MECHANICAL PROPERTIES OF SEVERAL PRODUCTS FROM A SINGLE HEAT
OF TYPE 304 STAINLESS STEEL¹

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Abstract

Tensile and stress-rupture tests were run on several products from a 90-ton heat of type 304 stainless steel. The yield stress of the products in the as-received condition varied from 26,500 to 57,200 psi at 75°F. There were significant differences between the strengths of various products and considerable variation for a single product due to nonuniform residual cold work. Reannealing 0.5 hr at 2000°F resulted in yield stresses in the 25,000 to 27,000 psi range; only the properties of the hot-reduced tubing fell below this range.

At a test temperature of 1100°F, the as-received products had yield stresses from 14,800 to 35,500 psi. Reannealing caused the yield stresses of all but three products to fall in the range 10,200 to 11,700 psi. Stress-rupture tests at 1100°F on the reannealed products did not reveal significant variation in properties.

Introduction

Although type 304 stainless steel has been used as a structural material for many years, its current and proposed use in nuclear systems presents new and more stringent operating conditions. Design rules must

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be conservative, yet realistic. Strength requirements and operating temperatures are now so high that the designer no longer can use very simple rules and large safety factors to cover the unknown. As new and more sophisticated design methods are developed, the need arises for an even greater degree of accuracy in materials property data. The detailed shapes of creep and tensile curves become of importance, and the wide scatter bands of data receive attention.

One factor that contributes to the scatter band of property data is the wide range of mechanical and thermal processing variables allowed in making a product. For example, the ASTM A240-70 specification for type 304 stainless steel plate states⁴ that "the chromium-nickel steels shall be heat treated to meet the mechanical property requirements of the specification and be capable of meeting the test for resistance to intergranular corrosion. . . ." The mechanical property requirements for type 304 stainless steel are that the material have a minimum tensile strength of 75,000 psi, a minimum yield strength of 30,000 psi, a minimum elongation of 40%, and a maximum hardness of 94 R_B. These properties can be obtained by a multiplicity of fabrication schedules involving various sequences of hot and cold working, annealing, and final straightening. The properties at elevated temperatures, where recovery and recrystallization can occur, are very dependent upon the amount of residual cold work in the plate.

In the present study 12 products from a single 90-ton heat of type 304 stainless steel were tested in tension at 75 and 1100°F and under stress-rupture conditions at 1100°F to investigate variations with product. Material

⁴1972 *Annual Book of ASTM Standards*, Part 3, American Society for Testing and Materials, Philadelphia, 1972, p. 135.

was tested in the as-received condition and after reannealing 0.5 hr at 2000°F. Ideally, one would correlate the property variations with the fabrication sequences used in making the products, but the details of the fabrication needed to do this are not available. However, the properties obtained in this study are useful since they were obtained on a large number of products from a single heat of material and, therefore, illustrates the variations that result only from fabrication and heat treatment.

Experimental Details

Material

The products included in this study were fabricated from one 90-ton electric-arc-melted heat of type 304 stainless steel. A brief description of each product is given in Table 1. The twelve products were of three basic forms: (1) plate from 3/8 to 2 in. thick, (2) bar from 1 3/4 to 4 1/2 in. in diameter, and (3) pipe (or tubing) from 2 1/2 in. to 8 5/8 in. (8 in. nominal) OD. Applicable ASTM and RDT standards are indicated in Table 1. Generally, the two standards differ only in that the RDT standard requires closer control of composition and additional inspection.

Hardness measurements were made before and after reannealing. A large range was noted for each as-received product, likely reflecting nonuniform working. After reannealing, the R_B hardness of all products decreased to the range 63 to 69.

A sample of each product was examined metallographically before and after reannealing. An oxalic acid etch was used to reveal the grain structure, and comparative grid charts were used to determine the ASTM grain size. The grain size of the as-received products ranged from 1-3 to 6-7 and that of the reannealed products from 1-2 to 4.

Each product was analyzed for carbon, oxygen and nitrogen. Carbon and nitrogen concentrations averaged 0.052 and 0.045%, respectively. Variations of both elements were within the limits of analytical error, except in the 1-in.-thick plate, which had a lower nitrogen content. Oxygen concentrations varied significantly among the various products.

Test Specimens

The specimens used for all mechanical property tests had a reduced section $1/4$ in. diam $\times$ $1\ 1/4$ in. long, a $5/8$ -in.-long section of $1/2$ -13 NC thread on each end, and an overall length of $3\ 1/4$ in. The taper on the reduced section of the specimen was 0.001 to 0.002 in. The specimens were lathe machined from each product, and the orientation of the specimen axis within each product was retained.

Annealing

The specimens were degreased in acetone and rinsed in alcohol before reannealing. The samples were pushed into the hot zone of a tube furnace purged with high-purity argon and maintained at 2000°F. After 0.5 hr at 2000°F, the samples were withdrawn into the water-cooled end of the tube furnace and cooled in argon. Under these conditions the specimen temperature dropped below 1000°F in 2 min.

Tensile Tests

The tensile tests were run in a 10,000-lb-capacity Instron universal testing machine. The strain rate was 0.004/min to 5% strain and then increased to 0.04/min until failure. Strain was measured by an averaging extensometer, which was attached by setscrews to the center 1 in. of the reduced section. One chart of load-strain was obtained from the averaging extensometer and a load cell in the load train, and an independent chart of

crosshead deflection vs load was obtained from the crosshead motion and another load cell. The yield stress was obtained from the first chart (using the 0.2% offset method) and the other properties from the deflection-load chart.

Stress-Rupture Tests

Stress-rupture tests were conducted in standard lever-arm creep machines calibrated to a load accuracy of $\pm 0.5\%$. Temperature was measured by three Chromel vs Alumel thermocouples ($\pm 3/8\%$ accuracy) wired to the gage section. The temperature variation among these was less than $\pm 4^\circ\text{F}$, with the highest temperature being the nominal test temperature. Proportioning temperature controllers were used to obtain temperature control of $\pm 2^\circ\text{F}$, with the highest temperature being the nominal test temperature. Length changes were measured by a nonaveraging extensometer attached by setscrews to a small groove in the specimen shoulders, and these were converted to strains by dividing by the reduced section length of $1\frac{1}{4}$ in.

Experimental Observations

Room-Temperature Properties

The results of tensile tests at 75°F on the 12 products in the as-received and reannealed conditions are given in Table 2. Samples were taken parallel, perpendicular, and at 45° to the primary working direction for the plate products, but no significant variation was found and the data are presented without identification of orientation. Samples made from the $4\frac{1}{2}$ -in.-diam bar were oriented parallel or perpendicular to the working direction, but no difference in properties was noted. All other products were sampled parallel to the primary working direction.

The initial portions of the stress-strain curves at 75°F are shown in Fig. 1 for the as-received products and in Fig. 2 for reannealed specimens. Typical stress-strain curves are shown, and the 0.2% offset yield stresses are indicated. Although there is considerable variation in the yield stress, the parallel curves indicate that the different products had similar work-hardening characteristics. Reannealing reduced the magnitude of the yield stress as well as the range observed for the various products.

The yield stresses of the plate products are shown in Fig. 3. Several significant observations can be made for the plate products.

1. Yield stress of the as-received material decreased with increasing plate thickness.
2. Yield stress after reannealing was the same for all plate thicknesses.
3. Variations in yield stress within for each plate were greater for the as-received product than for reannealed plate.
4. All the reannealed samples and several of the as-received had yield stresses less than the 30,000 psi minimum required by the ASTM A-240 specification.

The hardnesses in Table 1 follow the same trends noted in Fig. 3 for the yield stresses. The hardness and yield stress for the as-received plate generally decreased as the plate thickness increased. Reannealing resulted in a hardness of about 65 and an average yield stress of 25,800 psi for all plates. Hardness measurements reflected nonuniformity of working also in that the individual measurements on as-received samples had about a 15-point spread, whereas those for reannealed samples had a spread of 5 points or less.

The plates under discussion were rolled from slabs varying in thickness from 3 3/4 to 6 1/2 in. The slabs were soaked at 2225 to 2275°F and rolled

through multiple passes to obtain the final thicknesses. The final pass temperatures for the 3/8-, 1/2-, 3/4-, 1-, and 2-in.-thick plates were 1250, 1590, 1620, 1675, and 1850°F, respectively. The plates were given a final anneal at 1950°F for 25 to 70 min, water quenched, cleaned, and roller-leveled.

Several factors were likely important in determining the properties of the plates. These include the amount of work in the plates before annealing, the grain size before annealing, the temperature-time history of the plates during their final 1950°F anneal, and the amount of working as a result of roller leveling the plates after annealing. However, the details of the above are not known, and one can only assume that they were typical of commercial practice. Thus, the differences in properties are representative of what would be observed in commercial products.

Yield stresses of the bar products shown in Fig. 3 illustrate the following points: (1) the yield stress of as-received material was much higher than that of reannealed product; (2) the yield stress of the as-received material was very nonuniform for each product (e.g., it varied from 29,700 to 46,700 psi for the 4 1/2-in.-diam bar); (3) reannealing resulted in an average yield stress of 25,700 psi and much smaller variations in strength; and (4) there was no systematic variation of yield stress from one bar product to another in either the as-received or reannealed conditions.

No fabrication details are available for the bar products, but the yield strength data (Fig. 3) and the hardness values (Table 1) indicate that the as-received products contained considerable residual cold work. The spread in the yield stresses and the hardness measurements for the as-received products indicate that residual cold work was nonuniform. Reannealing reduced hardness to about 65 and increased grain size to ASTM No. 3.

The hot-reduced (HR) tubing was fabricated by gun drilling a bar. In the as-received condition the yield stress and hardness were higher than those of the bar products. Reannealing reduced the yield stress to an average value of 23,500 psi, reduced the hardness to 65, and increased the grain size to ASTM No. 3. We have no explanation for the yield stress of this product being about 2,000 psi lower after reannealing than that of the other rod products.

The yield stresses of two pipe products and one thick-walled tube all produced to ASTM Standard A-376 (given in Fig. 3) show the following significant features:

1. The yield stress in the as-received condition was about equal for all three products with an average value of 31,700 psi.

2. After reannealing the yield stress decreased to an average value of 26,200 psi.

The yield stresses for the three products in the as-received condition are in excellent agreement, the measurements being 73, 73, and 74. Reannealing resulted in hardness value of 63, 69, and 67.

Only the yield stress has been discussed this far, but several other properties are listed in Table 2. These other properties were less sensitive to fabrication variables than the yield stress. For example, the yield stress of the as-received products varied from 26,500 to 57,200 psi, a variation about the mean of $\pm 37\%$. The ultimate tensile stress varied from 78,000 to 96,000 psi, a variation about the mean of only $\pm 10\%$. The tensile stresses of the reannealed products fell in the range 81,300 to 86,800 psi. This range is smaller but within that of the as-received products. Generally, high ultimate tensile stresses were associated with high yield stresses. The fracture strains of the as-received products varied from

70 to 95% and those of the reannealed products from 77 to 89%. These values are all quite high and considerably above the specified minimum of 40%. Again, the range for the reannealed samples is smaller and contained within the range for the as-received materials. Measured reductions in area were quite high, ranging from 70 to 85% for as-received material and from 75 to 86% for the reannealed material. Based on the accuracy of the measurement and the reproducibility from specimen to specimen, none of the variation in ductility parameters is thought to be significant.

Elevated-Temperature Properties

The results of tensile tests on the 12 products at 1100°F are summarized in Table 3. The initial portions of the stress-strain curves for the reannealed products are shown in Fig. 4. The yield stresses are shown in Fig. 5. Most of the tests at 1100°F were performed on reannealed rather than as-received products. The only as-received plate tested was the 3/8-in.-thick plate, which has a yield stress about twice that of the reannealed material. As-received bar, pipe, and tubing products had yield stresses of 15,000 to 17,000 psi except for the gun-drilled (HR) tubing, which had a yield stress of 35,500 psi. The reannealed products had an average yield stress of 10,900 psi, with all but four tests giving values in the range of 10,200 to 11,700 psi. The yield stress of the 1 3/4-in.-diam bar fell above this range and that of the 2-in.-diam bar fell below. Since the hardnesses, grain sizes, and chemical analyses of these two products in the reannealed condition were almost identical, we have no explanation for the difference in yield strengths.

The other tensile properties showed less variation than did the yield strengths. The ultimate tensile strength of the as-received samples varied

from 47,000 to 57,000 psi and that of the reannealed material from 45,400 to 50,900 psi. The strength of the reannealed 1- and 2-in.-thick plates fell on the low side of this range. The fracture strains varied from 40.8 to 44.4% for the as-received samples and from 37.5 to 56.3% for the reannealed material. The reduction in area ranged from 56.9 to 69.8% for the as-received samples and from 32.4 to 72.9% for the reannealed material. The 1- and 2-in.-thick plates had lower ductility (fracture strain and reduction in area) than the other products. The slight differences in tensile strength and ductility for the two plates compared with the other products are likely due to the larger grain size of the plates.

Twelve products in the reannealed condition were stress-rupture tested at 1100°F, and the results are listed in Table 4 and shown in Figs. 6 and 7. The complete creep curves obtained at 25,000 psi and 1100°F are shown in Fig. 8. These data have been analyzed statistically, and we conclude that the properties of any one product were not significantly different from those of another. Some of the property variations may be significant, but the degree of reproducibility of tests on "identical samples" made it impossible to conclude that the properties of different products were significantly different. The creep properties agree reasonably well with those compiled by Smith⁵ but tend to fall on the weak side of the scatter band.

⁵*An Evaluation of the Yield, Tensile, Creep, and Rupture Strengths of Wrought 304, 316, 321, and 347 Stainless Steels at Elevated Temperature*, G. V. Smith, ASTM Data Series DS552, American Society for Testing and Materials, Philadelphia, 1969.

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Table 1. Information on Several Product Forms of Type 304 Stainless Steel, Heat 9T2796

Product Form	Specification	Hardness, R_B		Grain Size, ASTM No.		Chemical Composition, ^b %		
		Initial	Reannealed ^a	Initial	Reannealed	C	O	N
Plate, 3/8 in. thick	RDT M5-1T(A-240)	86	63			0.045	0.0033	0.091
Plate, 1/2 in. thick	RDT M5-1T(A-240)	73	66	5-6	3	0.052	0.0075	0.046
Plate, 3/4 in. thick	RDT M5-1T(A-240)	66	65	5-6	3	0.051	{0.011 0.014	{0.048 0.044
Plate, 1 in. thick	RDT M5-1T(A-240)	70	65	1-3	1-3	{0.048 0.050	0.0020	{0.039 0.031
Plate, 2 in. thick	RDT M5-1T(A-240)	69	65	1-3	1-2	0.055	0.0086	0.040
Bar, 1 3/4 in. diam	RDT M7-3T(A-479)	81	65	5-6	3	0.052	0.0062	0.048
Bar, 2 in. diam	RDT M7-3T(A-479)	89	65	5-6 ^c 6-7 ^d	3	0.053	0.0049	0.048
Bar, 4 1/2 in. diam	RDT M7-3T(A-479)	67	67	2-3 ^c 3-5 ^d	3	0.051	0.0062	0.049
Pipe, 4 in. sched 160	ASTM A-376	73	63	5-6	4	0.052	0.0089	0.051
Pipe, 8 in. sched 40	ASTM A-376	73	69	5-6	2	0.056	{0.018 0.019	{0.042 0.042
Tube, 2 1/2 in. OD × 5/8 ^e in. wall (hot reduced)	RDT M7-3T(A-479)	88	65	6-7	3	0.051	0.0053	0.050
Tube, 2 1/2 in. OD × 5/8 in. wall (cold drawn)	RDT M3-3T(A-376)	74	67	3-6	3	0.050	0.0046	0.047

^a1/2 hr at 2000°F.^bFour product forms were analyzed for trace elements, and the following levels apply to all four: <0.01% Ag, 0.05% Al, <0.01% B, <0.01% Ba, <0.005% Be, <0.02% Bi, <0.1% Ca, <0.1% Cd, 0.3% Co, 0.3% Cu, 0.01% Mg, <0.1% Nb, <0.02% Pb, <0.05% Pt, <0.02% Sn, <0.1% Sr, 0.05% Ta, <0.02% Ti, 0.03% V, <0.1% W, <0.2% Zn, <0.05% Zr, <0.05% Ge, <0.05% Ga. The concentrations of other alloying additions are 1.22% Mn, 0.029% P, 0.012% S, 0.47% Si, 18.5% Cr, 9.58% Ni, 0.10% Mo.^cLongitudinal plane.^dTransverse plane.

Table 2. Tensile Properties of Type 304 Stainless Steel (Heat 9T2796) at 75°F^a

Product	Yield Stress, ksi		Ultimate Tensile Stress, ksi		Fracture Strain, %		Reduction in Area, %	
	As Received	Annealed ^b	As Received	Annealed	As Received	Annealed	As Received	Annealed
Plate, 3/8 in. thick	41.2	25.0	89.4	82.6	75.2	85.8	82.5	84.9
	45.4		89.2		70.5		71.7	
Plate, 1/2 in. thick	29.3	25.2	87.0	85.0	79.8	81.1	73.0	75.0
	30.1	25.9	87.9	85.1	80.5	82.8	81.9	82.5
	32.9	26.2	87.0	83.7	81.8	84.0	82.5	82.7
Plate, 3/4 in. thick	34.4	26.0	85.9	83.5	80.0	79.0	82.6	81.3
	29.3	26.1	85.2	83.4	77.0	81.0	76.0	76.6
	29.4	25.3	83.8	81.9	85.2	88.1	80.5	83.5
Plate, 1 in. thick	32.4	26.4	84.0	84.7	70.0	85.0	80.0	85.5
	29.2		81.6		95.0		82.0	
Plate, 2 in. thick	26.5	26.0	78.8	82.9	91.0	88.0	85.2	82.3
	27.7		80.6		85.0		84.6	
Bar, 1 3/4 in. diam	42.0	26.6	85.6	83.1	80.9	88.7	83.5	84.2
	42.3	27.0	85.2	82.7	77.9	86.1	83.5	83.9
	41.6		85.2		79.5		82.3	
	44.5	25.2	86.4	82.9				
Bar, 2 in. diam	45.0	25.2	89.8	82.4	78.4	85.4	82.9	84.7
	40.0	23.7	88.1	81.9	76.8	82.6	80.8	83.8
	50.8	25.2	89.9	84.3	75.2	84.1	82.9	84.0
	48.9				74.6		80.9	
Bar, 4 1/2 in. diam	46.7	26.5	82.8	83.6	85.0	77.0	84.3	82.0
	30.8	26.1	82.4	86.8	85.0	84.0	84.6	82.6
	29.7		83.5		83.5		69.6	
Pipe, 8 in. sched 80	30.3	26.0	85.4	82.9	82.0	88.0	82.2	82.3
		26.5		83.0		80.0		82.6
Pipe, 4 in. sched 160	31.7	26.7	84.5	82.9	84.0	85.0	83.3	83.6
	32.3	26.5	84.6	82.8	83.0	87.0	83.3	83.1
Tube, 2 1/2 in. OD × 5/8 in. hot reduced	57.2	23.6	96.0	81.4	70.8	87.5	81.1	84.9
	57.0	23.2	93.3	81.3	71.8	88.9	83.2	85.7
		23.7		81.4		88.9		84.9
Tube, 2 1/2 in. OD × 5/8 in. cold drawn	32.2	25.6	86.5	84.0	78.4	80.0	83.1	83.3
	32.2	25.1	86.5	83.6	78.3	82.0	82.8	84.3

	As Received	Annealed ^b	As Received	Annealed	As Received	Annealed	As Received	Annealed
Plate, 3/8 in. thick	41.2	25.0	89.4	82.6	75.2	85.8	82.5	84.9
	45.4		89.2		70.5		71.7	
Plate, 1/2 in. thick	29.3	25.2	87.0	85.0	79.8	81.1	73.0	75.0
	30.1	25.9	87.9	85.1	80.5	82.8	81.9	82.5
	32.9	26.2	87.0	83.7	81.8	84.0	82.5	82.7
Plate, 3/4 in. thick	34.4	26.0	85.9	83.5	80.0	79.0	82.6	81.3
	29.3	26.1	85.2	83.4	77.0	81.0	76.0	76.6
	29.4	25.3	83.8	81.9	85.2	88.1	80.5	83.5
Plate, 1 in. thick	32.4	26.4	84.0	84.7	70.0	85.0	80.0	85.5
	29.2		81.6		95.0		82.0	
Plate, 2 in. thick	26.5	26.0	78.8	82.9	91.0	88.0	85.2	82.3
	27.7		80.6		85.0		84.6	
Bar, 1 3/4 in. diam	42.0	26.6	85.6	83.1	80.9	88.7	83.5	84.2
	42.3	27.0	85.2	82.7	77.9	86.1	83.5	83.9
	41.6		85.2		79.5		82.3	
	44.5	25.2	86.4	82.9				
Bar, 2 in. diam	45.0	25.2	89.8	82.4	78.4	85.4	82.9	84.7
	40.0	23.7	88.1	81.9	76.8	82.6	80.8	83.8
	50.8	25.2	89.9	84.3	75.2	84.1	82.9	84.0
	48.9				74.6		80.9	
Bar, 4 1/2 in. diam	46.7	26.5	82.8	83.6	85.0	77.0	84.3	82.0
	30.8	26.1	82.4	86.8	85.0	84.0	84.6	82.6
	29.7		83.5		83.5		69.6	
Pipe, 8 in. sched 80	30.3	26.0	85.4	82.9	82.0	88.0	82.2	82.3
		26.5		83.0		80.0		82.6
Pipe, 4 in. sched 160	31.7	26.7	84.5	82.9	84.0	85.0	83.3	83.6
	32.3	26.5	84.6	82.8	83.0	87.0	83.3	83.1
Tube, 2 1/2 in. OD	57.2	23.6	96.0	81.4	70.8	87.5	81.1	84.9
× 5/8 in. hot	57.0	23.2	93.3	81.3	71.8	88.9	83.2	85.7
reduced		23.7		81.4		88.9		84.9
Tube, 2 1/2 in. OD	32.2	25.6	86.5	84.0	78.4	80.0	83.1	83.3
× 5/8 in. cold	32.2	25.1	86.5	83.6	78.3	82.0	82.8	84.3
drawn		25.6		84.3		80.8		83.5

^a Strain rate of 0.004/min to 5% strain, 0.04/min to failure.

^b Annealed 0.5 hr at 2000°F in argon.

Table 3. Tensile Properties of Type 304 Stainless Steel (Heat 9T2796) at 1100°F^a

Product	Yield Stress, ksi		Ultimate Tensile Stress, ksi		Fracture Strain, %		Reduction in Area, %	
	As Received	Annealed ^b	As Received	Annealed	As Received	Annealed	As Received	Annealed
Plate, 3/8 in. thick	23.5	10.4	51.7	48.9	42.3	49.6	69.8	68.5
Plate, 1/2 in. thick		10.7		49.4		46.8		61.6
		11.0		50.1		48.2		67.8
		11.5		48.9		48.2		65.9
Plate, 3/4 in. thick		10.5		50.6		50.0		72.9
		10.8		50.4		49.1		63.2
		10.2		47.6		51.7		65.7
Plate, 1 in. thick		11.1		46.5		37.5		51.5
Plate, 2 in. thick		10.7		45.4		38.0		32.4
		11.0		45.7		45.4		43.2
Bar, 1 3/4 in. diam		13.1		48.8		49.4		65.8
		12.9		48.6		49.2		67.6
Bar, 2 in. diam		9.53		48.8		45.5		66.7
		9.51		48.8		50.5		68.3
Bar, 4 1/2 in. diam	14.8	10.6	47.0	47.7	43.3	52.1	61.6	68.7
		10.8		48.1		53.7		70.7
		10.6		46.7		43.3		61.9
		10.8		46.3		43.9		60.6
Pipe, 8 in. sched 80	15.9	11.2	49.5	49.2	50.6	53.9	65.9	68.9
Pipe, 4 in. sched 160	16.6	11.7	49.5	49.5	40.8	54.3	47.4	68.5
		11.7		49.5		56.3		68.7
Tube, 2 1/2 in OD × 5/8 in. hot reduced	35.5	9.55	47.1	48.5	42.9	48.7	56.9	65.3
		9.44		49.3		54.0		69.8
Tube, 2 1/2 in. OD × 5/8 in. cold drawn	15.5	11.4	52.0	50.9	44.4	44.2	66.9	69.2
		10.8		50.7		46.2		70.2
		10.6		50.6		47.7		66.2

^aStrain rate of 0.004/min to 5% strain, 0.04/min to failure.^bAnnealed 0.5 hr at 2000°F in argon.

Table 4. Stress-Rupture Properties of Type 304 Stainless Steel at 593°C^a

Product	At 35,000 psi			At 30,000 psi			At 25,000 psi		
	Rupture Life, (hr)	Minimum Creep Rate, (%/hr)	Creep Strain (%)	Rupture Life, (hr)	Minimum Creep Rate, (%/hr)	Creep Strain (%)	Rupture Life, (hr)	Minimum Creep Rate, (%/hr)	Creep Strain (%)
Plate, 3/8 in. thick	14.9	0.34	14.9	150.7	0.055	15.6	527.3	0.013	10.2
Plate, 1/2 in. thick	47.6	0.33	23.4	158.2	0.090	20.8	759.3	0.013	19.8
	29.9	0.55	22.8						
	30.9	0.49	30.0	117.0	0.13	23.8			
Plate, 3/4 in. thick	26.1	0.32	13.9	123.9	0.043	9.4	769.6	0.0065	11.8
	28.0	0.26	11.9						
Plate, 1 in. thick	23.5	0.41		107.1	0.10	17.4	440.1	0.011	16.0
Plate, 2 in. thick	22.2	0.37	16.2	92.8	0.078	11.4	423.3	0.0080	4.4
							291.0	0.010	7.4
Bar, 5/8 in. diam	43.7	0.35		168.8	0.061				
Bar, 1 3/4 in. diam	32.5	0.33	20.4	142.5	0.066	14.7	600.7	0.011	14.0
	35.4	0.29	19.3						
Bar, 2 in. diam	39.5	0.28	16.7	169.0	0.058	17.1	614.4	0.0084	12.8
	26.8	0.33	15.2						
Bar 4 1/2 in. diam	40.2	0.33	19.6	140.2	0.070	15.7	765.9	0.0072	12.6
				178.8	0.12	31.2	457.8	0.021	18.1
Pipe, 8 in. sched 20	37.4	0.29	15.4	187.8	0.041	11.1			
	27.0	0.30		143.7	0.057	15.7	630.4	0.011	13.6
Pipe, 4 in. sched 160	26.0	0.56	29.2	168.5	0.055	16.0			
	49.6		20.1	153.4	0.080	28.3	785.9	0.0074	13.0
Tube, 2 1/2 in. OD	23.9	0.41	17.6	126.6	0.056	10.3			
× 5/8 in. hot reduced	22.7	0.36	12.4	159.2	0.034	11.1	690.7	0.0076	11.1
Tube, 2 1/2 in. OD	38.7	0.25	17.2	203.3	0.038	13.6			
	× 5/8 in. cold drawn	38.3	0.28	154.9	0.053	12.5	758.4	0.0064	12.2

^aReannealed 0.5 hr at 2000°F.

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