2

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MECHANICAL BEHAVIOR OF 304 LN WELDMENTS

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February 22, 1979

Mr. A. J. Hodges
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Dear Jeff:

We are pleased to report the results on the mechanical properties of various weld configurations for 304 LN stainless steel. The results which follow include Charpy V-notch, tensile, and fracture toughness data. The determinations were made at temperatures of 300, 77, and 4.2 K. For the most part, the specimens have been returned to LLL for further evaluation. We still have the fracture toughness specimens in order to prepare a paper for presentation at the ICMC meeting in Madison, Wisconsin in August of 1979. These will be returned to your Chuck Witherell in the near future.

Each of the three types of mechanical evaluations will be treated separately in the following sections of this report. These results will constitute the completion of the work authorized under Agreement Serial No. 3025 (SANL 605). Questions of a technical nature can be directed to me at (614) 424-7472.

Charpy V-Notch Impact Evaluations

Nineteen (19) Lawrence Livermore Laboratory Charpy V-Notch impact specimens were tested at the Battelle West Jefferson Hot Laboratory using a 240-foot-pound Satec-Baldwin Model SI-1C impact machine fitted with an instrumented tup. The 240-foot-pound range was used in all tests. The velocity of the hammer at impact was 16.95 feet/second.

Verification of the Charpy machine was previously performed in accordance with ASTM-E 23-72 and proof tested using Charpy V-Notch impact specimens purchased from the US Army Materials Mechanics Research Center.

The Charpy machine is provided with instrumentation for obtaining load-time information of the fracture event. Essentially, the tup (striker) is instrumented with strain gages. The output of the strain gages is conditioned, amplified, and fed to a digital oscilloscope which digitizes

and records the load-time data generated during the impact tests. An x-y recorder is used to produce plots of the load-time curves.

ASTM procedures for specimen temperature control were utilized⁽¹⁾. The bath consisted of agitated liquid nitrogen. The container was a Dewar flask which contained a grid to keep the specimens at least 1 inch from the bottom; the height of the bath was enough to keep a minimum of 1 inch of liquid nitrogen over the specimen. The Charpy specimens were held at temperature a minimum of 5 minutes, the ASTM recommended time⁽¹⁾.

The specimens were manually transferred from the liquid nitrogen bath to the anvil of the impact machine by means of special centering tongs which had been previously verified according to ASTM specifications⁽¹⁾. The specimens were removed from the bath and impacted in less than 5 seconds.

The impact properties of the 19 specimens are summarized in Table 1. The energy required to break the specimens was recorded from the machine dial. The lateral expansion was determined from measurements made with a digital readout lateral expansion gage. Fracture appearance was difficult to estimate because of the nature of the structure.

The notch root contraction was measured using vernier calipers. The percent contraction was then calculated from this measurement and the pretest sample width. The load-time records for each of the specimens have been previously forwarded to LLL. The maximum load at fracture, as shown in Table 1, was obtained from this plot.

Tensile Tests

Ultimate tensile strength and 0.2 percent offset yield strength were evaluated on each of the weld configurations supplied by LLL. In addition, an additional set of specimens was furnished pre-machined by LLL. Measurements were made along the axis of the weld (i.e., specimen contained all weldment), and transverse or normal to the weld axis (i.e., base metal - HAZ - weld - HAZ - base metal). In all cases the specimens failed in the weld. Tests were made at 4.2 and 300 K. An Instron TT-D test machine with 20,000 pound capacity was used for all of the tests. For the low temperature tests a compression tube cryostat was used. The compression tube could withstand loads up to 6,000 pounds. As a result, the specimen size was scaled down according to ASTM standards, the average cross-sectional area of the gauge length being 0.0123

(1) "Notched Bar Impact Testing of Metallic Materials", ASTM Designation E 23-72, Book of ASTM Standards, Part 10 (1977), pp. 230-246.

TABLE 1. SUMMARY OF IMPACT DATA

Specimen Identification	Test Temp., F	Fracture Energy, ft-lb	Maximum Load to Fracture, lb	Lateral Expansion, mils	Notch Contraction, percent
1-304 T1	-320	40.5	4585	35.4	3.3
1-304 T2	-320	34.1	4568	31.6	4.7
1-304 T3	-320	32.0	4305	37.2	2.9
1-304 T4	-320	60.0	5575	30.8	6.7
2-304 T1	-320	23.1	4110	18.6	3.5
2-304 T2	-320	25.1	4390	23.4	1.2
2-304 T3	-320	30.0	4810	19.4	3.2
2-304 T4	-320	28.9	4600	16.6	3.6
3-304 T1	-320	31.0	4355	18.4	0.7
3-304 T2	-320	25.8	4760	10.8	1.6
3-304 T3	-320	29.4	4900	12.2	1.4
3-304 T4	-320	21.5	4960	14.2	1.0
4-304 T1	-320	9.8	4200	4.6	1.2
4-304 T2	-320	14.9	4915	7.4	2.0
4-304 T3	-320	17.9	5232	11.0	2.4
4-304 T4	-320	13.6	4785	11.6	1.2
5B-304-1	-320	110.5	5689	75.4	1.0
5B-304-2	-320	80.2	5451	63.6	0.3
5B-304-3	74	168.6	3518	86.6	7.4

square inches. The necessity for smaller specimen dimensions was further required by a shortage of weldment material.

The results of the tensile tests are shown in Table 2. On the pre-machined tensile bars furnished by LLL, the percent elongation and reduction in area were also determined. Sample specification 6-304-1 behaved in a manner uncharacteristic of stainless steel. The total elongation and reduction in area are much too low for this type of material. The alloy's behavior is more characteristic of an Inconel alloy. The balance of specimens behaved as expected for 300-series stainless steels at cryogenic temperatures.

Fracture Toughness (J-Integral Method)

The specimen design, precracking and test procedure used for the J-integral toughness characterization followed the proposed ASTM Standard Method for "The Determination of the Elastic-Plastic Toughness Parameter J_{IC} ".

Specimens were cut from the bulk material such that the crack would propagate within and along the axis of the weld. Similarly, the HAZ specimens were cut so the crack would propagate in the same direction but 70 to 100 mils outside the fusion line in the parent material. Specimens were machined according to the drawing shown in Figure 1.

Fatigue precracking was performed at room temperature at a nominal load of 1000 pounds to achieve fatigue crack lengths on the order of 0.07 inch. Nominal fatigue crack growth rates of 1×10^{-6} inch/cycle were obtained. During the fracture tests, crack opening displacements were monitored along the load line by the use of a clip gage as per ASTM specification E 399. The gage arms were constructed of spring steel and the gage was especially potted for low temperature use. All gages used in the work were suitably calibrated.

The fracture specimens were tested at a displacement rate of 0.20 inch/minute until a predetermined amount of load drop-off or total displacement was achieved. Specimens were then removed from the cryostat and heat-tinted in a gas-air burner. The specimens were then pulled apart in LN_2 . Stable fracture crack extension was measured at nine locations across the specimen and averaged to define the physical crack growth parameter Δa_p , and the fatigue crack length.

The J-integral fracture toughness was then calculated from the expression

$$J = \frac{A}{Bb} f \left(\frac{\Delta a}{W} \right),$$

TABLE 2. SUMMARY OF MECHANICAL TEST DATA ON
304-LN-316-LN TRIAL WELDMENTS

Sample No.	Test Temp.	.2% Y.S. (psi)	σ Ultimate (psi)	%E	%R.A.	Comments
5B-304-Bot 1	4.2 K	71,690	205,658	40.8	29.3	Machined specimens furnished by LLL
5B-304-Bot 2	300 K	32,352	77,588	48.3	59.6	
6-304-1	4.2 K	82,573	107,108	11.0	14.6	
6-304-2	300 K	34,890	75,245	32.9	36.9	
5B-304-Top 1	4.2 K	76,931	212,745	39.0	22.5	Specimens machined at BCL
5B-304-Top 2	300 K	29,271	74,706	46.5	55.1	
1-304-LN-Long.	4.2 K	108,000	178,200	-	-	
1-304-LN-Long.	300 K	66,800	102,200	-	-	
1-304-LN-Trans.	4.2 K	112,600	185,100	-	-	
1-304-LN-Trans.	300 K	64,700	91,000	-	-	
3-304-LN-Long.	4.2 K	114,300	211,400	-	-	
3-304-LN-Long.	300 K	77,200	107,500	-	-	
3-304-LN-Trans.	4.2 K	116,380	215,300	-	-	
3-304-LN-Trans.	300 K	75,600	91,514	-	-	
5B-304-Long.	4.2 K	75,520	193,890	-	-	
5B-304-Long.	300 K	33,820	79,200	-	-	
5B-304-Trans.	4.2 K	65,100	200,050	-	-	
5B-304-Trans.	300 K	29,630	69,200	-	-

FIGURE 1. FRACTURE SPECIMEN CONFIGURATION USED IN THE PRESENT STUDY (DIMENSIONS IN INCHES)

February 22, 1979

where A represents the total energy under the load-COD load line curve. Valid data was then determined by the expression

$$b \geq z = \frac{25J}{\sigma_y}$$

Where sufficient data exists the R-curve procedure was employed to define J_{IC} and J_{IC} was subsequently used to determine the plane-strain fracture toughness K_{IC} according to the following relationship:

$$K_{IC} = \left[\frac{J_{IC} E}{1 - \nu^2} \right]^{1/2}$$

In this work we assumed $E = 2.9 \times 10^7$ and $\nu = 0.3$.

J_{IC} and K_{IC} values generated by the foregoing procedure are shown in Table 3. It should be pointed out that additional material would have been desirable to obtain a clearer picture of the materials behavior. Based on the limited fracture toughness evaluations available, we can only conclude that all three weld configurations studied are suitably tough and most likely significantly exceed LLL design requirements.

In one material (3 - 304 LN) large pieces of weld rod were clearly observed along the fracture surface. In spite of this macroscopic defect, the K_{IC} value was quite high. All of the weldments can be considered to exhibit gross plasticity at cryogenic temperatures. In some specimens at liquid nitrogen temperatures the J-integral approach could not be reasonably applied and one must question whether the approach is at all suitable for these types of materials.

Certain background information on the weldments such as microstructure, composition, percent ferrite, and welding procedures have not been available to us. We therefore, do not include an indepth scientific analysis of the results in this report. However, we plan to work with other LLL personnel in preparing a paper for the ICMC meeting in August. A clearer understanding of our work, along with the work of others, should result from this interaction.

We have enjoyed working on this program and hope we can be of further assistance to you in the future.

Sincerely,

Frank J. Jelinek
Project Manager
Materials Application Section

FJJ/pap

cc: Special Materials Staff - J. Jepson - LLL

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TABLE 3. VALUES OF J_{IC} AND K_{IC} FOR VARIOUS STAINLESS
STEEL WELD CONFIGURATIONS

Sample	T(K)	$J_{IC} (\frac{in-lb}{in^2})$	$K_{IC} (ksi-in^{1/2})$
1-304-LN (Weld)	4.2	550	132
1-304-LN (Weld)	77	850	165
1-304-LN (HAZ)	4.2	635	142
1-304-LN (HAZ)	77	1000	179
3-304 LN (Weld)	4.2	320	101
3-304-LN (Weld)	77	970	176
3-304-LN (HAZ)	4.2	540	131
5B-304 (Weld)	4.2	670	146
5B-304 (HAZ)	4.2	515	128

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