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CHARACTERIZATION OF
ESR AND VAR 2¼Cr-1Mo ALLOY TUBING

H. J. Busboom

Prepared for the
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Under
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Ref. 189 No. SG029

DISCLAIMER

CHARACTERIZATION OF

ESR AND VAR 2¼Cr-1Mo ALLOY TUBING

H. J. Busboom

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ABSTRACT

Commercial tubing for LMFBR sodium-water steam generator applications was produced from ESR and VAR 2¼Cr-1Mo alloy (Grade T22) and characterized regarding chemical composition, microstructure, physical characteristics, and short and long term mechanical properties. These results demonstrate that tubing meeting RDT Standard RDT M3-33 can be produced from either the ESR or VAR process and is acceptable to ASME Code Section III requirements. Metallurgical and mechanical properties are similar for both ESR and VAR material, indicating that either remelting practice is acceptable.

CHARACTERIZATION OF
ESR AND VAR 2¼Cr-1Mo ALLOY TUBING

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1.0 INTRODUCTION

The materials selection for the sodium heated steam generators for CRBRP (Demonstration Plant) was 2¼Cr-1Mo ferritic alloy steel[1]. Tubing manufactured from this alloy is identified by ASME Code Specification ASME SA-213, Grade T22. To insure maximum integrity of the tubing for CRBRP, the base specification was upgraded by the preparation and use of RDT Standard, RDT M3-33.

To identify the additional requirements involved in the upgrading of ASME SA-213, Grade T22 tubing, a chart is shown in Table I comparing Code quality and RDT quality specifications. Of particular importance are the closer controls of the melt practice, heat treatment and chemical composition to facilitate a cleaner steel with a more reproducible optimum microstructure[1]. This added metallurgical quality was designed to reduce the likelihood of serious tubing flaws and to lessen problems associated with the tube-to-tubesheet weld joint. The more restrictive dimensional and nondestructive testing acceptance criteria were aimed at providing the most assurance that design strength of the tube will be met and that defects such as laps, cracks, and/or pits are minimized.

During FY75 and FY76, a development program was undertaken to insure that ESR and VAR tubing could indeed be commercially manufactured and inspected to meet RDT M3-33 quality. The program included the procurement and characterization of lengths, 2.1 m (7 ft.) long, to facilitate ease in manufacturing and inspection.

The actual prototype tubing for CRBRP will be 20.1 m (66 ft.) long which will require special equipment not presently available in most domestic tube manufacturing plants to meet requirements of RDT M3-33.

This report presents the results from this initial program and defines the problem areas of concern, which is essential for the successful production of full length CRBRP steam generator tubing.

2.0 MATERIALS

Three heats of material were purchased as tubing under PO #190-C8V13G from the Special Products Division of Carpenter Technology Corporation (CarTech) in El Cajon, California, including two VAR heats, #55262 and #91506, and one ESR heat, #91505. Heat #55262 was melted at Cameron Iron Works (CIW), Houston, Texas, and provided to CarTech as 4.13 cm (1 5/8") diameter forged bars. CarTech obtained the remaining two heats as 3.33 cm (1 5/16") diameter hot rolled bars from their Reading, Pennsylvania melt shop.

All bars were machined into precision tube hollows by gun drilling and OD machining. Tubing of proper size, 15.9 mm (0.625") OD X 2.77 mm (0.109") minimum wall, was obtained by a series of cold drawing and subcritical annealing steps. The final isothermal anneal was conducted in a batch furnace under vacuum to prevent any oxidation or decarburization and met the requirements of RDT M3-33 as follows:

heated to 926C $^{+8C}_{-11C}$ (1700F $^{+15F}_{-20F}$) and held for 30 minutes,

cooled to 704C (1300F) in 1½ hours and

held at 704C $^{+14C}_{-11C}$ (1300F $^{+25F}_{-20F}$) for 125 minutes,

cooled to < 260C (500F) in 15 minutes.

No temper or post weld heat treatments were added and the tubing was provided with the above heat treatment, followed by roller straightening to remove a slight bow introduced by the isothermal anneal. All tubing was inspected at

CarTech and met all testing and dimensional requirements shown in Table I with the exception of chemical analysis and inclusion rating for heat #55262 as will be explained below.

3.0 CHARACTERIZATION OF TUBING

The objective of the characterization work was to define the chemical composition, microstructure, physical characteristics, and selected short term and long term mechanical properties of the tubing. These data can then be used to demonstrate the acceptability of the tubing.

3.1 Chemical Composition

The ordering data for PO #190-C8V16G specified that the tubing must conform in chemical composition to that given in RDT M3-33 which includes the specified analysis in ASME SA-213, Grade T22 plus more specific limits on carbon, silicon, sulfur, phosphorus, nickel, titanium, vanadium, and copper. The specified analysis along with the ladle, product, and check analyses are shown in Table II. Both CarTech heats, #91505 (ESR) and #91506 (VAR) are within the specified analysis. CIW heat #55262 did not meet the specified limits for silicon since all three analyses, ladle, product, and check, were lower than the specified 0.02 w/o minimum. Only one analysis for both sulfur and phosphorus is out of specification and one can conclude that this heat is marginally acceptable regarding these elements. The fact that silicon was out of specification was recognized early in the program. Since all the other heats of remelted steel available at that time deviated from specified technical requirements to a much greater extent, it was prudent to continue with this heat of steel.

3.2 Physical Dimensions

The two ordering data dimensions requiring verification were outside diameter (OD) and wall thickness. The OD for all tubing lots was checked with micrometers and varied from 15.93 mm (0.627") to 15.95 mm (0.628"). Average wall thickness was quite similar for heats #91505 and #91506, nominally

2.93 mm (0.1155"). Ovality for heat #91505 ranged over ±38 μ (±0.0015") whereas heat #91506 ranged over ±51 μ (±0.002"). Average wall thickness was 2.96 mm (0.1165") for heat #55262 with the ovality ±51 μ.

3.3 Metallographic Examination

Metallographic examination included determination of inclusion content, ferritic grain size and microstructure. The inclusion rating and grain size are shown in Table III. All three tube lots exhibited a similar ferritic grain size, approximately ASTM 6.5. The inclusion ratings for two of the lots, heats #91506 and #91505, were within RDT M3-33 requirements, whereas heat #55262 was slightly out of specification regarding Type B (alumina) inclusions. Welding studies show that this tubing exhibited pore free butt welds of the CRBRP tube-to-tubesheet joint design suggesting this slightly high alumina inclusion rating does not seriously alter weld joint integrity.

The general microstructures of these tube lots are summarized in Figure 1 and presented in detail in Appendix A. The micrographs of etched samples clearly indicate that a rather complete isothermal transformation was obtained. Of prime interest is the homogeneity of the microstructure across the tube wall including a high ferrite content (light areas) and minimum amounts of transformation products (darker areas). Very little, if any, decarburization is evident in these tubes as shown in micrographs taken near the outside surfaces.

One readily observable difference in microstructure is evident in that the longitudinal sections, i.e., heats #91505* and #91506* exhibited a banding effect which is related to the distribution of transformation products, whereas heat #55262† did not. No significance can be attributed to this difference as banding is quite common in wrought products (plate, sheet, pipe and tubing) made from low carbon and low alloy grades of steels.

3.4 Mechanical Tests

Mechanical testing of these tubes included room temperature hardness, tensile, and burst tests, and burst and biaxial stress rupture tests at elevated temperatures. The hardness and tensile test results, Table IV, show that all three heats fully met the RDT Standard requirements. These results demonstrate that remelted commercial tubing given the isothermal heat treatment

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* CarTech Heats; † Cameron Iron Works Heats

in accordance with the RDT M3-33 standard should meet the required ASME Code mechanical property requirements.

Pneumatic burst tests were performed over a temperature range of approximately 25C to 600C (77F to 1112F). The wall thickness of these tubes were thinned to 1.02 mm (0.040") to allow bursting of standard CRBRP tubing (originally 2.77 mm; 0.109" minimum wall) with existing equipment. These tests were pressure rate controlled at 6.89 MPa (1000 psi) per minute and both gas pressure and diameter increase were recorded during the test. The specimens described in Figure 2 were brought to temperature and thermally stabilized for 30 minutes prior to pressurization. The results were analyzed in terms of stress-strain behavior for the transverse direction. The maximum stress at the inside diameter was calculated using the thick wall (Lamé) formula and strain was defined as $\Delta D/D_o$ where ΔD = the change in diameter and D_o = the nominal outside diameter of the specimens, 12.7 mm (0.485"). These parameters were chosen since they correlate best with available uniaxial data.

Before testing, all samples were given the temper treatment 727C (1340F) for 1 hour plus the post weld heat treatment 727C for 20 hours minimum as described in Table V. Table VI shows that the biaxial stress-strain behavior of all three materials were quite similar indicating little, if any differences in short term mechanical properties for these materials. These results would be expected from the similarity of microstructure shown in Figure 1. The biaxial ductility results were generally lower than elongation values measured in uniaxial tests on bar samples presented earlier[2]. This decrease demonstrates the effect of biaxial stress on ductility.

3.5 Biaxial Creep Rupture Tests

Biaxial creep rupture tests were initiated on all three materials after being given a heat treatment similar to the burst samples described above. These tests were conducted in argon at 510C (950F) under constant pressure conditions. Selected specimens were removed periodically for diameter measurements from which creep strain ($\Delta D/D_o$) values were calculated. The results from these tests are shown in Table VII. The maximum stress at the inside diameter

was calculated in a similar manner to that used for the burst tests. Only limited stress rupture data are available since most of the tests were designed to run more than 1000 hours. Both creep strain and rupture times indicate little, if any, difference between these materials. The biaxial stress rupture data are compared with available uniaxial data for material given similar isothermal and post weld heat treatments in Figure 3. Very little difference in stress rupture values is evident. The ductility was measurably reduced under biaxial stress conditions similar to that observed for burst testing.

Unfortunately, an over-temperature excursion occurred during June which resulted in heating all of the stress rupture samples above 523C (973F) for approximately 40 hours. All samples exhibited larger than expected diameter growth due to this excursion and thus, these tests were terminated. The final diameter measurements are shown in Table VII for information only, to illustrate the very strong temperature dependence of creep in this temperature region.

4.0 CONCLUSIONS

The following conclusions can be drawn from the characterization of short lengths of ESR and VAR 2¼Cr-1Mo alloy tubing:

1. Tubing meeting RDT M3-33 quality can be obtained commercially, fully meeting ASME Section II Code requirements.
2. Metallurgical and mechanical properties are similar for both ESR and VAR 2¼Cr-1Mo alloy tubing and are independent of remelting practice.

REFERENCES

1. G. J. Licina and J. F. Copeland, "A Review of 2¼Cr-1Mo Steel for Steam Generator Application in the Clinch River Breeder Reactor", GEAP 20589, (UC-79a), October 1974.

2. "Program for the Development of Design Data LMFBR Steam Generators", dated January 29 - 30, 1976.

APPENDIX A

METALLOGRAPHY OF CARTECH TUBING

ALLOY ASME SA-213, Gr. T-22

HEAT TREATMENT Isothermal Anneal

TEMPER None

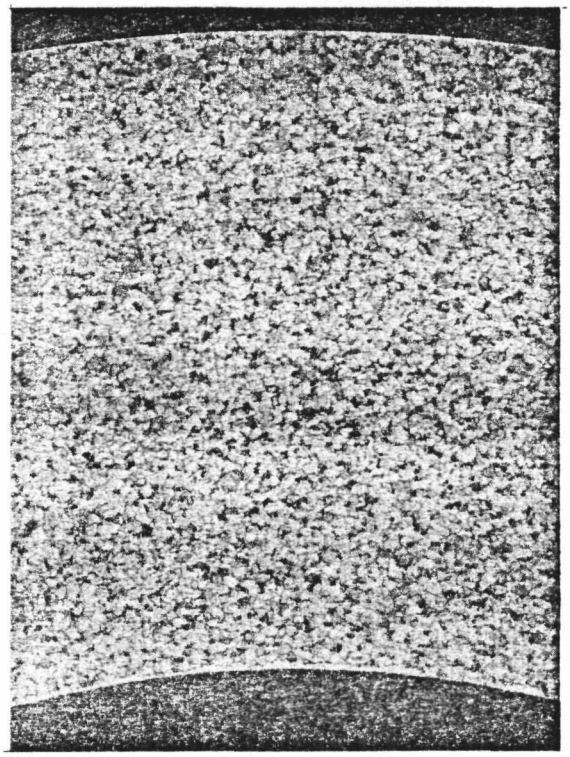
HEAT NO. 55262 (VAR)

MFG. CarTech

OD (in.) $.625^{+.005}_{-.0}$, WALL (in.) $.109^{+.010}_{-.0}$

P.O. NO. 190-C8V13G, Item 1

SECTION Transverse



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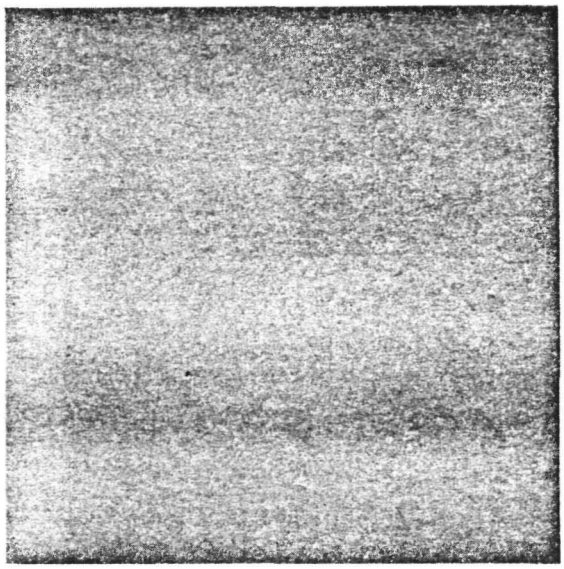

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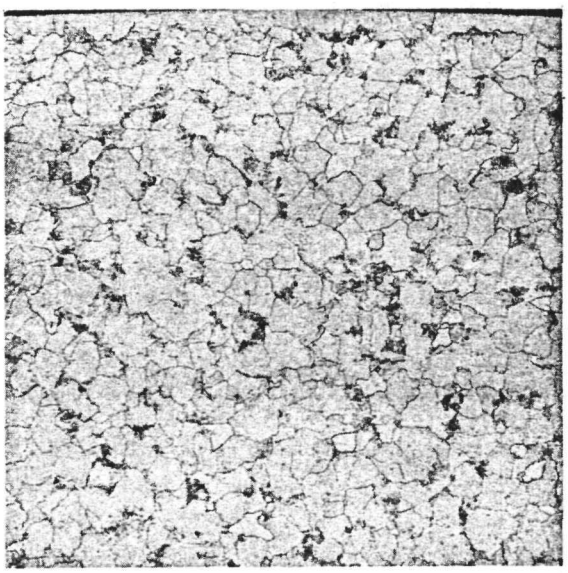

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ALLOY ASME SA-213, Gr. T-22

HEAT TREATMENT Isothermal Anneal

TEMPER None

HEAT NO. 55262 (VAR)

MFG. CarTech

OD (in.) .625 +.005 -.0, WALL (in.) .109 +.010 -.0

P.O. NO. 190-C8V13G Item 1

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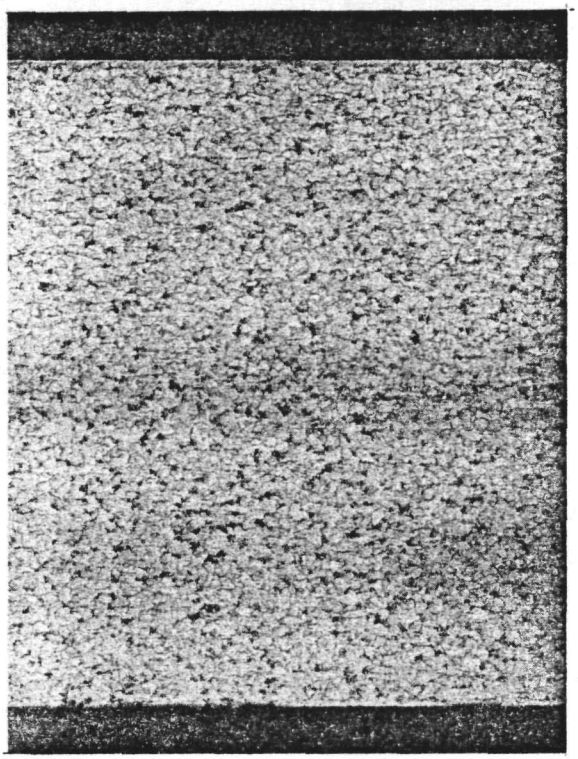

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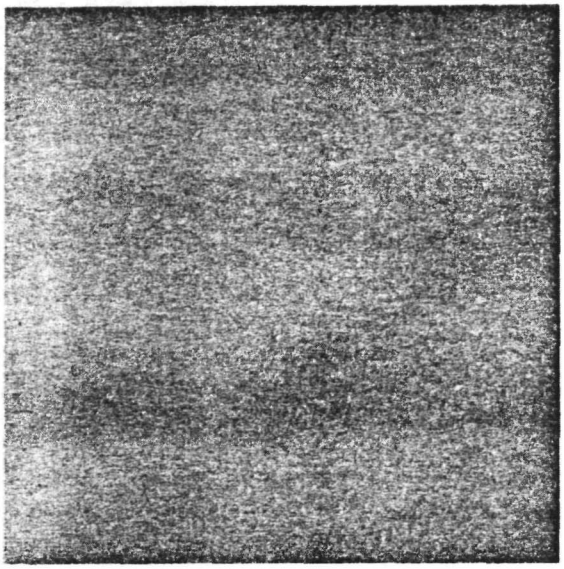

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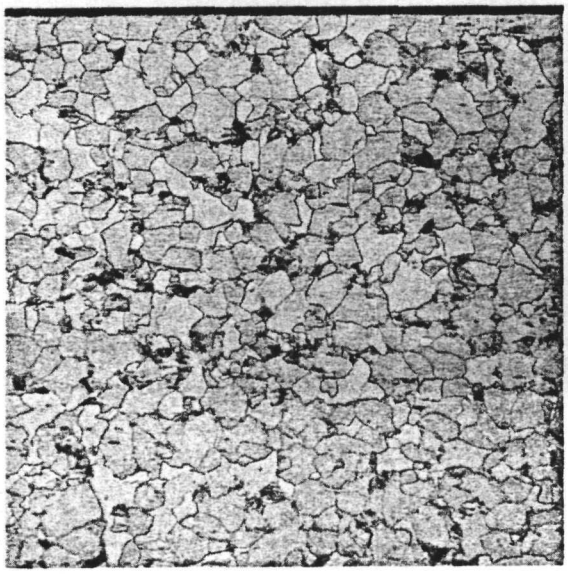

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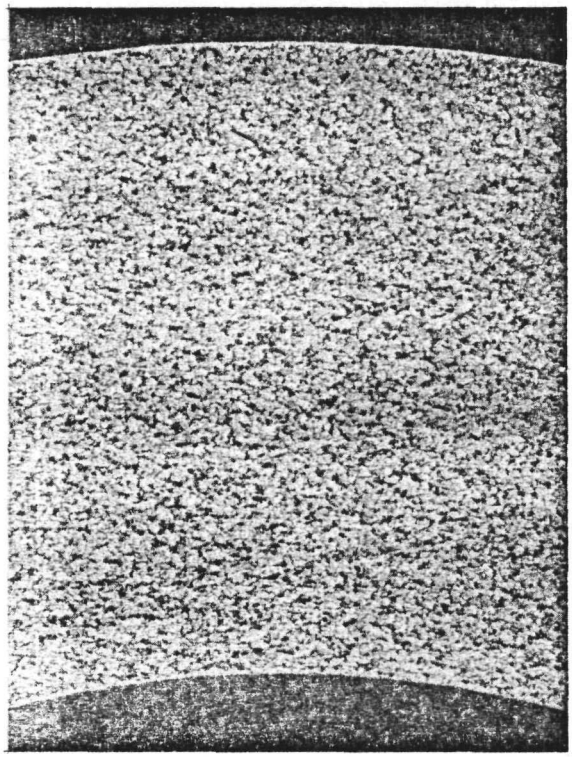
ALLOY ASME SA-213, Gr. T-22 MFG. CarTech

HEAT TREATMENT Isothermal Anneal OD (in.) $.625^{+.005}_{-.0}$, WALL (in.) $.109^{+.010}_{-.0}$

TEMPER None P.O. NO. 190-C8V13G, Item 3

HEAT NO. 91505 (ESR) SECTION Transverse



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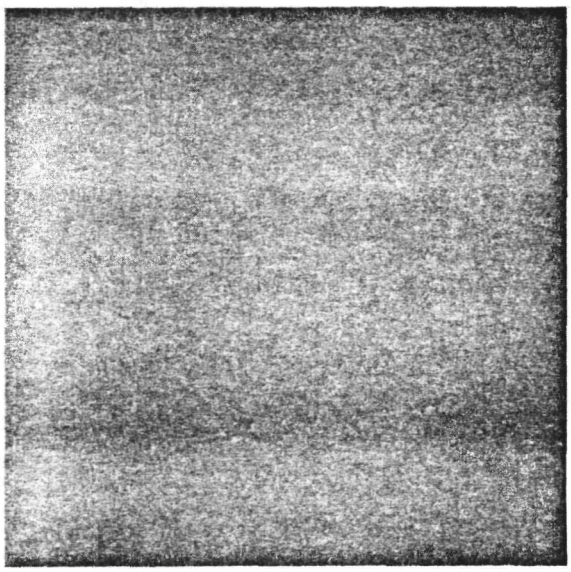

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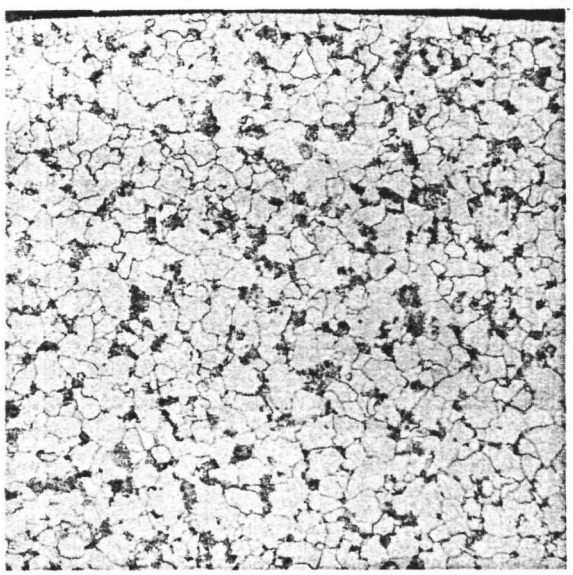

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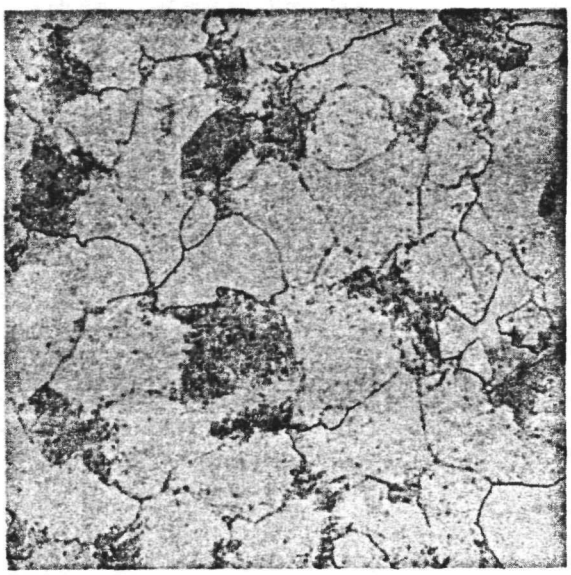

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ALLOY ASME SA-213, Gr. T-22

HEAT TREATMENT Isothermal Anneal

TEMPER None

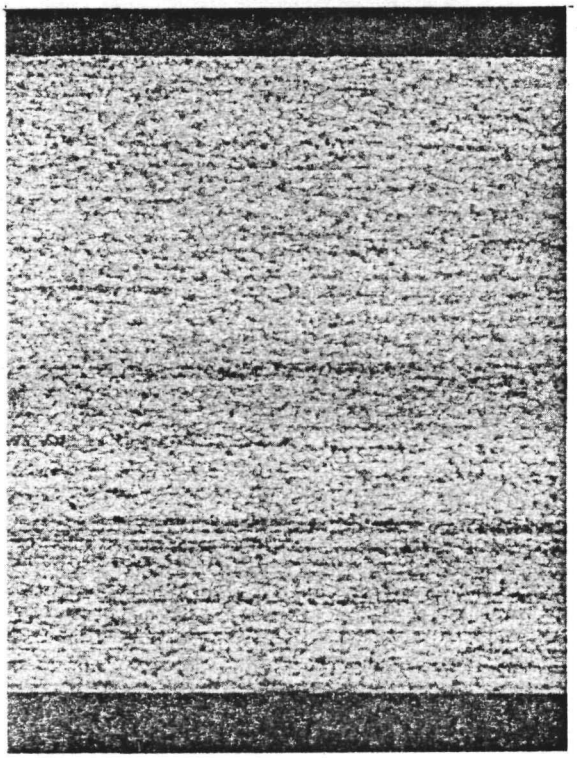
HEAT NO. 91505 (ESR)

MFG. CarTech

OD (in.) $.625^{+.005}_{-.0}$, WALL (in.) $.109^{+.010}_{-.0}$

P.O. NO. 190-C8V13G, Item 3

SECTION Longitudinal



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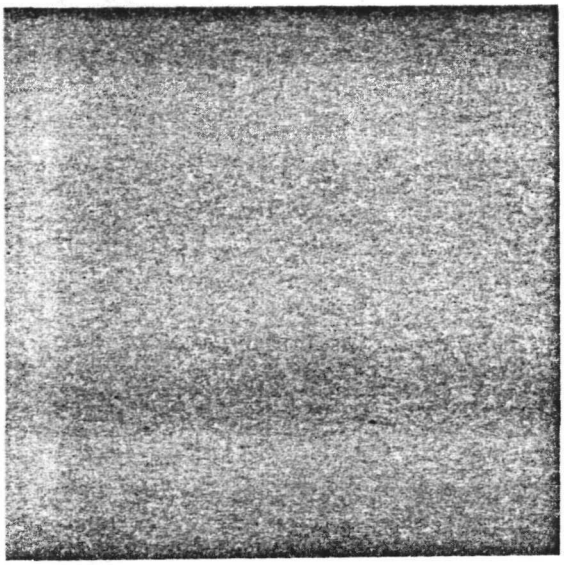

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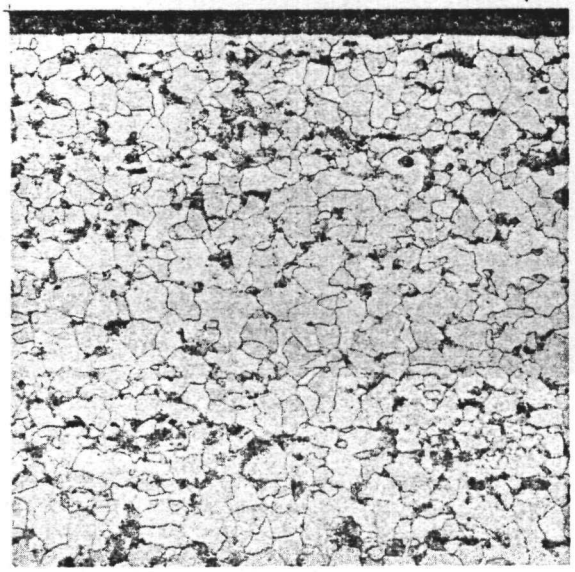

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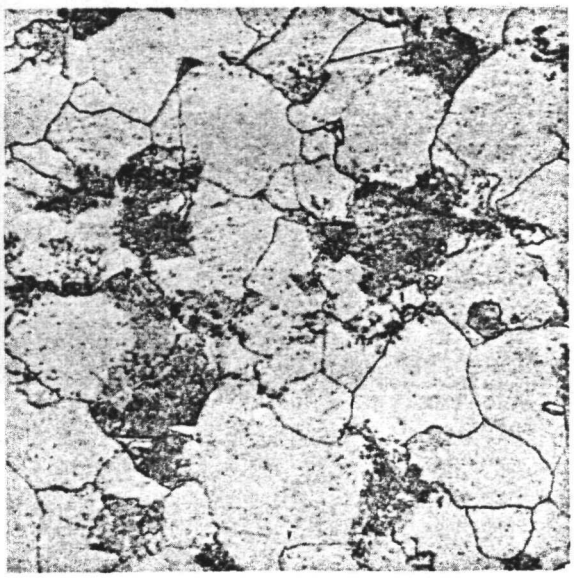

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ALLOY ASME SA-213, Gr. T-22

HEAT TREATMENT Isothermal Anneal

TEMPER None

HEAT NO. 91506 (VAR)

MFG. CarTech

OD (in.) $.625^{+.005}_{-.0}$, WALL (in.) $.109^{+.010}_{-.0}$

P.O. NO. 190-C8V13G, Item 2

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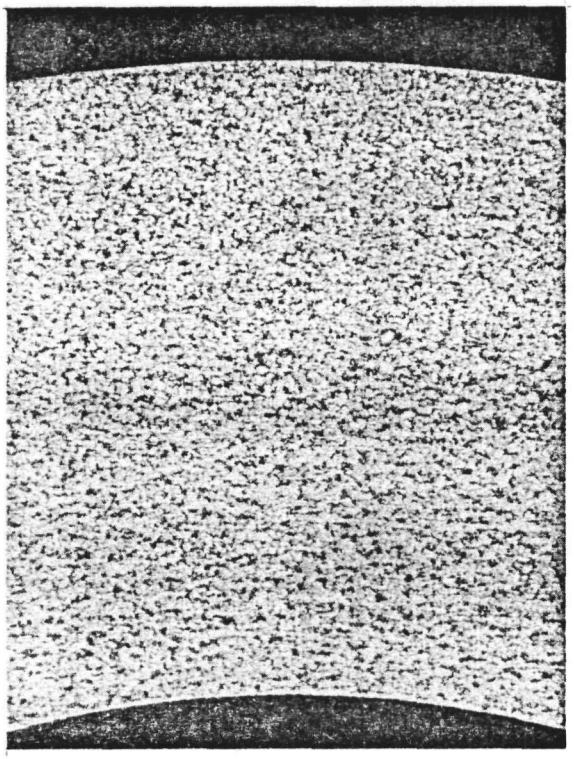

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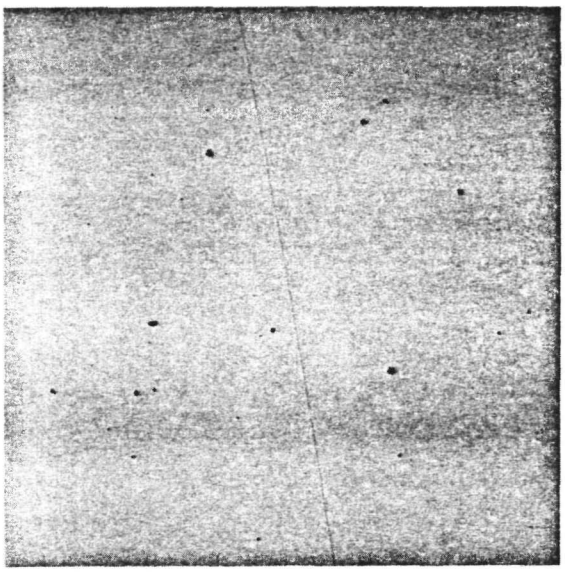

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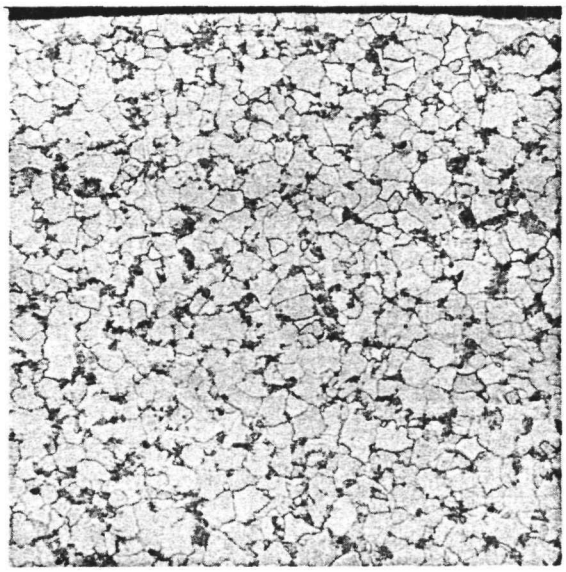

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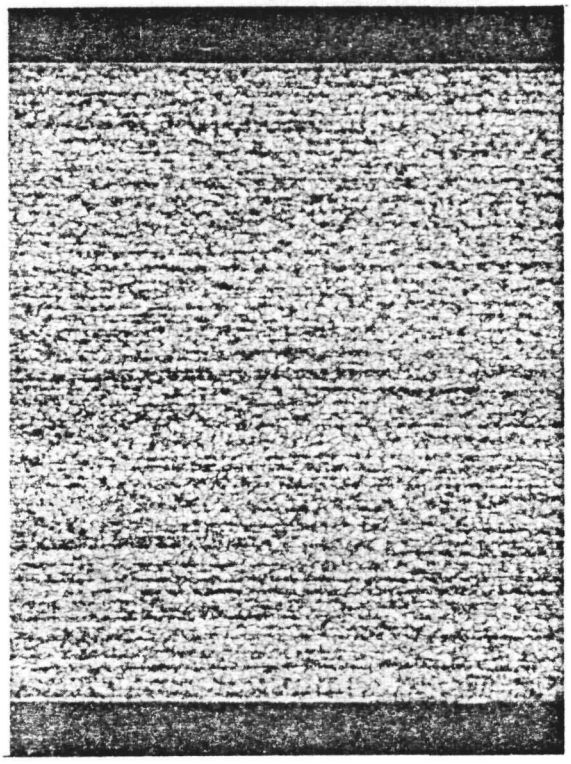
ALLOY ASME SA-213, Gr. T-22 MFG. CarTech

HEAT TREATMENT Isothermal Anneal OD (in.) $.625^{+.005}_{-.0}$, WALL (in.) $.109^{+.010}_{-.0}$

TEMPER None P.O. NO. 190-C8V13G, Item 2

HEAT NO. 91506 (VAR) SECTION Longitudinal



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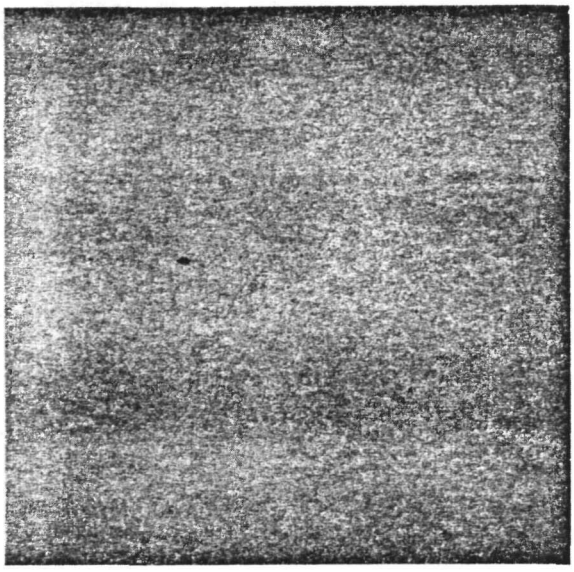

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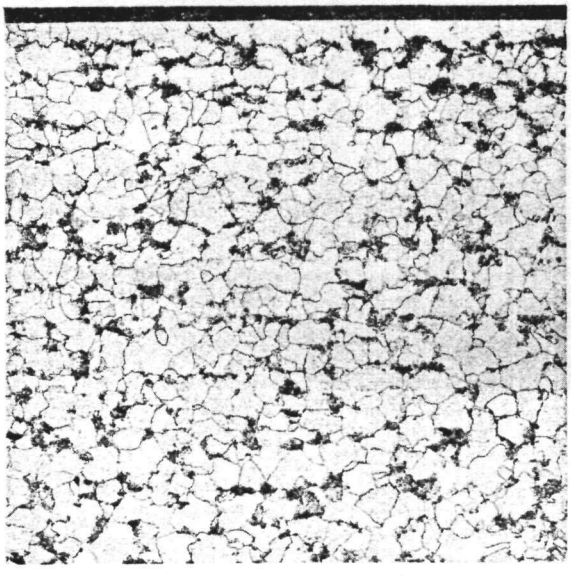

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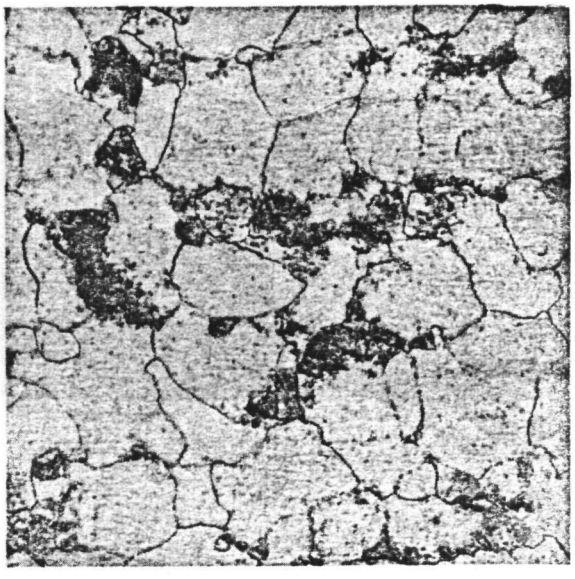

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TABLE I

ORDERING SPECIFICATIONS FOR CRBRP STEAM GENERATOR TUBING

	ITEM	ASME CODE SECTION III CLASS 1	RDT M3-33
1.	Basic Specification	ASME SA-213	ASME SA-213
2.	Melt Practice	Electric Furnace	VAR or ESR
3.	Inclusions	Not Specified	< 1½ Thin < 1 Heavy
4.	Manufacture	Seamless Cold Drawn	Seamless Cold Drawn or Cold Reduced
5.	Heat Treat	Slow Cooling thru A_3 - A_1 or Normalized + Temper (≥ 1250F)	1700F/½ hr. + 1300F/2 hr.
6.	Chemical Composition	SA-213 Grade T22	SA-213 Grade T22 + C, P, Si, S, Ni, Ti, V, Cu
7.	O.D. Tolerance	+0.004 -0.004	+0.005 -0
8.	Wall Tolerance	+0.02 -0	+0.010 -0
9.	Decarburization (Total)	Not Specified	5% Wall 0.0055
10.	Ultra. Test, Wall	Not Specified	SE-113
11.	Ultra. Test, Defects	5% Wall 0.0055	3% Wall 0.0033
12.	Liquid Penetrant	Not Specified	SE-165 A2, A3, B2 or B3
13.	Hydro. Test	1000 psi	4500 psi
14.	Helium Leak Check	Not Specified	ASME Code Section V
15.	Surface Finish	Not Specified	63 rms
16.	Tensile Properties		
	Y.S. U.T.S. Elong.	30 ksi min. 60 ksi min. 30% min.	30 ksi min. 60 - 85 ksi 30% min.
17.	Hardness	85 R_b max.	85 R_b max.
18.	Quality System	ASME Code NA-3700	ASME Code NA-3700

TABLE II

CHEMICAL ANALYSIS OF STEAM GENERATOR TUBING

Heat Identity	Melt Shop	CHEMICAL ANALYSIS (w/o) C	Mn	Cr	Mo	Si	P	S	Ni	Cu	Ti	V
RDT M3-33		0.07 to 0.110	0.30 to 0.60	1.90 to 2.60	0.87 to 1.13	0.20 to 0.40	0.015 max.	0.015 max.	0.25 max.	0.35 max.	0.03 max.	0.03 max.
55262 (VAR)[1]	CIW											
Ladle		0.09	0.52	2.22	1.01	0.08	0.016	0.014	--	--	--	--
Product		0.086	0.52	2.21	1.01	0.12	0.015	0.014	0.16	0.12	0.01	0.02
Check		0.099	0.50	2.26	1.00	0.07	0.013	0.016	0.15	0.09	<0.01	0.013
91505 (ESR)	CarTech											
Ladle		0.089	0.46	2.27	1.02	0.25	0.011	0.004	0.05	0.06	0.01	0.01
Product		0.092	0.45	2.30	1.01	0.25	0.007	0.004	0.05	0.05	<0.01	0.01
Check		0.087	0.47	2.31	0.99	0.26	0.007	0.003	0.05	0.04	<0.01	<0.01
91506 (VAR)	CarTech											
Ladle		0.097	0.42	2.31	1.02	0.36	0.011	0.005	0.06	0.05	0.02	0.01
Product		0.093	0.44	2.30	1.01	0.38	0.007	0.004	0.06	0.05	<0.01	-0.01
Check		0.102	0.42	2.32	1.00	0.32	0.007	0.008	0.06	0.04	<0.01	<0.01

[1] Silicon is out of specification requirements for all analyses. P and S were out of specification for Ladle and Check analyses, respectively.

TABLE III

RESULTS FROM METALLOGRAPHIC EXAMINATION

OF REMELTED ASME SA-213, GRADE T22 TUBING

Heat Number	Ferritic ASTM Grain Size	Inclusion Rating ASTM E-45 Method-D Worst Field							
		A		B		C		D	
		Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick
RDT M3-33	Not Specified	1.5 Max.	1.0 Max.	1.5 Max.	1.0 Max.	1.5 Max.	1.0 Max.	1.5 Max.	1.0 Max.
55262 (VAR)	6.5	---	---	2.5	1.5	---	---	1.0	---
91505 (ESR)	6.5	1.0	---	1.5	---	---	---	1.5	---
91506 (VAR)	6.5	0.5	---	1.5	---	---	---	1.0	---

TABLE IV

RESULTS FROM MECHANICAL TESTING

OF REMELTED ASME SA-213, GRADE T22 TUBING

Heat Number	Hardness R_b	0.2% Offset Yield Stress MPa	(ksi)	Ultimate Tensile Stress MPa	(ksi)	Elongation in 2 Inches (%)
RDT M3-33	≤ 85	207	(≥ 30)	414 to 586	(60 to 85)	≥ 30
55262 (VAR)	74	264	(38.3)	481	(69.8)	35
	76	264	(38.3)	485	(70.4)	36
	77	264	(38.3)	490	(71.1)	34
91505 (ESR)	67	337	(48.9)	472	(68.5)	38
	66	336	(48.8)	467	(67.8)	38
	64	265	(38.5)	471	(68.3)	35
91506 (VAR)	74	289	(41.9)	501	(72.6)	38
	73	301	(43.7)	505	(73.3)	36
	67	297	(43.1)	500	(72.5)	38

TABLE V

TOTAL HEAT TREATMENT OF BIAXIAL TEST SPECIMENS

1. Isothermal Heat Treatment

1700F±25F, hold for ½ hour minimum
Cool to 1300F, hold for 2 hours minimum
Cool to room temperature.

2. Temper Heat Treatment

1340F±35F, hold for 1 hour minimum
Cool to room temperature.

3. Post Weld Heat Treatment

1340F±35F, hold for 20 hours minimum
Heating rate not to exceed 150F/hour
Cooling rate not to exceed 200F/hour.

TABLE VI

BIAXIAL BURST TEST RESULTS

FOR REMELTED ASME SA-213, GRADE T22 TUBING[1]

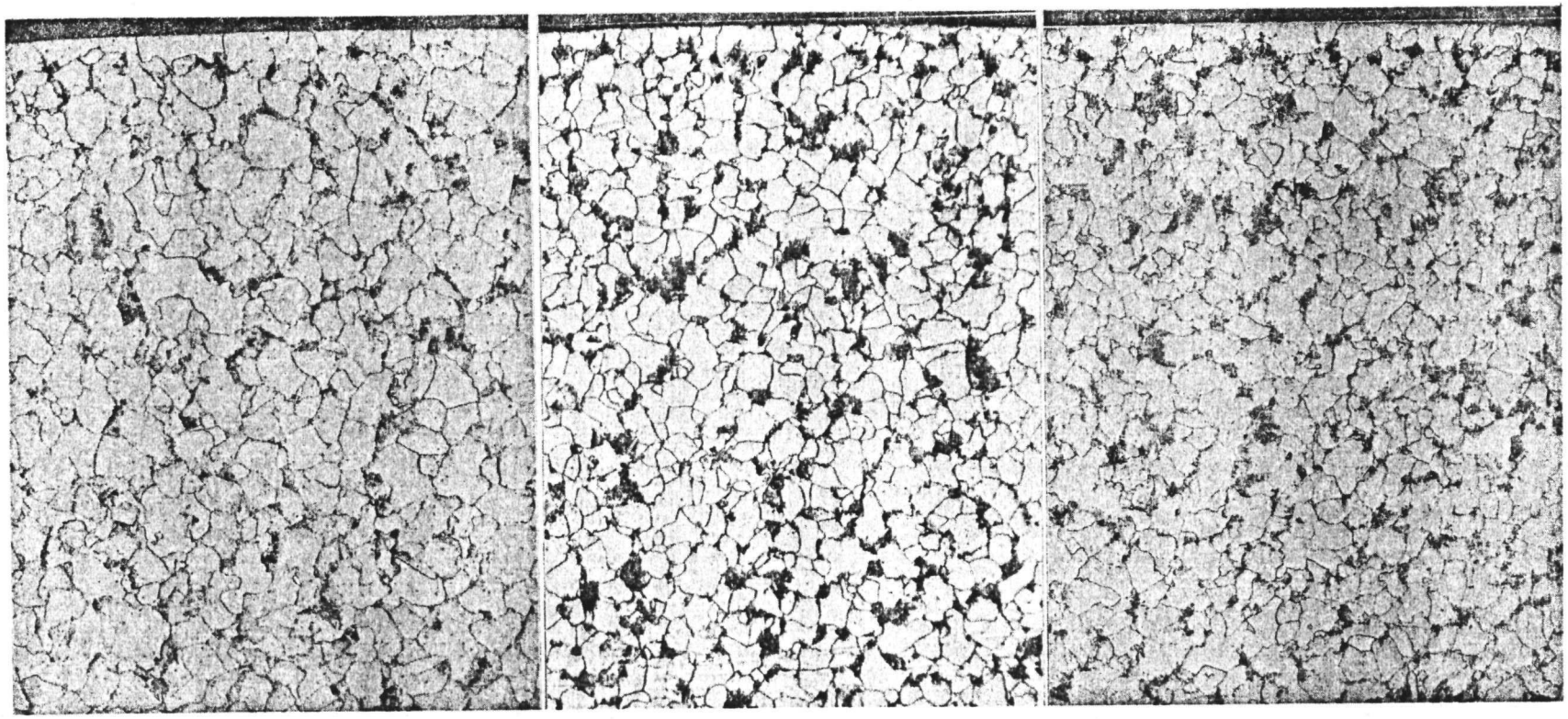
Specimen[2] Identity	Test Temp. °C	0.2% Offset Yield Stress MPa	(ksi)	Ultimate Burst Stress MPa	(ksi)	Burst Strain ($\Delta D/D_o$ %) Chart[3]	Final[4]
A-2	25	274	(39.8)	470	(68.2)	14.4	20.6
B-2	25	285	(41.4)	500	(72.5)	17.5	17.9
C-2	25	238	(34.5)	473	(68.6)	10.9	12.7
A-3	200	199	(28.9)	362	(52.5)	11.8	11.8
B-3	200	211	(30.6)	407	(59.1)	12.2	16.5
C-3	200	192	(27.9)	390	(56.5)	8.9	10.9
A-4	300	184	(26.7)	361	(52.3)	4.6	6.4
B-4	300	215	(31.2)	354	(57.3)	4.5	10.9
C-4	300	219	(31.8)	367	(53.2)	4.7	12.2
A-5	400	201	(29.1)	387	(56.1)	4.7	5.8
B-5	400	197	(28.5)	394	(57.2)	5.1	5.8
C-5	400	191	(27.7)	396	(57.4)	5.3	5.3
A-6	500	181	(26.2)	351	(50.9)	7.7	6.8
B-6	500	194	(28.2)	354	(51.4)	8.0	7.8
C-6	500	179	(26.0)	374	(54.2)	7.0	5.5
A-7	510	179	(25.9)	332	(48.1)	7.9	9.1
B-7	510	189	(27.4)	345	(50.0)	5.8	10.3
C-7	510	157	(22.8)	341	(49.5)	9.5	11.5
A-8	600	159	(23.0)	260	(37.7)	12.0	13.6
B-8	600	174	(25.3)	263	(38.2)	12.5	12.4
C-8	600	152	(22.1)	252	(36.6)	15.6	14.6

[1] Pressure rate during test = 1000 psi/minute
[2] All A specimens from lot 1 (VAR #55262), B specimens from lot 2 (ESR #91505), and C specimens from lot 3 (VAR #91506)
[3] Measured during test at time of rupture
[4] Measured after test on burst sample

TABLE VII

510°C CREEP RUPTURE TEST RESULTS FOR REMELTED ASME SA-213, GRADE T22 TUBING

Specimen	Pressure MPa (PSI)	Initial Hoop Stress MPa (KSI)	Time to Rupture (hrs.)	Measured Strain Time Under Pressure (%/hr.)	Burst Strain (%)
Lot 1 (Heat #55262)					
A18	44.7 (6490)	252 (36.5)	25		18
A19	44.7 (6490)	252 (36.5)	20		26
A20	37.3 (5410)	210 (30.4)	196		23
A21	37.3 (5410)	210 (30.4)	111	12.1/99	19
A22	37.3 (5410)	210 (30.4)	92		29
A23	29.9 (4330)	168 (24.3)	>645	1.0/141, 8.2/645	
A24	29.9 (4330)	168 (24.3)	553		32
A25	29.9 (4330)	168 (24.3)	607		38
A30	25.4 (3680)	143 (20.7)	>1500	2.8/690, 7.4/1541	
A31	25.4 (3680)	143 (20.7)	>1500	7.8/1626	
A32	25.4 (3680)	143 (20.7)	>1500	7.2/1626	
A26	22.4 (3250)	126 (18.3)	>3500	4.6/3590	
A27	22.4 (3250)	126 (18.3)	>3500	0.2/136;0.8/643;2.7/1980;6.1/3505	
A28	22.4 (3250)	126 (18.3)	>3500	8.0/3601	
A33	19.4 (2815)	109 (15.8)	>1400	5.7/1405	
A34	19.4 (2815)	109 (15.8)	>1400	6.1/1484	
A29	14.9 (2165)	84.1(12.2)	>1500	5.6/1674	
A16	14.9 (2165)	84.1(12.2)	>1500	0.1/161, 5.23/1592	
A17	14.9 (2165)	84.1(12.2)	>1500	5.6/1684	
Lot 2 (Heat #91505)					
B23	29.9 (4330)	168 (24.3)	492	2.4/140	26
B24	29.9 (4330)	168 (24.3)	626		26
B25	29.9 (4330)	168 (24.3)	>628	14.6/628	
B30	25.4 (3680)	143 (20.7)	>1500	2.7/690, 7.0/1543	
B31	25.4 (3680)	143 (20.7)	>1500	7.1/1626	
B32	25.4 (3680)	143 (20.7)	>1500	5.8/1607	
B26	22.4 (3250)	126 (18.3)	>2800	0.2/140;0.5/709;0.9/1306;7.5/2855	
B27	22.4 (3250)	126 (18.3)	>2800	1.0/738, 1.4/1358, 6.6/2961	
B28	22.4 (3250)	126 (18.3)	>2800	2.1/2996	
B19	19.4 (2815)	109 (15.8)	>1300	4.9/1242	
B20	19.4 (2815)	109 (15.8)	>1400	6.0/1483	
B16	14.9 (2165)	84.1(12.2)	>1600	0/161, 5.4/1594	
B17	14.9 (2165)	84.1(12.2)	>1600	5.5/1674	
B29	14.9 (2165)	84.1(12.2)	>1600	5.6/1674	
Lot 3 (Heat #91506)					
C23	29.9 (4330)	168 (24.3)	>622	1.1/142, 5.7/622	
C24	29.9 (4330)	168 (24.3)	628		26
C25	29.9 (4330)	168 (24.3)	628		28
C30	25.4 (3680)	143 (20.7)	>1500	1.9/671, 5.4/1525	
C31	25.4 (3680)	143 (20.7)	>1500	5.4/1607	
C32	25.4 (3680)	143 (20.7)	>1500	2.6/1607	
C26	22.4 (3250)	126 (18.3)	>2800	0.3/164;1.2/732;2.0/1352;3.67/2880	
C27	22.4 (3250)	126 (18.3)	>2800	4.41/2961	
C28	22.4 (3250)	126 (18.3)	>2800	4.35/2995	
C19	19.4 (2815)	109 (15.8)	>1200	6.1/1243	
C20	19.4 (2815)	109 (15.8)	>1300	5.7/1486	
C16	14.9 (2165)	84.1(12.2)	>1600	0.06/161, 5.4/1595	
C17	14.9 (2165)	84.1(12.2)	>1600	5.5/1674	
C29	14.9 (2165)	84.1(12.2)	>1600	5.5/1674	



LOT NO. 1
55262
VAR

LOT NO. 2
91505
ESR

LOT NO. 3
91506
VAR

Figure 1 Microstructure of 2-1/4 Cr-1 Mo Alloy Tubing Isothermally Annealed by Cartech

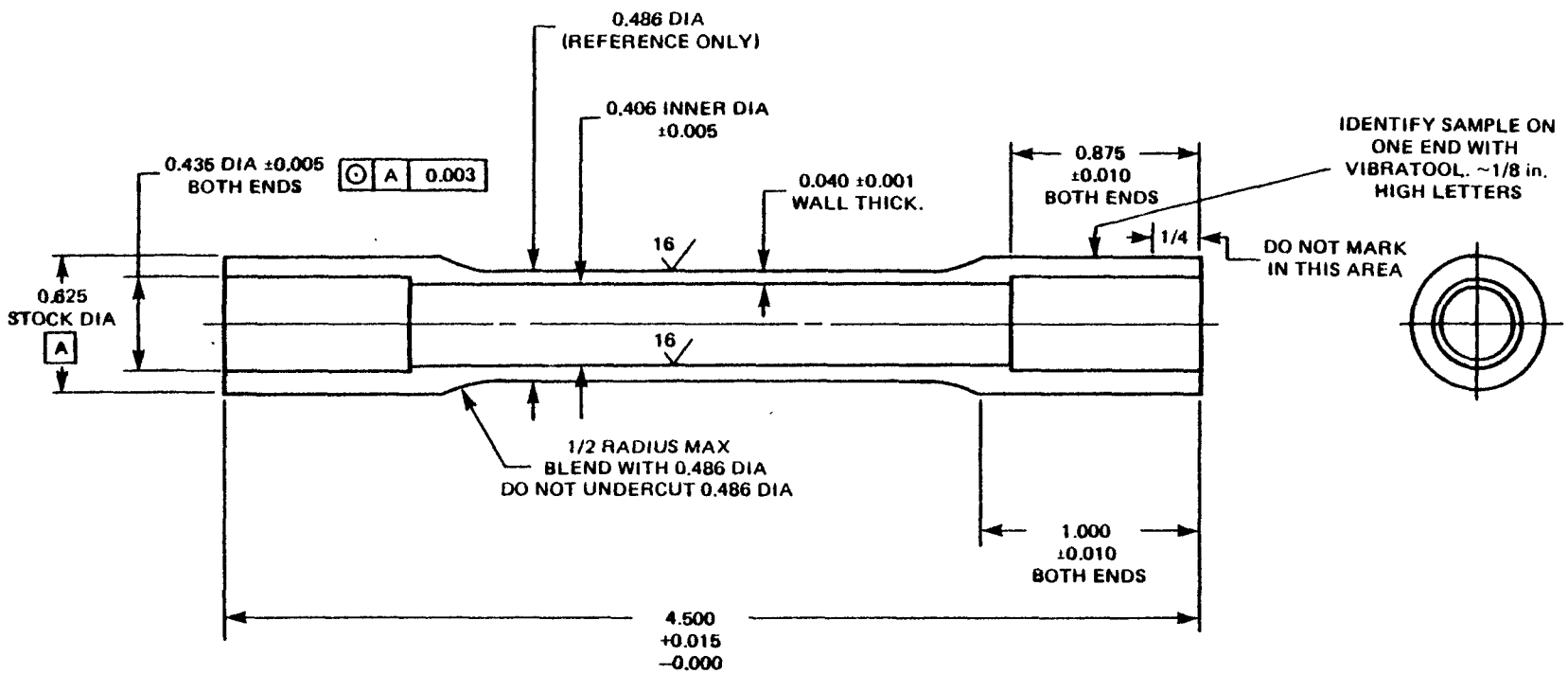


Figure 2. Biaxial Test Specimen

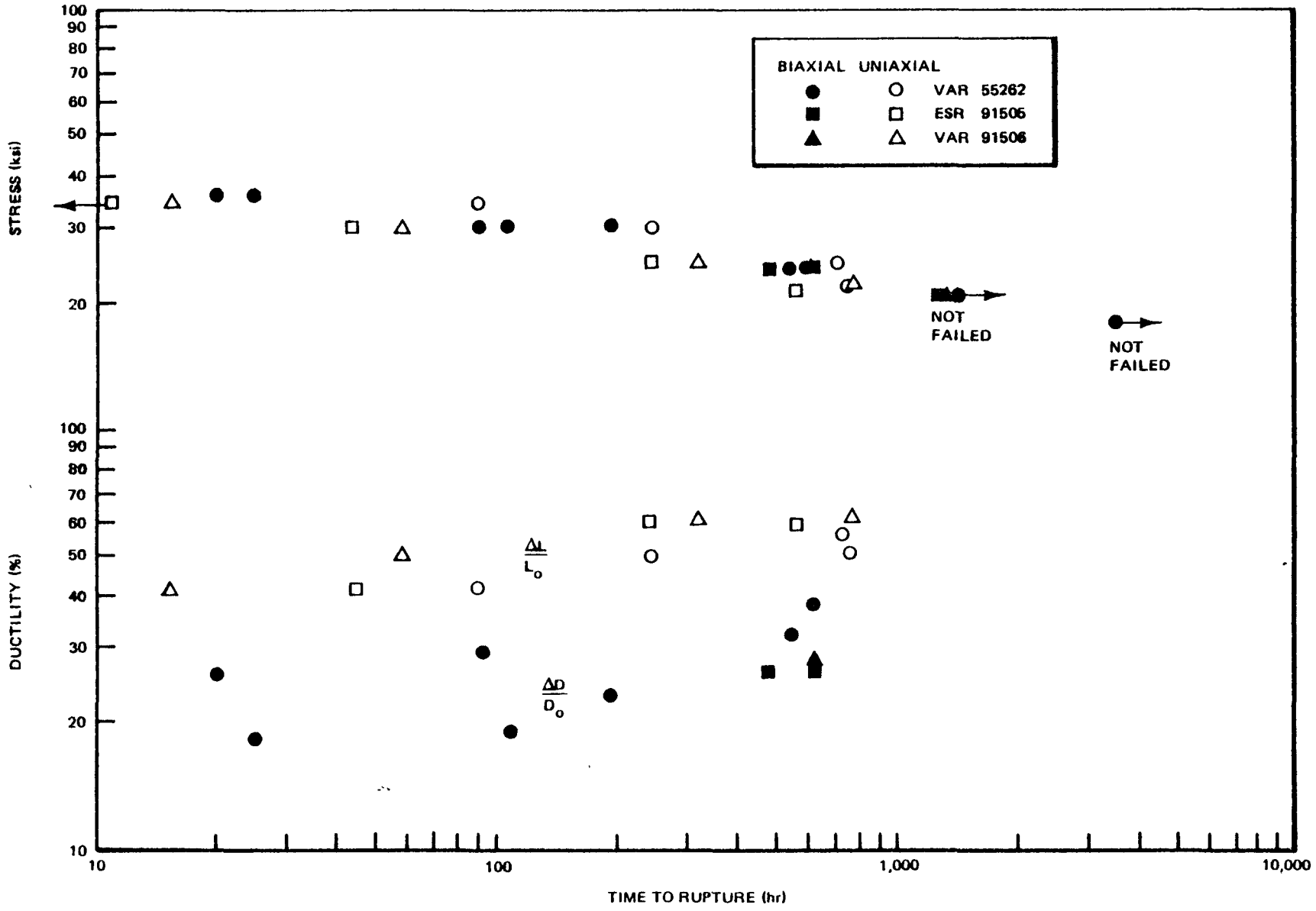


Figure 3. Comparison of Biaxial and Uniaxial Stress Rupture Data for Remelted 2-1/4 Cr - 1 Mo Alloy