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DISCLAIMER

SUMMARY

1. Combustion Engineering, Inc.

Four (4) 3" O.D. x 0.470" nominal wall thickness (NWT) hot rotary pierced/roll reduced modified AOD/ESR tube hollows were cold pilger reduced through one pass to 2" O.D. x 0.250" NWT tubing. Two (2) additional hollows of same size and process history were cold pilger reduced through one pass to 2 1/8" O.D. x 0.200" NWT. Six (6) 3 3/4" O.D. x 0.600" NWT hot extruded tube hollows were cold pilger reduced through two passes to 2" O.D. x 0.250" NWT tubing. Four of the extrusions represented duplex AOD/ESR melting practice and two extrusions represented AOD melting practice. Twelve (12) pieces of 2 1/8" O.D. x 0.200" NWT x ∿9' long tubing were final heat treated, straightened, and ultrasonically tested. Twelve (12) more pieces of 2 1/8" O.D. tubing have been solution austenitized (1177°C) and are to be reaustenitized (1066°C), tempered (760°C), straightened, and ultrasonically inspected. All 2" O.D. x 0.250" NWT tubing is in the solution austenitized condition.

A purchase order was placed with Universal Cyclops Specialty Steel Division, Cyclops Corporation, for the ESR remelting of three (3) AOD electrode ingots and conversion of ESR ingots to plate and bar. Electrode ingots were originally produced from a nominal 15T AOD heat by the Electralloy Corporation, Oil City, Pennsylvania. Negotiations have been initiated with both the Bethlehem Steel Corporation and the Phoenix Steel Corporation for conversion of nominal 19" rounded square Electralloy AOD ingots to bar and pipe respectively.

Creep and stress rupture testing has continued on aged material from CarTech heat 91887 and on unaged material from CarTech heat 30182A.

1. C-E POWER SYSTEMS
Combustion Engineering, Inc.

C. T. Ward

1.1 INTRODUCTION

Comprehensive development by Combustion Engineering Metallurgical and Materials Laboratory (C.E.-MML), under contract to ORNL, established a modified 9Cr-1Mo ferritic alloy with improved elevated temperature strength, weldability, and ambient temperature fracture toughness. The development activity included evaluation of data obtained from test specimens representing numerous flat rolled and tubular sections produced from laboratory heats, one pilot commercial size argon oxygen decarburized (AOD)/electroslag refined (ESR) heat, and four small (∿4 Ton) AOD heats. The detail of this development phase is included in references 1 through 8. The modified 9Cr-1Mo alloy development has been substantially scaled up with primary direction towards future acceptance as a viable and reliable commercial alloy. This effort has resulted in the successful conversion of commercial size AOD heats (15 Ton) to AOD and AOD/ESR ingots, in turn, converted to plate, round, and tubular product forms. In addition, several air induction melted (AIM) heats were centrifugally cast (CC) as hollows and converted by cold pilger reduction (CPR) to quality tubing. The success of these processing activities should establish modified 9Cr-1Mo alloy as a promising engineering material for energy systems application.

1.2 MATERIALS PROCESSING - G. C. Bodine

Combustion Engineering (C-E) Metallurgical and Materials Laboratory (MML) materials processing included:

(1) Production of cold finished 2" O.D. x 0.250" NWT tubing cold reduced by C-E Tubes from four (4) hot rotary pierced/roll reduced 3" O.D. x 0.470" W.T. tube hollows. Tube hollows had been previously converted by the Timken Co. from rounds rolled from CarTech AOD/ESR heats 30182 and 30394. Tubing presently is in the solution austenitized condition (1177°C 5 min./rapidly cooled in hydrogen furnace atmosphere). Tube inventory is shown in Table 1.1.

(2) Production of cold finished 2 1/8" O.D. x 0.200" NWT tubing cold reduced by C-E Tubes from two (2) hot rotary pierced/roll reduced as in (1) above. Twelve pieces, 2 1/8" O.D. x 0.200" NWT x 7-8', have been solution austenitized (1177°C), reaustenitized at 1066°C for 15 min. and tempered at 760°C for one (1) hour. Four (4) additional pieces, 2 1/8" O.D. x 0.200" NWT x 25-26', have been solution austenitized. Tube inventory is shown in Table 1.2.

(3) Production of cold finished 2" O.D. x 0.250" NWT tubing cold reduced by C-E Tubes from six (6) hot extruded 3 3/4" O.D. x 0.600" NWT tube hollows. Tube hollows had been previously converted by AMAX Specialty Metals from 9" diameter extrusion billets machined from round bar press forged from CarTech AOD/ESR heats 30182 and 30394; and from CarTech AOD heat 30383. Twelve (12) pieces of 2" O.D. tubing, 16-17' long, have been solution austenitized at 1177°C. Tubing inventory is shown in Table 1.3.

(4) A purchase specification was prepared for ESR remelting of three (3) 18" diameter AOD electrode ingots (reference 8) and for conversion of the ESR ingots to bar and plate. Universal Cyclops Specialty Steel Div., Cyclops Corp., has accepted a purchase order for ESR remelting and conversion of ESR ingots to:

a. 8" thick forged and ground slab.
b. 2" thick x 24" wide ground plate.
c. 9 1/2" diameter forged round bar.
d. 5" square bar.

Plates are to be furnished in the annealed/ground condition and bars are to be provided in the as forged/annealed/straightened condition.

(5) Preliminary negotiations have been made with Bethlehem Steel Corp. and Phoenix Steel Corp. for conversion of Electralloy 19" rounded square AOD ingots (reference 8). Conversion products are intended to be bar from Bethlehem and pipe from Phoenix.

Process format for the production of cold reduced tubing is shown in Figure 1.1. Cold workability of the hot rotary pierced/roll reduced hollows and of the hot extrusions was found to be very satisfactory. No difficulties were encountered during the pass reductions which were as much as 65% reduction in area per pass. Ultrasonic inspection results of twelve pieces of 2 1/8" O.D. tubing reduced from hot rotary pierced/roll reduced hollows detected no rejectable defects (1" x 5% wall thickness depth O.D./I.D. notch calibration standard, double circumferential shear wave, 2 1/4 MHz search unit) except for one at the end extremity of one tube. This defect was found to be of mechanical origin and not related to any material deficiency.

Table 1.1. C-E MML Inventory of 2" O.D. x 0.250" W.T. Tubing Cold Reduced from 3" O.D. x 0.470" NWT Rotary Pierced Tube Hollows.

Ht. No.	Tube Identity	Length	Condition
30182	A-A	19' 2"	Solution austenitized at
30182	A-B	19' 1"	2150F 5 min. at heat
30182	B-A	19' 8"	" " "
30182	B-B	18' 7 1/2"	" " "
30394	A-A	22' 1 3/4"	" " "
30394	A-B	23'	" " "
30394	B-A	23' 5 1/2"	" " "
30394	B-B	23' 2"	" " "

Table 1.2. C-E MML Inventory of 2 1/8" O.D. x 0.200" W.T. Tubing Cold Reduced from 3" O.D. x 0.470" NWT Rotary Pierced Tube Hollows.

Ht. No.	Tube Identity	Length	Condition
30182	C1A	7'	Solution austenitized
30182	C1B	8'	at 2150F and normalized
30182	C1C	7' 3"	at 1950F 15 min. at
30182	C2A	7' 11 1/2"	heat and tempered at
30182	C2B	8'	1400F 1 hour at heat.
30182	C2C	7' 8"	" " "
30394	C1A	7' 9"	" " "
30394	C1B	7' 8 3/4"	" " "
30394	C1C	7' 8 3/4"	" " "
30394	C2A	7' 8"	" " "
30394	C2B	7' 8 3/4"	" " "
30394	C2C	7' 7"	" " "
30182	DA	25' 3"	Solution austenitized
30182	DB	25' 7"	at 2150F.
30394	DA	25' 2"	" "
30394	DB	26' 3"	" "

Table 1.3. C-E MML Inventory of 2" O.D. x 0.250" W.T. Tubing Cold Reduced from 3 3/4" O.D. x 0.600" NWT Hot Extruded Tube Hollows.

Ht. No.	Tube Identity	Length	Condition
30182	2-8	16' 7 1/2"	Solution austenitized
30182	2-8A	16' 11"	" "
30182	2-6	17' 6 1/2"	" "
30182	2-6A	17' 3"	" "
30394	4-14A	16' 6"	" "
30394	4-14	16' 5"	" "
30394	4-14FA	16' 4"	" "
30394	4-14F	16' 5"	" "
30383	3-3A	17' 4"	" "
30383	3-3	17' 7 1/2"	" "
30383	3-3F	17' 8 3/4"	" "
30383	3-3FA	17' 7"	" "

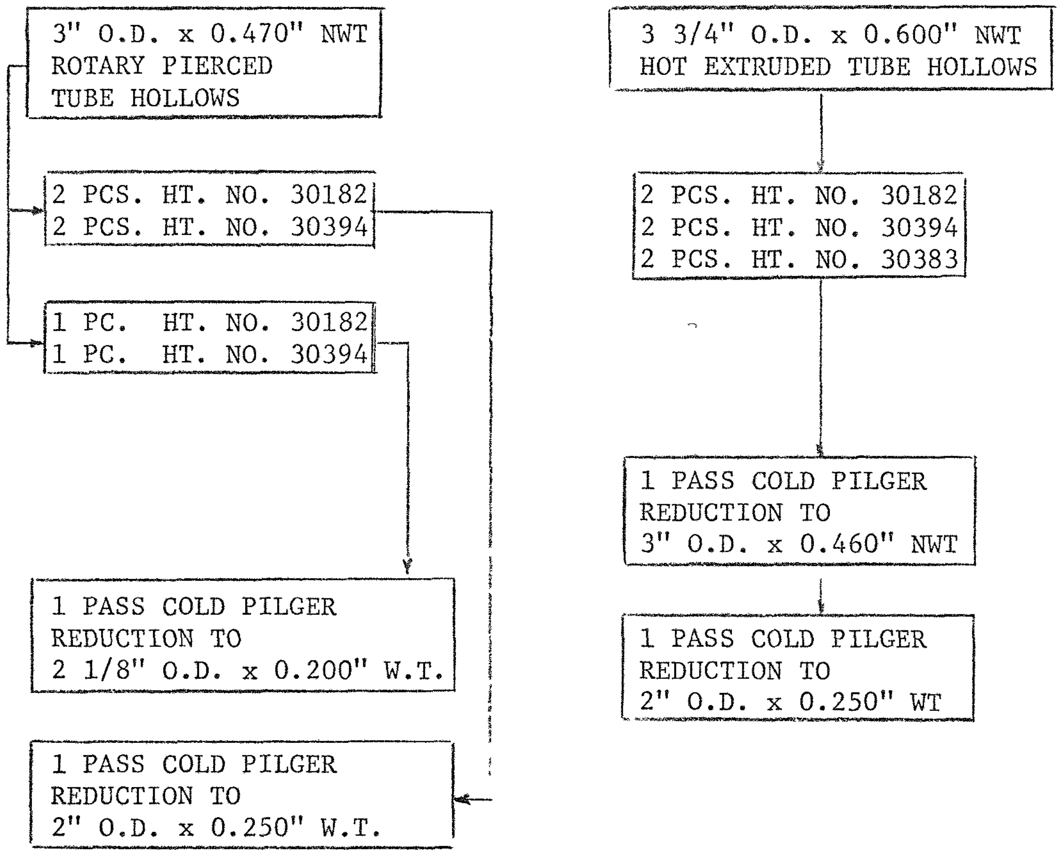

Figure 1.1. Format for cold pilger reduction of hot worked annealed tube/hollows.

1.3 CREEP AND STRESS RUPTURE TESTING - B. W. Roberts

In this six-month's reporting period, a modest experimental program has continued at C-E on aged material from heat 91887 and on the commercial size ESR Cartech heat 30182A. Updated results obtained from analysis of the individual creep curves are shown in Table 1.4. The tabulated values for the end of primary and onset of tertiary are total strains based on a visual assessment of the creep curve and are reasonably dependent on the judgment of the analyst. The values for onset of tertiary creep based on the 0.2% offset definition give more reproducible results.

Sample EXDT for heat 30182A, which is being tested at 7 ksi and 1250°F, is the final test for this isotherm. Based upon a visual isothermal extrapolation of the four other tests at 1250°F, this test should last approximately 28,000 hours which will require two more years of testing.

Sample EXDU for heat 91887, lot "GU", is the final test to evaluate the influence of thermal aging on the creep properties. The "GW", "GV", and "GU" lots of heat 91887 were each taken from the same plate and aged for 10,000 hours at 1250°F, 1050°F and 850°F respectively prior to creep testing. Even though sample EXDU has not failed, the present duration is sufficient to indicate that aging at 850°F has no apparent deleterious influence on the rupture properties. It appears that sample EXDU will fail in the time range expected from prior tests on unaged material of lots "DP" and "WC" of heat 91887.

Table 1.4. Creep and Stress Rupture Results

Sample Ident.	Heat No.	Stress ksi	Temp. °F	Atm.	Ld. Str., in/in	End Primary Str., in/in	End Primary Time Hour	Min. Creep Rate, $Hr.^{-1}$	Secondary Intcpt., in/in	Onset Tertiary Str., in/in	Onset Tertiary Time Hour
EXDV	30182A	8.5	1250	Air	0.00058	0.0058	400	5.78×10^{-6}	0.0035	0.0193	2700
EXDT	30182A	7	1250	Air	0.00051	(A)	(A)	(A)	(A)	(A)	(A)
EXDU	91887GU	15	1200	Air	0.00084	0.0045	900	1.59×10^{-6}	0.0031	0.0112	5000

Sample Ident.	Heat No.	Stress ksi	Temp. °F	Atm.	0.2% Offset Str., in/in	Tertiary Time Hrs.	Time to 1% Total	Rupture Time, Hrs.	Rupture Elong.,%	Red. in Area, %
EXDV	30182A	8.5	1250	Air	0.0270	3704	1110	5697	21	87
EXDT	30182A	7	1250	Air	(A)	(A)	(A)	>9100	(A)	(A)
EXDU	91887GU	15	1200	Air	0.0163	7054	4373	>7700	(A)	(A)

NOTES: Primary and tertiary strains are total strains.

Elongations for heats 30182A and 91887 are for gage lengths of 1 1/4 and 2 inches respectively.

(A) Test in progress.

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