FFTF PRIMARY PIPING FABRICATION COMPARISON

(RM-27)

By

J. M. Steichen

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J. J. Chaudron 10/15/72
Manager, Reactor Metals Date

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INTRODUCTION

The Rollmet fabrication process* is now being used to produce primary and secondary piping for the FFTF. The purpose of this study was to determine the effects of this process on the physical and mechanical properties of extruded pipe material. The material chosen for this evaluation was AISI Type 304 stainless steel. Techniques employed in this study include tensile, stress rupture, and corrosion tests and optical metallography. Results of these tests and metallography are presented in this report.

SUMMARY AND CONCLUSIONS

The effects of fabrication by the Rollmet process on annealed Type 304 stainless steel piping properties has been determined. Results of the completed evaluation indicate Rollmet fabrication enhances piping properties. General observations from the test results are as follows:

- Rollmet fabrication slightly enhances the tensile strength of piping material while maintaining good ductility.
- Stress rupture properties at 1050°F are significantly improved by Rollmet fabrication. This improvement is the result of increased ductility in the Rollmet material.
- The corrosion behavior of the base extrusion and Rollmet piping appear to be essentially the same.
- The grain size of the Rollmet piping was slightly finer than that of the base extrusion. The finer grain size may be responsible for the improvement in mechanical properties.

*The Rollmet fabrication process is a method for producing large diameter piping. This process forms piping by internal rollers working against a fixed external die ring (as with material in this study) or by external rollers working against a fixed internal mandrel.

Piping was fabricated by Rollmet, Inc., Santa Ana, California

TEST MATERIAL

The material selected for this fabrication study was Type 304 stainless steel. Details of the material selection have been reported previously⁽¹⁾ and have indicated that the material has a low carbon content (0.032%) which could result in the room temperature tensile strengths not meeting the minimum strengths required for Type 304 stainless steel piping per ASME SA-376. The chemical composition for the base material is listed in Table I.

The steel used for this study was obtained from Cameron Iron Works in the form of a heavy-walled extrusion. This extrusion was machined to the blank size required by Rollmet for production of 28-inch diameter pipe. A sample of the machined starting blank was sent to HEDL for evaluation and the remainder was then reduced to pipe by the Rollmet process. After reduction, a sample of the Rollmet pipe was also sent to HEDL for evaluation. Heat treatments performed on the samples of the base extrusion and Rollmet piping to be evaluated by HEDL are included in Table II.

EXPERIMENTAL PROCEDURE

The tensile tests on the base extrusion and Rollmet piping were performed on an Instron tensile machine at a strain rate of 0.008 in/in/min and temperatures from room temperature to 1200°F. Results from each test included the ultimate and 0.2% yield stress, total and uniform elongation, and reduction of area. All tests were performed in air in accordance with ASTM recommended practices E8-69 and E21-70. The tensile specimen geometry is illustrated in Figure 1. Detailed tensile tests procedures have been described previously.⁽²⁾

Constant load stress rupture tests were performed on the subject materials in air at a temperature of 1050°F. These tests were conducted at stress levels to produce specimen ruptures in approximately 1000 hours.

Information obtained from each test included the stress level, minimum creep rate, rupture time, and elongation at fracture. ASTM recommended practice E139-70 was used to perform these tests. An illustration of the stress rupture specimen is presented in Figure 1. Detailed test procedures for the stress rupture testing have also been described previously.⁽³⁾

The corrosion tests were performed on both materials to determine susceptibility to intergranular attack. The corrosion test which was employed is described in detail in ASTM A262-70, Part E. In brief, samples of the materials were exposed to a boiling copper-copper sulfate-sulfuric acid solution for 24 hours. After exposure to this solution, the specimens were bent through 180 degrees over a diameter equal to the thickness of the specimen. After bending, the specimens were examined for evidence of cracks.

RESULTS AND DISCUSSION

The results of the tensile, stress rupture, and corrosion tests and optical metallography on the base extrusion and Rollmet piping are described in the following sections.

Tensile Properties

The results of the room and elevated temperature tensile tests are listed in Table III and illustrated in Figures 2-5. In Figure 2, the effect of temperature on the 0.2% yield stress of the subject material is presented. Included in the figure are curves from G. V. Smith⁽⁴⁾ which indicate the minimum 0.2% yield stresses of 304 and 304L stainless steels. The 304L stainless steel curve is included for comparison because of the low carbon content of the base material. The data points from tests on the base extrusion and Rollmet piping fall on the line representing minimum behavior for

304L stainless steel. For all temperatures except 1050°F, the Rollmet piping exhibits higher strengths than the base extrusion. At 1050°F, the results of single tests on the two materials are essentially identical.

The ultimate stress of the tested materials is influenced by temperature as illustrated in Figure 3. At temperatures to 900°F, the strength of both materials is similar to the minimum 304 stainless steel behavior and at higher temperatures to the 304L stainless steel behavior. At all test temperatures the Rollmet piping exhibits higher strength than the base extrusion.

To illustrate more clearly the influence of the Rollmet process on the tensile strength of the 304 stainless steel, the test results have been replotted as presented in Figures 4 and 5. In these figures, the direct comparison between the base extrusion and Rollmet piping strength properties indicates that Rollmet fabrication enhances the tensile strengths of the base extrusion.

The tensile ductility (total and uniform elongation and reduction of area) of the subject materials does not appear to be greatly different as indicated by the values listed in Table III. For both materials, good ductility is observed at all test temperatures.

Stress Rupture Properties

Stress rupture results from tests at 1050°F on both materials are listed in Table IV and illustrated in Figures 6-9. In Figure 6, the stress vs. rupture life for the subject materials is presented. Curves included in the figure represent average and minimum stress rupture behavior for Type 304 stainless steel as presented in ASME Code Case 1331-5. Data for minimum behavior of 304L stainless steel was not available. The test results

in the figure indicate the stress rupture behavior of the base extrusion and Rollmet piping are similar to the minimum behavior for 304 stainless steel. The data for the Rollmet piping indicates this fabrication process enhances stress rupture properties. The test on the Rollmet piping at a stress level of 28,000 psi is in progress, the estimated rupture life is ~ 1230 hours.

The reason for the enhancement of stress rupture properties of the base extrusion by Rollmet fabrication is shown in Figures 7, 8, and 9. Stress vs. minimum creep rate plotted in Figure 7 indicates both materials have essentially the same stress dependence on minimum creep rate. Plotting minimum creep rate vs. time to rupture (Figure 8) indicates that for equivalent creep rates the Rollmet piping has significantly higher rupture lives. This increase in rupture life is the result of increased ductility in the Rollmet piping as dramatically illustrated in Figure 9.

Corrosion Behavior

Visual observation of the corrosion specimens after exposure to the copper-copper sulfate-sulfuric acid solution and subsequent bending indicated that no intergranular attack had occurred. To insure that visual observations were valid, optical metallography on one base extrusion specimen and one Rollmet specimen was performed. Results of this metallography (Figure 10) show that intergranular attack did not occur in either of the specimens. This corrosion behavior is as expected since the low carbon content of the test material would significantly reduce the potential for intergranular attack.

Optical Metallography

Optical metallography (Figure 11) indicates the Rollmet piping has a slightly finer grain size than the base extrusion. This grain refinement

may be responsible for the increased tensile and stress rupture properties of the Rollmet piping. Inclusions in the Rollmet piping are more elongated than those in the base extrusion and give the microstructure a wavy appearance. This appearance has been observed previously in cold formed stainless steel tubing.⁽⁵⁾

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TABLE I

CHEMICAL COMPOSITION OF TYPE 304 SS USED
FOR PRIMARY PIPING FABRICATION COMPARISON

Cameron Heat J-3185

C - 0.032	Cr - 19.02
Mn - 1.77	Ni - 10.55
P - 0.018	Mo - 0.03
S - 0.007	Co - 0.04
Si - 0.33	Cu - 0.11

TABLE II

HEAT TREATMENT OF TYPE 304 SS USED
FOR PRIMARY PIPING FABRICATION COMPARISON

Sample B001 - Primary Piping Extrusion (Prior to Rollmet Extrusion)

Size - 28.125 inch O.D. x 1.52 inch wall

Anneal - 1850°F for 2 hours - Argon fan cool to room temperature
(Attained 1000°F in ~ 15 minutes)

Sample B001-2 - Rollmet Primary Piping (After Rollmet Extrusion)

Size - 28.034 inch O.D. x 0.401 inch wall

Anneal - 1850°F for 45 minutes--water quenched.

TABLE III
TENSILE PROPERTIES FOR PRIMARY PIPING FABRICATION COMPARISON
TYPE 304 STAINLESS STEEL (0.032% C)

MATERIAL	TEST TEMP. °F	STRESS - KSI		ELONGATION - % (1.250 Gauge Length)		REDUCTION OF AREA %
		0.2% Yield	Ultimate	Total	Uniform	
Primary Piping Extrusion (Sample B001)	R.T.	25.17	75.84	78.6	70.8	83.6
	R.T.	24.92	77.94	68.6**	63.4	81.4
	700	14.14	55.65	50.8	46.4	76.6
	900	11.64	52.94	53.9	46.6	77.7
	1050	13.15	45.59	44.6	40.5	71.8
	1100	11.34	52.82	31.6	29.5	48.3
	1200	11.00	35.17	40.0	30.5	55.9
Rollmet Primary Piping (Sample B001-2)	R.T.	26.50	81.71	70.0**	63.6	85.4
	R.T.	26.07	82.13	90.3	83.5	85.2
	700	15.77	60.16	47.9	43.6	74.0
	900	13.85	57.62	43.9	40.0	76.2
	1050	12.95	49.67	41.6	36.6	75.4
	1100	12.21	45.90	40.7	34.4	66.4
	1200	12.26	36.29	42.4	29.5	53.2

** Fracture occurred outside gauge length.

TABLE IV

STRESS RUPTURE TEST RESULTS AT 1050°F FOR
PRIMARY PIPING FABRICATION COMPARISON
TYPE 304 SS (0.032% C)

MATERIAL	STRESS LEVEL KSI	RUPTURE TIME HOUR	MINIMUM CREEP RATE HOUR ⁻¹	ELONGATION AT FRACTURE %
Primary Piping Extrusion (Sample B001)	40	11.5	1.0×10^{-2}	33.0
	35	56.9	2.1×10^{-3}	26.4
	31	194.9	4.2×10^{-4}	18.1
	27	833.8	1.2×10^{-4}	19.4
Rollmet Primary Piping (Sample B001-2)	40	33.0	5.0×10^{-3}	36.8
	35	115.5	1.4×10^{-3}	32.4
	32	313.3	4.9×10^{-4}	31.2
	28	N.A.	1.2×10^{-4}	N.A.

N.A. = Not available, test in progress

STRESS RUPTURE SPECIMEN

TENSILE SPECIMEN

FIGURE 1. Configuration of the stress rupture and tensile specimens

PRIMARY PIPING FABRICATION COMPARISON
 TYPE 304 SS (0.032% C)
 CAMERON HEAT J-3185

FIGURE 2. Effect of Temperature on the 0.2% Yield Stress of the Base Extrusion and Rollmet Piping.

PRIMARY PIPING FABRICATION COMPARISON
TYPE 304 SS (0.032% C)
CAMERON HEAT J-3185

FIGURE 3. Effect of Temperature on the Ultimate Stress of the Base Extrusion and Rollmet Piping.

FIGURE 4. Comparison of the 0.2% Yield Stress of the Base Extrusion and Rollmet Piping.

PRIMARY PIPING FABRICATION COMPARISON
TYPE 304 SS (0.032% C)
CAMERON HEAT J-3185

FIGURE 5. Comparison of the Ultimate Stress of the Base Extrusion and Rollmet Piping

PRIMARY PIPING FABRICATION COMPARISON
TYPE 304 SS (0.032% C)
CAMERON HEAT J-3185

FIGURE 6. Stress Versus Time to Rupture Plot for the Base Extrusion and Rollmet Piping.

PRIMARY PIPING FABRICATION COMPARISON
TYPE 304 SS (0.023% C)
1050 °F
CAMERON HEAT J-3185

FIGURE 7. Plot of Stress Versus Minimum Creep Rate for the Base Extrusion and Rollmet Piping

FIGURE 8. Minimum Creep Rate Versus Time to Rupture for the Base Extrusion and Rollmet Piping

FIGURE 9. Effect of Rupture Time on the Ductility of the Base Extrusion and Rollmet Piping

Base Extrusion After Corrosion Testing
Bent Specimen - 50X
Neg. No. 472 - 1459

Rollmet Piping After Corrosion Testing
Bent Specimen - 50X
Neg. No. 472 - 1460

FIGURE 10. Metallography on the Base Extrusion and Rollmet Piping After Corrosion Testing.

Base Extrusion - 100X
Grain Size ~ ASTM 2-1/2
Neg. No. 472-1399C

Rollmet Piping - 100X
Grain Size ~ ASTM 3-1/2 - 4
Neg. No. 472-1355A

FIGURE 11. Metallography on the Base Extrusion and Rollmet Piping

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