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ROOM-TEMPERATURE CHARACTERIZATION DATA FOR TYPE 304 STAINLESS STEEL (Heat 9T2796) PLATE

R. W. Swindeman

OAK RIDGE NATIONAL LABORATORY

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ABSTRACT

One-inch plate obtained from a reference heat of type 304 stainless steel was characterized at room temperature. This characterization consisted of composition, microstructure, and mechanical property evaluations relative to data available for other heats of type 304 stainless steel. The influence of laboratory reannealing was also examined. The composition was fairly typical except for below average carbon and nitrogen levels. The microstructure was fairly free of inclusions, and the grain size was coarse. The yield strength was near the 30,000 psi minimum specified for type 304 stainless steel in the A 240 condition and below the minimum in the reannealed condition. Possibly this was due to the coarse grain size in combination with low interstitial element content. Little, if any, differences were observed between specimens reannealed in the 1800 to 2000°F range.

INTRODUCTION

As part of the United States Atomic Energy Commission's effort to develop the liquid metal fast breeder reactors (LMFBR), the Oak Ridge National Laboratory is pursuing a program entitled "High-Temperature Structural Design Methods for LMFBR Components." At the heart of the program are a number of inelastic structural tests at high temperatures. The prediction of the behavior of the structural test specimens requires that accurate descriptions of material behavior under elastic, plastic, and creep conditions be developed. To this end, uniaxial mechanical property data on identical material and tested over similar time, temperature, and stress conditions are essential. Large reference heats of types 304 and 316 stainless steel are involved.

Eighteen different product forms from the heat of type 304 stainless steel (heat 9T2796) are available. Because of the differences in the fabrication schedules, these various product forms, as delivered, exhibit a broad range of mechanical properties and grain sizes. We recognized that some standard laboratory reanneal was necessary to minimize the variation in properties from one product form to another. We also intended that this reanneal should occur after the major fabrication was completed on each test specimen. This was to ensure that the influence of mechanical work associated with the specimen fabrication would also be eliminated as a variable in the testing program.

This report is concerned with characterizing one product form that is being used both for simple structural tests and materials studies. The latter are aimed at exploring the fundamental stress-strain-time relationships under uniaxial loading conditions. The specific product form is 1-in. plate.

The report presents the description of chemical analysis, room-temperature mechanical properties, and metallurgical structure in the as-received and reannealed conditions. Where possible, comparisons are made with histograms or scatter bands representing the variation in properties expected for type 304 stainless steel bar and plate product forms.

FABRICATION AND HEAT-TREATING INFORMATION

The material was procured from U.S. Steel Corporation through the Liquid Metals Engineering Center (LMEC). Information supplied by the vendor to LMEC stated that the original slab used to fabricate the plates was soaked 2 hr at 2250°F then rolled from 6 1/2 to 1 in. thickness in 21 passes. The final pass temperature was estimated to be 1675°F. Final annealing was in an oxidizing atmosphere (air and natural gas) at 1950°F for 70 min. The plates were burnished by grit blasting and wash pickling.

Three plates 1 × 48 × 96 in. and meeting the USAEC specification RDT M5-1T were delivered to ORNL. Three similar plates were retained by LMEC, who also performed some characterization tests on this material. The sectioning scheme for the plate that we examined is indicated in Fig. 1. The data reported here were obtained from specimens machined

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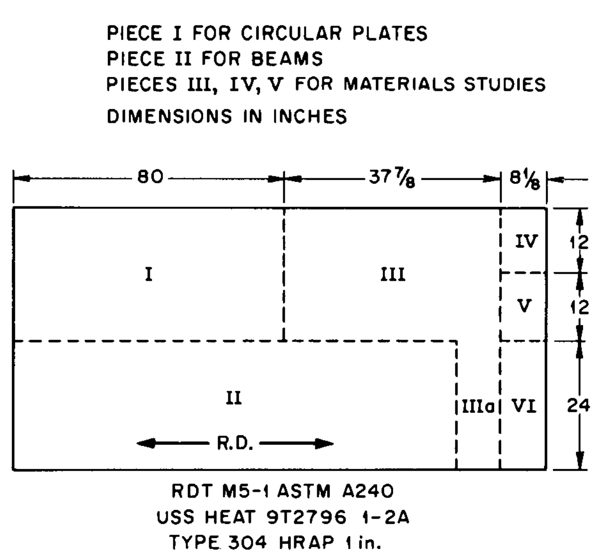

Fig. 1. Sectioning Diagram of 1-in. Plate.

from pieces IIIa, IV, and V. Pieces IV and V were sheared from the plate by the vendor, and no record was made as to which plate was actually at the corner. Piece IV was arbitrarily placed at the corner.

Laboratory reannealing was performed in the facility sketched in Fig. 2. A horizontal metallic chamber passed through a 30-in. silicon carbide resistance furnace. One end of the chamber was welded shut, and the other was attached to a water-cooled metal fore-chamber with a removable plug. After ultrasonic cleaning, specimens were placed in a wire boat. This rested in the metal fore-chamber during evacuation and argon purging. A valve was opened, leading to the annealing chamber, and the boat was plunged into the hot zone. To cool, the boat was retracted into the cold zone in the main chamber. A sheathed thermocouple centered in the boat was used to approximate the rate of cooling of the specimens. Typically, the thermocouple would drop from 2000 to 1000°F in about 3 min.

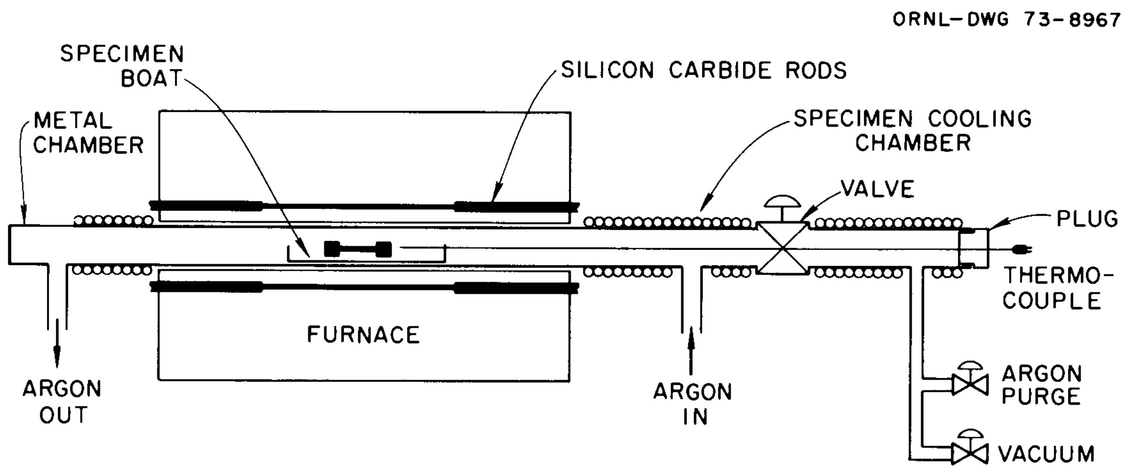

Fig. 2. Argon Reannealing Facility.

CHEMICAL ANALYSIS

The RDT specification M5-1T required that the composition conform to the ASTM specification A 240 and also that two check analyses, in addition to the ladle analysis, be supplied by the vendor for each product form. These data for the 1-in. plates are provided in Table 1. Also included are the results of an analysis performed at ORNL and a check by LMEC of carbon and nitrogen contents. The data show a fair degree of consistency. The composition is within the limits set forth in ASTM A 240. Figure 3 shows the contents of selected elements in histograms constructed from the analyses of some 50 heats of type 304 stainless steel. Also located

Table 1. Chemical Analysis of Type 304 Stainless Steel Heat 9T2796 1-in. Plate

Element	Content, wt %							
	Ladle	Vendor Checks		ORNL Checks		LMEC Checks		ASTM A 240
C	0.048	0.049	0.048	0.051	0.049[a]	0.043	0.044	0.04–0.08
Mn	1.22	1.31	1.24	1.37				2.00 max
P	0.028	0.030	0.030	0.041				0.045 max
S	0.015	0.017	0.016					0.03 max
Si	0.48	0.49	0.47	0.40				1.00 max
Cr	18.6	18.44	18.44	18.5				18–20
Ni	9.7	9.76	9.68	9.87				8–12
Mo	0.32	0.32	0.32	0.30				
Cu	0.24	0.20	0.25	0.24				
Co	0.18			0.10				
Pb	0.001			0.002				
Nb+Ta	0.003			0.002				
Sn	0.015			0.018				
N				0.031	0.034[a]	0.036	0.029	
Ti	0.010			<0.02				

[a]After annealing at 2000°F in argon for 0.5 hr.

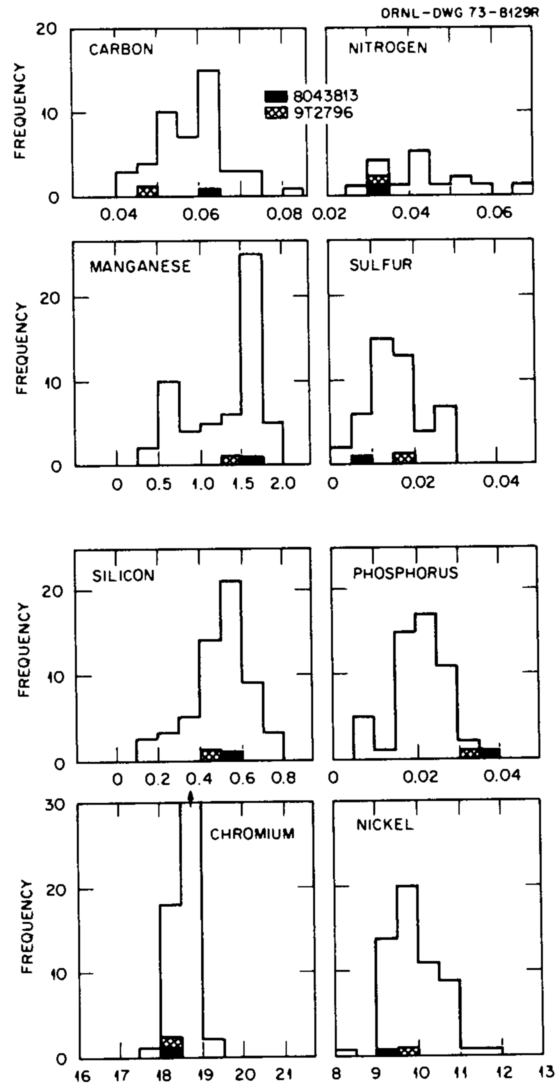

Fig. 3. Positions of Heat 9T2796 and Heat 8043813 in Histograms Describing the Variation in Weight Percentage of Eight Elements Contained in Approximately 50 Heats of Type 304 Stainless Steel Plate and Bar.

in these histograms is the composition of another heat of type 304 stainless steel being studied in the uniaxial exploratory test program (heat 8043813).[1]

Heat 9T2796 falls near the center of the compositional range for Cr, Ni, Mn, Si, and S. The phosphorus content is near the upper end of the range, and the carbon and nitrogen contents are toward the lower extremes.

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[1] R. W. Swindeman and C. E. Pugh, *Creep Studies on Type 304 Stainless Steel (Heat 8043813) Under Constant and Varying Loads*, ORNL-TM-4427 (in preparation).

It is generally thought that these two interstitial elements have a pronounced strengthening effect, both in regard to tensile yield properties and creep resistance;[2] hence, relative to other heats, this heat might be expected to exhibit below average mechanical properties.

Of some concern to us is the possibility of changes in the interstitial content as a consequence of high-temperature laboratory reannealing. Many complex reactions with the reannealing environment can be envisioned that might alter the nitrogen and carbon levels, especially near the surface. Included in Table 1 are the results of analyses for interstitials performed on small samples (1/4 × 1/4 × 3/8 in.) reannealed in argon for 0.5 hr at 2000°F. No gross changes in carbon and nitrogen were detected in this particular case.

MICROSTRUCTURE

The 1-in. plates were inspected ultrasonically as required by RDT M5-1T. Checks on the inclusion content were performed by LMEC, and, based on ASTM E 45, the plate was placed in classification B. This implies a fairly clean material. The inclusions that were seen consisted of slags and ferrite stringers. The ferrite was identified by the ferromagnetic etching technique developed by Gray.[3] The composition of the δ-ferrite was determined by microprobe. This information, along with a typical area, is provided in Fig. 4.

The plate was examined by light microscopy to determine what, if any, grain size variation occurred through the thickness. None was observed.

Typical microstructures observed in the as-received material and after several laboratory reanneals are represented by the photomicrographs provided in Figs. 5 and 6. These were obtained from longitudinal sections through the plate. In other words, the cross sections represent the plane that is parallel to the thickness and "primary" rolling directions.

Examination of microstructures at magnifications ranging from 50 to 500× produced the following observations:

1. There is no evidence of cold work in the as-received microstructures. As apparent in Fig. 5, the annealing twins are straight, and no "slip bands" or martensitic areas are present.

2. Some solute element inhomogeneity is present. Bands perpendicular to the thickness direction are spaced on a 0.001-in. interval. This is typical of type 304 stainless steel plate.

3. There is no evidence that any of the heat treatments appreciably alter the microstructure. Photomicrographs representing the microstructure produced by the reanneal at temperatures from 1800 through 2000°F are shown in Fig. 6.

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[2]K. Natesan, T. F. Kassner, and C. Y. Li, "Effect of Sodium on Mechanical Properties and Friction-Wear Behavior of LMFBR Materials," *Reactor Technol.* 15: 244 (Winter 1972/1973).

[3]R. J. Gray, "Epitaxial Ferromagnetic Etching," *Metals and Ceramics Div. Annu. Progr. Rep. June 30, 1972*, ORNL-4820, pp. 163–65.

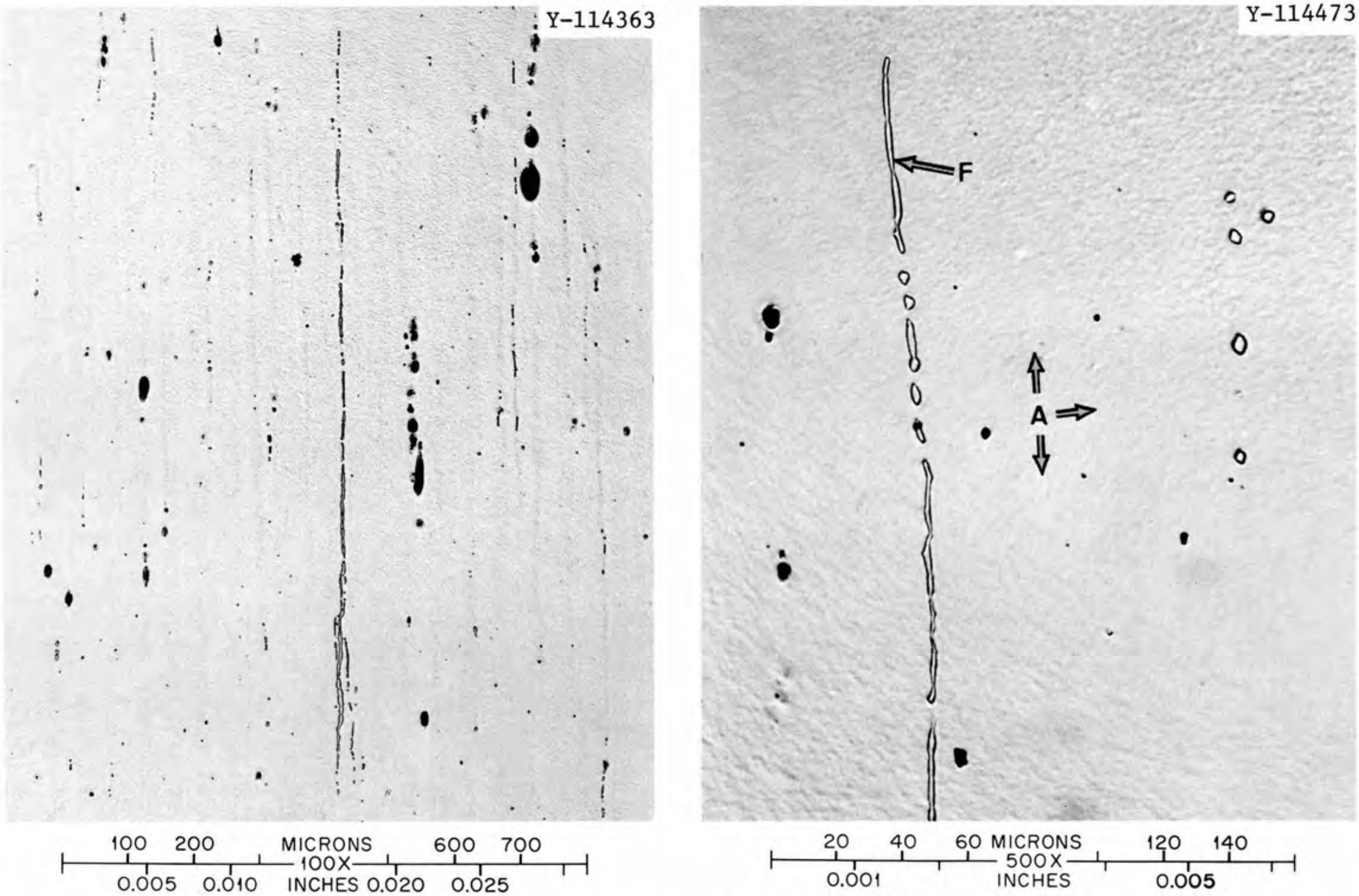

Fig. 4. Ferrite Stringers in Type 304 Stainless Steel.

	Composition, %			
	Fe	Cr	Ni	Mn
Ferrite (F)	67	27	5	1
Austenitic matrix (A)	67	19	11	1

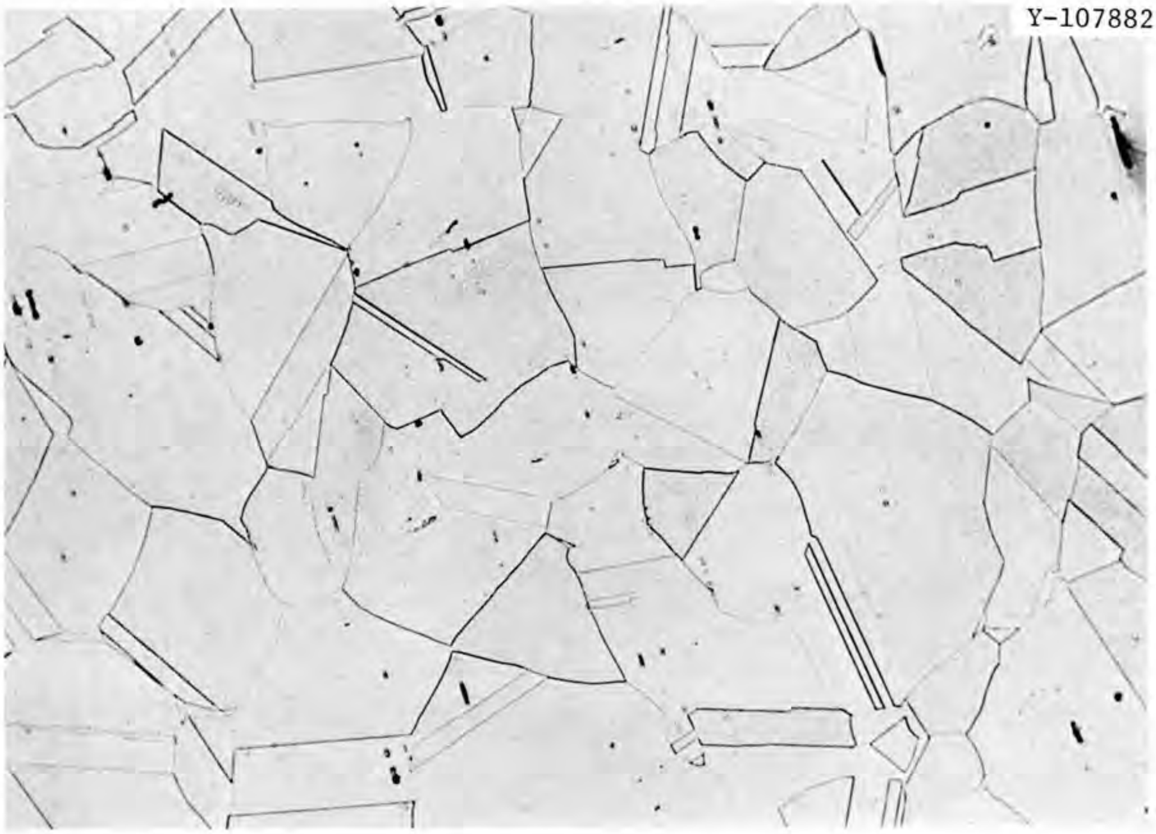

Fig. 5. Microstructure of Type 304 Stainless Steel (Heat 9T2796) 1-in. Plate in the As-Received Condition (A 240). Etchant: glyceria regia. 100×. DPH: 130.

4. All structures can be characterized as consisting of coarse equiaxed grains with a moderate density of annealing twins. The stringers identified previously lie parallel to the primary rolling direction. There are few, if any, globular carbide, nitride, or sulfide particles.

We checked the grain size after every anneal using the comparison and intercept procedures described in ASTM E 112-63. The estimated grain size falls between ASTM Nos. 1 and 3 (0.254 to 0.127 mm). This range represents a coarse grain size relative to the grain sizes covered by the ASTM charts (0.508 to 0.0025 mm). Some data regarding grain sizes for type 304 stainless steel plate, bar, and sheet product forms are provided in the compilation of Simmons and Van Echo.[4] These were used in addition to some ORNL data to develop the histogram shown in Fig. 7. Heat 9T2796 is located toward the lower end of the distribution, thus indicating, perhaps, coarser grain size than average.

Transmission electron microscopy was performed on samples sliced from material in the as-received condition (A 240) and after reannealing at

[4]W. F. Simmons and J. A. Van Echo, *The Elevated Temperature Properties of Stainless Steels*, ASTM DS-5-S1, Alpha, New Jersey (1965).

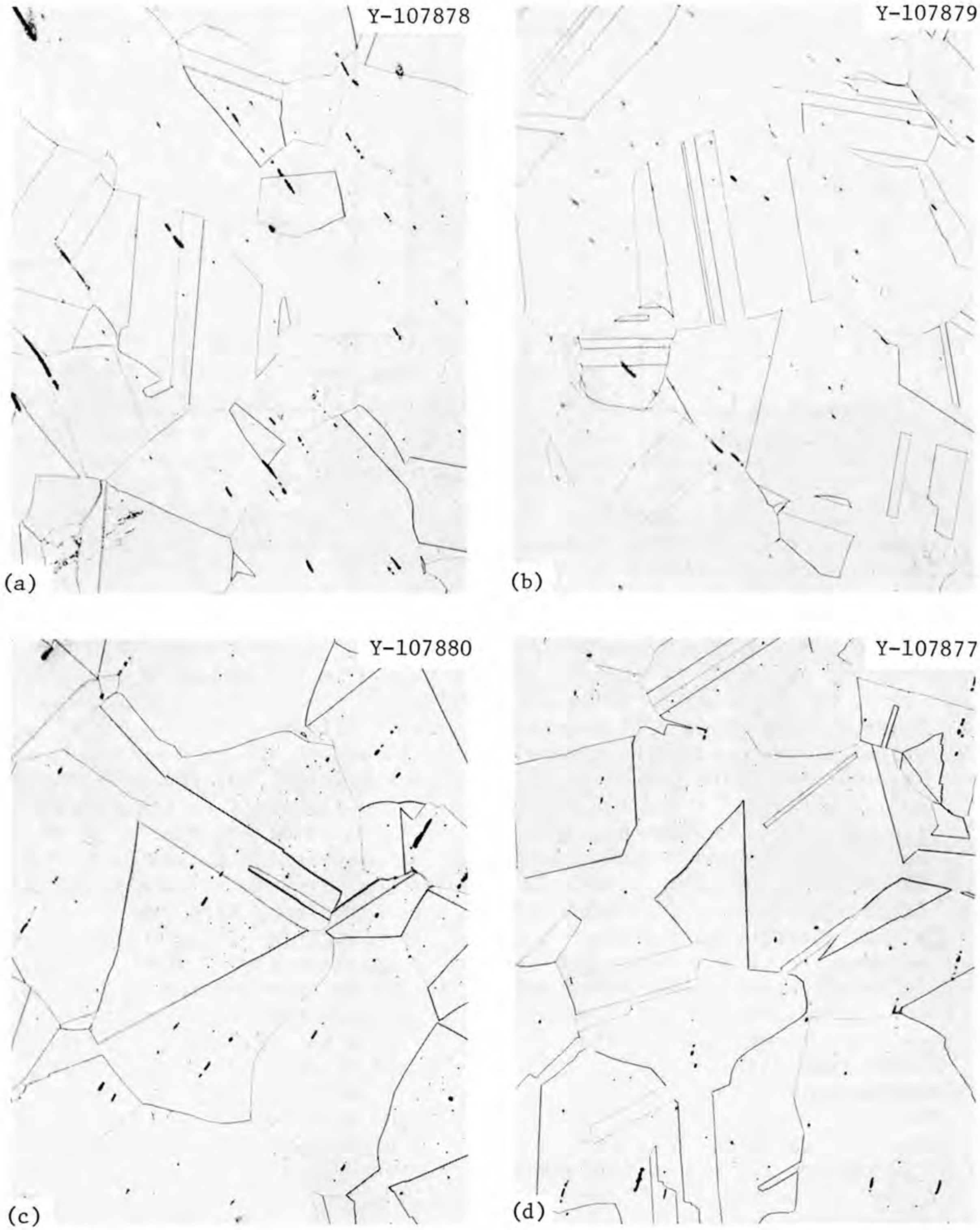

Fig. 6. Microstructure of Type 304 Stainless Steel Plate (Heat 9T2796) Reannealed in Argon and Cooled in Argon. Etchant: glyceria regia. 100×. (a) Reannealed at 1800°F; DPH: 121. (b) 1900°F; 119. (c) 1950°F; 121. (d) 2000°F; 119.

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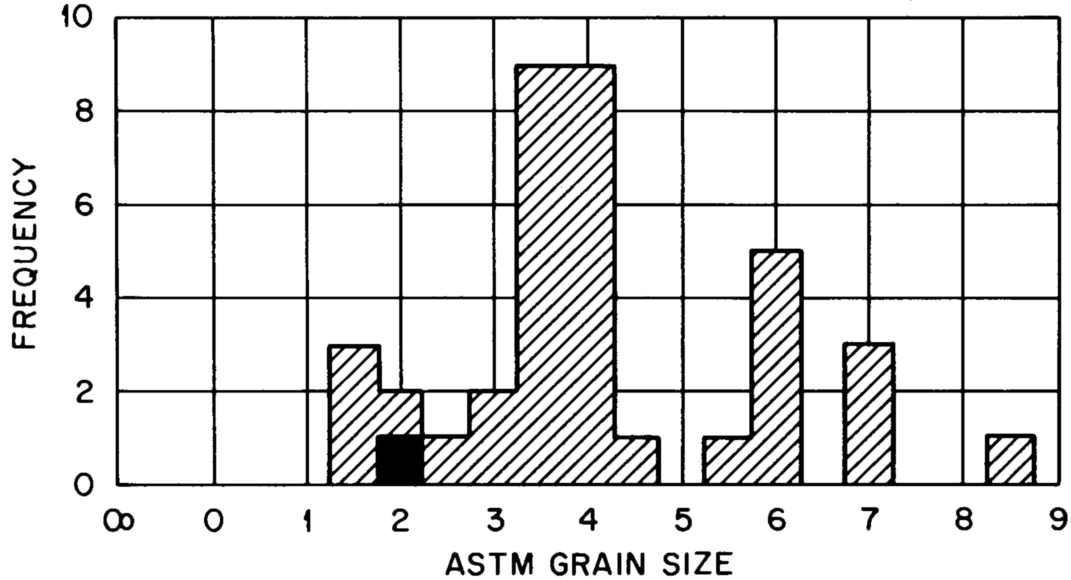

Fig. 7. Distribution of ASTM Grain Size Numbers Reported for Type 304 Stainless Steel Plate and Bar Product Forms (A 240 and A 479). Solid block represents heat 9T2796.

2000°F for 0.5 hr. The structure observed in foils prepared from as-received material is represented by Fig. 8. This consists of regular arrays of dislocations lying on intersecting slip traces. Such a configuration is typical of low-stacking-fault alloys, such as type 304 stainless steel, that have received small amounts of low-temperature deformation.[5] The structure observed in the foils prepared from reannealed material is not too dissimilar. This structure is represented in Fig. 9. Although, in the region shown, there is no evidence of intersecting slip traces, the overall dislocation density is similar to that in the as-received condition. The grain boundary, shown running across diagonally on the right-hand side of the micrograph, is a region of higher dislocation density. This structure differs slightly from one we observed in another heat of type 304 stainless steel, shown in Fig. 10. In this instance, less dislocation activity is apparent near the grain boundaries, and dislocations within the grains exist in more stable configurations.[5] The differences observed by us are not necessarily associated with the fact that we have two different heats, but could reflect differences in annealing condition, cooling conditions, foil preparation, or the selection of the region of examination. In both instances, the grain boundaries are free of carbides, which suggests that the cooling rates from the annealing temperatures were sufficient to

[5]Private Communication, K. Farrell, Oak Ridge National Laboratory.

Fig. 8. Transmission Electron Micrograph of Structure Representative of Type 304 Stainless Steel Plate (Heat 9T2796) in the As-Received (A 240) Condition. 25,000×.

Fig. 9. Transmission Electron Micrograph of Structure Representative of Type 304 Stainless Steel (Heat 9T2796) in the Reannealed Condition. Specimen was reannealed for 0.5 hr in argon at 2000°F. 25,000×.

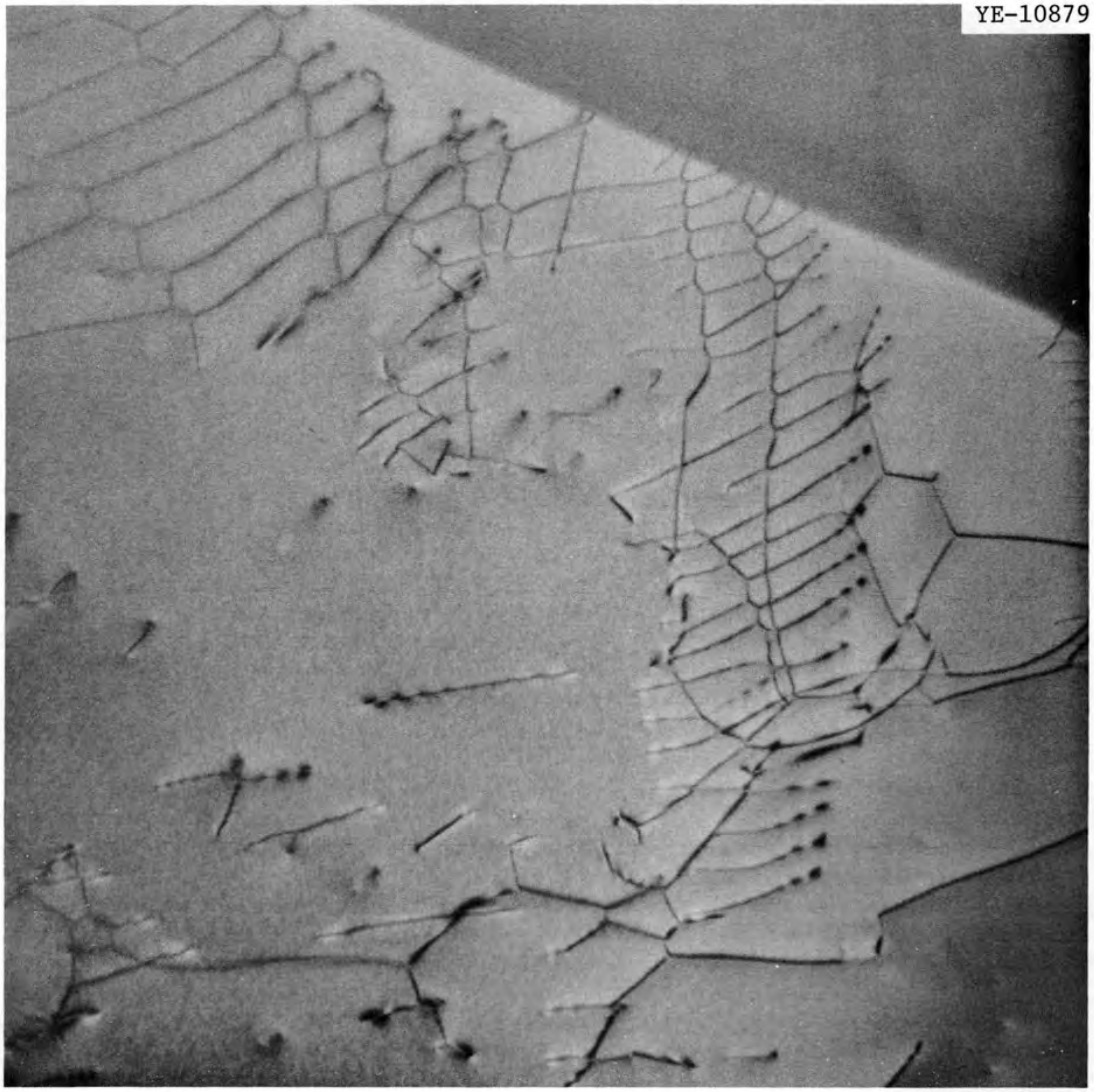

Fig. 10. Transmission Electron Micrograph of Structure Representative of Type 304 Stainless Steel (Heat 8043813) in the Reannealed Condition. Specimen was reannealed for 0.5 hr in argon at 1950°F. 25,000×.

suppress carbide precipitation. This occurs most rapidly between 1400 and 1600°F for type 304 stainless steel.[6]

The stacking fault energy for heat 9T2796 has been estimated by Challenger and Moteff[7] to be near 28 ergs/cm^2. They used a technique described by Whelan.[8]

TENSILE PROPERTIES

The vendor reported the yield stress at 43,900 psi, the ultimate to be 81,400 psi, the elongation in 2 in. at 55%, and the reduction of area to be 67%. The yield stress was taken at 0.5% total strain, and, although it conforms to the requirements of RDT Standard M-5-1T, it is higher than a yield stress based on 0.2% offset strain. No mechanical property check data were supplied by the vendor for the plate product forms.

The tensile tests performed at ORNL to characterize the 1-in. plate covered a wide range of variables. As mentioned previously, specimens were machined from three locations in the plate: pieces IIIa, IV, and V in Fig. 1. Four specimen geometries were involved and these dimensions, tabulated in Fig. 11, included 1/2, 1/4, and 1/8 in. gage diameters. The 1/2- and 1/4-in.-diam specimens were tested in both the longitudinal and transverse directions, while the 1/8-in.-diam specimens were machined in the longitudinal direction but from three thickness levels: near each surface and at the center line. Four different tensile machines and five different extensometers were also involved. Care was taken to assure that the testing methods conformed to the ASTM specification on Mechanical Testing of Steel Products (A 370-68).

The results of the test series on material in the A 240 condition are summarized in Table 2. Only variables considered by us to be important are included. In regard to the yield strength, we observed one unusually low value, 23,000 psi, and one unusually high value, 39,000 psi. All other values fell between 29,200 and 33,700 psi. This range agrees with data reported by LMEC. In the case of ORNL data, however, the specimens machined from pieces IIIa and IV appear to be stronger than those machined from piece V, on the average. We are not sure whether this reflects a material variability or a specimen fabrication variability, since the specimens from different pieces were machined at different shops. Either way, the yield strength data establish that this product form is very close to minimum yield strength specified for type 304 stainless steel in ASTM A 240.

The ultimate strength, elongation, and the reduction of area are all acceptable. Data are located on histograms developed for type 304 stainless steel in Fig. 12. These histograms are based on data obtained from the ASM Handbook, the compilation of Simmons and Van Echo, and vendor certification sheets for heats on hand at ORNL.

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[6]R. Stickler and A. Vinckier, "Morphology of Grain-Boundary Carbides and Its Influence on Intergranular Corrosion of 304 Stainless Steel," *Trans. Amer. Soc. Metals* 54: 362 (1961).

[7]Private Communication, J. Moteff, University of Cincinnati.

[8]M. J. Whelan, *Proc. Roy. Soc. (London)* 249: 114 (1959).

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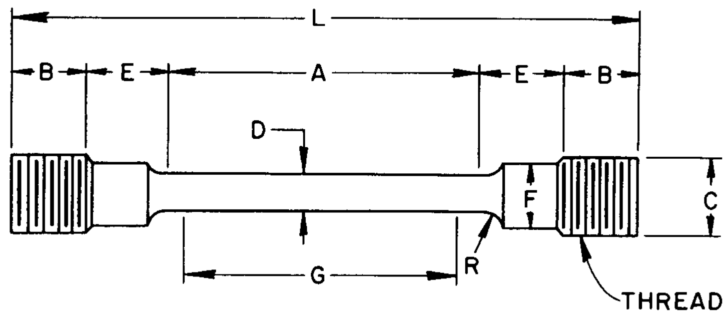

Dimensions

Specimen	a	b	c	d
G – Gage length	2.0 ± 0.005	2.0 ± 0.005	2.250 ± 0.005	1.125 ± 0.005
D – Diameter	0.50 ± 0.005	0.250 ± 0.0005	0.250 ± 0.0005	0.125 ± 0.0005
R – Radius of fillet	1/2	5/32	1/4	$0.188^{+0.000}_{-0.005}$
A – Length of reduced section	2-1/4	2.0 ± 0.005	2.250 ± 0.005	1.125 ± 0.005
L – Over-all length	5-1/2	4	4-1/4	1-7/8
B – Length of end section	1	1/2	1/2	None
C – Diameter of end section	3/4	1/2	1/2	None
E – Length of shoulder and fillet	5/8	1/2	1/2	3/8
F – Diameter of shoulder		7/16	1/2	1/4
THD – Thread size	3/4 – 10	1/2 – 13	1/2 – 13	None

Fig. 11. Specimen Dimensions. All values are in inches.

It is clear that heat 9T2796 1-in. plate is well below average in yield strength. The ultimate strength is about average, and the elongation is fairly high.

Tensile data after stress relief or reannealing are provided in Table 3. The yield strengths after annealing range from 25,600 to 28,600 psi, while the differences between specimens machined from different pieces of the plate are less apparent. The yield strengths average 27,000 psi, which is below the figure of 29,000 psi determined by LMEC. Possibly, the higher yield strengths observed by LMEC could be due to their practice of water quenching from 2000°F. This has not been conclusively established, however.

Very little data are available with which to construct histograms describing the heat-to-heat variation in tensile properties of laboratory-reannealed type 304 stainless steel. What data are available, however, suggest that yield strengths cluster near or below 30,000 psi; hence, the average yield of heat 9T2796 in the reannealed condition (27,000 psi) is not too unusual.

The ultimate tensile strengths and ductility values are within acceptable limits.

Table 2. Summary of Room-Temperature Tensile Tests on Type 304 Stainless Steel Plate (Heat 9T2796) in the As-Received (A 240) Condition

Specimen		Strength, psi		Elongation[b] (%)	Reduction of Area (%)	Apparent Modulus (psi)	Location in Plate[c]	Strain Rate (min^{-1})
Type	Number[a]	Yield	Ultimate					
		$\times 10^3$	$\times 10^3$			$\times 10^6$		
a	5RPT3	39.0	83.0	75.0	74.9	23.0	V	0.2
a	5RPT1	30.4	81.4	75.0	75.0	30.6	V	0.05
a	5RP1	31.1	82.2	75.0	82.9	42.0	V	0.05
a	5RP4	30.5	82.0	75.0	82.4	30.0	V	0.05
a	5RP5	23.0	81.3	75.0	82.6	22.0	V	0.05
c	RP51	33.1	83.3	84.0	85.9	27.2	IIIa	0.05
c	RP52	32.8	*d*	*d*	*d*	28.7	IIIa	0.05
d	1RPS1	33.3	88.9		83.0		IIIa	0.05
d	1RPS2	33.3	88.9		85.0		IIIa	0.05
d	1RP1	32.8	87.6		83.0		IIIa	0.05
c	RP36	29.8	82.0	84.0	80.9	28.0	V	0.025
c	RPT1	29.7	81.6	99.0	77.7	26.7	V	0.025
c	RPT2	30.8	*d*	*d*	*d*	28.0	V	0.025
a	5RP6	29.5	81.0	87.5	78.5	27.2	V	0.005
c	RP39	29.2	81.6	95.0	82.0	26.0	V	0.005
b	RP0	32.4	84.0		80.0	30.8	IV	0.005
d	1RPS3	33.7	*d*	*d*	*d*		IV	0.005

[a]RP denotes longitudinal orientation, RPT transverse orientation, RPS near surface of plate.

[b]Measured over a length equal to four times the gage diameter.

[c]According to Fig. 1.

[d]Test discontinued.

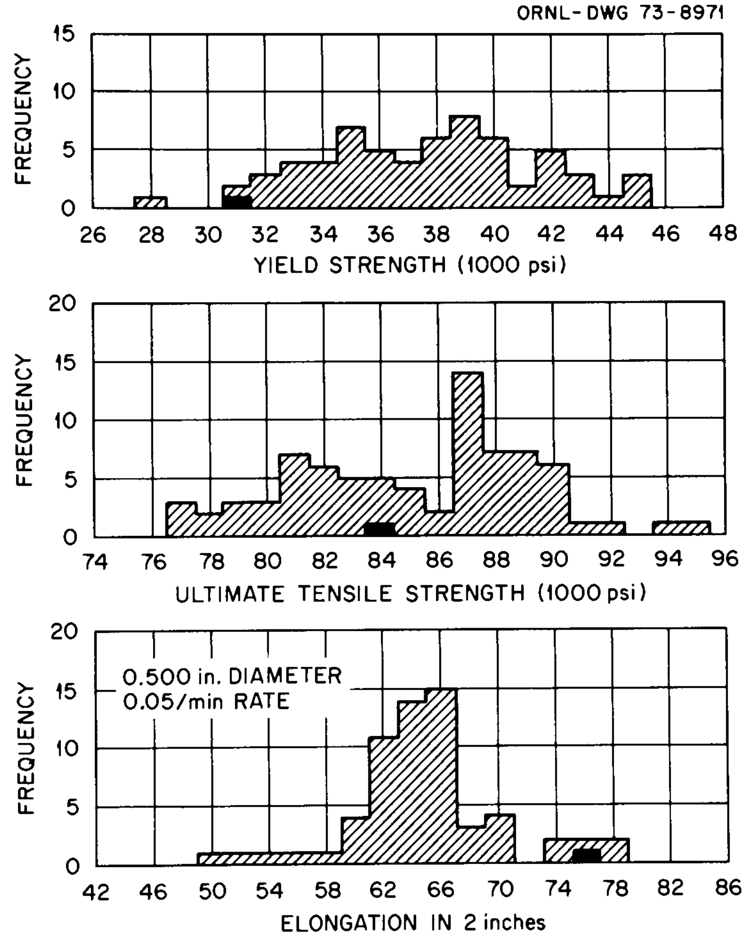

Fig. 12. Histograms Representing the Distribution of Yield Strength, Ultimate Strength, and Elongation for Type 304 Stainless Steel Plate and Bar (A 240 and A 479). Solid block represents heat 9T2796.

ISOTROPY

Comparison of tensile data in the transverse and longitudinal directions did not reveal any pronounced anisotropy. Likewise, we observed no differences in the microstructures in these two directions. Differences were apparent in the thickness direction relative to the other two. In addition to the microstructural differences previously described, we observed that the reduction in diameter in tensile-tested specimens was greater in the thickness direction than in either the transverse or longitudinal. The ratio of thickness strain to transverse strain for room-temperature tests falls between 0.88 and 0.95. Values as low as 0.79 were sometimes obtained in elevated-temperature tests not reported here. Measurements of diametral strains in other product forms of heat 9T2796 and in other heats of type 304 stainless steel plate show little or no differences for strains in the transverse and thickness directions; hence, this behavior for the 1-in. plate is quite singular.

Table 3. Summary of Room-Temperature Tensile Tests on Type 304 Stainless Steel Plate (Heat 9T2796) Tested in the Stress-Relieved or Reannealed Condition

Specimen		Annealing Temperature (°F)	Strength, psi		Elongation[b] (%)	Reduction of Area (%)	Apparent Modulus (psi)	Location in Plate[c]	Strain Rate (min^{-1})
Type	Number[a]		Yield	Ultimate					
			$\times10^3$	$\times10^3$			$\times10^3$		
c	RP38	1400[d]	28.0	81.0	81.0	81.7	28.0	V	0.025
c	RPT3	1400[d]	29.8	*e*	*e*	*e*	28.7	V	0.025
c	RP42	1800	26.6	84.6	86.0	81.7	28.7	V	0.025
c	RP43	1800	27.6	*e*	*e*	*e*	28.7	IIIa	0.025
c	RP44	1900	28.0	83.6	90.0	81.7	28.0	IIIa	0.025
c	RP45	1900	27.4	*e*	*e*	*e*	28.0	IIIa	0.025
c	RP46	1950	26.8	83.6	92.0	83.4	28.0	IIIa	0.025
c	RP47	1950	27.4	*e*	*e*	*e*	28.7	IIIa	0.025
a	5RP2	2000	26.5	80.8	80.0	83.1	29.0	V	0.05
a	5RP3	2000	26.7	81.5	80.0	82.5	36.7	V	0.05
a	5RPT2	2000	26.1	79.8	77.0	75.6	34.3	V	0.05
d	1RPS5	2000	28.6	87.6		81.0		IIIa	0.05
c	RP49	2000	27.0	84.2	91.0	77.9	28.7	IIIa	0.025
c	RP37	2000	25.6	80.2	80.0	78.5	28.0	V	0.025
b	RP10	2000	26.4	84.7		85.5	23.8	IV	0.005
a	1RPS6	2000	27.7	*e*	*e*	*e*		IIIa	0.005

[a] RP denotes longitudinal orientation, RPT transverse orientation, RPS near surface of plate.

[b] Measured over a length equal to four times the gage diameter.

[c] According to Fig. 1.

[d] Stress relief below annealing temperature range.

[e] Test discontinued.

A small degree of anisotropy in this same material has also been observed by Mar-Test[9] in regard to Poisson's ratio in the elastic range.

HARDNESS DATA

The Brinell hardness number, supplied by the vendor, was 146 under a 3000 kg load. No checks on this number were made at ORNL. Rather, we obtained Rockwell R_B numbers from the shoulders of tensile specimens in both the as-machined (A 240) and reannealed conditions. A hardness traverse was also taken across the plate thickness. Vickers DPH numbers were obtained from specimens that were examined metallographically.

The results of the hardness traverse are summarized by Fig. 13. Values observed at the surfaces range from 70 to 80 and average about 77. About 0.2 in. deep from either surface, the hardness number drops to about 70 and is more or less steady. The R_B hardness data obtained from the shoulders of tensile specimens and the DPH numbers obtained from metallography specimens are summarized in Table 4. The R_B hardness values decrease monotonically with increasing annealing temperature, although the change is rather small. The DPH numbers are about the same for the as-received, 1400°F-stress-relieved, and the 2000°F-plus-water-quenched conditions. Values are about the same for annealing between 1800 and 2000°F. Some idea as to the hardness of heat 9T2796 relative to other heats of type 304 stainless steel can be gleaned from Fig. 14. This plots the relationship of yield stress to the R_B hardness value. Included are data from several heats, obtained from the data compilation of Simmons and Van Echo. Conditions include ASTM A 240, A 479, and laboratory reanneals from 1800 to 2000°F. The hardness values obtained for heat 9T2796 cluster within the overall data band and are consistent with the observed low yield strengths.

Extensometer plots covering at least 1% strain were obtained from all tensile tests. Typical results are presented in Fig. 15. This includes two stress-strain curves for the A 240 and for each of the reannealed conditions. All curves representing behavior of reannealed material fall within a narrow band and exhibit a very characteristic pattern. Behavior is close to elastic up to stresses near 20,000 psi. The transition from elastic response to plastic flow is quite sharp, and by the time 0.2% plastic strain is attained the plastic flow curve is nearly linear. The variation in the curves for different reannealing temperatures does not appear to be significant and probably represents experimental variability.

Behavior of specimens tested in the as-received (A 240) condition differs from the reannealed pattern. Deviation from elastic response is observable at stresses between 15,000 and 20,000 psi, although this is not very apparent in the figure. The transition from elastic to primarily plastic flow is much more gradual; hence, although "yielding" begins at the same or lower stresses, by the time the 0.2% plastic strain is introduced, the flow stresses are higher than for the reannealed specimens. At large strains, the plastic flow curves for as-received specimens

[9]Private Communication, J. B. Conway (Mar-Test).

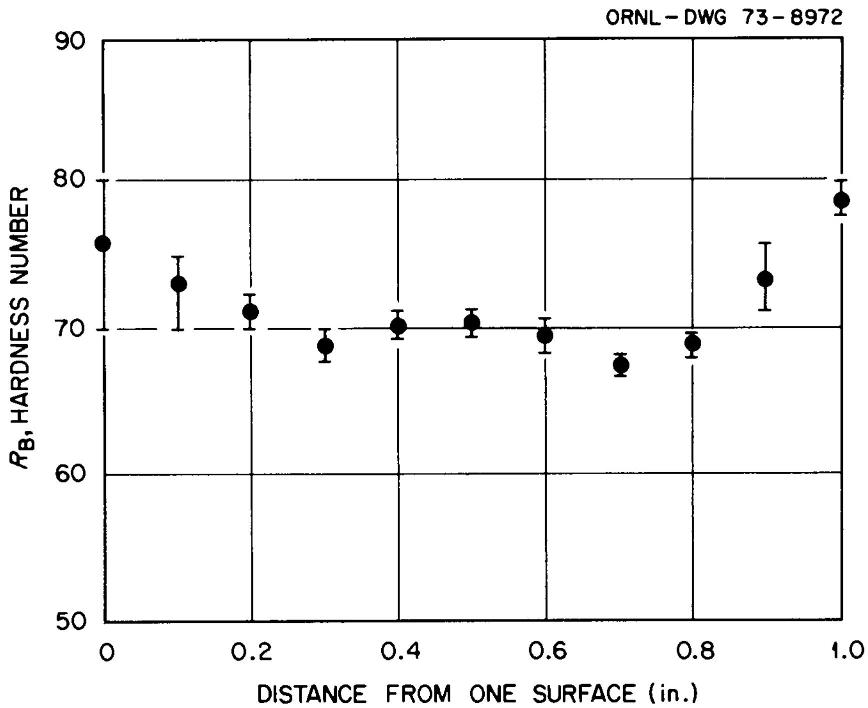

Fig. 13. Variation of Hardness Values Through the Thickness of a 1-in. Plate of Type 304 Stainless Steel (Heat 9T2796) in the A 240 Condition.

Table 4. Hardness Data Obtained on Type 304 Stainless Steel Heat 9T2796 1-in. Plate

Condition	Hardness	
	Rockwell B[a]	Vicker's DPH
As-received (A 240)	70.4 (4)	130
1400°F, 1/2 hr	70.2 (2)	130
1800°F	67.8 (2)	121
1900°F	67.4 (2)	119
1950°F	66.2 (5)	121
2000°F	65.4 (4)	119
2050°F	64.1 (1)	
2000°F, water quench	63.6 (2)	128
2000°F, furnace cool	64.0 (1)	

[a]Number in parentheses represents number of specimens sampled.

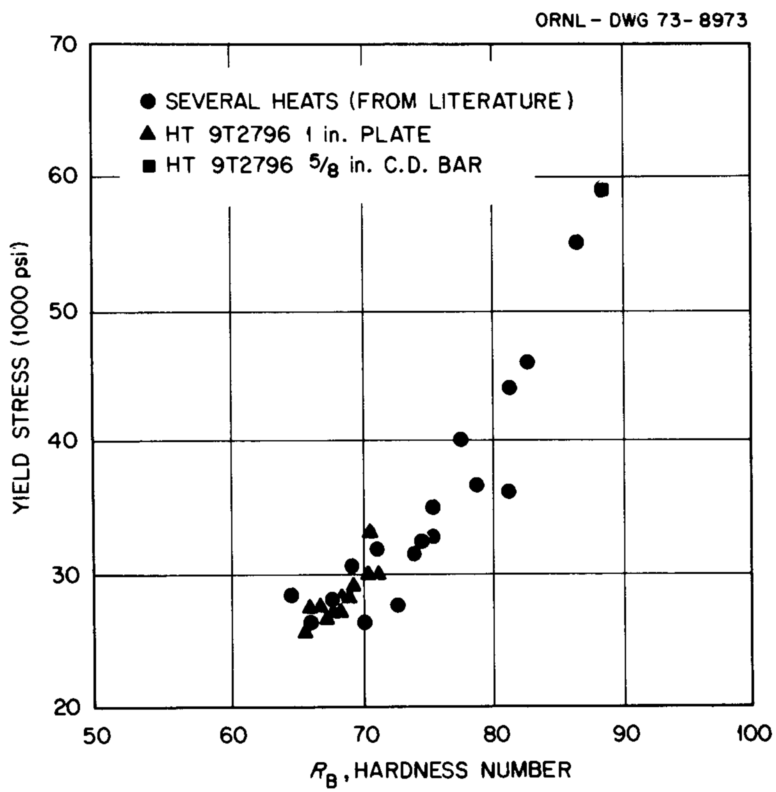

Fig. 14. Comparison of Rockwell (R_B) Hardness Number with the Yield Stress for Type 304 Stainless Steel.

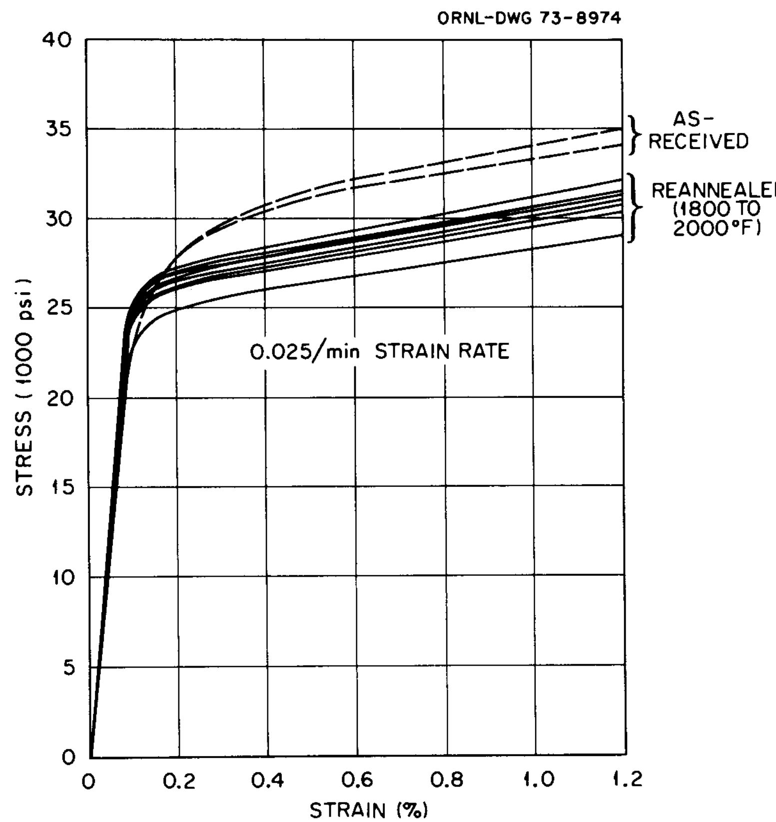

Fig. 15. Selected Yield Curves Traced from Tensile Tests on Type 304 Stainless Steel (Heat 9T2796). The reannealed group includes two tests at each reannealing temperature, 1800, 1900, 1950, and 2000°F.

become parallel to the curves for reannealed material. The lower stresses required to initiate inelastic deformation in the as-received material, relative to reannealed specimens, could be a manifestation of the Bauschinger effect brought about by the plastic strain introduced during the flattening of the plate or fabrication of specimens. As indicated by the transmission electron micrographs, arrays of dislocations exist on favorable slip planes, and either short-range back stresses associated with dislocation pileups or long-range stresses introduced by inhomogeneous deformation from grain to grain could assist in activating dislocations at stresses below the value required for reannealed specimens.

Load-time charts were obtained from the electromechanical testing machines, and these we used to construct stress-strain plots extending to rupture. Typical data are presented in Fig. 16. Assuming Poisson's ratio as 0.5 for plasticity and that deformation was homogeneous up to the ultimate, true-stress and true-strain values were calculated, and we constructed the curves shown in Fig. 17. Finally, the strain-hardening exponent, m, and strength coefficient, κ, of the Holloman[10] expression were calculated. The equation,

$$\bar{\sigma} = \kappa\bar{\varepsilon}_p^m \quad ,$$

[10] J. H. Holloman, "Tensile Deformation," *Trans. AIME* 162: 268 (1945).

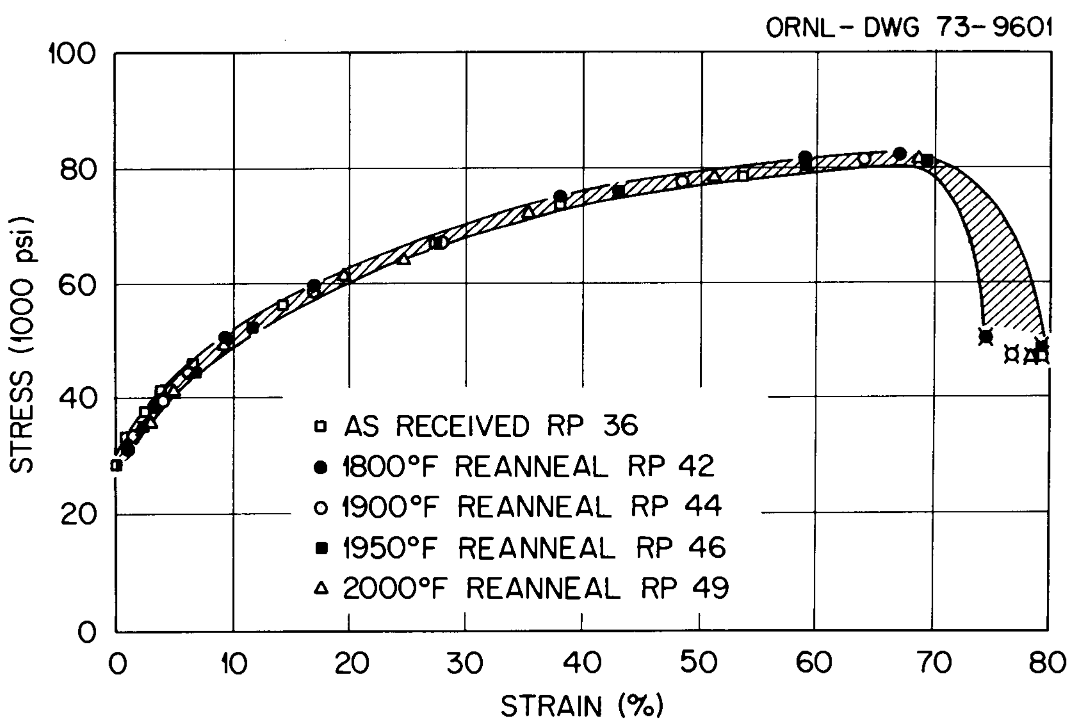

Fig. 16. Room-Temperature Engineering Stress-Strain Behavior for Type 304 Stainless Steel Heat 9T2796 1-in. Plate Tested at 0.025/min.

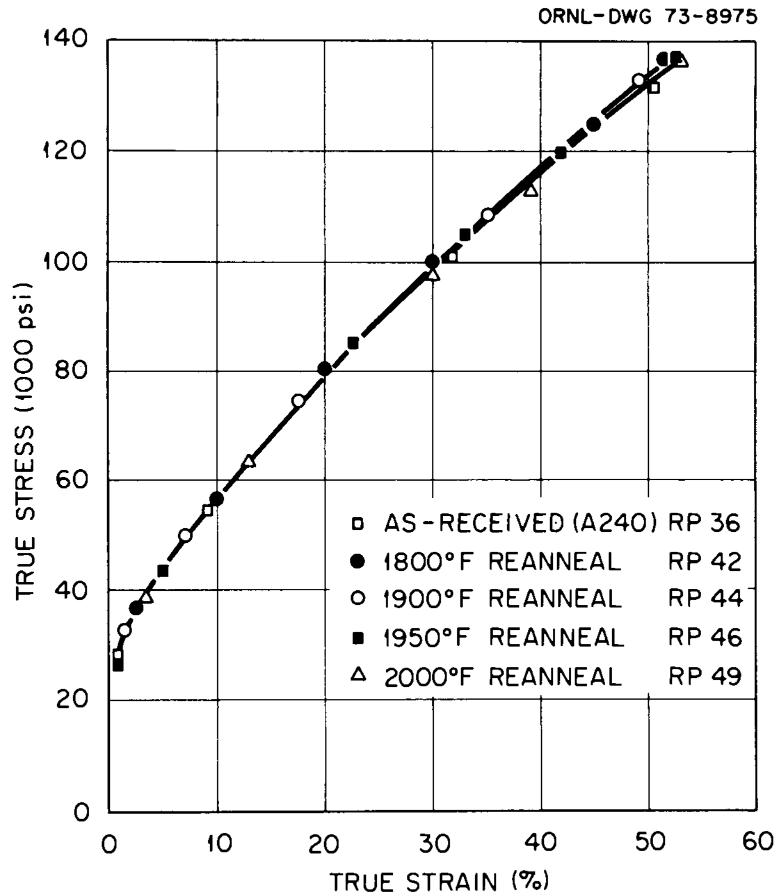

Fig. 17. Room-Temperature True Stress vs True Strain for Type 304 Stainless Steel Heat 9T2796 1-in. Plate Tested at 0.025/min.

where $\bar{\sigma}$ is true stress (psi) and $\bar{\varepsilon}_p$ is true strain, was fitted to experimental data by a least squares method. The value for K ranged from 117,000 to 129,300 psi and for m, 0.249 to 0.299 for the test results plotted in Fig. 17.

Modulus data were collected, but, since the extensometers used in the test series were rated at class B-2, they did not conform to the requirements of ASTM E 111 on the determination of Young's modulus at room temperature. Strain gages attached to one specimen produced a modulus value of 27.2×10^6 psi. The average of 25 determinations using extensometers is 27.5×10^6 psi, which is close to the strain gage value. The standard deviation is 3×10^6 psi, however, and this is a rather high figure. For type 304 stainless steel, the ASME Boiler and Pressure Vessel Code (SIII) suggests a value at room temperature of 28.3×10^6 psi. Most of our data were fairly close to this.

CONCLUSIONS

1. Heat 9T2796 1-in. plate has below average carbon and nitrogen content but is within the composition specifications set forth in RDT M-1T.

2. Heat 9T2796 1-in. plate is a relatively clean, coarse-grained material that exhibits near-minimum yield strength in the RDT M-1T condition (A 240) and below minimum yield strength in the laboratory reannealed condition. Such behavior is not particularly unusual.

3. The laboratory reanneal sharpens the transition from elastic to plastic behavior and produces a tensile curve that is more nearly linear at strains to at least 1%.

4. The reannealing temperature is not very important providing that it is within the range from 1800 to 2000°F. Very little, if any, variation in hardness, grain size, or tensile properties is observed.

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