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OBSERVATIONS ON STEEL FOR RCN TANKER/SUPPLY SHIP (PROVIDER)

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY

The Physical Metallurgy Division has carried out Charpy V-notch control tests on samples of steel for construction of the tanker/supply ship "Provider". The reference standard was Lloyd's Grade D which requires the average absorbed energy of three bars broken at 32°F (0°C) to be 35 ft-lb or more. The results of 750 control tests of samples of plate ranging from $\frac{1}{4}$ inch to $2\frac{1}{2}$ inches in thickness are incorporated. Full Charpy curves were determined and the microstructures examined for thirteen plates, and the tensile properties were determined for nine of these. Consideration is being given to the use of CSA G40.8B as a specification for ship steel for future construction; hence comparisons are made with the requirements of this specification.

The failure rate in the Charpy V-notch test was low, being just over 2% for both producers. There was no systematic variation with plate thickness in energy absorbed at 32°F (0°C). Statistical analysis of data from 7/8 - 27/32 inch plate showed no significant difference between the product of two producers, nor between 1/2 inch and the 7/8 - 27/32 inch group for one producer. Based on the eighty-five samples in the above mentioned groups, it was calculated that the true average-of-three value would lie within $\pm$ 18 ft-lb of the determined value. The composition of $\bar{}$95% of the samples from Producer A fell within the limits of CSA G40.8B.

The more detailed examination and testing of thirteen plates showed a good correlation of grain size with plate thickness over a narrow range of grain sizes (ASTM 8.2 - 10.1, calculated), but no correlation between plate thickness and transition temperature at either the 25 or 15 ft-lb level. Parenthetically, all samples were

"fine-grained" in the conventional sense. The energy absorbed at 32°F (0°C) as determined from the curves fell within $\pm$ 18 ft-lb of that determined by the control tests in most cases. The full Charpy curves illustrate the impossibility of transposing criteria in the Charpy V-notch test in this type of material. The 15 ft-lb transition temperatures of these plates were lower than those "anticipated" in CSA G40.8B except in one case. The tensile properties of nine samples either met the requirements of G40.8 or fell short by so little that the adjustment in composition necessary to ensure meeting these requirements would be slight.

INTRODUCTION

Steel plate for the construction of a 20,000 ton tanker/supply ship, (Provider), for the R.C.N. was purchased to specification ASTM A-131, Grade C. This specification, the equivalent of the American Bureau of Shipping Grade C, does not require a notch ductility test. However, such a test was considered necessary and the Charpy V-notch requirements of Lloyd's Grade D were invoked in a special agreement. Lloyd's specification for Grade D ship plate requires the average absorbed energy of three Charpy V-notch specimens broken at 32°F (0°C) to be 35 ft-lb or higher. There are, of course, further detailed provisions regarding tolerances, retesting, etc. Under the special arrangement for this purchase, the steelmakers prepared three Charpy V-notch specimen blanks, which were then notched and broken at 32°F (0°C) by the Physical Metallurgy Division, Department of Mines and Technical Surveys. For the purposes of this report, these are designated "control tests". A further small portion of plate was forwarded so that additional Charpy specimens could be prepared in those cases where additional testing was required. The steel was made by two producers, hereinafter designated Producer A and Producer S. All the steel from Producer S is believed to be open hearth. Most of the steel from Producer A was made by the oxygen converter process, the remainder being open hearth.

This report presents an examination of the data available from the control testing to the end of February, 1962. While a few additional tests have been carried out since that date, the results have not altered the general pattern shown here. The results of some 750 Charpy V-notch control tests are incorporated. The results of these tests and the ladle analyses (heat composition) are summarized graphically. The individual items are on record but the data are considered too extensive to be usefully shown in tabular form. In a few cases where sufficient information was available, the data were analyzed statistically. It is pointed out the data are based on plates tested, not on heats, and that there are many cases of more than one sample per heat. The tests represent some 3295 tons of plate from Producer A and 1644 tons of plate from Producer S. Plate thicknesses varied from $\frac{1}{4}$ inch to $2\frac{1}{2}$ inch. The results of a few tests on structural shapes representing 329 tons from Producer A and 132 tons from Producer S are also included.

Full Charpy V-notch curves were determined and the microstructures examined for a number of representative plates. Tensile tests were carried out on those samples in this group for which sufficient plate was available. The results of this additional laboratory testing are compared with the results for the control tests.

Some consideration is being given to CSA G40.8, "Structural Steels with Improved Resistance to Brittle Fracture", as a specification for steel for certain applications in the future. Hence the data are compared with the requirements of this specification although different specifications were invoked in this particular purchase.

CONTROL TESTS

Figures 1 and 2 show, for each thickness, the range of absorbed energy at 32°F (0°C), the average (the break in the bar), and the number of samples tested. The values used were the averages for the three bars tested in each sample. It will be noted that the range for Producer A is generally wider than that of Producer S and that the average absorbed energy at 32°F (0°C) appears somewhat higher. From the individual results it was determined that the "weighted average" energy absorbed for all thicknesses for Producer A is 78 ft-lb and for Producer S, 60 ft-lb. It will be noted that there is no apparent correlation between plate thickness and average absorbed energy. Based on the number of samples tested, the failure rate for Producer A was determined as 2.13% and that for Producer S, 2.68%.

Figure 3 shows the frequency distributions of absorbed energy at 32°F (0°C) in four cases where a reasonable number of plates of similar thickness had been tested. In three cases the frequency distribution appears to conform well to the normal Gaussian curve. The greatest departure from the normal distribution is found for the thickest plate. From inspection there appears to be no significant difference between the 7/8 - 27/32 inch plates from the two producers.

Figures 4 and 5 show the range and frequency distribution of carbon, manganese, sulfur, and phosphorus contents for the two steelmakers. While differences in phosphorus and sulfur contents between the two groups are apparent, it is not considered that these are significant from the viewpoint of notch ductility. With regard to the other two elements, it will be noted that the plates from Producer A were generally lower in carbon and higher in manganese than those of Producer S. It is apparent from Figure 4 that the carbon and manganese contents of the plate from Producer A approximated the requirements of CSA G40.8B; i.e. 0.20% carbon maximum and 0.80% manganese minimum. An examination of the data showed the compositions of all heats to conform to relevant specifications as follows:

Specification	Producer A	Producer S
	Percent of Samples Meeting Specification	
CSA G40.8 "B"	95%	3.5%
Lloyd's "D"	100%	100%
ASTM A-131 "C"	78%	100%

An inspection of the individual ladle analyses showed that there was no apparent systematic variation in chemical composition with plate thickness, i.e., it was not necessary to increase carbon and/or manganese content to maintain tensile properties as the thickness increased.

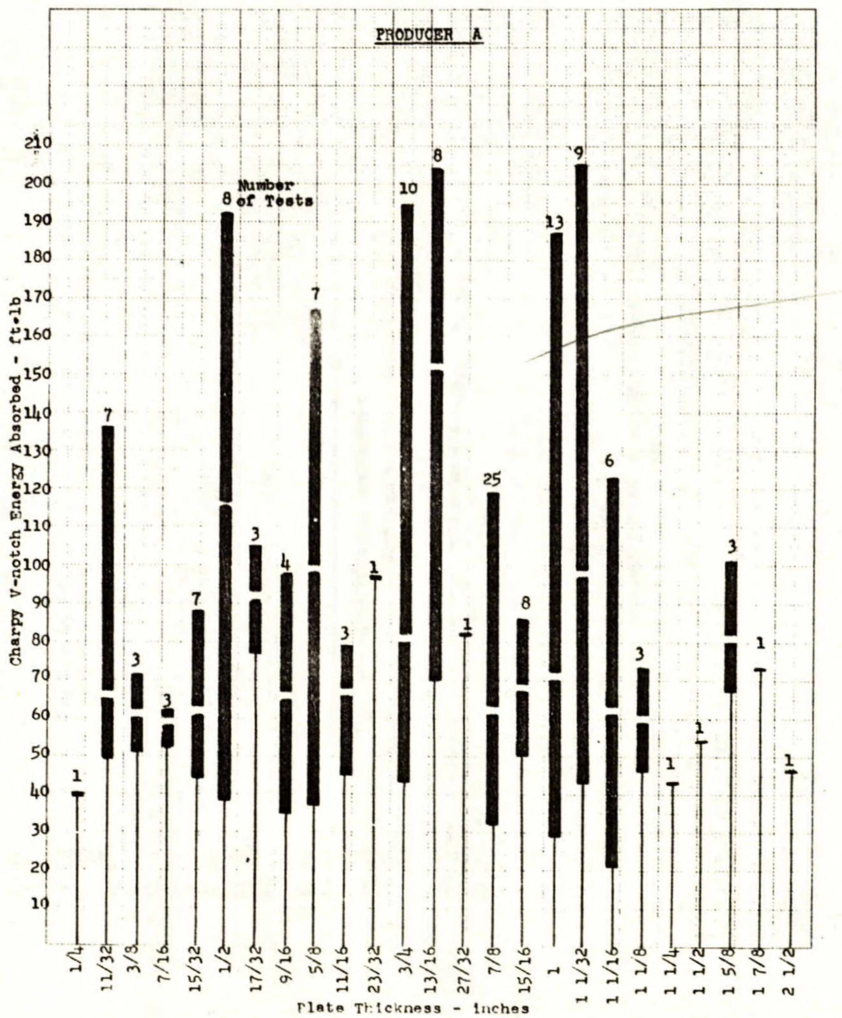


Figure 1. Range and Average Impact Test Results by Plate Thickness.

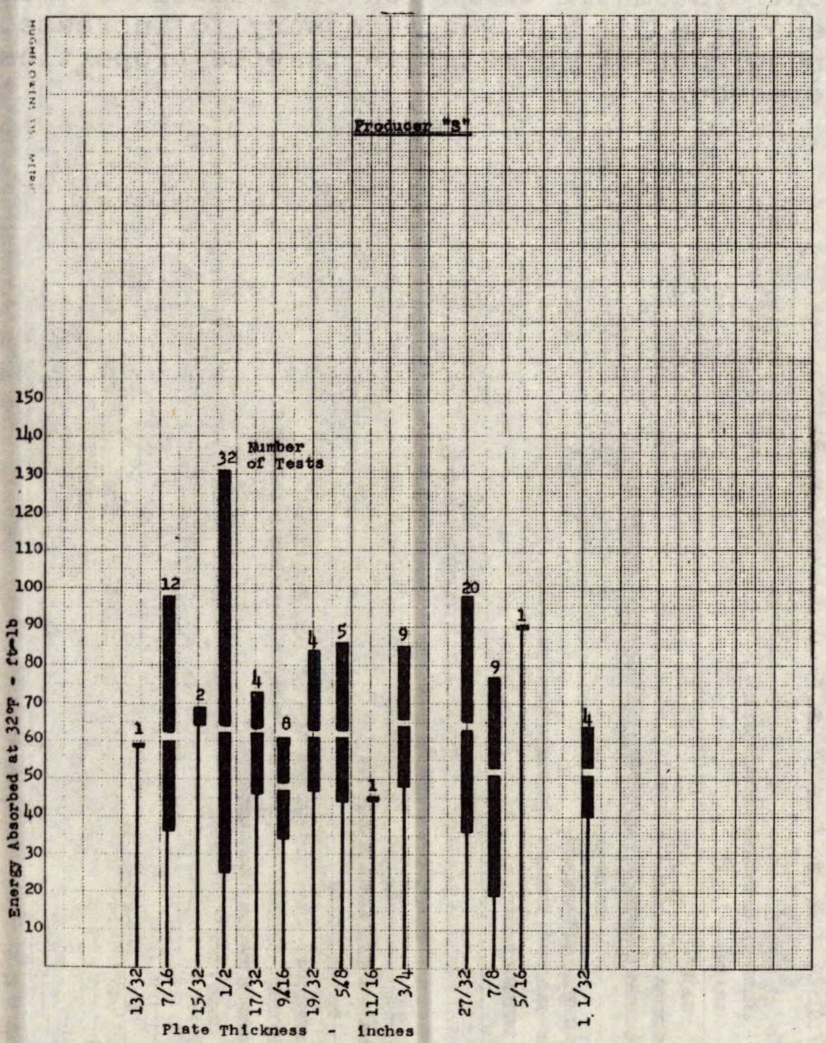


Figure 2. Range and Average Impact Test Results by Plate Thickness.

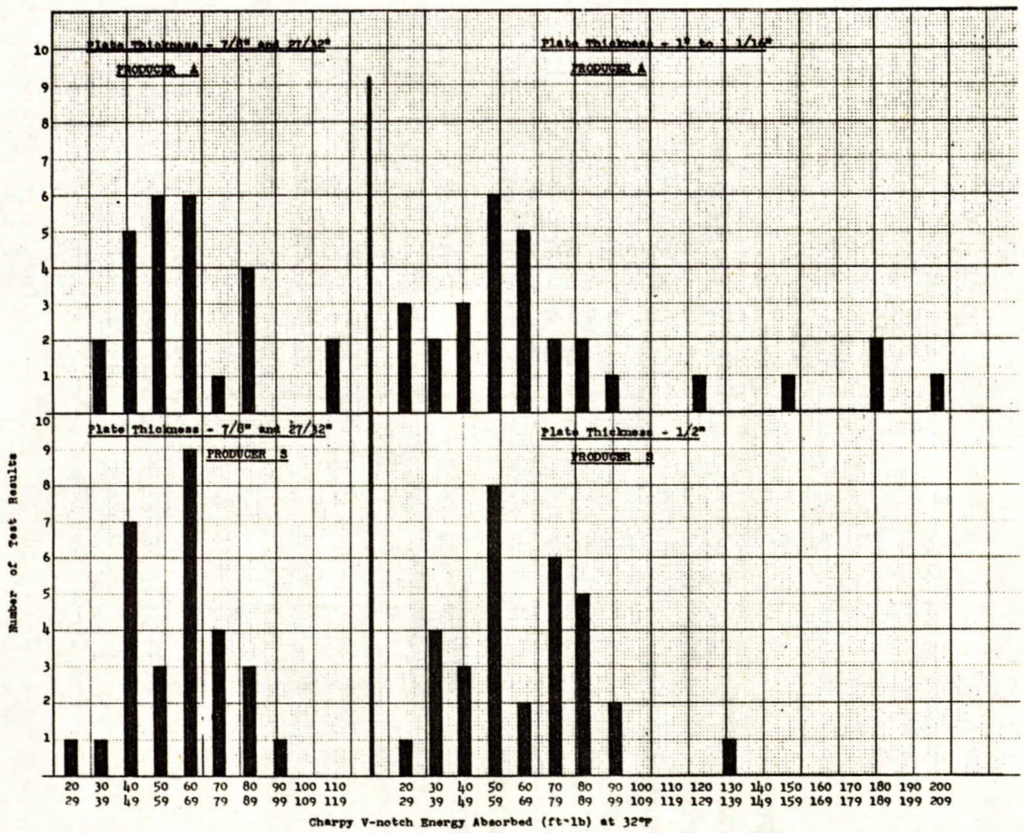


Figure 3. Frequency Distribution Impact Energy Absorbed for Plates of Similar Thickness.

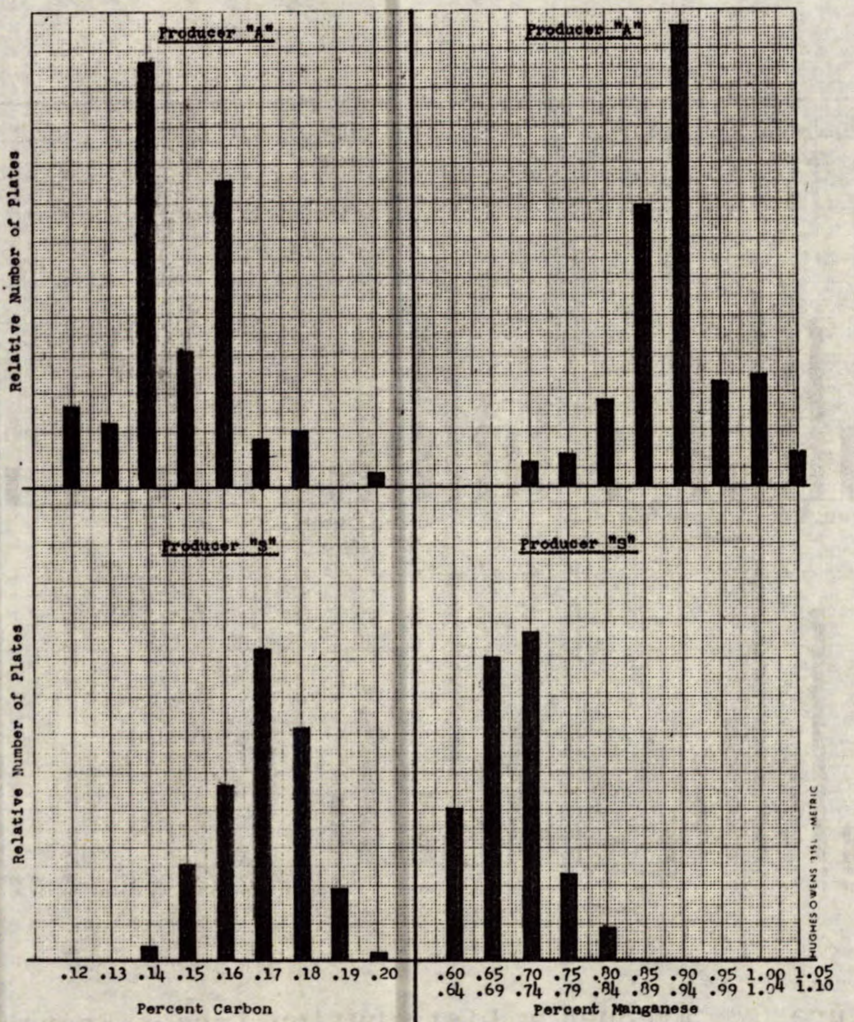


Figure 4. Frequency Distribution of Carbon and Manganese Contents.

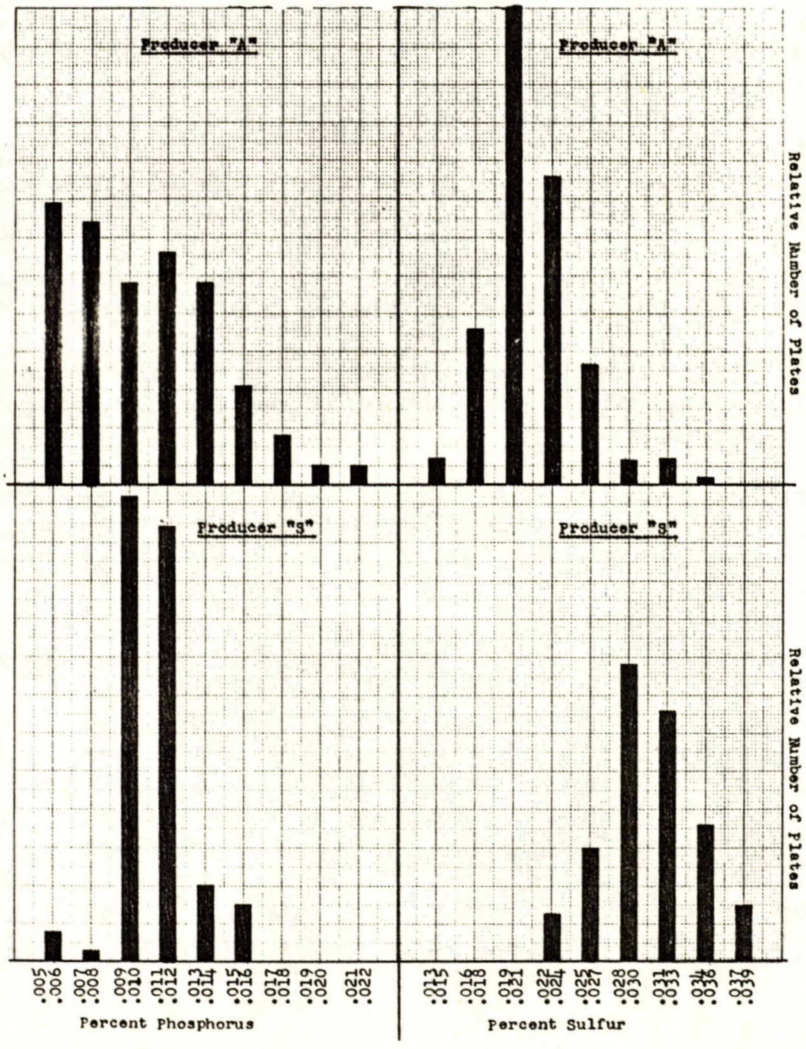


Figure 5. Frequency Distribution of Phosphorus and Sulphur Contents.

STATISTICAL ANALYSIS

The impact data for a total of 85 plates (26 representing 7/8 inch and 27/32 inch plate from Producer A, 28 representing 7/8 inch and 27/32 inch plate from Producer S, and 31 representing 1/2 inch plate from Producer S) are shown in Table 1. A Chi-square test of goodness-of-fit showed that the average-of-three values may be considered to be normally distributed at the 5% level of significance. Analysis of variance of the impact results has been summarized in Table 2. The main points shown by the statistical analysis are:

(a) The impact values did not differ significantly with plate thickness (7/8 inch and 27/32 inch versus ½ inch) at the 5% level of significance.

(b) At the 5% level of significance, there was no difference between the plates of the two producers.

(c) Variation in impact strength from plate to plate is highly significant, accounting for 70.8% of the total variation.

(d) The residual error, i.e., error not attributed to variation due to the influence of thickness, steel producer, or plates, accounts for 28.4% of the total variation.

The standard deviation of an individual impact value, calculated from the residual error, is 15.863 ft-lb. This means that at the 5% level of significance the true individual value lies within a range of $\pm$ 31 ft-lb of the test result. At the same level of significance the true average-of-three values lies within $\pm$ 18 ft-lb of the test average. This means that to assure, statistically, that 97.5% of the average-of-three results will exceed 35 ft-lb, the average-of-three test results must exceed 53 ft-lb. Reference to the data in Table 1 shows that on this basis 29 of the 85 plates are unacceptable. In point of fact, only three of the plates failed.

TABLE 1

Impact Results

Producer A 7/8" and 27/32"				Producer S 7/8" and 27/32"				Producer S 1/2"			
Test Results (ft-lb)				Test Results (ft-lb)				Test Results (ft-lb)			
1	2	3	Av.	1	2	3	Av.	1	2	3	Av.
70	46	47	54.3	84	90	88	87.3	76	84	69	76.3
68	75	70	71.0	59	62	63	61.3	89	57	95	80.3
86	100	60	82.0	58	72	80	70.0	64	97	105	88.6
41	40	44	41.6	60	59	59	59.3	69	99	77	81.6
31	32	33	32.0	53	82	61	65.3	85	104	97	95.3
60	58	69	62.3	94	92	74	86.6	71	44	58	57.6
62	47	55	54.6	57	61	67	61.6	82	86	69	79.0
44	42	36	40.6	34	39	34	35.6	63	55	52	56.6
58	71	52	60.3	87	76	87	83.3	74	83	67	74.6
94	78	81	84.3	52	62	41	51.6	86	81	45	70.6
87	82	88	85.6	12	60	64	45.3	82	69	66	72.3
44	42	50	45.3	66	64	61	67.0	52	42	38	44.0
54	58	46	52.6	84	70	83	79.0	41	57	49	49.0
190	99	69	119.3	58	43	19	40.0	89	119	187	130.6
74	195	69	112.6	96	98	98	97.3	74	67	70	70.8
65	44	50	53.0	73	94	70	79.0	79	47	42	56.0
30	62	36	42.6	49	83	69	67.0	48	55	51	51.3
76	66	42	61.3	77	52	57	62.0	87	92	94	91.0
89	91	86	88.6	48	32	40	40.0	57	52	56	55.0
65	72	41	59.3	38	45	39	40.6	64	62	44	56.6
53	65	80	66.0	55	49	77	60.3	26	26	24	25.3
67	68	63	66.0	27	14	16	19.0	50	44	58	50.6
36	46	48	43.3	61	56	60	59.0	43	36	36	38.3
58	44	48	50.0	61	40	92	64.3	68	54	33	51.6
34	49	34	39.0	43	50	37	43.3	36	32	43	37.0
62	67	54	61.0	34	54	44	44.0	86	93	86	88.3
				53	68	58	59.6	53	71	57	60.3
				32	48	41	40.3	44	38	37	39.6
								60	56	73	63.0
								33	32	36	33.6
								81	90	85	85.3

Producer A 7/8" and 27/32": $\alpha = 0.05$, $\bar{x} = 62.66 \pm 3.52$

Producer S 7/8" and 27/32": $\alpha = 0.05$, $\bar{x} = 59.51 \pm 3.39$

Producer S 1/2": $\alpha = 0.05$, $\bar{x} = 64.86 \pm 3.33$

TABLE 2

Analysis of Variance

Source of Variation	Sums of Squares	d.f.	Mean Squares	F Ratio
Between Producer A (7/8" & 27/32") Producer S (7/8" & 27/32" and Producer S (1/2") plates	1,268.902	2	634.451	2.52*
Between Slabs (Producer S and Producer A) Plates 4 (all thicknesses)	107,016.849	82	1,305.0845	5.186**
Residual	42,776.638	170	251.6274	
Total	151,062.408			

*Significant at the 10% level.
**Significant at the 1% level.

LABORATORY TESTING AND EXAMINATION

The principal results of the laboratory testing and examination are shown in Figures 6 to 24 and Tables 3 to 5. The compositions shown are those reported by the steelmaker. The fracture appearance curves must be considered approximate as they were drawn from points established by estimation, not measurement, of the percent crystallinity in the fracture. However, since the fractures are shown, it was deemed that this approximate method was sufficiently accurate. Discrepancies between the number of tests on the graphs and the number of test bars shown will be found. Some bars did not break completely on test. The values from these are not included in the graphs as they are quantitatively invalid. The bars were subsequently broken and are included to illustrate more fully the fracture appearance and ductility. The yield and ultimate strength, the thickness, and the microstructure are also shown. Full tensile test results are given in Table 3 along with the tensile requirements of CSA G40.8. The grain sizes were established by the Heyn Intercept Method and are shown in Table 4 expressed as grains per square inch at a magnification of 100 and also as calculated ASTM Grain Size Numbers.

Plates A1 and A2 (Figures 6, 7, and 9) are both 1 5/8 inch thick, have the same yield strengths and similar compositions, but different transition temperatures, the 25 ft-lb transition temperature of A2 being 26 F degrees (14.5 C degrees) higher than that of A1. The difference is probably due to variation in rolling conditions. This is a good illustration of grain configuration appearing to be more influential than a small difference in grain size per se. A2 is finer grained than A1 (184 vs 153 grains per square inch at X100), but has the higher transition temperature. A2 is somewhat acicular and contains some Widmanstatten structure.

Plates A5, A6, and A7 (Figures 10 to 13) are all 3/4 inch thick, and of very similar composition. However, A5 is an open hearth heat whereas A6 and A7 are oxygen converter heats. The energy curves show A5, A6 and A7 to have successively lower transition temperatures. At temperatures of 32°F (0°C) and higher, the Charpy bars of A7 did not break on test and the results are therefore quantitatively invalid. It is noteworthy that in this case, a high level of notch ductility at higher temperatures was associated with low transition temperature. Another point to note is that crystallinity was observed on the fracture faces of the bars of A5 and A6 up to room temperature, whereas in A7 the highest temperature for the occurrence of crystallinity was 20°F (-6.7°C).

Plates A8 and A9 (Figures 14 to 16) are 1/2 inch thick, of similar composition and yield strength, but A8 is open hearth and A9 oxygen converter steel. There is a considerable difference in the slopes of the energy curves. Attention is also drawn to the remarkable consistency of the results of the Charpy V-notch tests on A8 at the various temperatures. The wider scatter in the results for A9 is more usual for this type of steel.

Plates S2 and S3 (Figures 18 to 20), 3/4 inch thick, open hearth steel, have similar compositions. The maximum absorbed energies of the Charpy curves are similar but the slopes of the curves in the transition zone are different; the change from ductile to brittle occurs more rapidly in S2 than in S3. At higher temperatures there is considerable scatter in the results for S3.

Plates S5a and S5b (Figures 21 to 23) 1/2 inch thick, are from the same open hearth heat. It will be noted that there is quite wide variation in Charpy V test results within the single heat. There is a slight variation in grain size (Figure 23) but the finer grained material has the poorer notch ductility.

Figure 24 shows the grain size as a function of plate thickness. The relationship between the two is clear, the grain size increasing with plate thickness. The lower half of the figure shows the 25 ft-lb transition temperature as a function of plate thickness. It is clear that there is no correlation between plate thickness and transition temperature. This lack of correlation holds true at the 15 ft-lb level also. These results confirm more generally what was indicated in the previous examination of individual plates; i.e. within the narrow range of grain sizes of these plates (ASTM 8.2 to 10.1), other factors, presently undetermined, obscure the known influence of grain size on transition temperature. It is pointed out that all samples were "fine grained" in the conventional sense.

DISCUSSION

It will be recalled that 95% of the samples of Producer A conformed to the composition requirements of CSA G40.8B. Table 5 shows the 15 ft-lb transition temperature to be below that "anticipated" in G40.8 in the case of 7 of the 8 plates from this producer for which full impact test curves were established. From Table 3, it will be seen that the tensile properties of 3 of the 5 samples tested conform to the requirements of this specification and that the other two samples fell short by very little. While the number of samples tested is much too small to generalize with authority, it would appear that the adjustment in composition which would be necessary to meet the tensile requirements of G40.8 is slight.

A similar pattern is found in the mechanical properties of plate from Producer S, although the composition of this steel conformed to ASTM A131 rather than CSA G40.8B. It should be pointed out the divergence from the requirements of 40.8B is not great in these samples, as the only discrepancy is a somewhat lower manganese content, i.e., 0.67% - 0.76% manganese against 0.80% minimum.

In Table 5, a comparison is made between the values for energy absorbed at 32°F (0°C) as determined by the control tests and as derived from the curves. It will be recalled that the statistical analysis calculations determined that, at the 95% confidence level, the <u>true</u> average-of-three value would lie within ± 18 ft-lb of the <u>test</u> average (the value actually found). In the ten reliable values of Table 5, it is noted that 9 samples fell within the predicted range. The reason for the discrepancy in the case of A3 is not apparent from the examination.

The full Charpy V-notch curves illustrate the difficulty, if not impossibility, of transposing criteria. For this program, the question was asked as to whether Lloyd's criterion of 35 ft-lb at 32°F (0°C) could not be expressed in the more common form of some 15 ft-lb transition temperature. It was the view of both the writer and the steelmakers that this was not feasible. The difficulty is well shown by reference to the data of Table 5. Plates A8 and A9, both 1/2 inch thick, absorbed 51 and 52 ft-lb respectively at 32°F (0°C), i.e., their properties appeared to be identical. However, they have 15 ft-lb transition temperatures of -44°F (-42°C) and -22°F (-30°C) respectively. The discrepancy of about 20 F degrees (11 C degrees) at the two levels is considered significant. The data of plates A3 and S5b are even more convincing. Here the plate thicknesses differ. However, the single Lloyd's criterion is applied to all thicknesses, hence the comparison between these two plates is valid. Plate A3 absorbed 20 ft-lb at 32°F (0°C) and plate S5b, 23 ft-lb, i.e., virtually identical. The 15 ft-lb transition temperatures are +24°F (-4.4°C) and -10°F (-23°C) respectively, a difference of 34 F degrees (19 C degrees). At the 25 ft-lb level the transition temperatures are +39°F (3.9°C) and +42°F (5.6°C) respectively. These curves demonstrate the severe limitations of the Charpy V-notch test and appear to lend support to our contention that Charpy V correlations are empirical in the most rigorous sense of the word and very little extrapolation or interpolation is acceptable.

It is apparent that a high maximum absorbed energy is not a reliable indicator of transition temperature. Plate A7 compared to A5 shows the high maximum absorbed energy to be significant, but the results of A8 and A9 show the reverse.

Early in the testing it was noted that a high percentage crystallinity in the fracture often accompanied high energy absorption. In such cases, considerable plastic flow preceeded the fracture as evidenced by the lateral contraction under the notch. The bars of Plate A-9, broken at 60°F (15.6°C) (Figure 15), illustrate this point. In this case, approximately 60% crystallinity accompanied 85 ft-lb energy absorption. It was also noted there was a general tendency for steel from Producer A to show greater crystallinity in the fractures than that from Producer S, although there are individual cases where the reverse was true. This difference can be expressed in two ways. Based on a similar energy level, it was found that at the 25 ft-lb transition temperature the average crystallinity for Producer A was 97% and for Producer S, 87%. Basing the comparison on a similar fracture appearance, at the temperature for 75% crystallinity, the samples from Producer A absorbed an average energy of 71 ft-lb, those from Producer S, 56 ft-lb. With relation to fracture initiation and propagation in a structure, the significance of a high percentage crystallinity accompanying high energy absorption in the Charpy V-notch test is not clear.

Considering the general relationship between Charpy curves and microstructure, it was noted that there was a general tendency for increasing scatter of energy values at the various temperatures as the amount of Widmanstatten structure increased. While there was a tendency for increase in scatter as the structure became somewhat acicular rather than equiaxed, the pronounced change occurred with the first appearance of Widmanstatten structure.

CONCLUSIONS

The more important observations are as follows:

1. Most samples met the requirements of the Charpy V-notch test. Just over 2% of the samples of both producers failed.

2. The difference in the weighted average energy absorbed for all thicknesses between the two producers was not great, being 78 ft-lb for Producer A and 60 ft-lb for Producer S.

3. There was no uniform variation in average absorbed energy with plate thickness; i.e. in general the thick plate is as good as the thin plate.

4. There was a distinct difference in composition, the carbon/manganese ratio of steel from Producer A being lower than that of material from Producer S.

5. The heat composition of 95% of the samples from Producer A conformed to the requirements of CSA G40.8B.

6. Of 8 samples from Producer A and 5 from Producer S for which full Charpy V-notch curves were obtained, all but one sample from Producer A had 15 ft-lb transition temperatures lower than that "anticipated" in G40.8B.

7. The tensile properties of 3 of 5 samples of Producer A and 1 of 3 samples of Producer S met the requirements of G40.8B. The amount by which the remaining samples failed is very slight.

ACKNOWLEDGEMENTS

The ladle analyses (heat compositions) and the tonnage of steel represented by the samples were supplied through the courtesy of the Materials Section, Director General Ships, Royal Canadian Navy.

The work of Mr. D.K. Faurschou, Senior Scientific Officer, Ferrous Metals Section, in carrying out the statistical analysis is gratefully acknowledged.

Mr. D.A. Munro, Technician, Ferrous Metals Section, contributed materially by the preparation of the photomicrographs and the determination of the grain sizes.

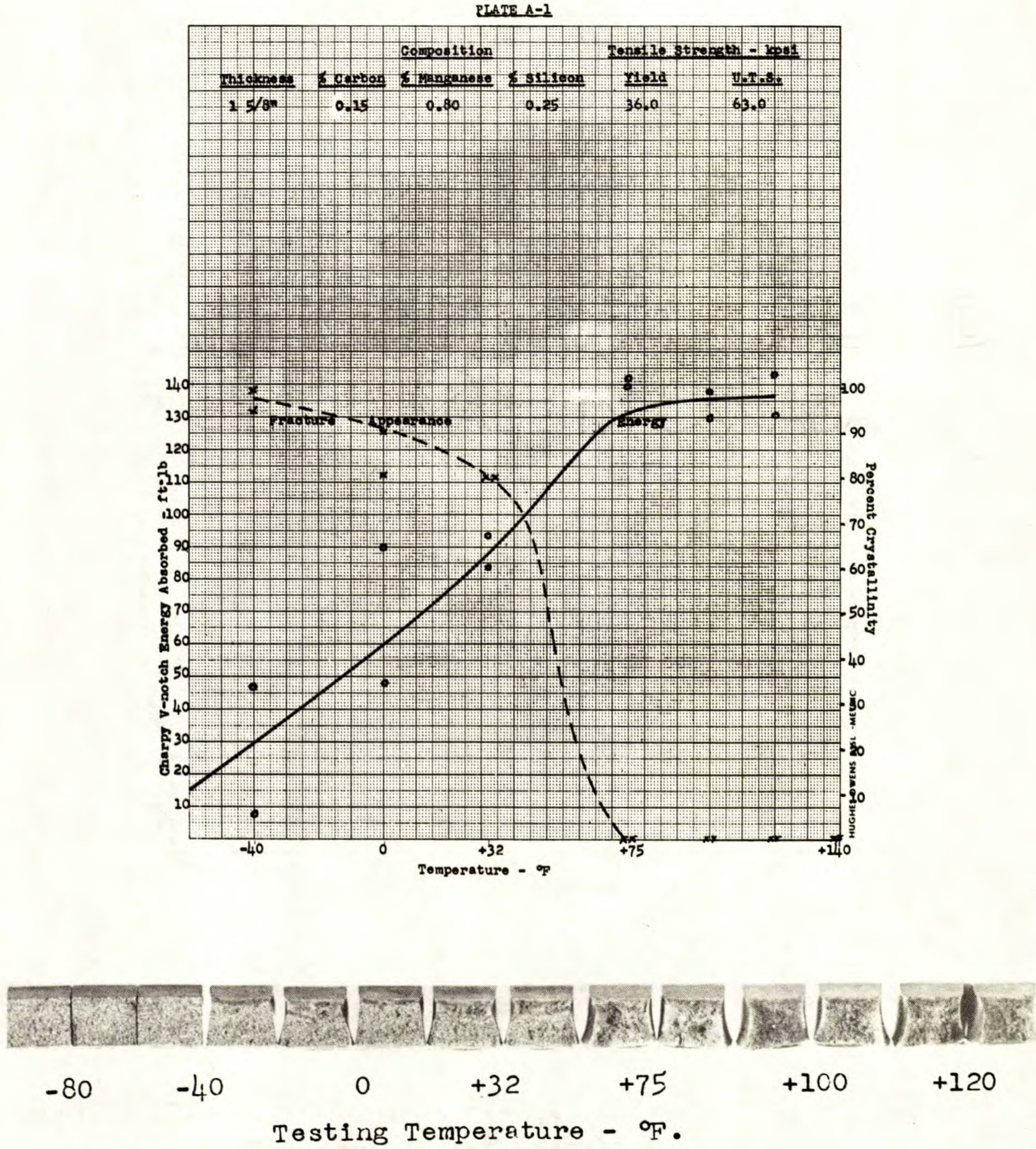


Figure 6. Charpy V-notch test results and principal composition and tensile data for Plate A-1.

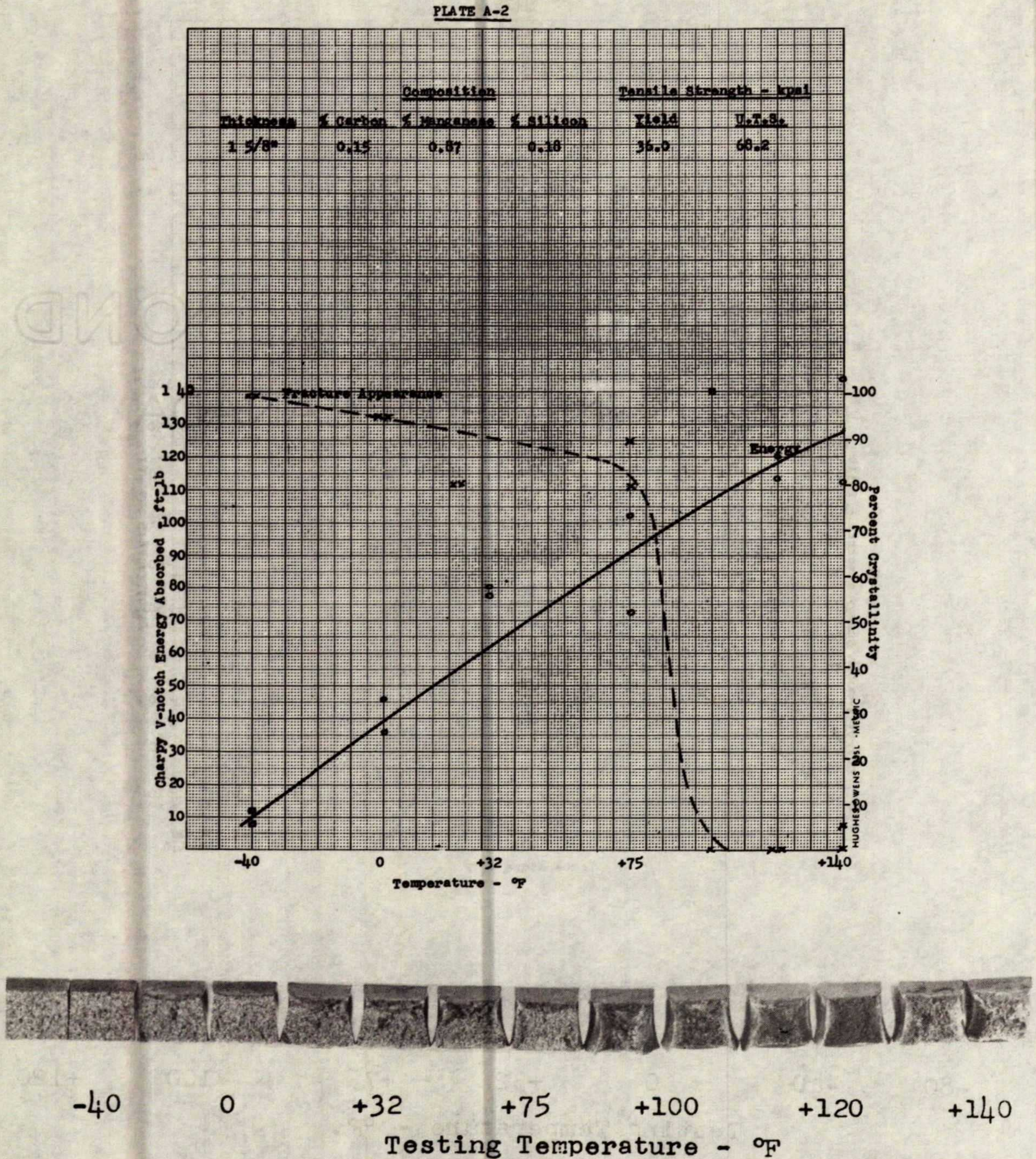


Figure 7. Charpy V-notch test results and principal composition and tensile test data for Plate A-2.

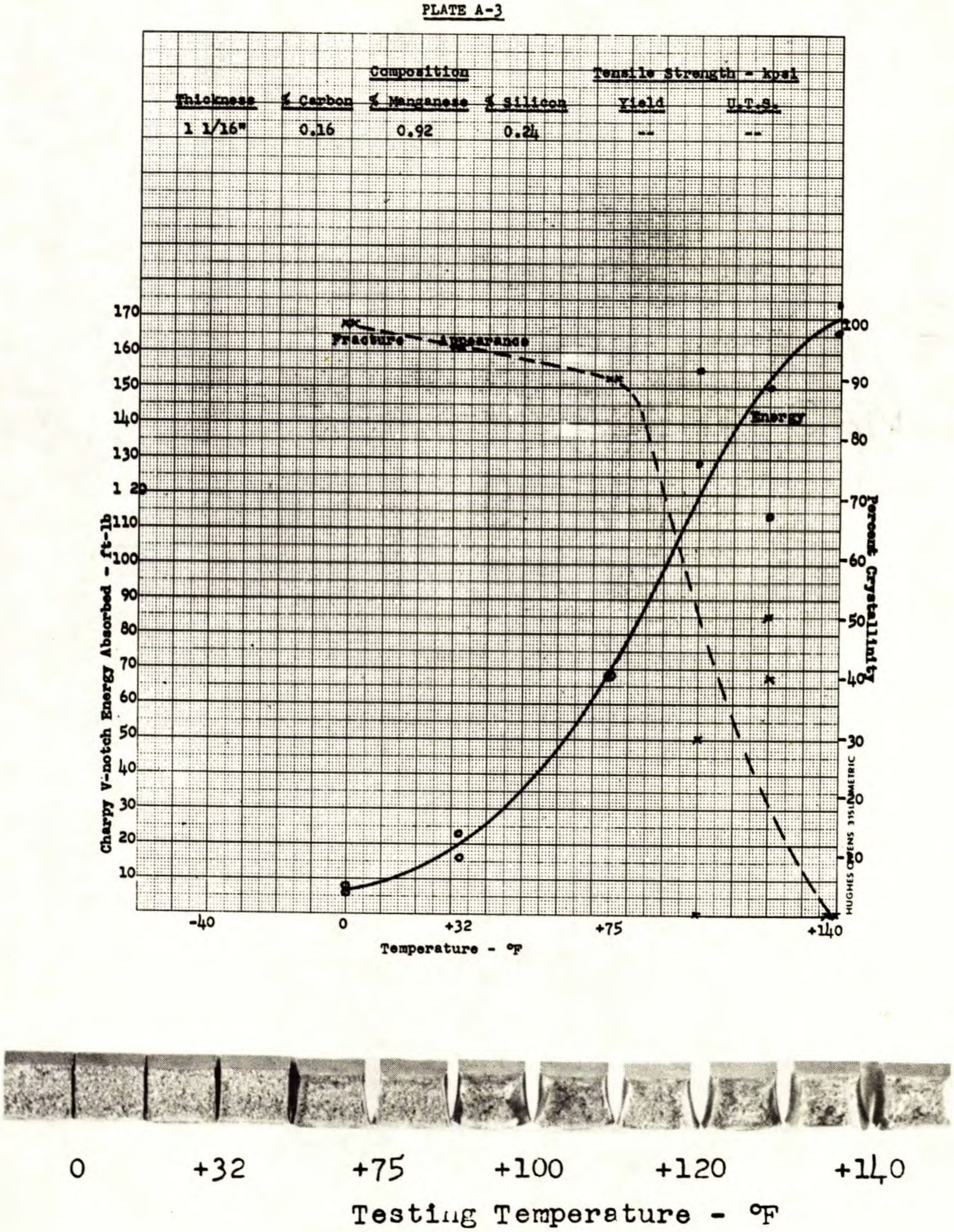


Figure 8. Charpy V-notch test results and principal composition and tensile test data for Plate A-3.

Plate A-1

Plate A-2

Plate A-3

Figure 9. Photomicrographs of Plates A-1 to A-3.
All X100, nital etch.

PLATE A-5

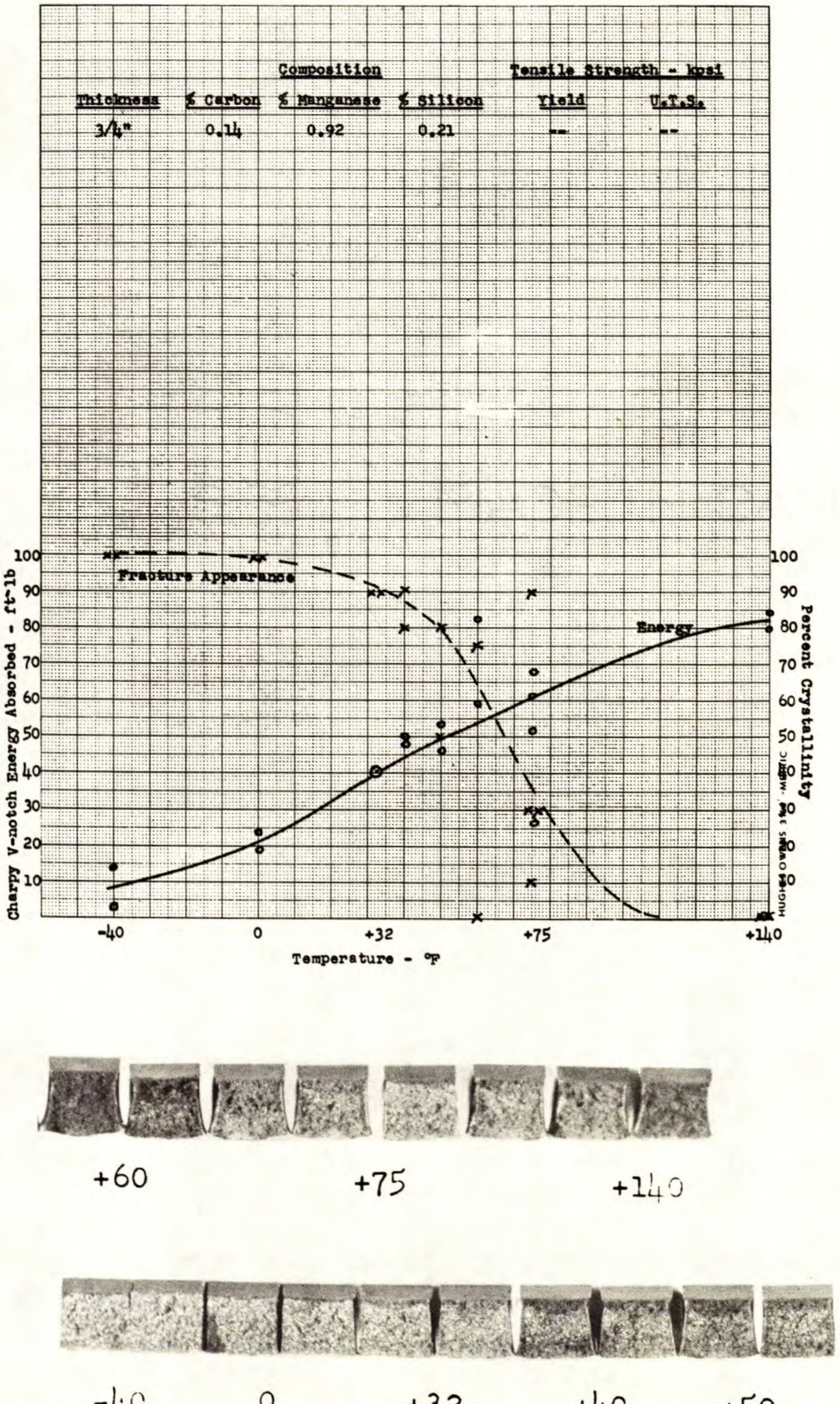


Figure 10. Charpy V-notch test results and principal composition and tensile test data for Plate A-5.

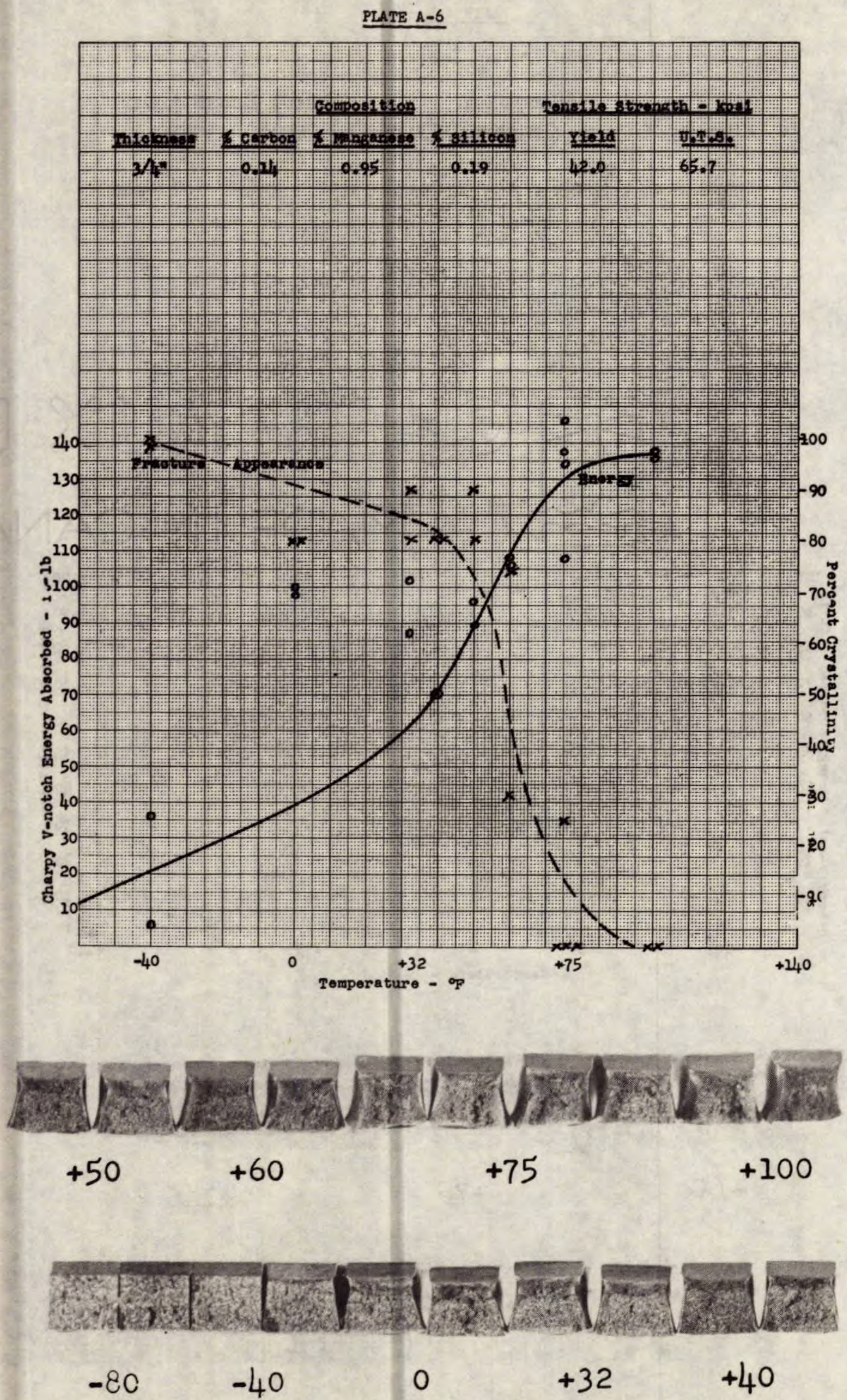
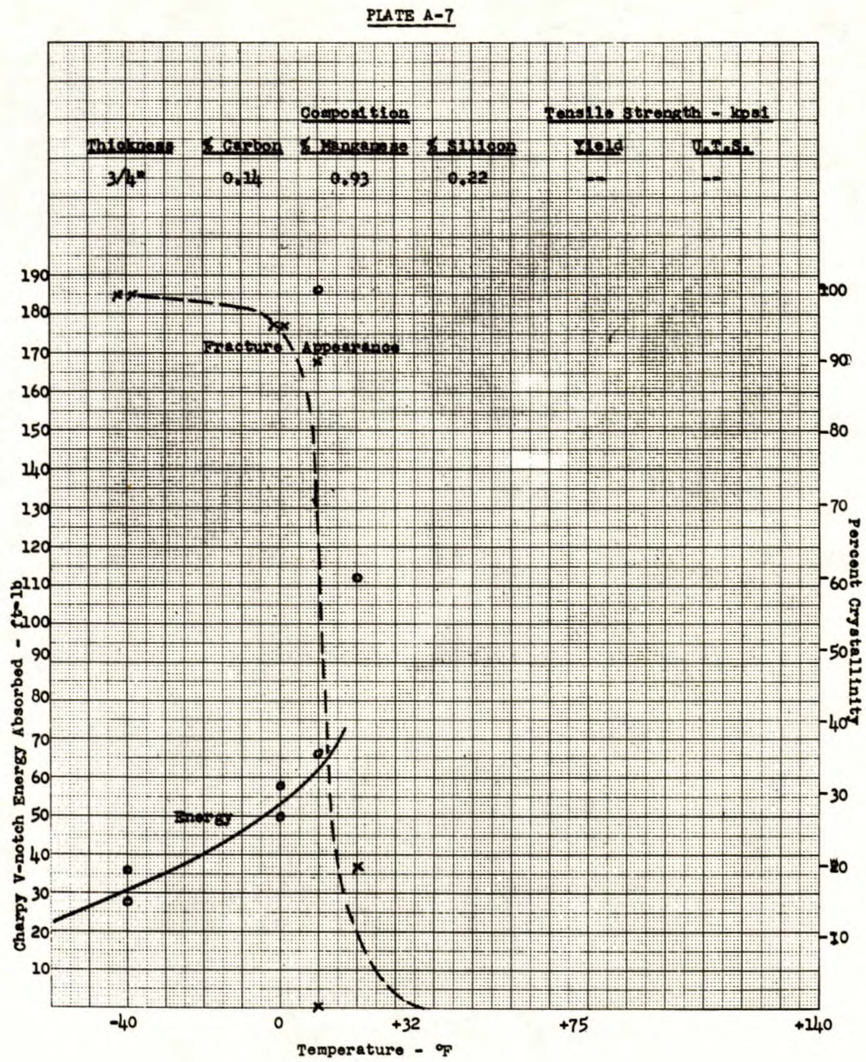


Figure 11. Charpy V-notch test results and principal composition and tensile test data for Plate A-6.



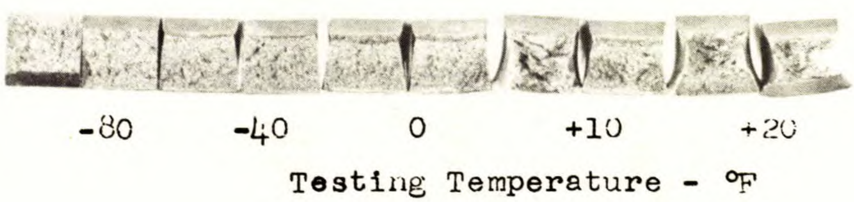


Figure 12. Charpy V-notch test results and principal composition and tensile test data for Plate A-7.

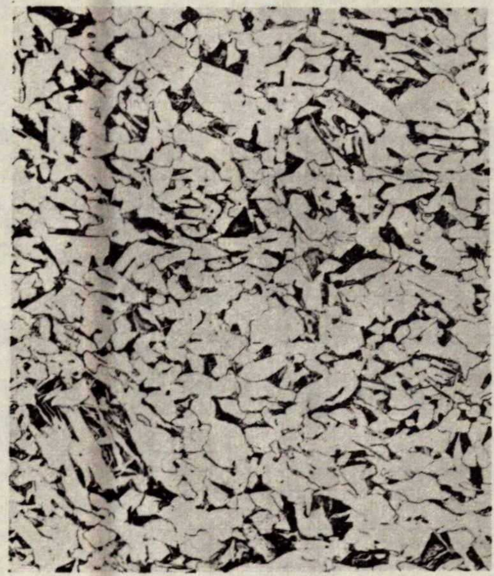


Plate A-5

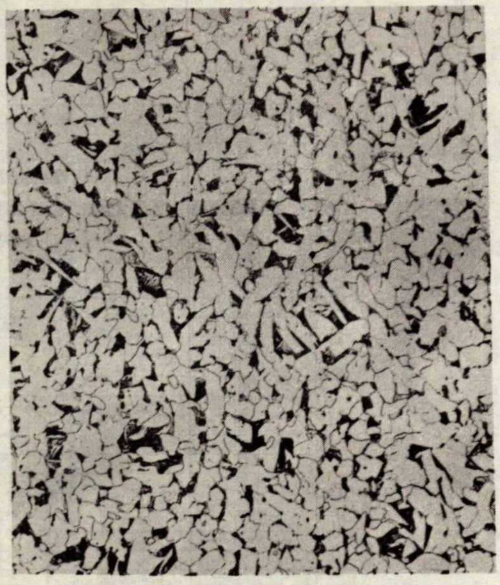


Plate A-6

Plate A-7

Figure 13. Photomicrographs of Plates A-5 to A-7. All X100, nital etch.

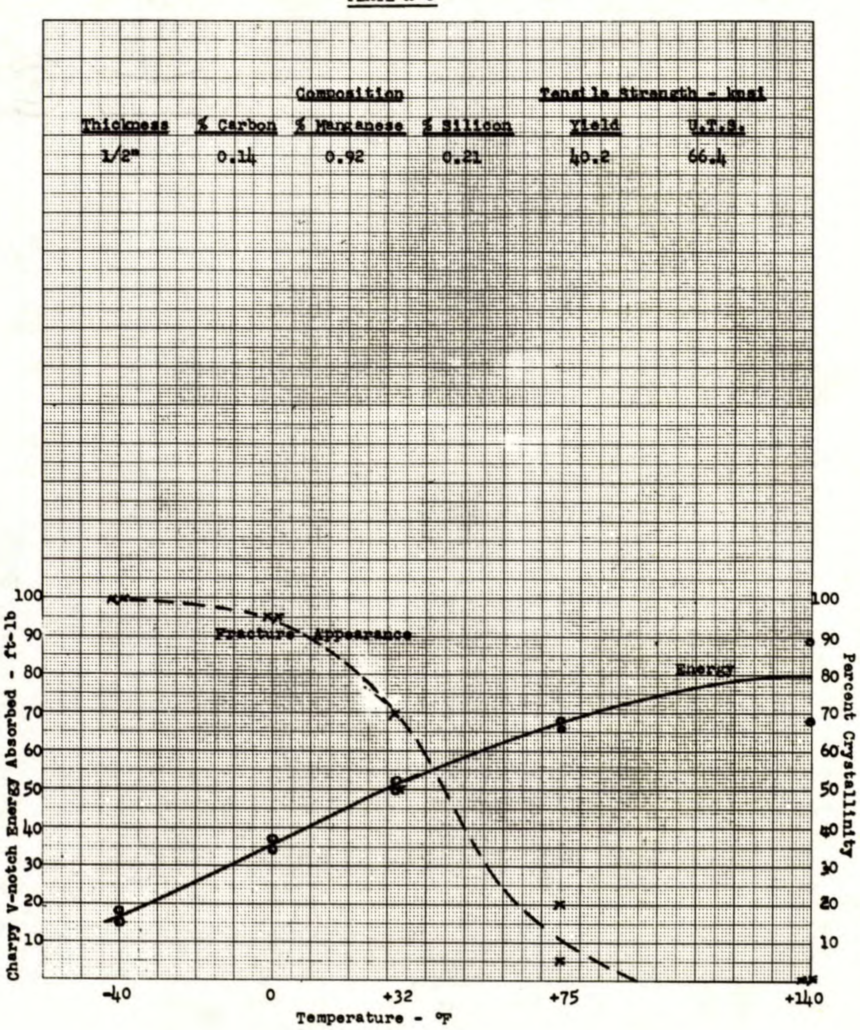


Figure 14. Charpy V-notch test results and principal composition and tensile test data for Plate A-8.

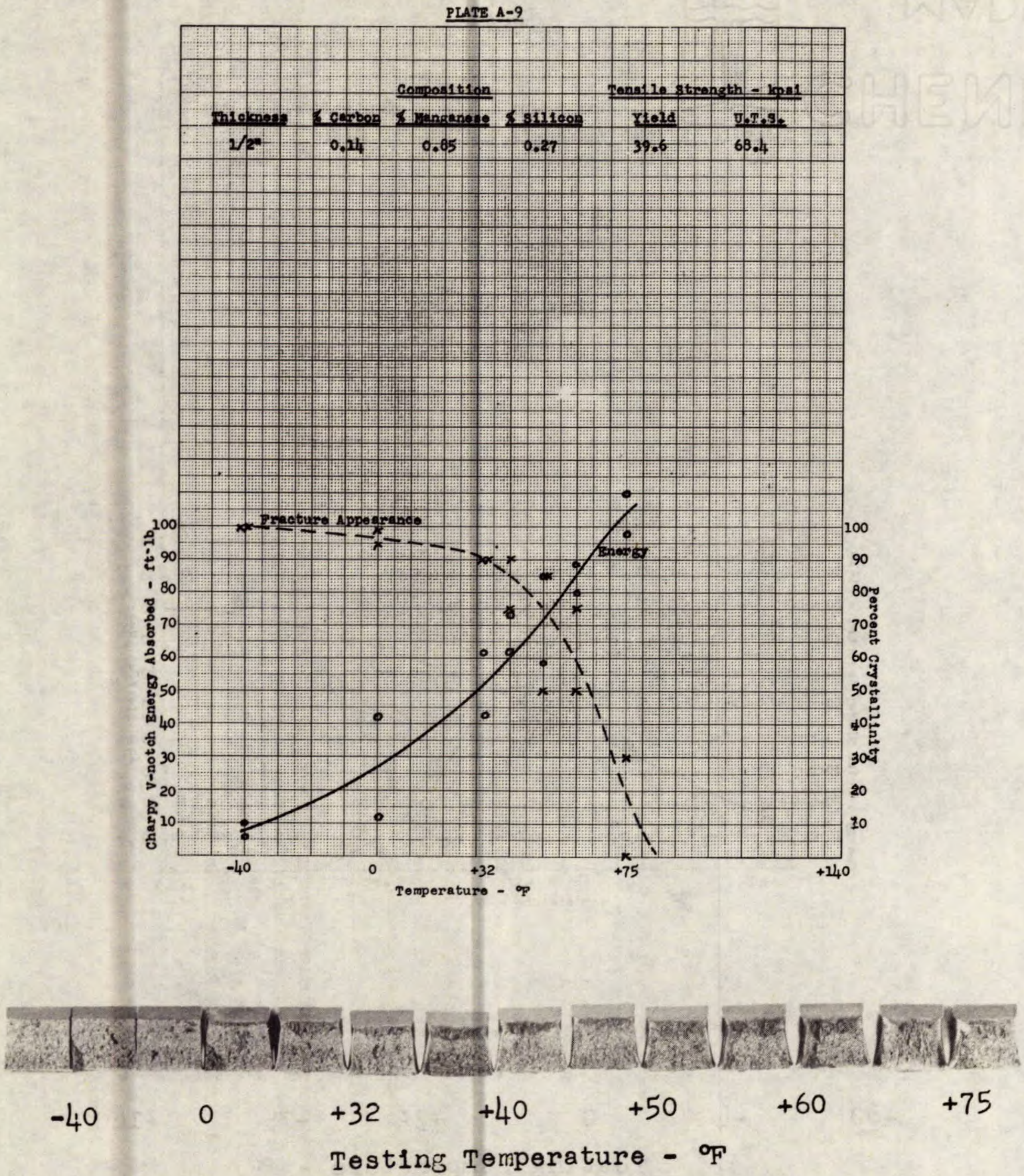


Figure 15. Charpy V-notch test results and principal composition and tensile test data for Plate A-9.

Plate A-8

Plate A-9

Figure 16. Photomicrographs of Plates A-8 and A-9. Both X100, nital etch.

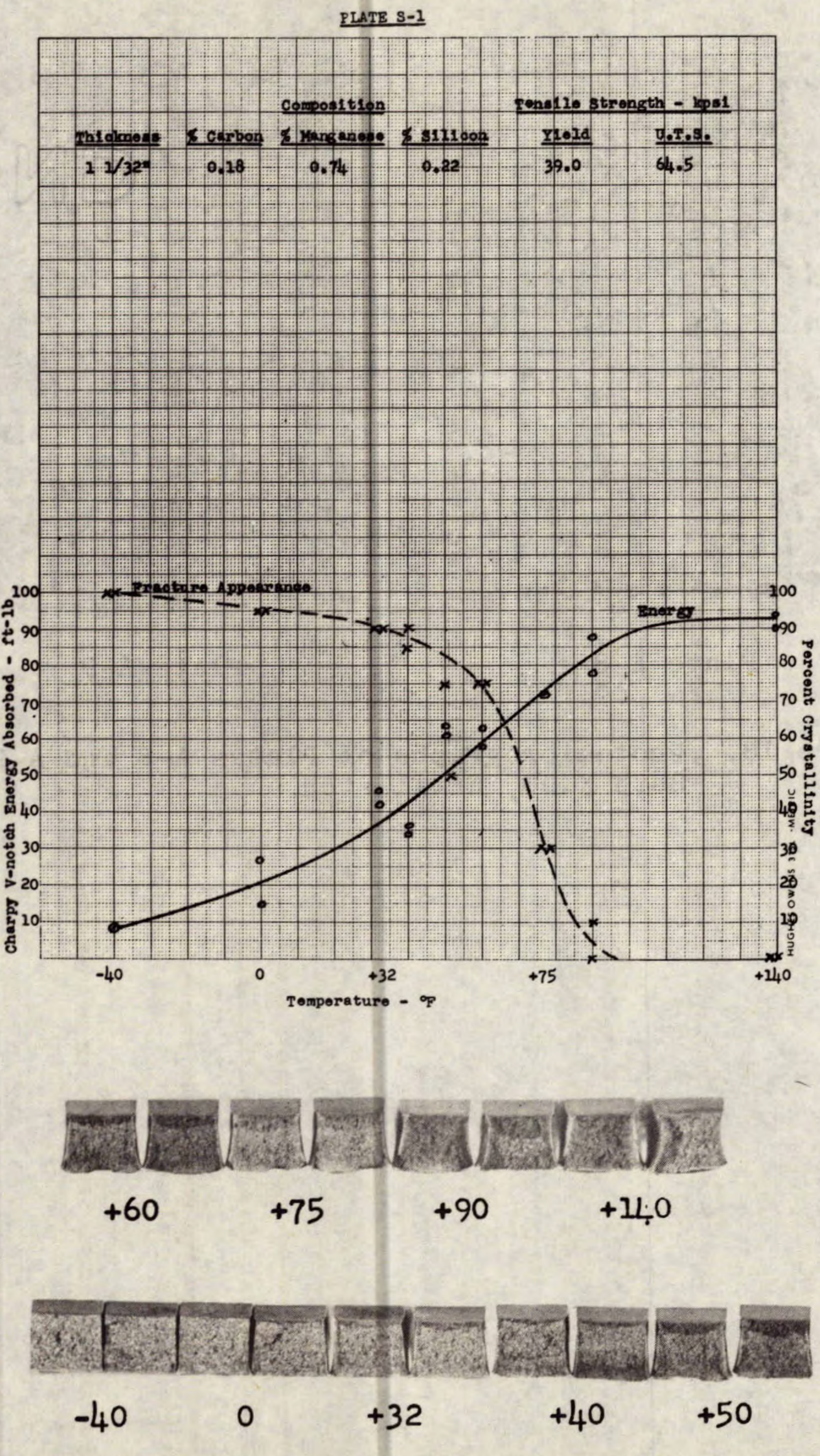


Figure 17. Charpy V-notch test results and principal composition and tensile test data for Plate S-1.

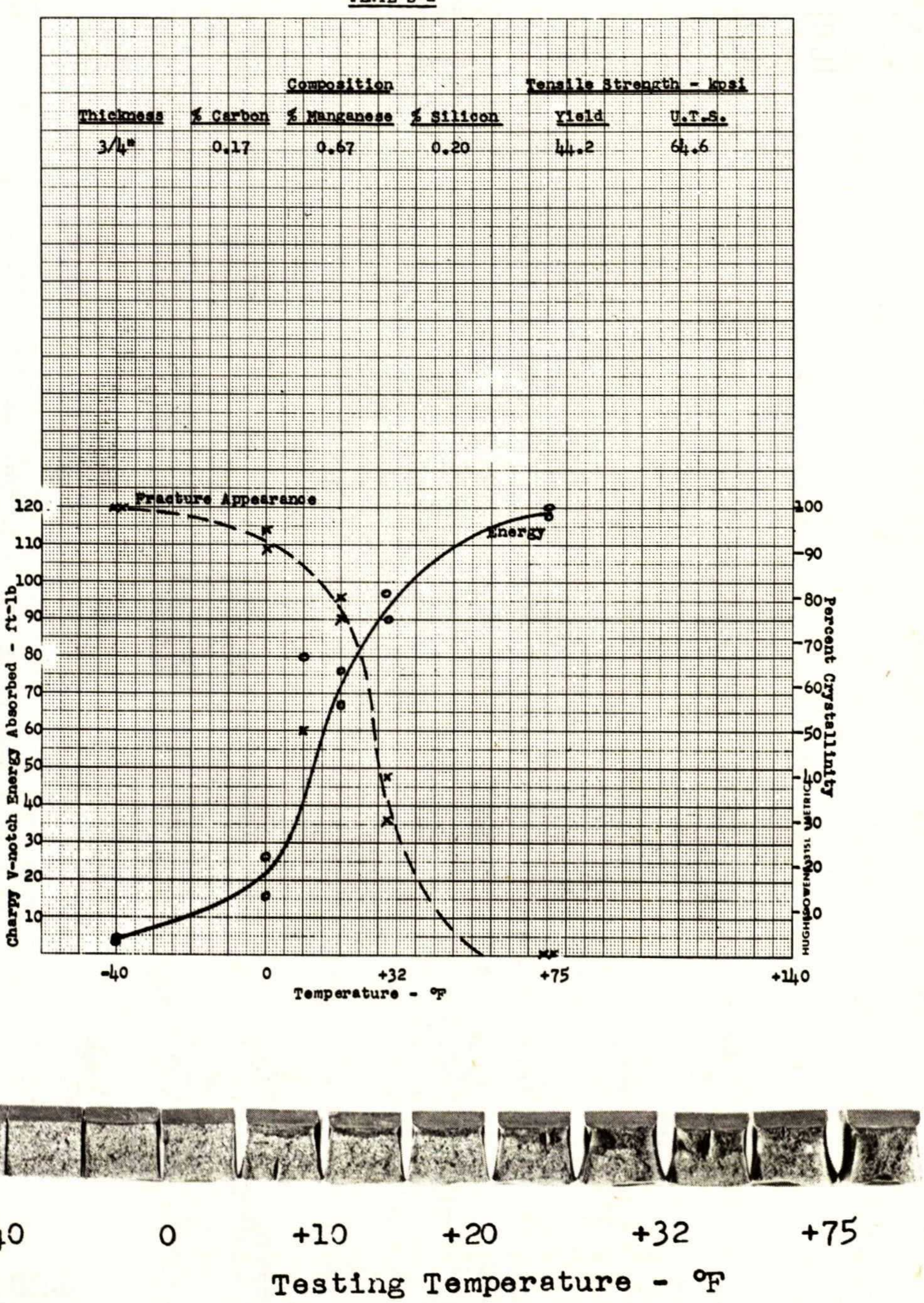
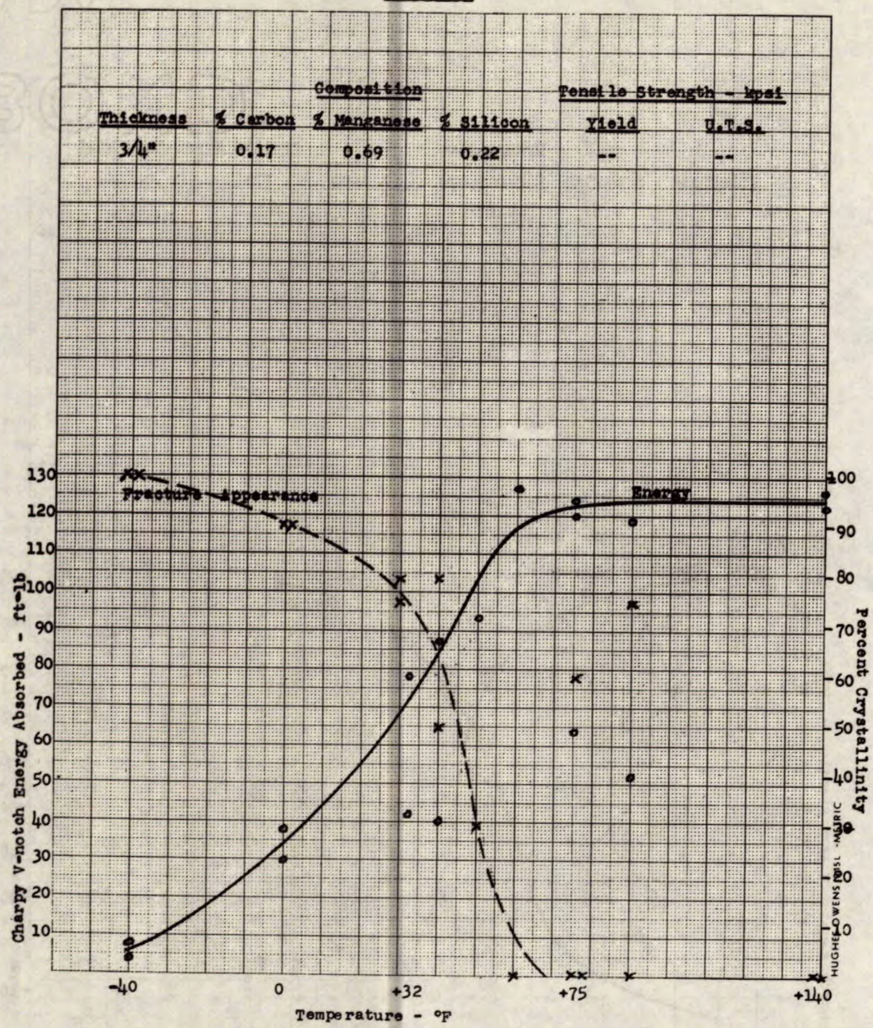


Figure 18. Charpy V-notch test results and principal composition and tensile test data for Plate S-2.

PLATE S-3



+75 +90 +140

-40 0 +32 +50 +60

Figure 19. Charpy V-notch test results and principal composition and tensile test data for Plate S-3.

Plate S-1

Plate S-2

Plate S-3

Figure 20. Photomicrographs of Plates S-1 to S-3. All X100, nital etch.

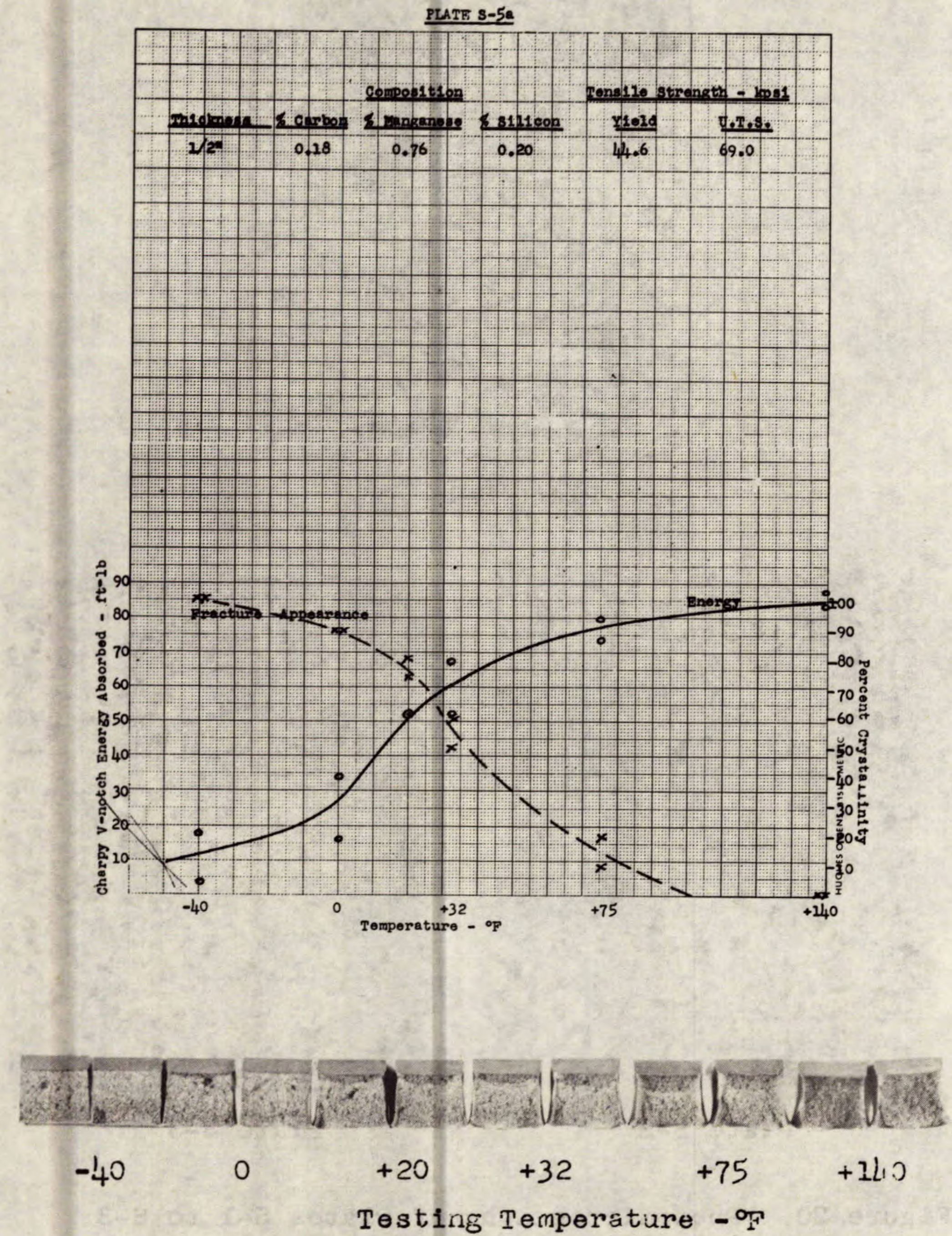
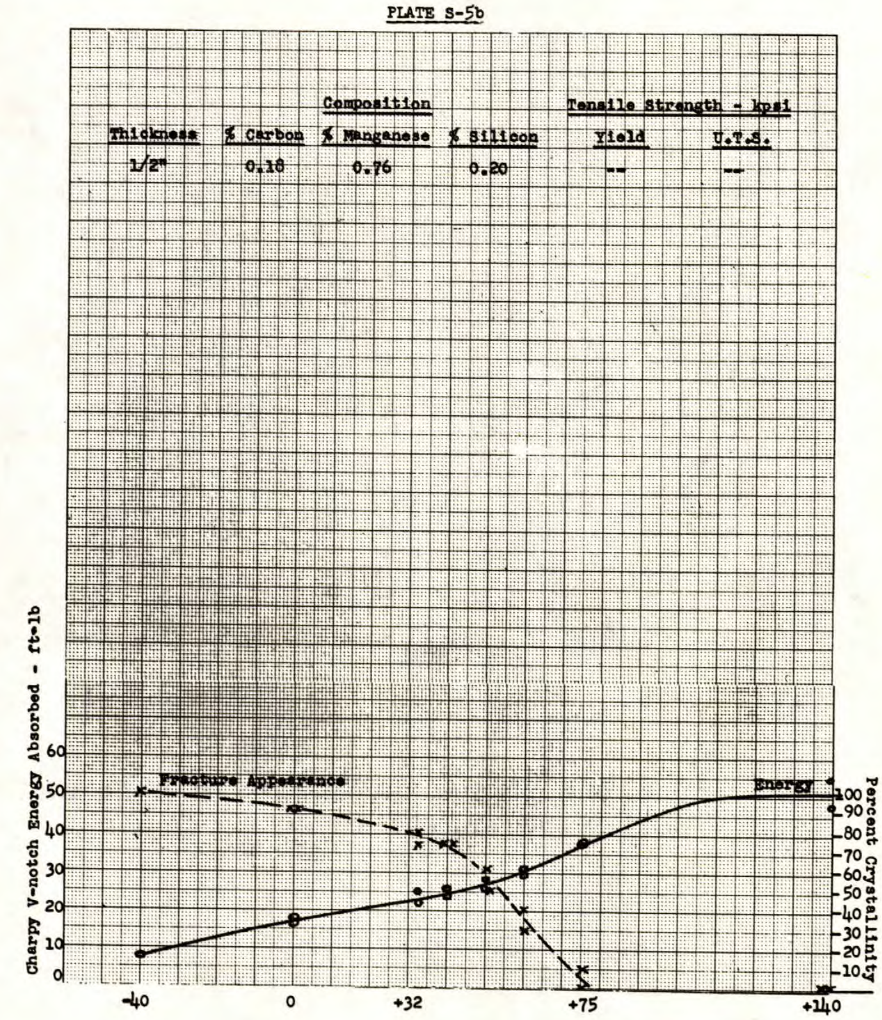
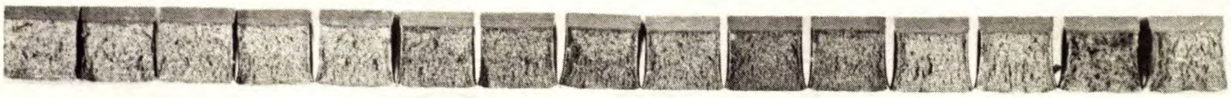


Figure 21. Charpy V-notch test results and principal composition and tensile test data for Plate S-5a.

PLATE S-5b

	Composition			Tensile Strength - kpsi	
Thickness	% Carbon	% Manganese	% Silicon	Yield	U.T.S.
1/2"	0.18	0.76	0.20	--	--





-40 0 +32 +40 +50 +60 +75 +140

Testing Temperature -°F

Figure 22. Charpy V-notch test results and principal composition and tensile test data for Plate S-5b.

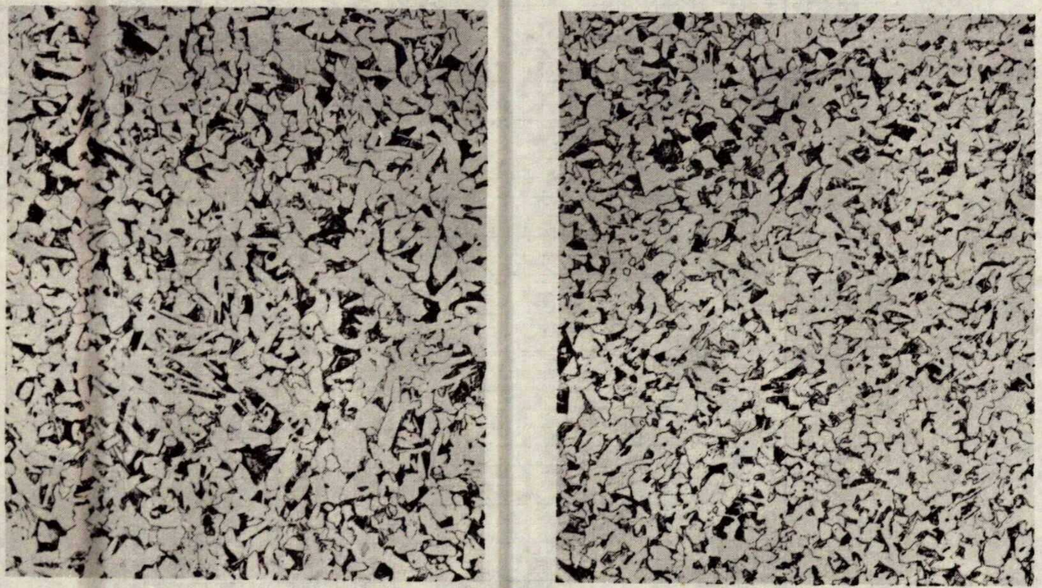


Plate S-5a

Plate S-5b

Figure 23. Photomicrographs of Plates S-5a and S-5b. Both X100, nital etch.

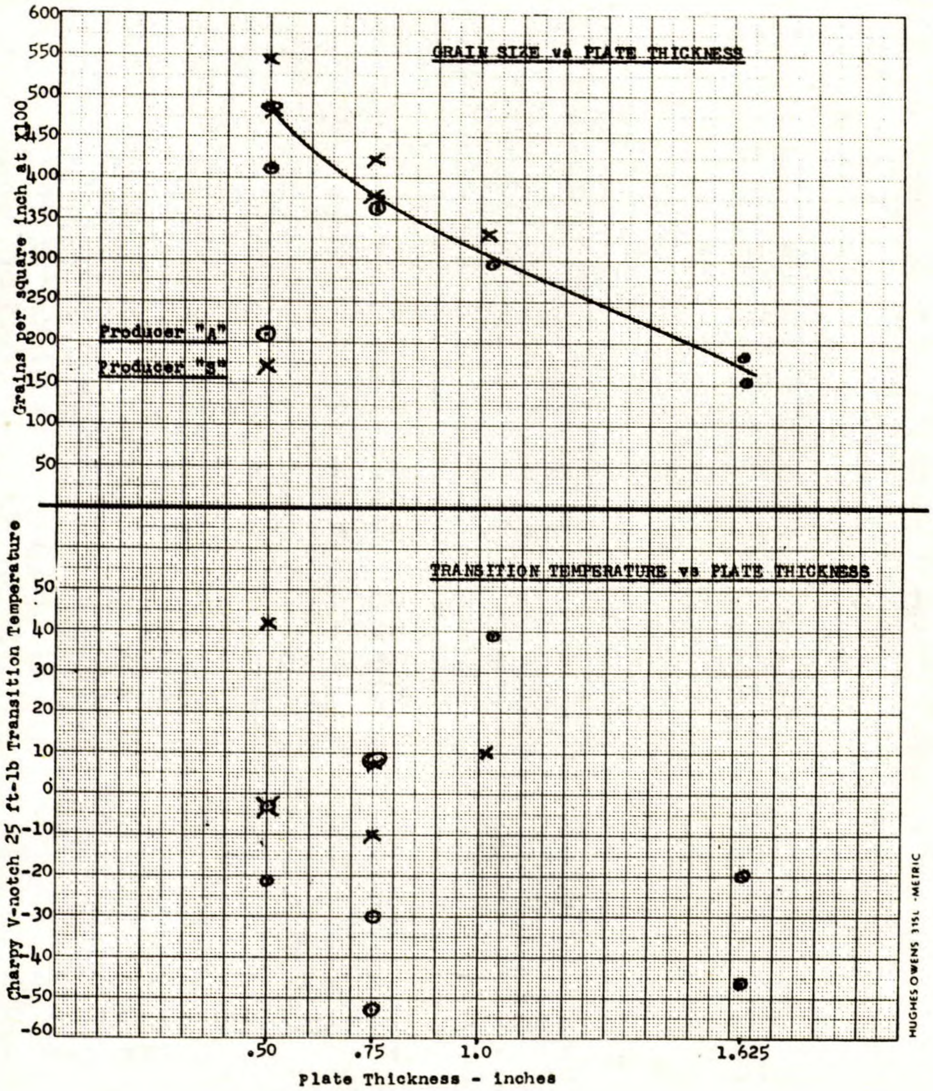


Figure 24. Correlation between grain size and plate thickness is shown in the upper half. The lack of correlation between the 25 ft-lb transition temperature and plate thickness is evident in the lower half.

TABLE 3

Tensile Test Results

Plate	Thickness	Yield kpsi	Ultimate kpsi	% Elong. in 2"	% Reduction in Area
G40.8	Over 1" to 1 1/2"	36 min	65-85	20 in 8"	
A-1	1 5/8"	36.0	63.0	37	67.5
A-2	1 5/8"	36.0	68.2	36	64.7
S-1	1 1/32"	39.0	64.5	36	63.0
G40.8	Over 5/8" to 1"	38 min	65-85	20	
A-6	3/4"	42	65.7	40	70.6
S-2	3/4"	44.2	64.6	41	65.9
G40.8	To 5/8" incl.	40	65-85	20	
A-8	1/2"	40.2	66.4	40	68.6
A-9	1/2"	39.6	68.4	38.4	68.4
S-5a	1/2"	44.6	69	38.4	63.2

TABLE 4

Grain Size

Sample	Thickness	Grain Size	
		n*	ASTM Grain Size**
A-1	1 5/8"	153	8.2
A-2	1 5/8"	184	8.5
A-3	1 1/16"	293	9.2
S-1	1 1/32"	334	9.4
A-5	3/4"	364	9.5
A-6	3/4"	361	9.5
A-7	3/4"	368	9.5
S-2	3/4"	375	9.6
S-3	3/4"	423	9.7
A-8	1/2"	411	9.7
A-9	1/2"	484	9.9
S-5a	1/2"	477	10.0
S-5b	1/2"	547	10.1

*n = Number of grains at a magnification of 100X.
**ASTM Grain Size calculated from the expression:

$$N = \frac{\log n}{0.301} + 1$$

TABLE 5

Charpy Test Result Summary

Plate	Thickness in inches	Energy Absorbed at 32°F Control Test	Energy Absorbed at 32°F Full Curve	Transition Temperature 15 ft-lb*	Transition Temperature 25 ft-lb
A-1	1 5/8	101	87	-60	-46
A-2	1 5/8	67	61	-33	-20
A-3	1 1/16	46	20	+24	+39
S-1	1 1/32	44	37	-16	+10
A-5	3/4	43	40	-15	+ 8
A-6	3/4	194	61	-53	-30
A-7	3/4	77	Unbroken	-77	-53
S-2	3/4	85	93	-10	+ 7
S-3	3/4	53	71	-24	-10
A-8	1/2	43	51	-44	-21
A-9	1/2	191	52	-22	- 3
S-5a	1/2	51	60	-26	- 3
S-5b	1/2	25	23	-10	+42

*Note: GSA G40.8 "B" indicates an expected 15 ft-lb transition temperature of 0°F.