Naval Surface Warfare Center
Carderock Division
Bethesda, MD 20084-5000

NSWCCD-TR-61-96/01 September 1996

Survivability, Structures, and Materials Directorate

Research and Development Report

Progress Report - Mechanical Properties Evaluation of ASTM A945 (HSLA-65) Steels

by

Eric M. Focht

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This report documents the mechanical properties of steel plates for Navy use. These plates conform to American Society for Testing and Materials (ASTM) Standard A945, High-strength, Low-alloy (HSLA), Class 65. Plates of various thickness were purchased from two different producers to determine if the steel could be obtained on a production scale, as opposed to a custom order. Tensile and Charpy V-notch impact tests were performed on the steels, and the results are reported within. All of the plates met the minimum mechanical property requirements. The plates also met the minimum Charpy impact energy requirements. Future testing will include dynamic tear testing, static and dynamic fracture toughness testing. A plate supplied by a third producer will also be evaluated.

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Abstract

This report documents the mechanical properties of steel plates for Navy use. These plates conform to American Society for Testing and Materials (ASTM) Standard A945, High-strength, Low-alloy (HSLA), Class 65. Plates of various thickness were purchased from two different producers to determine if the steel could be obtained on a production scale, as opposed to a custom order. Tensile and Charpy V-notch impact tests were performed on the steels, and the results are reported within. All of the plates met the minimum mechanical property requirements. The plates also met the minimum Charpy impact energy requirements. Future testing will include dynamic tear testing, static and dynamic fracture toughness testing. A plate supplied by a third producer will also be evaluated.

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Administrative Information

This report was prepared as part of the Ship and Submarine Materials Technology Program sponsored by the Office of Naval Research (ONR), Code 332 (Dr. George Yoder). Dr. William Messick of the Naval Surface Warfare Center, Carderock Division (NSWCCD), Code 011, is the Technical Area Manager for this program. This effort was performed by the Fatigue and Fracture Branch, NSWCCD, Code 614 under Program Element 62234N, Structural Alloys RS34S60, Work Unit 1-6140-561, and was supervised by the Branch Head, Mr. T.W. Montemarano.

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Introduction

The Navy is currently evaluating high-strength, low-alloy steels for potential use. These steels are designed to meet the chemical and mechanical property requirements of ASTM A945 "High-Strength, Low-Alloy (HSLA) Steel Plate with Low Carbon and Restricted Sulfur for Improved Weldability, Formability and Toughness." ASTM A945 covers two classes of steels: Class 50 and Class 65. Class 50 has a minimum yield strength of 50 ksi and Class 65 has a minimum yield strength of 65 ksi. This project is aimed at evaluating Class 65 steels.

The chemical composition limits and mechanical property requirements for Class 65 are shown in the Table 1.

Steel plates were purchased from two different producers. They are being evaluated to determine whether or not they meet the specification and to characterize their full transition static and dynamic fracture toughness behavior. The producers are identified as Producer 1 and Producer 2. The results of the evaluation to date are reported herein.

Experimental Procedure

Material

Table 2 shows the thickness of each plate received from the companies. The manufacturers' processing technique depended on the thickness of the plate. The table shows what method was employed for each plate thickness and manufacturer. Table 2 also shows that the Producer 1 plates were controlled rolled (CR) and the Producer 2 plates were reheated, quenched and tempered (RQT). The maximum thickness of the plates was determined by each company. Producer 1 offered to supply plates up to 1" thick and Producer 2 offered to supply plates up to 1-1/4" thick.

The chemical compositions of the plates are shown in Table 3, along with the limits set in ASTM A945. The results indicate that each plate met the ranges prescribed by the specification. The microstructures are shown in Figure 1. Figures 1(a) and 1(b) show the microstructures of the 1/2" and 1" thick plates supplied by Producer 1. It was difficult to resolve each constituent using only light microscopy, but the microstructure appeared to consist mainly of ferrite and pearlite and possibly some bainite. Figures 1(c), and 1(d) show the microstructures of the 1" and 1-1/4" thick plates supplied by Producer 2 and they appeared to consist of ferrite and a small amount of a second phase.[1] The second phase was difficult to resolve with light microscopy, but it may be small amounts of a martensite-austenite (M-A) constituent. The grain sizes are listed in the figure captions. Although the average grain sizes of the plates were approximately equal, there appeared to be a difference in the grain size distribution between the plates of the two producers. The Producer 1 plates had a multi-modal ferrite grain size distribution, whereas, the Producer 2 plates appeared to have uniform grain size distribution. The grain morphology of the Producer 2 plates were fairly equiaxed, while that of the Producer 1 plates exhibited elongation parallel to the rolling direction.

Testing

Tensile and Charpy impact tests were completed. Static and dynamic fracture toughness testing will begin in FY96 and will be completed in FY97. The tensile tests were performed using standard 0.505" diameter specimens on plates thicker than 1/2", and standard 0.252" diameter specimens were used for the 1/2" thick plate (Producer 1). Tensile tests have not been performed on the 1/4" thick Producer 2 plate. Full Charpy impact transition curves were developed for the 1" and 1/2" thick Producer 1 plates and the 1-1/4" and 1" thick Producer 2 plates. Dynamic tear (DT) tests through the transition

[1] The 1/4" thick plate microstructure has not been characterized yet.

region on the 1" thick Producer 1 plate the 1-1/4" and 1" Producer 2 plates will be completed in FY96.

Results and Discussion

The differences observed between the microstructures of the plates can be explained by the processing techniques. The microstructure of the Producer 1 plates appeared to be the result of controlled rolling followed by air cooling. The deformed ferrite grains (and possibly their non-uniformity) was most likely the result of controlled rolling in the two-phase ($\gamma + \alpha$) field. The fine, uniform and equiaxed grain structure of the Producer 2 plates is typical of a hot rolled and RQT plate. Controlled rolling usually results in anisotropic mechanical properties, as will be shown.

Table 4 summarizes the results of the tensile and Charpy V-notch tests performed on the candidate plates. All of the plates met the minimum yield strength requirements considered.

The tensile strengths of all of the plates were within the specified range shown in Table 2. The Producer 1 plates exhibited anisotropic strength levels between the longitudinal and transverse directions; the specimens oriented in the transverse direction had higher strengths than the longitudinal specimens. There was slight anisotropy between the longitudinal and transverse directions in the 1-1/4" Producer 2 plate. The ductility of all of the plates was above the minimum value required.

Table 4 also shows that the 30 ft-lb Charpy impact transition temperature for all of the plates was well below -40°F.[2] However, Figures 2 and 3 show that the Charpy impact transition behavior was different for the Producer 1 and Producer 2 plates. The upper shelf toughness of the Producer 2 plates was higher than the Producer 1 plates and the

---

[2] There were not enough specimens to obtain a full transition curve for the 1" Producer 2 plate.

ductile-to-brittle-transition temperature was lower for the Producer 2 plates. At -40°F, the Producer 2 plates were on upper shelf while the 1" Producer 1 plate appeared to be near the upper shelf and the 1/2" plate was still in transition. The open symbols in Figures 2 and 3 represent specimens that did not break into two pieces ("no break") following impact during Charpy testing. More of the specimens from CR plates did not fully separate compared to the RQT plates. Splitting parallel to the rolling direction was observed on the fracture surfaces of the "no break" specimens from the CR plates. Splitting may be the result of texture development in the plate during severe controlled rolling causing low energy fracture along preferred planes[3].

Summary

The results to date show that an HSLA steel with minimum yield strength of 65 ksi can be produced commercially and meet the strength and impact toughness requirements set forth in ASTM A945. The producers used different processing techniques such as controlled rolling and hot rolling plus RQT to manufacture the plates. All of the plates met the minimum yield strength requirements. Controlled rolling resulted in anisotropic mechanical properties while RQT resulted in isotropic mechanical properties. Although all of the plates exhibited sufficient Charpy impact energies, the RQT plates had lower transition temperatures and higher upper shelf toughness than the controlled rolled plates.

Future Work

Dynamic tear testing, and static and dynamic fracture toughness testing of the 1-1/4" thick Producer 2 and 1" thick Producer 1 plates will be performed. A third producer supplied a section of 3/4" plate that will be evaluated as well.

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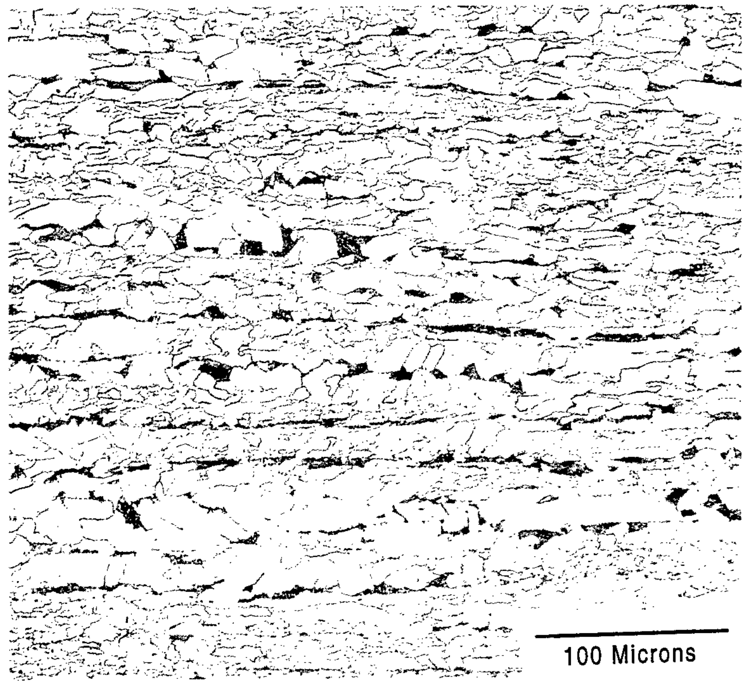
[3] Bramfitt, B.L. and A.R. Marder, "Splitting Behavior in Plate Steels," *Proceedings of the Symposium on Toughness Characterization and Specifications for HSLA and Structural Steels*, Ed. P.L. Mangonon, Jr., TMS-AIME, ppg 236-256, 1977.

a) 1/2" thick plate, Producer 1, average grain size = 5.71 µm.

Magnification is 250X.



(b) 1" thick plate, Producer 1, average grain size = 6.07 µm.

Magnification is 250X.

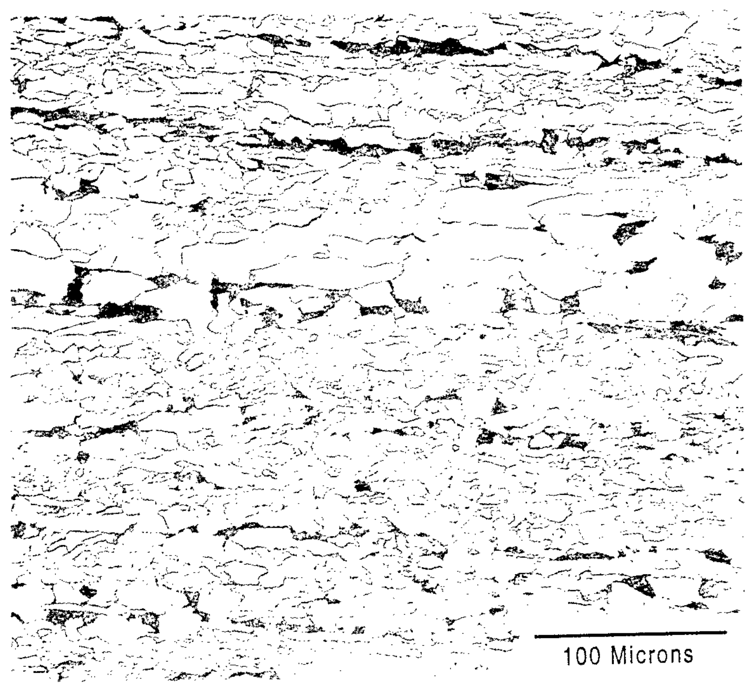
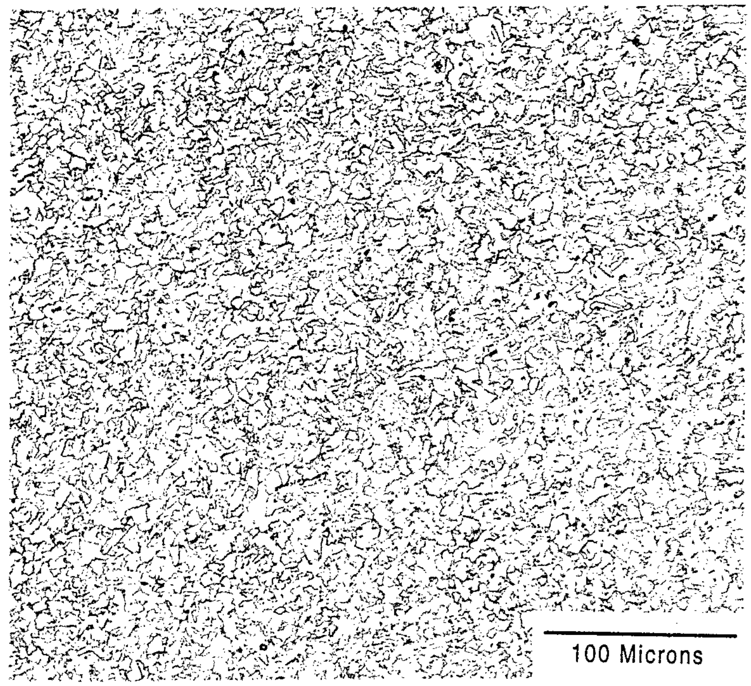


Figure 1. Microstructures of Candidate ASTM A945, Class 65 Steels. (1 of 2)

(c) 1" thick plate, Producer 2, average grain size = 5.07 µm.

Magnification is 250X.



(d) 1-1/4" thick plate, Producer 2, average grain size = 4.76 µm.

Magnification is 250X.

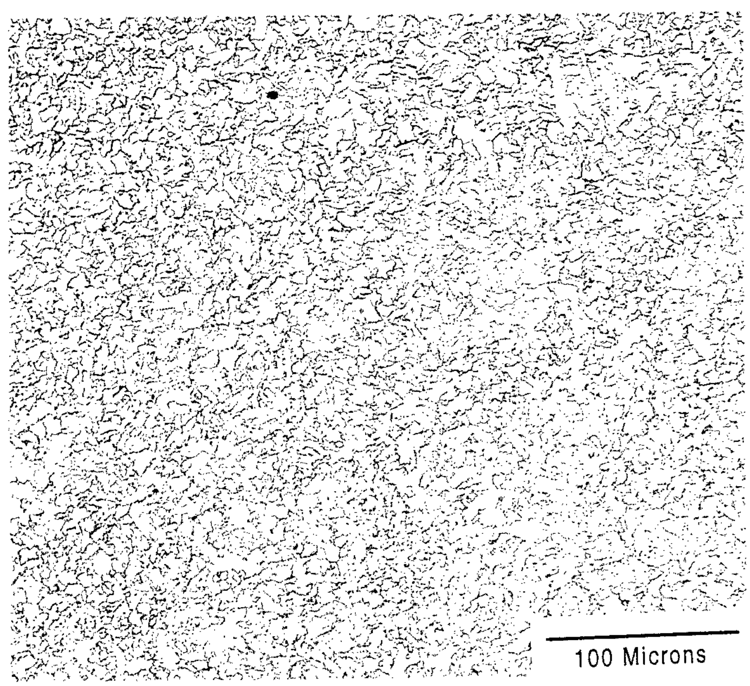
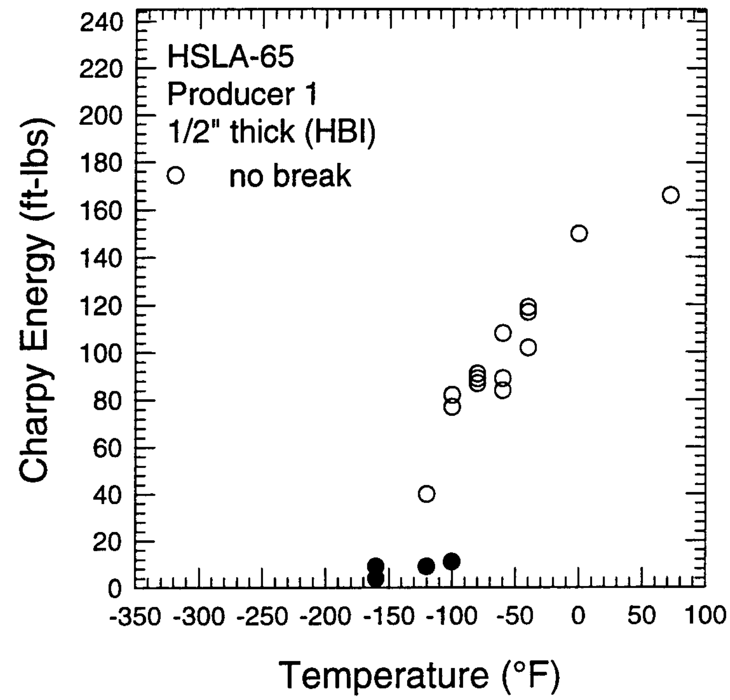


Figure 1. Microstructures of Candidate ASTM A945, Class 65 Steels. (2 of 2)

(a)



(b)

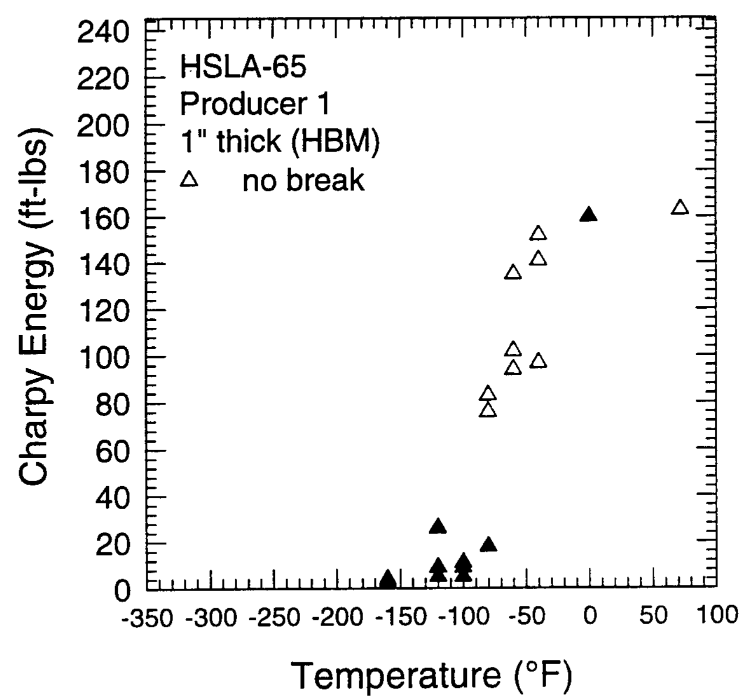
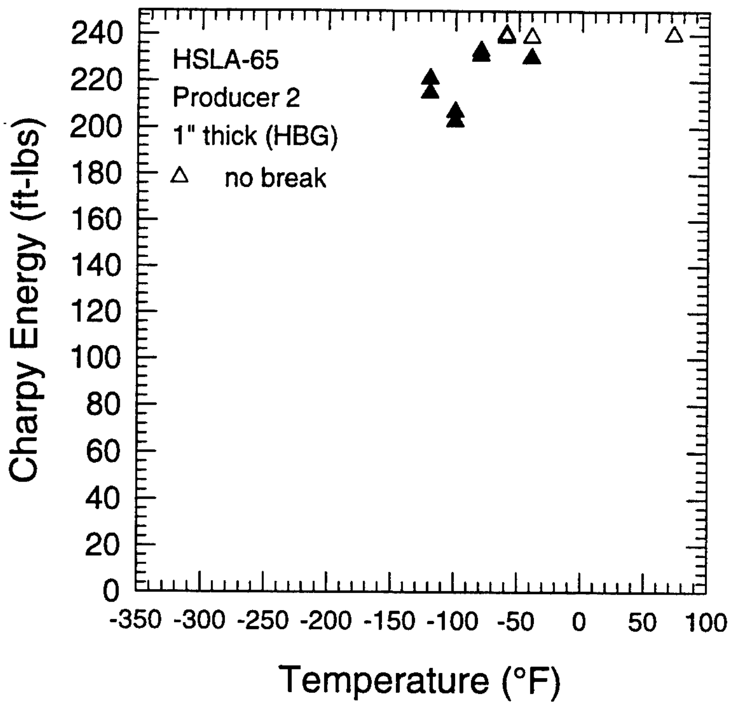


Figure 2. Charpy V-notch Energy Versus Temperature Results for Producer 1.

(a)



(b)

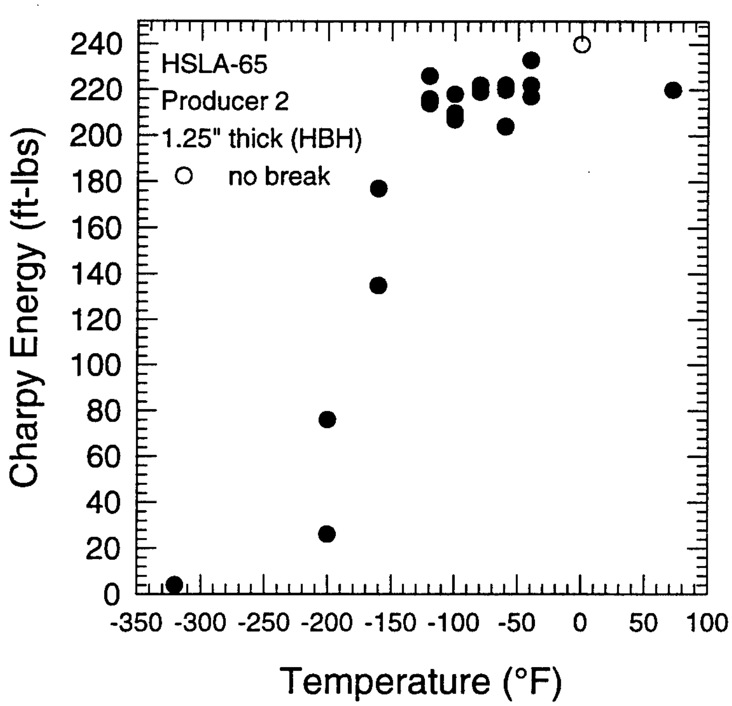


Figure 3. Charpy V-notch Energy Versus Temperature Results for Producer 2.

Table 1. Chemical Composition and Mechanical Property Requirements of ASTM A945, HSLA, Class 65 Steel.

Element	wt%	Property	Requirement
C	0.10 max	Yield Strength	65 ksi (450 MPa)
Mn	1.10 -1.65	Tensile Strength	78 - 100 ksi (540-690 MPa)
P	0.025 max	% Elongation	18 (in 8 in.) 22 (in 2 in.)
S	0.010 max	Charpy V-Notch Impact @ -40°F (-40°C)	30 ft-lbs (41 J) long. 20 ft-lbs (27 J) trans.
Si	0.10 - 0.50		
Ni	0.40 max		
Cr	0.20 max		
Mo	0.08 max		
Cu	0.35 max		
V	0.10 max		
Nb (i.e. Cb)	0.05 max		
Al	0.08 max		

Table 2. Producer, Processing Technique and Thickness of the Plates Evaluated.

	Producer 1	Producer 2
Thickness of Plate Received	1/2", 1"	1/4", 1", 1-1/4"
Processing	$t \leq$ 1-1/4" CR	$t \leq$ 1-1/4" RQT

Table 3. Chemical Compositions of ASTM A945 Plates.

Element	Producer 1 1/2" thick	Producer 1 1" thick	Producer 2 1" thick	Producer 2 1-1/4" thick	ASTM A945 (maximums unless range is given)
C	0.076	0.068	0.077	0.079	0.10
Mn	1.22	1.21	1.31	1.25	1.10-1.65
P	0.015	0.013	0.007	0.007	0.025
S	0.005	0.003	0.002	0.003	0.01
Si	0.26	0.26	0.24	0.22	0.1-0.5
Ni	0.033	0.026	0.36	0.36	0.40
Cr	0.036	0.031	0.14	0.13	0.20
Mo	0.001	0.001	0.051	0.048	0.08
Cu	0.016	0.019	0.25	0.23	0.35
V	0.065	0.059	0.054	0.052	0.10
Nb (or Cb)	0.035	0.036	0.031	0.024	0.05
Al	0.30	0.035	0.013	0.012	0.08
N	0.0065	0.0075	0.0064	0.0063	---

Table 4. Summary of Results of Tensile and Charpy V-notch Testing.

Plate		Y.S. (ksi)	T.S. (ksi)	% el.	% R.A.	30 ft-lb transition temperature (°F)
			Producer 1			
1"	long.	71.5	82.8	28.9	80.1	-100
	trans.	74.0	86.2	25.4	72.7	not tested
1/2"	long.	74.9	85.7	25.2	78.9	-125
	trans.	80.1	89.7	24.8	69.7	not tested
			Producer 2			
1-1/4"	long.	72.9	83.26	32.6	79.5	-200
	trans.	69.9	82.7	29.9	76.7	not tested
1"	long.	76.0	86.8	29.9	78.7	< -120
	trans.	76.3	86.9	29.7	79.1	not tested

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