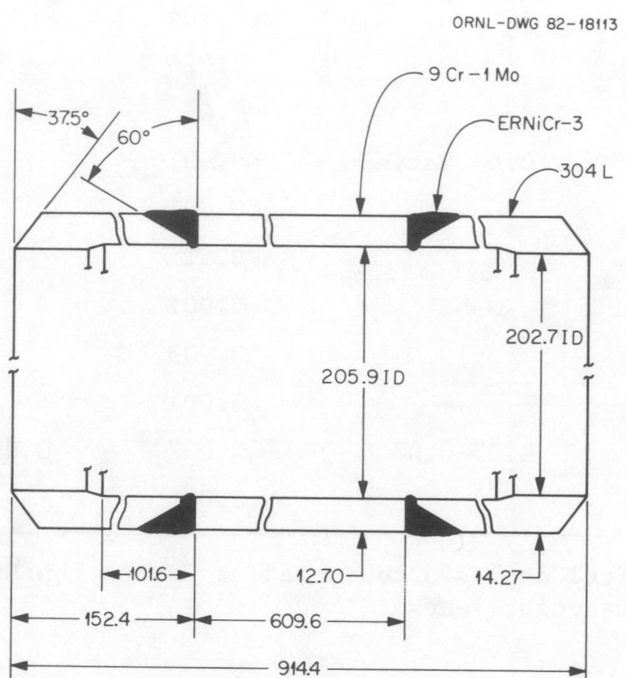


Fig. 2. Dimensions of the modified 9 Cr-1 Mo steel test article for exposure in the Sodium Components Test Loop at the Energy Technology Engineering Center.

As shown in Fig. 2, the final dimensions of the 9 Cr-1 Mo pipe were a 609.6-mm length, a 231.3-mm outer diameter, a 12.7-mm wall thickness, and zero bevel. The modified 9 Cr-1 Mo pipe was ultrasonically inspected before welding. The type 304L stainless steel spool pieces were of 152.4-mm length, 231.24-mm diameter, and a wall thickness stepped from 14.27 mm at the outside ends. The outside ends were machined to a standard 37.5° bevel with a root face of 1.59 to 2.10 mm, and the ends toward the 9 Cr-1 Mo to a 60° bevel with a root face of 0.38 to 0.89 mm. The nonsymmetric geometry for the dissimilar-metal weld (0° on the 9 Cr, 60° on the 304L) was selected because of the available positioning equipment and the desire to make the welds in the 2G (pipe vertical) position.

Welding began on September 29, 1983. The procedure is given in Fig. 3. An internal argon purge was maintained with stainless steel purge blocks and a stainless steel collar. The preheat of 232°C minimum was accomplished with propane burners. The joints were tacked at 90° locations and gas tungsten arc welded with ERNiCr-3 filler of 2.4 mm in diameter for root passes and 3.2 mm in diameter for fill passes. The chemical analyses of 2.4- and 3.2-mm wire of ERNiCr-3 are given in Table 2. Welding was in accordance with ORNL procedure WPS-2104.

Table 2. Chemical analysis of 2.4- and 3.2-mm wire of ERNiCr-3 used in the gas tungsten arc welding of modified test article

Element	Content (wt %)	
	2.4 mm (3/32-in.)	3.2 mm (1/8-in.)
Carbon	0.03	0.03
Manganese	3.11	3.05
Silicon	0.18	0.10
Sulfur	0.002	0.002
Phosphorus		0.006
Chromium	20.05	19.95
Nickel	72.55	71.36
Copper	0.09	0.16
Iron	1.0	2.31
Titanium	0.52	0.45
Niobium plus tantalum	2.47	2.50
Cobalt	0.04	
Tantalum	0.01	0.01
Others		0.50

DEVELOPMENT RECORD OF WELDING PROCEDURE

DATE: 9/29/83

PROCEDURE	POSITION OF WELD	WELDING OPERATOR	BUILDING NO.	WORK ORDER NO.
PC-82, weld #1, test article	2G Rotated	V. T. Houchin	4508	

MATERIAL	TYPE	SPEC. NUMBER	ALLOY OR GRADE	MANUFACTURER	HEAT NUMBER
Mod 9 Cr-1 Mo	[X] PIPE - PLATE [ ] OTHER -		9 Cr-1 Mo		10148
304L	[X] PIPE - PLATE [ ] OTHER -				

FILLER METAL	TYPE	SPEC. NUMBER	AWS CLASS.	MANUFACTURER	LOT OR HEAT NO.
ERNiCr-3	[X] ROD [ ] ELECTRODE	3/32" diam	ERNiCr-3	Tech Alloy	Nx 94CIDS
ERNiCr-3	[X] ROD [ ] ELECTRODE	1/8" diam	ERNiCr-3	H. A.	Nx 94COS

WELDING PROCESS: [ ] METALLIC [X] TIG [ ] MIG

MATERIAL PREPARATION: [X] MACHINING [ ] GRINDING [ ] FILING — SURFACE FINISH

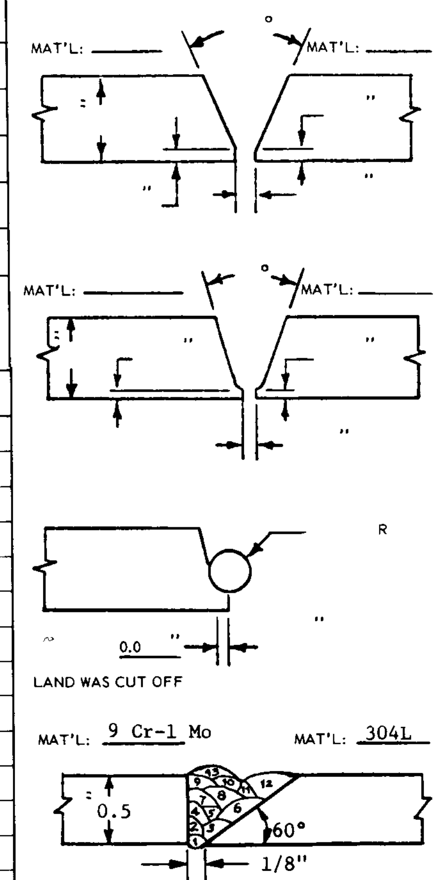
CLEANING: [ ] VAPOR [ ] HAND — SOLVENT — DETERGENT

INERT GAS COVER: TORCH % PURE — [X] ARGON [ ] HELIUM; PURGE % PURE — [X] ARGON [ ] HELIUM

GRINDING BETWEEN PASSES: [ ] NO [ ] YES — METHOD — ABRASIVE

MACHINING COOLANT: [ ] NO [ ] YES — COOLANT USED

PASS NO.	PRE-HEAT	INTER PASS TEMPERATURE	CURRENT AMPS.	VOLTAGE	FILLER DIA.	FILLER LENGTH	WELDING TIME MINUTES	POST-HEAT	VISUAL	LIQUID PENETRANT	RADIO-GRAPHY
1	400°F		150–175	12–14	3/32						
2	400°F		220–240	18	1/8						
3	400°F		220–240	18	1/8						
4	400°F		260–280	22	1/8						
5	400°F		260–280	22	1/8						
6	400°F		260–280	22	1/8						
7	400°F		260–280	22	1/8						
8	400°F		220–260	22	1/8						
9	400°F		220–260	18–20	1/8						
10	400°F		220–260	18–20	1/8						
11	400°F		220–260	18–20	1/8						
12	400°F		220–260	18–20	1/8						
13	400°F		220–260	18–20	1/8						
14											



(COMPLETE SKETCH AS REQUIRED)

INSPECTOR

REMARKS: Root face was large ≈0.075", I.D. root pass made to smooth surface. Preheat maintained 1 h after welding, PWHT 1350/1 h. Weld 2 was similar to 1 except welded in 1G position, 11 passes and less amperes.

UCN-3312
(3 12-61)

Fig. 3. Development record of welding procedure.

The outer weld surface was ground smooth. Figure 4 shows the equipment setup for welding type 304L stainless steel ends to modified 9 Cr-1 Mo pipe. A preheat of 204°C minimum is being supplied by propane torches. Figure 5 shows the gas tungsten arc welding in the 2G position.

Y-187547

Fig. 4. Equipment setup for welding type 304L stainless steel end pieces to modified 9 Cr-1 Mo steel test article. Propane torches supply a preheat of 204°C minimum.

Fig. 5. Gas tungsten arc welding of modified 9 Cr-1 Mo steel test article in the 2G position.

The welded assembly was postweld heat treated 1 h at 732°C. After sandblasting, the assembly was radiographed in accordance with *ASME Boiler and Pressure Vessel Code*, Sect. V (details to be described in the next section), and the root surface was ground smooth with abrasive burrs. The finished article before inspection is shown in Fig. 6. The final

CYN-5161

Fig. 6. Finished article of modified 9 Cr-1 Mo steel, which was sand blasted before final inspection. The weld root surfaces were ground smooth by hand.

overall length of the test article was 937 mm. The article was delivered to ETEC on schedule on October 4, 1982. (Details will be presented in a later section.)

After the fabrication of the test article for delivery to ETEC, we fabricated an additional piece of the same dimensions by the same procedure for archive purposes, for mechanical property testing, and for comparison with the actual test article after test.

INSPECTION OF THE TEST ARTICLE

INSPECTION OF THE PIPE BEFORE WELDING

The modified 9 Cr-1 Mo pipe was ultrasonically inspected before welding. The inspection was performed with a manual scan for indication of flaws oriented parallel to the pipe axis (longitudinal flaws). The inspection was performed from the outer surface of the specimen with a 13-mm-diam 2.25-MHz search unit (SN 11768). A Lucite wedge provided a near 45° shear wave in the pipe wall. A USIP-11 commercial flaw detector, with the receiver turned to the 0.5- to 2.5-MHz position, provided a visual readout for the level II inspector. A lightweight machine oil was used for couplant. The specimen was placed horizontally on a four-wheel cradle to enable rotation. The pipe was rotated with one hand while the search unit was manipulated with the other. We attempted 100% coverage, but the method has an inherent possibility of error (as do all nonmechanized scans).

Before the manual scanning, the instrument was calibrated with a similar size type 316 stainless steel pipe section (i.e., the only readily available specimen with the needed configuration). A simulated flaw (a notch cut with a hacksaw), which varied in depth from zero to 2.8 mm (0.11 in.) in approximately a 0.1-m (4-in.) distance, was cut on the inner surface of the stainless steel specimen calibration section at one end. The ultrasonic system was calibrated at a distance of about 64 mm (2.5 in.) from the deep end, where the notch depth is about 1 mm (0.04 in.).

The approach that was dictated here (i.e., using a different material for transfer calibration) is valid only for specific narrow-range calibrated gain changes. Fortunately, no gain adjustments were necessary, and this fact adds confidence to this application. When we compared the two specimens by monitoring the amplitude of the signals from the pipe section end reflections at V/2, V, and 3V/2 sound paths, no measurable amplitude differences were observed (i.e., the attenuation properties for 2.25-MHz shear waves was nearly identical for these two particular specimens, and no gain adjustment was required). Machining marks produced many very small amplitude indications, but only one significant indication was detected in the 9 Cr-1 Mo section. This indication was about 220 mm (8 3/4 in.) from an end and was on the inner surface. The amplitude was about one-tenth that measured at the 1-mm (0.04-in.) saw-cut position.

Subsequently, minimal grinding of the visually detectable surface discontinuity located at this position reduced the reflecting area and removed the ultrasonic indication.

In summary, a best-efforts approach (using a manual scan, pulse-echo, contact ultrasonic method) was employed to inspect the modified 9 Cr-1 Mo steel pipe section before welding. A transfer standard that contained a simulated flaw about 1 mm (0.04 in.) deep was successfully used to calibrate the inspection system. No indications equivalent to or greater than the response from the simulated flaw were detected.

RADIOGRAPHIC EXAMINATION OF WELDS IN THE MODIFIED 9 Cr-1 Mo ARTICLE

The girth welds at the ends of the section of modified 9 Cr-1 Mo steel pipe were radiographed. (These welds join the 9 Cr-1 Mo steel pipe to end pieces of type 304 stainless steel pipe.) The procedures were in accordance with the *ASME Boiler and Pressure Vessel Code*, Sect. V, Article 2. The film cassettes were placed on the curved inner surface of the pipe wall for the single-wall exposures. Five radiographs at 72° rotational intervals were made on each weld for one complete examination set. In addition to the code-required No. 15 penetrameter (thickness in thousandths of an inch), a No. 10 penetrameter was also placed on the weldment, and good image quality was evident.

The first set of radiographs showed several areas of lack of fusion. These were confirmed to be on the inner surface of the weldment by both visual and penetrant examination. After two series of grinding operations by welding personnel followed by radiography, the areas of lack of fusion were determined to be sufficiently reduced for shipment to ETEC for the intended test. The final radiographs and a copy of the inspection report were sent with the test article to ETEC.

Figure 7 represents the radiographic report containing additional radiographic parameters and the findings during film interpretation. Figure 8 shows the arrangement of film markers.

RADIOGRAPHIC REQUEST/REPORT

NO. **16038**

PART I TO BE COMPLETED BY REQUESTER

REQUESTER	DATE	PROJECT	PART IDENTITY
V. K. Sikka	10-2-82	ETEC Na Test	ETEC 1

DRAWING NO.	W.O. NO./CHARGE NO.	MATERIAL	THICKNESS	WELD REPORT NO.	WELD NO.'S
	0774	*See Below	0.500" nom.		

WELDING PROCEDURE	WELD SURFACE CONDITION	ACCEPTANCE CRITERIA

PART II TO BE COMPLETED BY RADIOGRAPHER

X-RAY UNIT	KV	MAM	ISOTOPE	CURIE-MIN.
"A"	265	10 Ma 8 1/2"	----	----

FOCAL SPOT OR SOURCE SIZE: 5mm

SOURCE-FILM-DISTANCE:

[X] SINGLE WALL EXP.
[ ] DOUBLE WALL EXP.

[X] SINGLE WALL VIEWING
[ ] DOUBLE WALL VIEWING

FILM/SCREEN ARRANGEMENT	FILTER THICKNESS	NO. EXPOSURES
10-M-20	FRONT 0.010" Pb BACK @ Tube	

PENETRAMETER SIZE & MATERIAL	SHIM THICKNESS	ORIENTATION OF LOCATION MARKERS	TECHNIQUE
#10 & #15 steel	----	†See below and attached sketch	

ASME B. & P.V.C. Sect. V, 1980 Edition

RADIOGRAPHER	QUALIFICATION LEVEL	DATE
Earl V. Davis	II	

PART III TO BE COMPLETED BY INTERPRETER

WELD NUMBER	FILM AREA LOCATION	INTERPRETATION (ACCEPT/REJECT)	FLAW DESCRIPTION OR OTHER REMARKS
1	0–1	1 Scratch, transverse to weld (artifact)	
1	1–2	Grinding area 1 - lack of fusion 0.125" long, 1- lack of fusion 0.150" long	
		2 Lack of fusion 0.050" long	
1	2–3	2 Gouges (probable) grinding 0.030" diam	
		2 Lack of fusion 0.050" long	
1	3–4	2 Film (screen) artifacts 0.090" long, grinding area	
		1 Gouge (probable) grinding 0.040" diam	
1	4–0	1 Pore 0.020" diam @ fusion line. 1 Gouge (probable) grinding 0.040" long	
		1 - Lack of fusion 0.075" long	
2	0–1	1 - Gouge (probable) grinding 0.040" diam & 10.045" diam	
		1 - Linear 0.100" long probable grinding groove; 1 Pore @ fusion	
		line 0.030" diam	
2	1–2	1 - Pore 0.040" diam, 2 lines in 9 Cr-1 Mo HAZ (artifacts 0.090" long	
		(see area 3-4 above)	
2	2–3	1 - Lack of fusion 0.300" long, 1 - lack of fusion 0.0250" long, 1 - gouge	
		0.041" probable grinding, 2 - lack of fusion lines, 10.100" & 10.050" long	
2	3–4	3 - Lack of fusion 0.075" long, 2 - lack of fusion 0.050" long, 2 - L.F.	
		0.100" long, 1 - pore 0.030" diam, 3 gouges (probable) grinding 1 hi ε inclusion	
2	4–0	1 Hi ε inclusion @ fusion line 0.040" long	
*304L SS	to 9 Cr-1 Mo	steel.	
†Weld 1 markers 0 through 4, run CW; weld 2, 0 through 4, CCW (see sketch)			

INTERPRETER	LEVEL	PROJECT INSPECTOR ACCEPTANCE
E. V. Davis		

FILM DISPOSITION: Component and film to J. King, 11-2-82

UCN-9351 (3 12-75)

Fig. 7. Radiographic report on test article of modified 9 Cr-1 Mo steel.

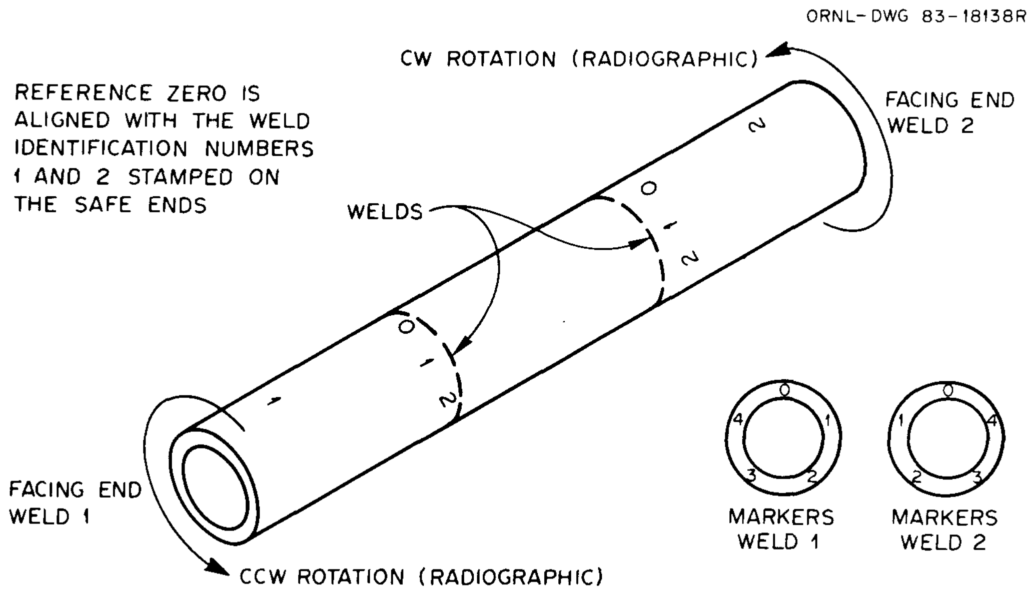


Fig. 8. Arrangement of film markers used during the radiography of the welded test article of modified 9 Cr-1 Mo steel.

NONDESTRUCTIVE EXAMINATION STANDARD FOR IN-SERVICE INSPECTION

A nondestructive examination standard was requested by ETEC for the in-service inspection of the test article. The modified 9 Cr-1 Mo archival article was used to prepare the nondestructive examination standard. The detailed sketch of the standard is given in Fig. 9. This standard was shipped to ETEC early in 1983.

SHIPMENT OF THE TEST ARTICLE

J. W. Hendricks delivered the test article to R. I. Jetter and Horace Neely of ETEC on October 4, 1982. The radiographs and inspection reports were delivered with the test article. Ultrasonic inspection of both welds of 9 Cr-1 Mo to type 304L stainless steel at ETEC gave results that compared favorably with the ORNL inspection report. The radiographs were returned to ORNL. The ETEC personnel were well pleased with the overall fit of the test article to their component and with the delivery, which was on schedule.

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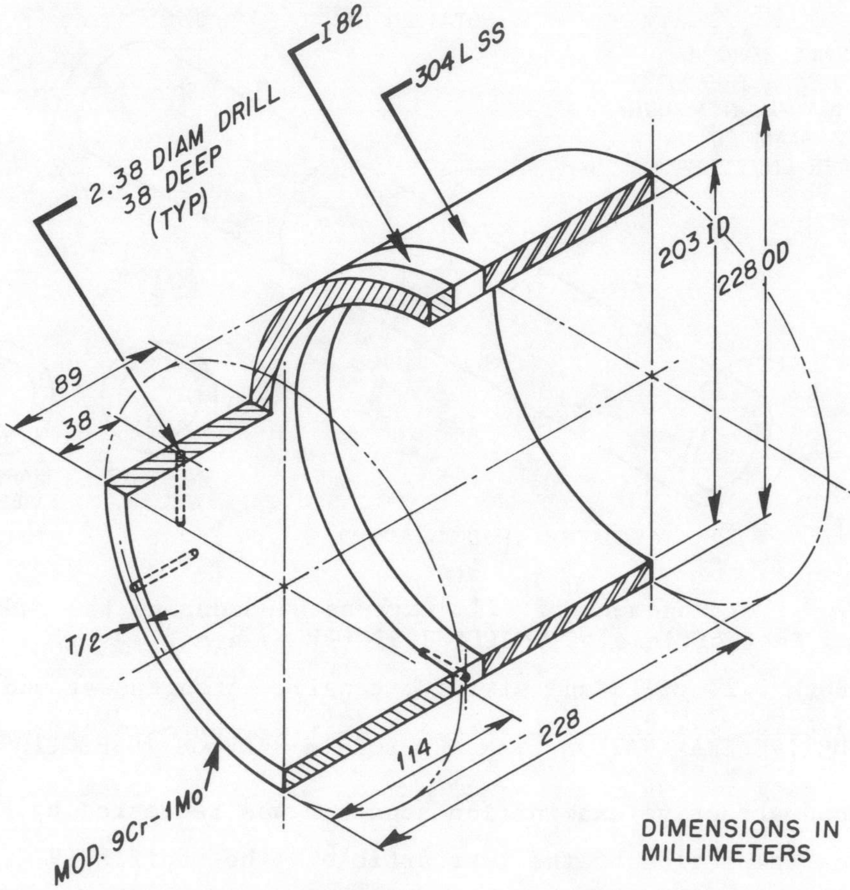

Fig. 9. Nondestructive examination standard supplied to Energy Technology Engineering Center for in-service inspection.

MECHANICAL PROPERTIES

To assure the long-term integrity of the test article, we conducted tensile tests on modified 9 Cr-1 Mo pipe, type 304L stainless steel, and the weldment specimens containing 9 Cr-1 Mo, ERNiCr-3, and their associated heat-affected zones. Because type 304L was used for the transition piece instead of the customary type 304H, we also conducted one creep test on this material to check its relative strength. Creep tests were also conducted on 9 Cr-1 Mo/ERNiCr-3/304L and 9 Cr-1 Mo/ERNiCr-3/316 weldment specimens. This section describes the mechanical properties of various sections of the test article.

TENSILE PROPERTIES

Tensile tests were conducted at room temperature, 93, 204, 316, 538, 593, 649, and 760°C on the modified 9 Cr-1 Mo steel pipe used in the test article. The data are summarized in Table 3. Specimens of type 304L stainless steel stock used for machining the safe ends were tensile tested at room temperature and at 593°C. Our data along with the vendor-certified data at room temperature are presented in Table 4. Tensile properties of the modified 9 Cr-1 Mo/ERNiCr-3/304L joint unaged and after aging for 2000 h at 510°C are summarized in Table 5 along with data on the modified 9 Cr-1 Mo/ERNiCr-3/316 joint. Yield and ultimate tensile strength data on modified 9 Cr-1 Mo base metal, modified 9 Cr-1 Mo/ERNiCr-3/304L, modified 9 Cr-1 Mo/ERNiCr-3/316, and modified 9 Cr-1 Mo/ERNiCr-3/304L aged for 2000 h at 510°C are plotted as functions of test temperature in Figs. 10 and 11. These figures show the following.

1. Both 0.2% yield and ultimate tensile strengths of modified 9 Cr-1 Mo/ERNiCr-3/304L and modified 9 Cr-1 Mo/ERNiCr-3/316 stainless

Table 3. Tensile properties of modified 9 Cr-1 Mo pipe (Electralloy heat 10148) used in the fabrication of the Energy Technology Engineering Center test article

Test	Temperature (°C)	Strength (MPa)		Elongation (%)		Reduction of area (%)
		0.2% Offset	Ultimate tensile	Uniform	Total in 25 mm	
23315	25	602.6	739.2	6.2	26.8	69.1
23316	93	569.6	687.6	5.6	23.7	72.9
23317	204	539.6	652.6	5.2	21.8	72.5
23318	316	525.8	638.3	4.4	20.8	71.4
23319	427	504.4	595.5	3.9	16.7	72.9
23320	538	411.5	443.9	1.8	24.1	86.6
23321	593	292.3	340.6	1.1	37.2	90.0
23322	649	202.0	239.9	2.1	39.8	90.6
23323	760	72.8	96.7	2.5	56.6	93.4

Table 4. Tensile properties of type 304L stainless steel (heat 696626) used for safe ending the modified 9 Cr-1 Mo pipe installed in Energy Technology Engineering Center

Test	Temperature (°C)	Strength (MPa)		Elongation (%)		Reduction of area (%)
		0.2% Offset	Ultimate tensile	Uniform	Total in 25 mm	
			Vendor			
	25	207	510		65[a]	77.0
			ORNL			
23413	25	268	577	74.7	88.8	85.2
23483	593	145	318	31.2	44.4	65.3

[a]Elongation in 51-mm gage.

Table 5. Tensile properties of transition joint in Energy Technology Engineering Center (ETEC) pipe weld between modified 9 Cr-1 Mo and type 304L stainless steel

(Tensile properties of a trial transition joint between modified 9 Cr-1 Mo and type 316 stainless steel are also included)

Test	Specimen	Temperature (°C)	Strength (MPa)		Elongation (%)		Reduction of area (%)	Failure location
			0.2% Offset	Ultimate tensile	Uniform	Total in 25 mm		
			ETEC postweld heat treated for 1 h at 732°C					
23580	1	25	304	569	30.46	38.65	79.95	304L
23581	2	510	209	371	14.10	19.80	66.29	304L
23582	3	593	165	304	11.18	21.95	86.69	9 Cr-1 Mo
			9 Cr-1 Mo/ERNiCr-3/316 stainless steel postweld heat treated for 1 h at 732°C					
23583	1R	25	301	580	27.07	34.21	69.03	316
23584	2R	510	192	429	14.34	21.61	77.32	9 Cr-1 Mo
			ETEC postweld heat treated for 1 h at 732°C and aged 2000 h at 510°C					
23642	8	25	309	568	24.22	29.31	82.10	304L
23643	9	510	195	371	11.58	15.55	63.03	304L

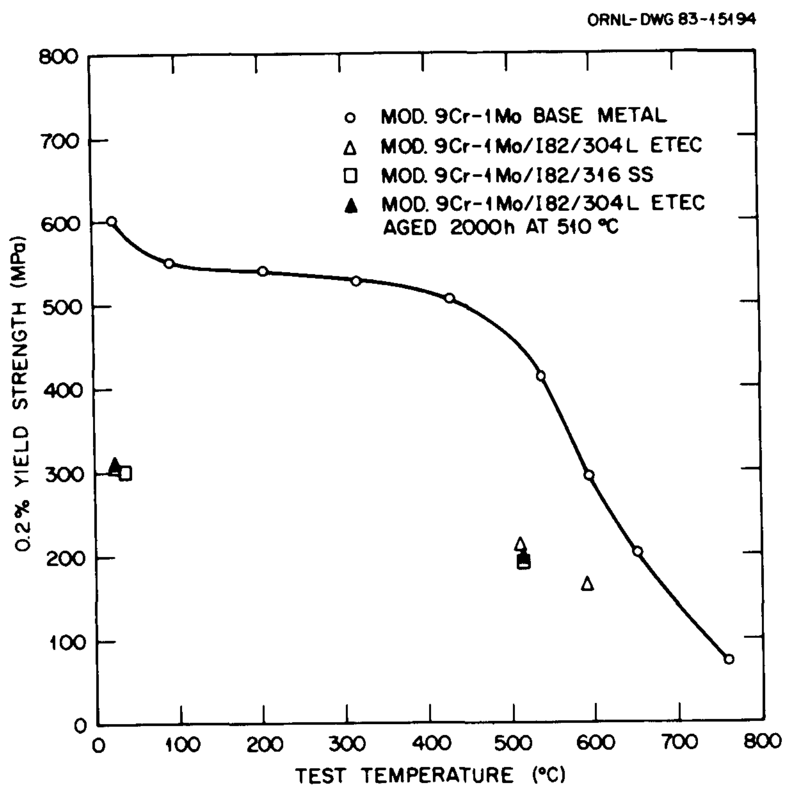

Fig. 10. Yield strength (0.2%) plotted against test temperature for modified 9 Cr-1 Mo base metal and its welds to type 304L or 316 stainless steel with ERNiCr-3 (I82). Data on an aged dissimilar joint of modified 9 Cr-1 Mo/ERNiCr-3/304L are also included.

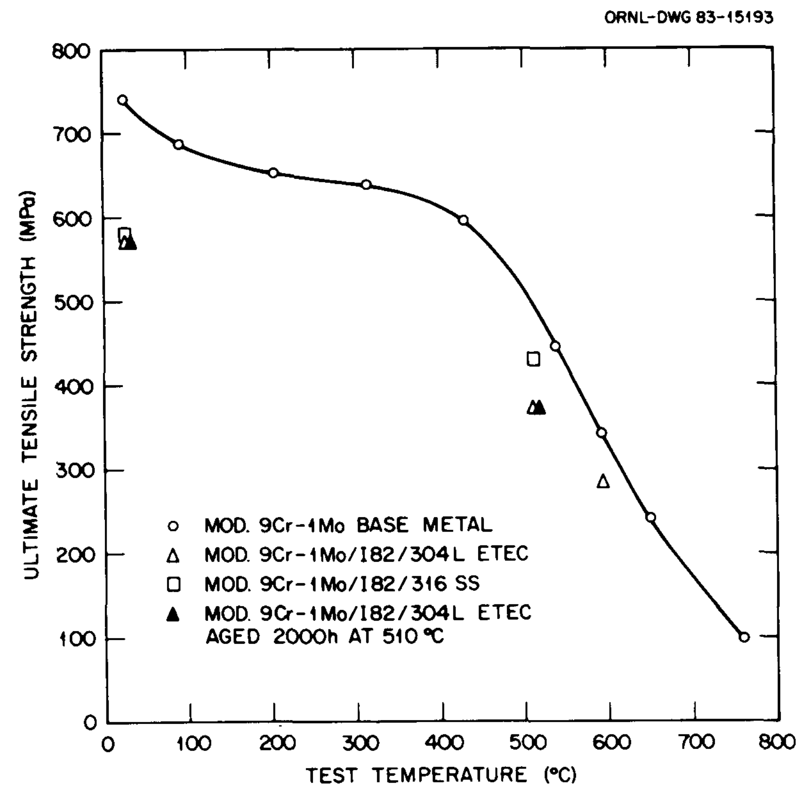

Fig. 11. Ultimate tensile strength plotted against test temperature for modified 9 Cr-1 Mo base metal and its welds to type 304L or 316 stainless steel with ERNiCr-3 (I82). Data on an aged dissimilar joint for modified 9 Cr-1 Mo/ERNiCr-3/304L are also included.

steel joints were lower than the corresponding values for the base metal for the entire test temperature range. The failures were generally in the stainless steel base metal.

2. Thermal aging for 2000 h at 510°C produced no change in the yield and ultimate tensile strengths of modified 9 Cr-1 Mo/ERNiCr-3/304L specimens.

3. The total elongation values of weldment specimens were generally higher than those of the modified 9 Cr-1 Mo steel base metal.

Data in Table 4 show that the yield strength, ultimate tensile strength, and total elongation of the type 304L stainless steel used for the safe ends far exceeds the minimum property requirements for type 304 stainless steel. We believe that the higher strength of type 304L used here comes from its higher nitrogen content. The next section shows that the creep strength of the same type 304L also far exceeds the minimum properties for type 304 stainless steel.

CREEP DATA

The creep test (test 23463) on heat 696626 of type 304L stainless steel used for safe ending the pipe was discontinued after 6416 h at 172 MPa and 593°C. This is more than 30 times the minimum time to rupture of 210 h under the same conditions for type 304 stainless steel according to ASME Code Case N-47. Because of this result, we have planned not to conduct any additional creep tests on this material.

The creep data on transition joints of modified 9 Cr-1 Mo/ERNiCr-3/304L and modified 9 Cr-1 Mo/ERNiCr-3/316 are presented in Table 6. The status of creep tests on transition joints compared with the modified 9 Cr-1 Mo base metal data are given in Figs. 12 through 14. These plots show that at 510°C the test in progress has already exceeded the curve for average minus twice the standard error of estimate (SEE) for the base metal. At 593°C three tests have exceeded the average minus 2 SEE for the base metal. The other two tests are expected to fail in approximately 10,000 and 30,000 h. At 649°C the only test in progress is close to the average minus 2 SEE for the base metal. The creep data on modified 9 Cr-1 Mo transition joints are also compared with similar data on 2 1/4 Cr-1 Mo/ERNiCr-3 joints in Figs. 15 and 16. The minimum stress-rupture curves for 2 1/4 Cr-1 Mo and modified 9 Cr-1 Mo base metal are

Table 6. Creep data on modified 9 Cr-1 Mo steel transition joint specimens with ERNiCr-3 weld metal

Test	Temperature (°C)	Stress (MPa)	Time[a] (h)
	Modified 9 Cr-1 Mo/ERNiCr-3/304L		
23718	510	276	>1603
23756	593	172	>834
23769	593	124	>382
23733	593	97	>1197
23759	649	76	>787
	Modified 9 Cr-1 Mo/ERNiCr-3/316		
23762	593	172	>690.0
23684	593	145	2304.2R

[a]R, ruptured; > indicates test in progress.

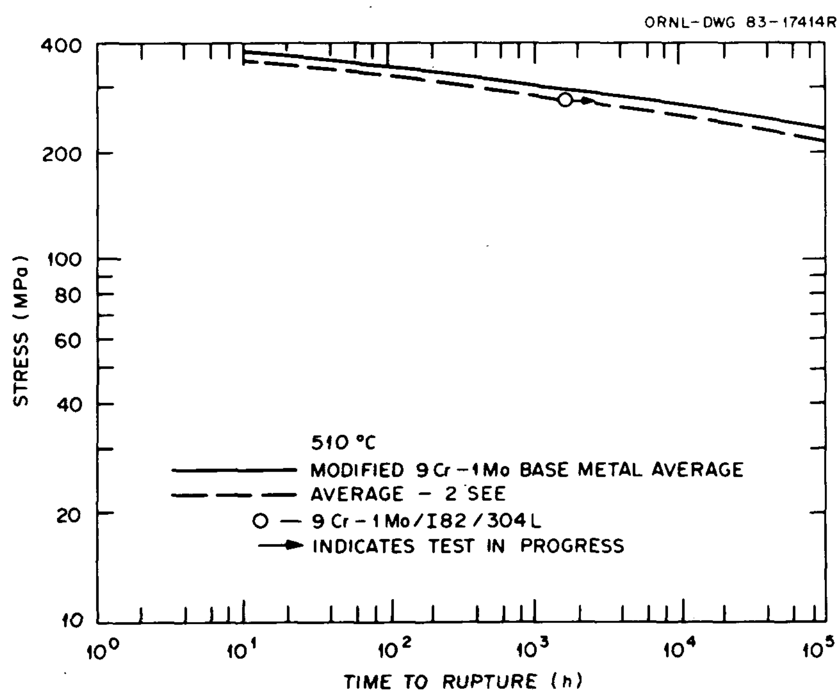

Fig. 12. Stress-rupture plot at 510°C for transition joint specimens of 9 Cr-1 Mo/ERNiCr-3/304L. Average and average minus 2 SEE curves for the base metal are included for comparison.

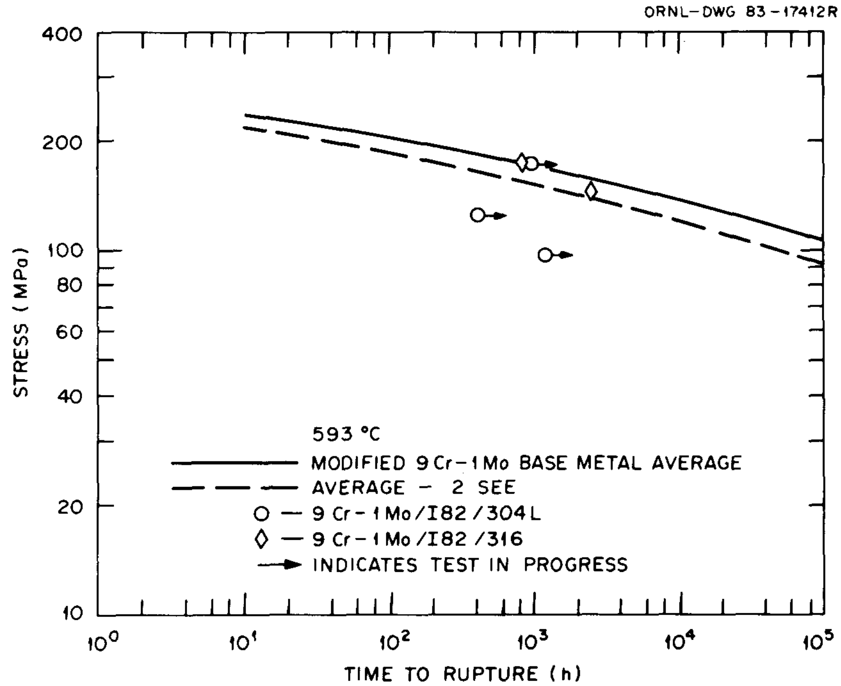

Fig. 13. Stress-rupture plot at 593°C for transition joint specimens of 9 Cr-1 Mo/ERNiCr-3/304L and 9 Cr-1 Mo/ERNiCr-3/316. Average and average minus 2 SEE curves for the base metal are included for comparison.

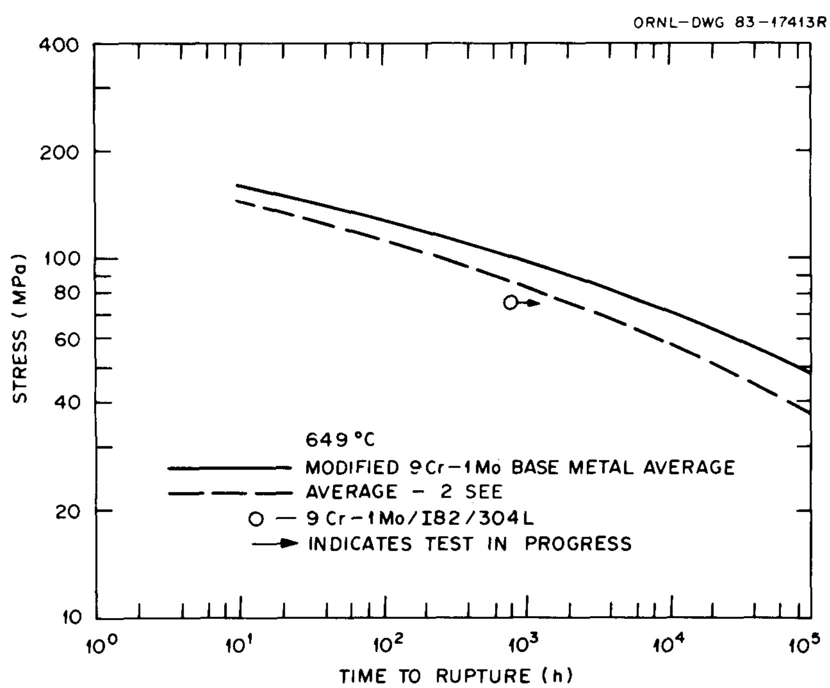

Fig. 14. Stress-rupture plot at 649°C for transition joint specimens of 9 Cr-1 Mo/ERNiCr-3/304L. Average and average minus 2 SEE curves for the base metal are included for comparison.

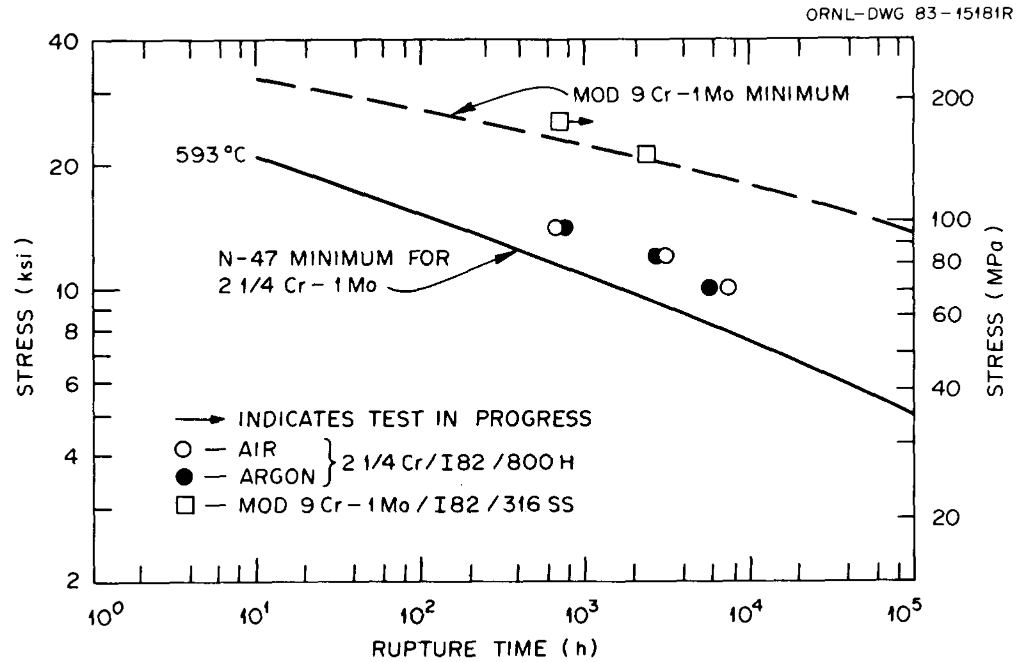

Fig. 15. One creep test is in progress at 593°C and another was concluded on modified 9 Cr-1 Mo/ERNiCr-3/316 stainless steel weldment specimen. These tests exceeded by a large factor the rupture time expected from a similar weld with 2 1/4 Cr-1 Mo steel.

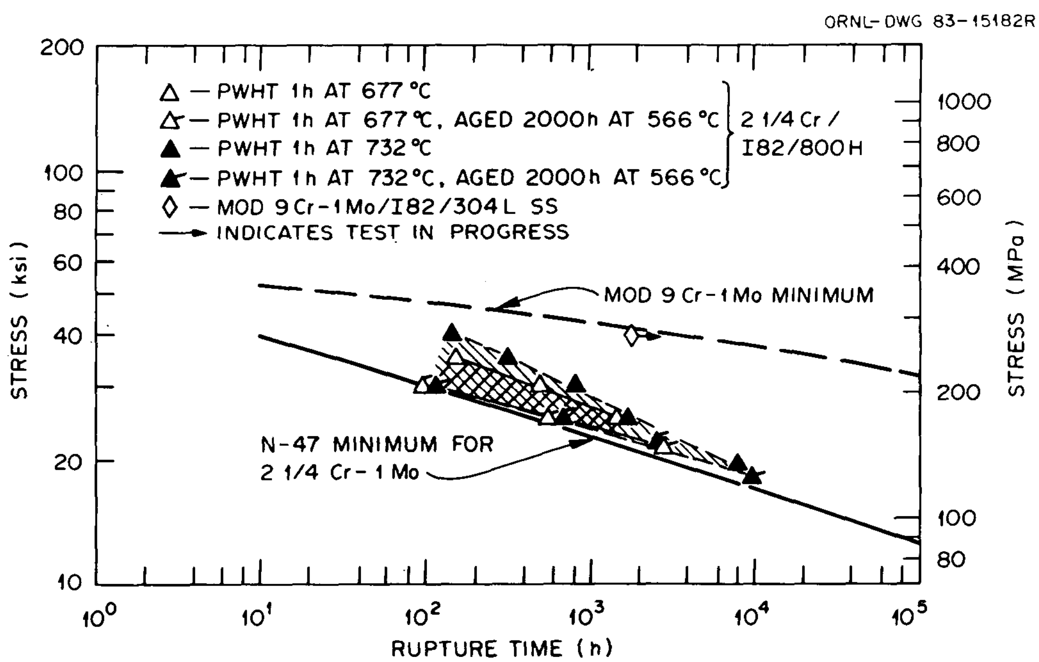

Fig. 16. One creep test is in progress at 510°C on modified 9 Cr-1 Mo/ERNiCr-3/304L stainless steel weldment specimen. The test has already exceeded the rupture time expected from a similar weld made with 2 1/4 Cr-1 Mo steel.

also included for comparison. These figures show that the rupture life of modified 9 Cr-1 Mo/ ERNiCr-3 joints is at least an order of magnitude longer than that of 2 1/4 Cr-1 Mo/ERNiCr-3 joints. Creep rupture strength is doubled. Additional long-term creep tests are required to validate these observations.

METALLOGRAPHY

A macroeteched section of the transition joint used in the ETEC test article is shown in Fig. 17. The microstructures of the interface between modified 9 Cr-1 Mo and ERNiCr-3 unaged and aged for 2000 h at 510°C are shown in Fig. 18. This figure shows that the interface microstructure is unaffected by aging at 510°C for 2000 h. Note, however, that unusually large grains are present in the modified 9 Cr-1 Mo side of this interface.

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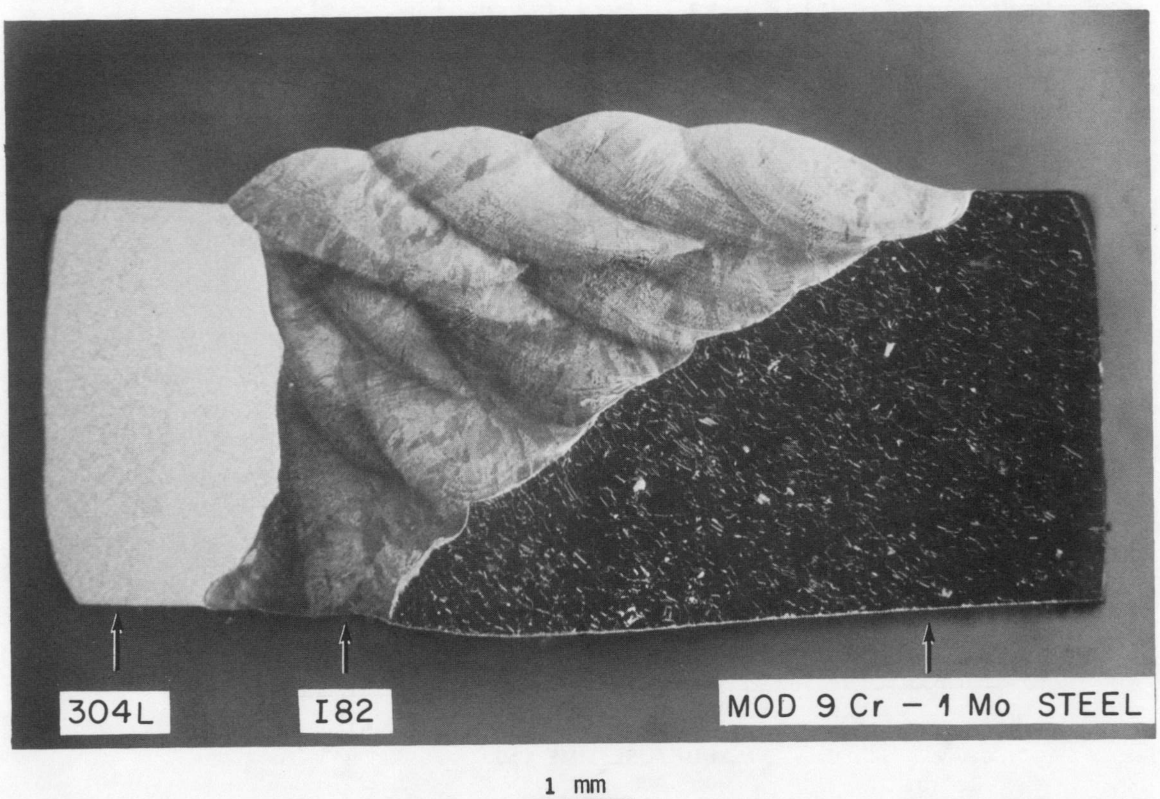

Fig. 17. Weld like that used in the fabrication of the test article of modified 9 Cr-1 Mo steel for installation in Energy Technology Engineering Center.

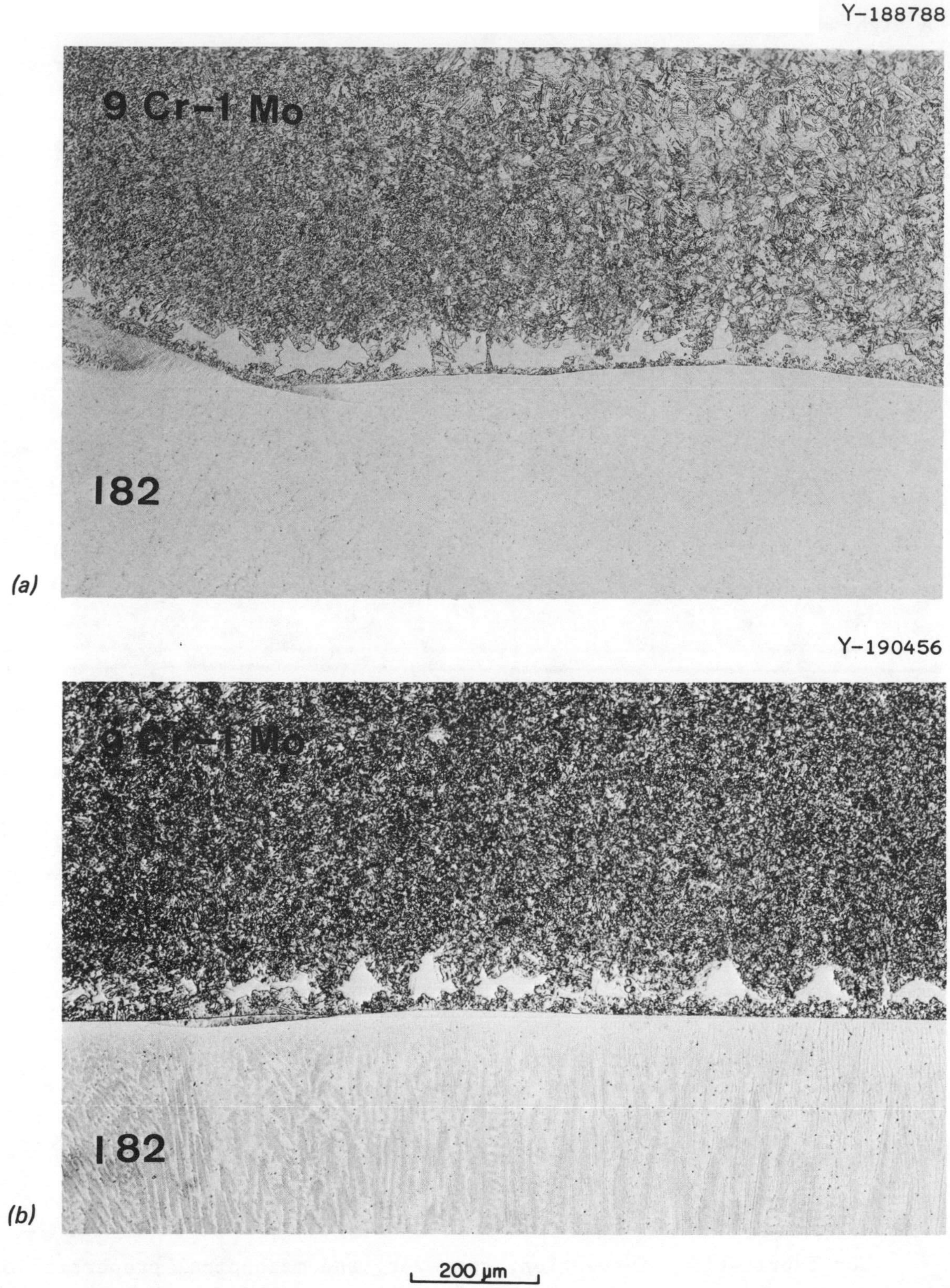

Fig. 18. Modified 9 Cr-1 Mo/ERNiCr-3 joint (*a*) as welded and (*b*) aged for 2000 h at 510°C. Note that they are nearly the same except that the aged specimen was slightly overetched.

A high-magnification micrograph of the interface with microhardness of various phases is shown in Fig. 19. This figure shows that the large-grain regions have significantly lower microhardness than do areas surrounding them. The reason for the large-grain regions is not yet known.

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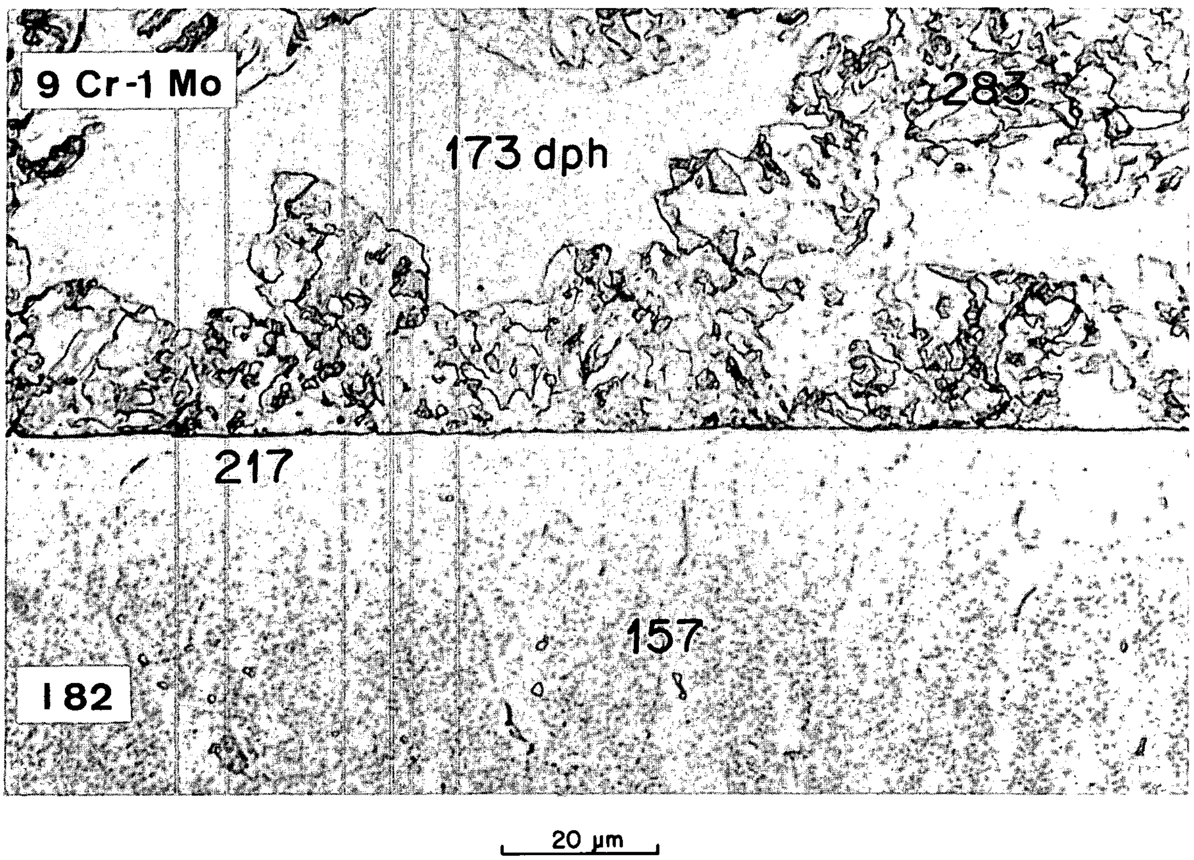

Fig. 19. High magnification of the modified 9 Cr-1 Mo/ERNiCr-3 interface. Microhardnesses of selected regions are included.

SUMMARY AND CONCLUSIONS

The fabrication, inspection, shipment, and mechanical properties of a modified 9 Cr-1 Mo steel test article for exposure in the sodium SCTL at ETEC are described in this report. The test article that was delivered consisted of a modified 9 Cr-1 Mo steel pipe 232 mm in diameter by 12.7-mm wall by 610 mm length. It was safe ended by type 304L spool pieces of 152-mm length on each end. The joint between modified 9 Cr-1 Mo and type 304L was made with ERNiCr-3 filler wire. The entire test article was postweld heat treated 1 h at 732°C. Modified 9 Cr-1 Mo pipe was ultrasonically inspected before use for this job. Radiography was used to inspect the welds between modified 9 Cr-1 Mo and type 304L stainless steel. The test article was delivered to ETEC on schedule on October 4, 1982. After delivery of the test article to ETEC, we fabricated an additional piece of the same dimensions according to the same procedure for archive purposes, mechanical property testing, and comparison with the actual test article after test. A part of this archive piece was also used in supplying a nondestructive examination standard for in-service inspection to ETEC. The archive specimen has been subjected to tensile testing, creep testing, microstructural examination, and thermal aging for 2000 h at 510°C.

The following conclusions are possible from this study.

1. The modified 9 Cr-1 Mo test article with two transition joints has been operating in the sodium loop at 510°C since its installation in October 1982.

2. Tensile properties of the type 304L stainless steel safe ends far exceed the vendor-certified data. The creep-rupture life of this type 304L also exceeds the ASME Code Case minimum for type 304 by over a factor of 30.

3. The weldment tensile strength properties for all specimens were lower than those of modified 9 Cr-1 Mo base metal. The ductility of these specimens exceeded that of modified 9 Cr-1 Mo specimens.

4. The creep-rupture life of weldment specimens was between the average and average minus 2 SEE for the base metal.

5. The creep-rupture life of modified 9 Cr-1 Mo/ERNiCr-3/(304L or 316) specimens exceeded by at least an order of magnitude that of similar specimens of 2 1/4 Cr-1 Mo steel. Tests are in progress to compare the same behavior for long-term creep tests.

6. Metallography showed large grains in the modified 9 Cr-1 Mo heat-affected zone. The reasons for this structure are not yet known.

ACKNOWLEDGMENTS

The authors gratefully acknowledge J. W. Hendrix, V. T. Houchin, and R. H. Baldwin for their contributions in welding and testing of the test article. We also acknowledge the efforts of Shirley Frykman for typing the draft; J. H. Smith, M. L. Santella, C. R. Brinkman, and G. M. Slaughter for reviewing; Sigfred Peterson for editing; and Gwendolyn Sims for preparing the final report.

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