NISTIR 4300

Report No. 20

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INTRODUCTION

At a meeting on August 24, 1989, mechanical property and fracture toughness test results for two steels tested by the Mechanical Properties and Performance Group of the National Institute of Standards and Technology (NIST) for the Federal Railroad Administration (FRA) were presented. Attending the meeting were Ms. Claire Orth, Chief of the Equipment and Operating Practices division of the FRA, Messrs. Coughlin of AFC Industries, Slimmon of Bethlehem Steel Corporation, and Smith of the NIST. At that meeting, NDT temperatures, full Charpy V-notch curves, and tensile data from -60°F to room temperature were presented for normalized AAR TC128 grade B steel and the new micro-alloyed and control-rolled A 8XX grade B steel. The NIST's NDT temperature and Charpy V-notch test results revealed that the new A 8XX grade B steel had lower impact properties at low test temperatures, and a higher NDT temperature than the AAR TC128 grade B steel. In addition to the normalizing heat treatment, the AAR TC128 grade B steel was found to have been made using inclusion shape control practice. The micro-alloyed and control-rolled steel, A 8XX, was also found to have been made using inclusion shape control practice.

In a letter dated September 6, 1989, from Mr. Earl Phillips, Project Director of the Railroad Tank Car Safety Research and Test Project Committee of the AAR, to Ms. Orth of the FRA, the NIST was requested to retest the "new grade B steel" and verify their initial results. In compliance with this request, the NIST has retested the new A 8XX grade B steel, and has also retested the AAR TC128 grade B steel. This report presents the results of that retesting.

EXPERIMENTAL PROCEDURE

Eight plates of steel, approximately 9/16 inch thick by 72 inches square, were received from the Bethlehem Steel Corporation through Mr. T. Dalrymple of the Union Tank Car Company. There were four plates of AAR TC128 grade B steel with heat number 803A66600 stenciled on them, and four plates of A 8XX steel with heat number 803A71430 stenciled on them. The A 8XX grade B plates were coded with the letters A, B, C, and D and the AAR TC128 grade B plates were coded E, F, G, and H.

Figure 1 shows photographs of plates A and E that were used in the retesting program. These are the same plates that were used in the initial study. For reference purposes only, the rolling direction of each plate as determined in the initial study was transferred to these plates. The arrows marked RD in the figure show these directions. Prior to marking the areas on each plate that were to be used for Charpy V-notch (CVN) and nil-ductility transition (NDT) temperature test specimens, specimens used for chemical analysis and rolling direction determinations were cut from each plate. Care was taken in the removal of these specimens from the large plates so that the long axis of the specimens remained parallel to the rolling direction arrow marked on each plate. The areas used for these determinations can be seen in figures 1a and 1b at the lower right hand corner of each plate.

Charpy V-notch impact tests were performed according to ASTM test method E 23-86. The Charpy impact testing machine had been verified approximately one month prior to these tests. Test specimen orientation, i.e. ASTM LT (conventionally referred to as "longitudinal" specimens) or TL (conventionally referred to as "transverse" specimens), is shown in Appendix 1. Impact testing was performed in a temperature controlled and constantly stirred bath. The bath contained ethyl alcohol and the temperature was monitored by both a thermocouple and a thermometer. The temperature of the bath did not vary more than ±2°F. CVN test specimens were immersed in the bath for at least 30 minutes prior to testing, and there were at least three specimens tested at each temperature. The lateral expansion, as descibed in ASTM test method E 23-86, was measured on each fractured specimen. The percentage shear fracture was not measured on any of the impact specimens.

Using P3 type specimens, the NDT temperatures were determined for each steel using ASTM test method E 208-87a. The same cooling units and medium (ethyl alcohol) used to cool the CVN impact specimens were used for the NDT specimens. No more than two NDT specimens at a time were immersed in the bath, and they remained in the cooling medium, at temperature, for at least one hour prior to testing. The initial temperature chosen for testing the A 8XX grade B steel was -10°F, the NDT temperature found in the initial study. The starting temperature chosen for the AAR TC128 grade B steel was -40°F, the same NDT temperature found in the initial study.

RESULTS

Microscopic Observations (as-polished specimens)

The specimens used for the rolling direction and microstructure determination were mechanically polished and observed in three orthogonal directions. Figures 2a and 2b show three-dimensional composites of the surfaces of the A 8XX grade B and AAR TC128 grade B steels in the as-polished condition. A comparison of the composite of the as-polished A 8XX steel, figure 2a, shows a number of elongated inclusions in one direction. The presence of the elongated inclusions (arrow) suggests that this was the primary rolling direction of this plate of steel. Hence, this direction was identified as the longitudinal or LT, and the direction normal to LT was identified as the transverse, or TL. The rolling direction was the same as that determined in the initial study. These findings were transferred to the plate of steel, and the orientation from which the LT and TL CVN impact test specimens were machined and notched from the A 8XX steel plate is shown in figure 1. Noteworthy in the composite of the as-polished microstructure of the A 8XX steel, figure 2a, is the shape of the inclusions for the other orientations. Normally, inclusions in conventional steels are predominately elongated in shape, but the presence of the round inclusions corroborated our findings presented in the initial report that the control-rolled A 8XX grade B steel was probably made using inclusion shape control practice.

The same procedures were used to determine the rolling direction for the AAR TC128 grade B steel. A three-dimensional photographic composite of the as-polished surfaces of the AAR TC128 grade B steel is shown in figure 2b. The inclusions observed in the AAR TC128 steel were not elongated, but were round in shape. Therefore, from the metallographic examinations, the rolling direction was not as obvious in the AAR TC128 steel as it was in the A 8XX steel, figure 2a. Careful scrutiny of the surface corresponding to photograph X of the AAR TC128 grade B photographic composite revealed "ruptures" at the ends of the round inclusions. This evidence led us to choose that direction as the primary rolling direction in the plate, and was the same as that determined in the initial study of the AAR TC128 grade B steel. The orientation from which the LT and TL CVN impact test specimens were machined and notched from the AAR TC128 grade B steel plate is shown in figure 1b. Examination of the other photographs of the composite reveal that, like the A 8XX steel, the inclusions were primarily round, again indicating that the AAR TC128 grade B steel was probably made using inclusion shape control practice.

Microstructure Observations (etched specimens)

Figures 3a and 3b show three-dimensional composites of both steels in the etched condition. The microstructure of both steels consisted of a mixture of ferrite and pearlite. The microstructure of the A 8XX steel consisted of coarse ferrite (grey) and pearlite (black), whereas the microstructure of the AAR TC128 steel consisted of both fine and uniform ferrite and pearlite. This suggests that the AAR TC128 steel was normalized. Grain size measurements were performed on both steels. The average grain size of the A 8XX grade B steel was 10½ (9.4 μm), and 11½ (6.7μm) for the AAR TC128 grade B steel.

Chemical Results

The results of the chemical composition determinations for both steels are shown in Table 1. The results show that both steels are within their allotted specifications. The low sulfur contents and the presence of calcium suggest that both steels were made using inclusion shape control practice.

The chemical redetermination also reconfirms the identity of each plate. Those plates that were labeled A 8XX grade B were A 8XX grade B steel, and those labeled AAR TC128 grade B were AAR TC128 grade B steel.

NDT Temperature Determinations

The NDT temperature was determined for both steels, and the test results are shown in Tables 2 and 3. The NDT temperature for the AAR TC128 grade B steel was approximately -60°F, and the NDT temperature for the A 8XX grade B steel was -20°F. In the previous investigation (1), the NDT temperatures for the AAR TC128 grade B and A 8XX steels were -40°F and -10 °F, respectively.

Impact Test Results

The CVN impact test results for both steels are shown in Tables 4,5,6,and 7, and plotted in figures 4 through 13. Figure 4 shows energy absorbed versus test temperature for the A 8XX grade B steel, as well as a curve representing an average of those data. Figure 5 shows a similar plot for the data obtained for the AAR TC128 grade B steel. For identification purposes and for comparison in future work, the A 8XX grade B steel is coded in figure 4 as CR + ISC. This code identifies the steel as having been control rolled and made using inclusion shape control practice. Similar coding is shown in figure 5 for the AAR TC128 grade B steel test results. The N + ISC indicates that the steel was normalized and made using inclusion shape control practice.

Figure 6 shows plots comparing the energy absorbed versus test temperature results for both steels for both LT (longitudinal) and TL (transverse) specimens. The energy absorbed of LT specimens tested from the AAR TC128 grade B steel, over the entire range of test temperatures, was slightly greater than that for the TL specimens. Whereas there was a pronounced difference between the energy absorbed results for LT and TL specimens tested from the A 8XX grade B steel. This difference was more pronounced at higher test temperatures. It is generally agreed that because of inclusion orientation and spacing in conventional steels, the energy absorbed for impact specimens tested from the LT orientation, or the direction of primary rolling in plate, is greater than that for specimens taken from the TL orientation. Even though the inclusions observed in both of these steels were primarily round, the orientation effect (i.e., LT was slightly greater than TL) was still observed.

Figure 7a shows a plot comparing the energy absorption results for LT specimens for both steels, and figure 7b shows a similar plot comparing the energy absorption results for TL specimens. At the lowest test temperature, -70°F, the average energy absorbed for the AAR TC128 grade B LT specimens was 34 ft-lb, whereas the average energy absorbed, at the same test temperature, was 9.5 ft-lb for the A 8XX grade B LT specimens. The average energy absorbed for AAR TC128 grade B LT specimens tested at -50°F was 47 ft-lb, and for A 8XX grade B LT specimens, the average energy absorbed at -50°F was 17 ft-lb.

At approximately -12°F, the energy absorbed for LT specimens taken from the A

8XX grade B steel becomes greater than those taken from the AAR TC128 grade B steel. There was no similar transition observed for the TL CVN test specimens. In the initial investigation, the temperature where the A 8XX grade B steel's impact properties were greater than those of the AAR TC128 grade B steel occurred at about +16°F. We believe this shift is due to the variability that exists in the microstructure of the A 8XX grade B steel. For comparison purposes, figure 8 shows overlay of the energy absorbed versus test temperature for LT and TL specimens taken from both steels.

Figures 9 through 13 are plots of the lateral expansion versus test temperature for these steels. The AAR TC128 grade B steel was found to have a better lateral expansion at the low temperatures compared to the A 8XX grade B steel. The improvement in lateral expansion for the A 8XX grade B steel occurs at about the same temperature, -12°F, that the impact properties surpass those for the AAR TC128 grade B LT specimens.

Discussion

CVN impact and NDT temperature test results presented from an earlier investigation by the Mechanical Properties and Performance Group of the Metallurgy Division of the National Institute of Standards and Technology were not in agreement with those obtained by the AAR-RPI Research Committee or those certified by the Bethlehem Steel Corporation in its Certificate of Analysis. Retesting was requested by the Committee and initiated by NIST. Even though retesting was requested only on the new A 8XX grade B steel, retesting was also undertaken on the AAR TC128 grade B steel.

Specimens used for the redetermination of the rolling direction and chemical composition were sectioned from both steels. CVN and NDT specimens were machined from plates A and E, used in the first investigation, and tested. The microstructure and chemical analysis confirmed initial rolling direction and chemical composition determinations. The CVN impact test specimens had been aligned properly, and the steels that were tested were those that were received and certified by the Bethlehem Steel Corporation. The CVN and NDT test results also confirmed our initial impact test results and NDT temperature determinations. At low test temperatures, the AAR TC128 grade B steel had better impact properties than the new A 8XX grade B steel. The NDT temperature obtained in the retesting of the AAR TC128 grade B steel was even lower (again better notch toughness than the A 8XX) than that obtained in the initial study.
Table 8 shows for comparison the CVN impact test results obtained at -50°F by NIST on retesting, and those reported by Bethlehem Steel Corporation in its Certificate of Analysis. There is a significant difference between the confirmed NIST CVN impact values and those certified by the Bethlehem Steel Corporation. The normalized and inclusion shape controlled AAR TC128 grade B steel had a lower NDT temperature and better impact properties at low test temperatures than the new, control-rolled and inclusion shape controlled A 8XX grade B steel.

Conclusions

1) Retesting of the control-rolled and inclusion shape controlled A 8XX grade

B steel and the normalized and inclusion shape controlled AAR TC128 grade B steel confirmed our initial test specimen orientation, Charpy V-notch impact, nil-ductility transition temperature, chemical, and inclusion analyses results presented in an earlier report.

2) Test specimen orientation was verified. Those specimen that were identified in the earlier report as LT were LT, and those specimen identified as TL were TL.

3) The normalized and inclusion shape controlled AAR TC128 grade B steel had better impact properties, at low test temperatures, than the control-rolled and inclusion shape controlled A 8XX grade B steel.

4) The normalized and inclusion shaped controlled AAR TC128 grade B steel had a lower NDT temperature than the new control rolled and inclusion shape controlled A 8XX grade B steel.

5) Chemistry results confirmed that we had tested AAR TC128 grade B steel and A 8XX grade B steel.

6) Both the AAR TC128 grade B steel and the A 8XX grade B steel were made using inclusion shape control practice.

Reference

1) Hicho, G.E. and Smith, J.H.," Mechanical Properties and Fracture Toughness of AAR TC128 Grade B Steel and a Micro-alloyed, Control- Rolled Steel, A 8XX Grade B Steel from -80°F to +73°F. (to be published).

Table 1. Chemical Compositions (wt%), AAR Specifications, and Heat Analysis for Both Steels.

	AAR TC128 grade B			A 8XX grade B		
	Specification[1]	Heat[2] Analysis	Check[3] Analysis	Specification[4]	Heat[2] Analysis	Check[3] Analysis
Carbon	0.25 max	.22	.17	0.16 max	.15	.15
Manganese	1.0-1.50	1.25	1.31	1.0-1.75	1.49	1.44
Phosphorus	0.035 max	.024	.026	0.035 max	.016	.018
Sulfur	0.040 max	.007	.009	0.010 max	.006	.007
Silicon	0.15-0.50	.213	.23	0.10-0.55	.277	.28
Nickel	0.25 max	.03	.01	NR	.03	.01
Chromium	0.25 max	.19	.23	NR	.04	.04
Molybdenum	0.08 max	.074	.09	NR	.011	.01
Copper	0.35 max	.017	.02	NR	.023	.03
Aluminum	NR[5]	.045	.053	NR	.054	.054
Niobium (Cb)	NR	NR	<.005	0.06 max[6]	.035	.034
Vanadium	0.08 max	.033	.035	0.11 max[6]	.075	.075
Nitrogen	NR	NR	.0073	NR	NR	.014
Calcium	NR	NR	.009	NR	NR	.011
C.E.[7]	0.62 max	.49	.46	0.47 max	.43	.42

1) AAR Specification for Tank Cars: Specification M-1002, M128.
2) Bethlehem Steel Corp.
3) NIST
4) Preliminary draft specification: A 8XX, Pressure vessel plates, high strength low alloy.
5) NR: Not reported
6) Niobium plus vanadium: 0.16 max
7) C.E.= Carbon Equivalent = C + Mn/6 + (Cr + Mo + V)/5 + (Cu +Ni)/15

Table 2. Nil-Ductility Temperature Test Results for AAR TC128 Grade B Steel. Break Indicates Standard Test Specimen Fractured at that Test Temperature.

Test Temperature, °F	Break	No Break
-70	X	
-70	X	
-60		X
-60	X	
-60	X	
-40		X
-40		X

NDT Temperature: -60°F

Table 3. Nil-Ductility Temperature Test Results for A 8XX Grade B Steel. Break Indicates Standard Test Specimen Fractured at that Test Temperature.

Test Temperature, °F	Break	No Break
-30	X	
-20	X	
-20	X	
-10		X
-10		X

NDT Temperature: -20°F.

Table 4. Impact Test Results for A 8XX Grade B LT Specimens.

Specimen Number	Test Temperature, °F	Energy Absorbed, Ft-lb	Lateral Expansion, Mils
A7	-70	11.5	8.0
A8	-70	11.0	10.0
A9	-70	6.0	2.5
A3	-50	12.0	10.5
A4	-50	12.0	10.0
A5	-50	36.0	39.0
A6	-50	8.5	7.0
A10	-25	84.0	64.0
A11	-25	21.0	19.5
A12	-25	79.0	59.5
A13	-25	23.0	21.0
A14	0	110.0	82.0
A15	0	34.0	31.0
A16	0	95.0	69.5
A17	+25	110.0	80.5
A18	+25	77.0	61.0
A19	+25	122.0	87.5
A20	+50	143.0	91.0
A21	+50	131.0	91.5
A22	+50	140.0	90.0
A1	+69	152.0	97.0
A2	+69	152.0	76.5
A23	+71	119.0	91.0

Table 5. Impact Test Results for A 8XX Grade B TL Specimens.

Specimen Number	Test Temperature, °F	Energy Absorbed, Ft-lb	Lateral Expansion, Mils
A74	-70	7.5	5.5
A75	-70	9.0	8.0
A76	-70	12.0	11.5
A71	-50	12.5	10.5
A72	-50	12.0	11.5
A73	-50	9.5	9.0
A77	-25	23.0	20.5
A78	-25	18.0	19.0
A79	-25	52.0	42.0
A80	-25	20.0	19.5
A81	0	30.0	31.0
A82	0	54.0	43.5
A83	0	29.0	25.0
A84	+25	83.0	64.5
A85	+25	60.0	54.0
A86	+25	79.0	62.0
A87	+50	102.0	81.0
A88	+50	110.0	80.0
A89	+50	101.0	79.5
A69	+69	110.0	76.5
A70	+69	108.0	82.0
A90	+72	100.0	75.0

Table 6. Impact Test Results for AAR TC128 Grade B LT Specimens.

Specimen Number	Test Temperature, °F	Energy Absorbed, Ft-lb	Lateral Expansion, Mils
E6	-70	39.5	30.0
E7	-70	32.0	24.0
E8	-70	29.0	21.5
E3	-50	49.0	38.5
E4	-50	51.0	40.0
E5	-50	41.0	32.5
E9	-25	59.0	48.0
E10	-25	47.0	38.5
E11	-25	54.0	45.0
E12	0	75.0	63.0
E13	0	76.0	64.0
E14	0	66.0	55.5
E15	+25	89.0	71.0
E16	+25	98.0	78.0
E17	+25	78.0	64.0
E18	+50	120.0	88.5
E19	+50	122.0	84.5
E20	+50	111.0	81.5
E1	+69	120.0	86.5
E2	+69	121.0	89.5
E21	+72	118.0	71.0

Table 7. CVN Impact Test Results for AAR TC128 Grade B TL Specimens.

Specimen Number	Test Temperature, °F	Energy Absorbed, Ft-lb	Lateral Expansion, Mils
E70	-70	38.0	30.5
E71	-70	27.0	23.0
E72	-70	27.0	21.0
E67	-50	48.0	36.0
E68	-50	38.0	32.0
E69	-50	36.0	31.0
E73	-25	51.0	43.0
E74	-25	42.0	39.0
E76	-25	49.0	42.0
E77	0	68.0	55.5
E78	0	68.0	58.0
E79	0	68.0	57.0
E80	+25	79.0	65.5
E81	+25	94.0	74.0
E82	+25	78.0	66.0
E83	+50	100.0	80.0
E84	+50	110.0	83.5
E85	+50	108.0	79.5
E65	+69	100.0	81.0
E66	+69	112.0	85.0
E86	+72	96.0	76.5

Table 8. Comparison of the CVN Impact Test Results Obtained at -50°F by the NIST and Those Reported by the Bethlehem Steel Corporation in its Certificate of Analysis. Values are in Ft-Lb.

	NIST				BETHLEHEM STEEL CORPORATION	
	A 8XX		AAR TC128		A 8XX	AAR TC128
	LT	TL	LT	TL	LT	LT
	12.0					
	12.0	12.5	49.0	48	38	78
	36.0	12.0	51.0	38	52	85
	8.5	9.5	41.0	36	33	70
Average	17.1	11.3	47.0	40.7	41.0	77.7

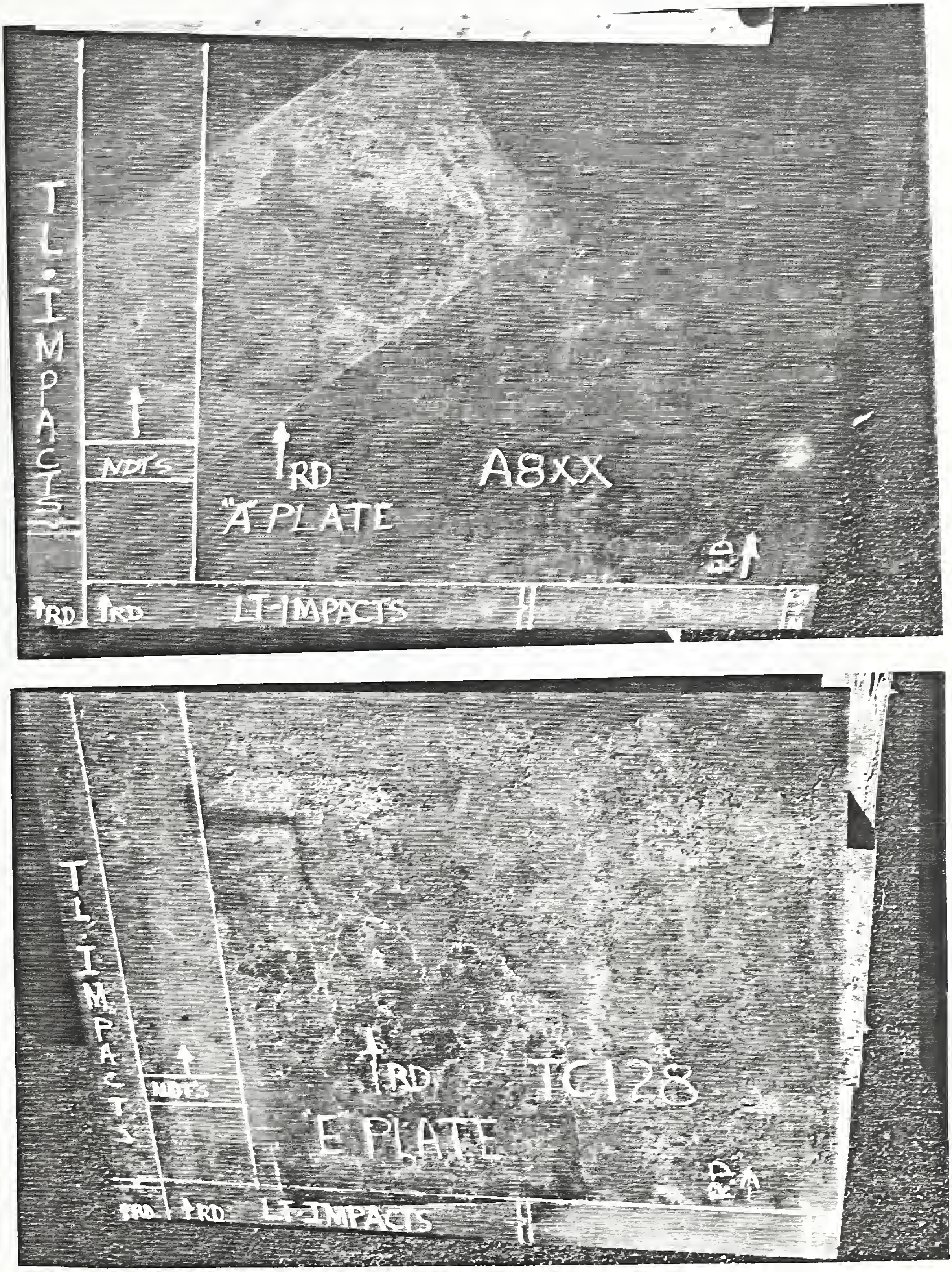


Figure 1. Photographs of the plates used in the redetermination of the rolling direction, microstructure, CVN impact properties, and NDT temperatures for both steels. Specimen locations are shown.

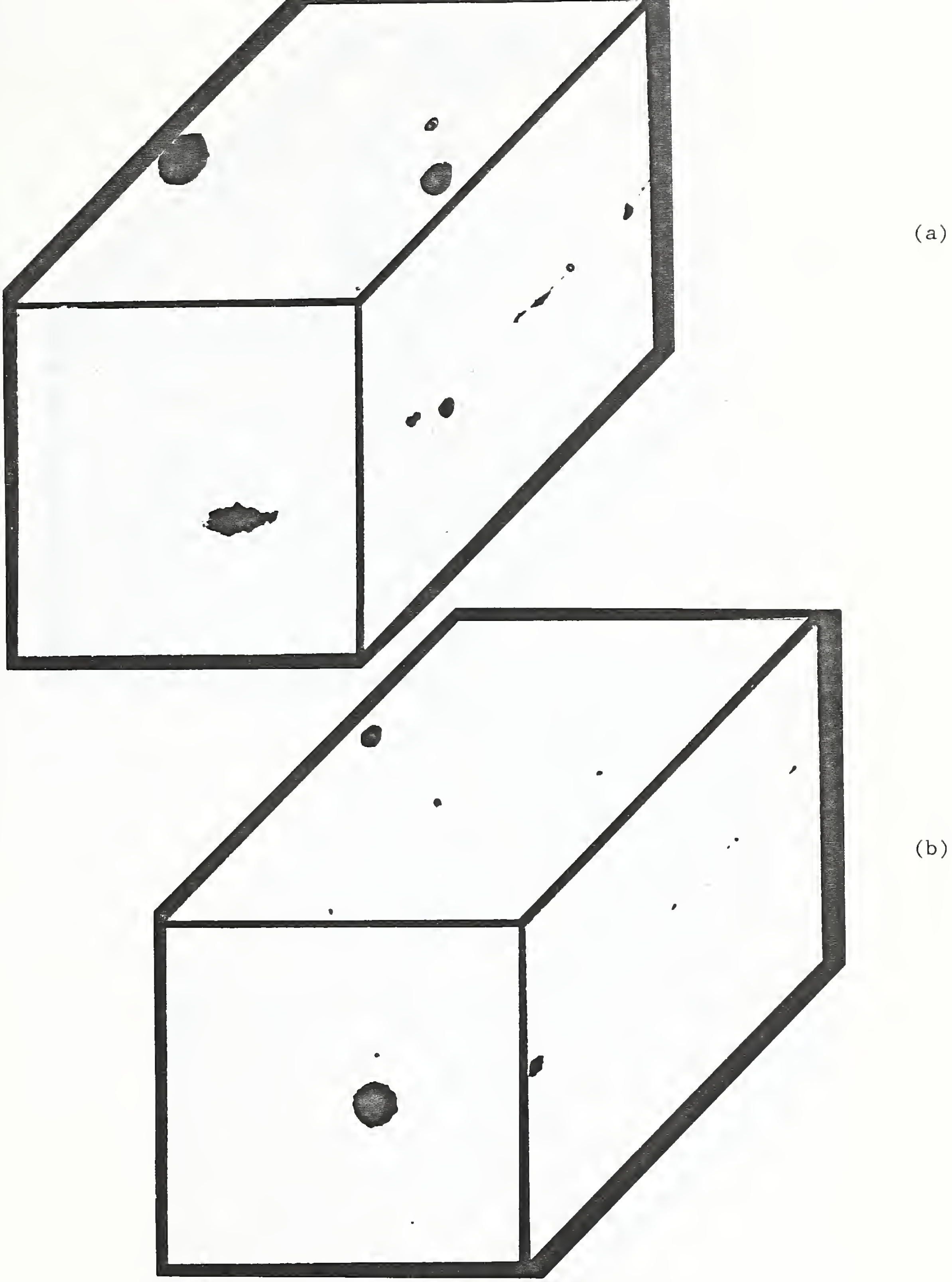


Figure 2. Three-dimensional photographic composite of both steels in the as-polished condition. Photographs in (a) are of the A 8XX steel, and (b) are of the AAR TC128 steel.
Magn. All X250.

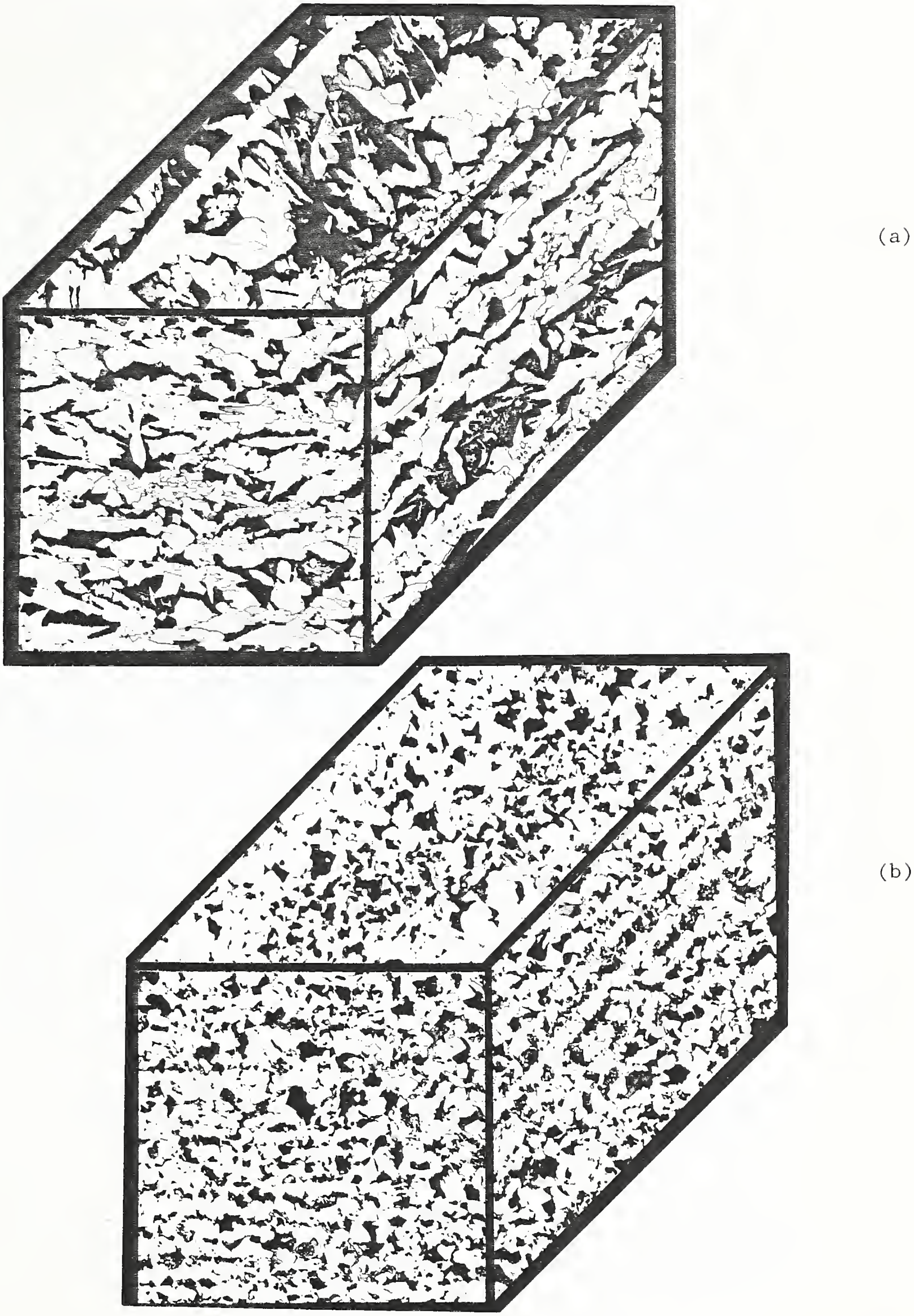
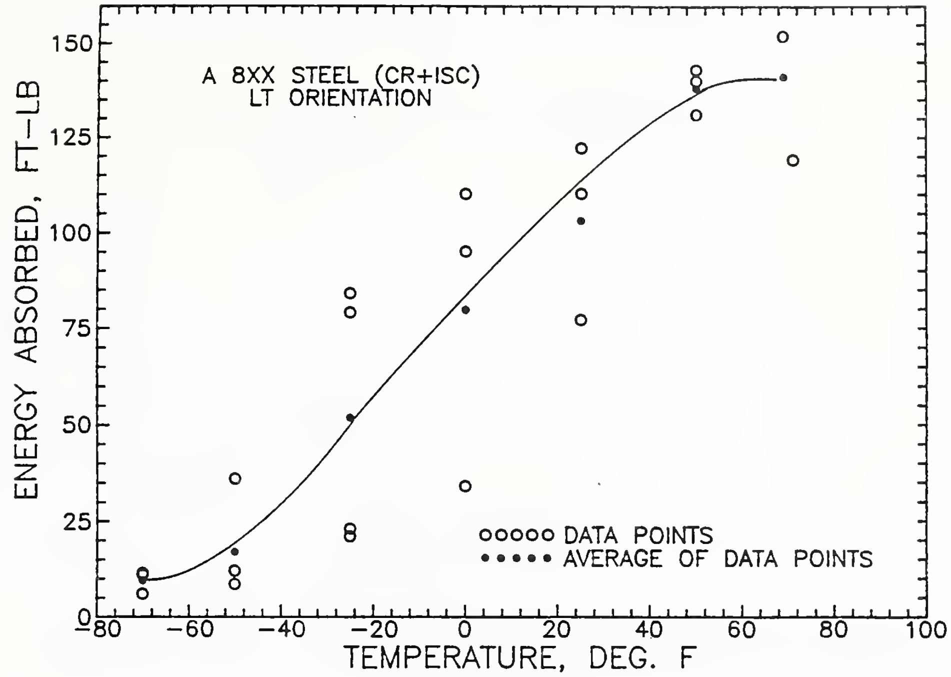


Figure 3. Three-dimensional photographic composite of both steels in the etched condition. Photographs in (a) are of the A 8XX steel, and (b) are of the AAR TC128 steel.
Magn. All X250. Etch. 1% Nital



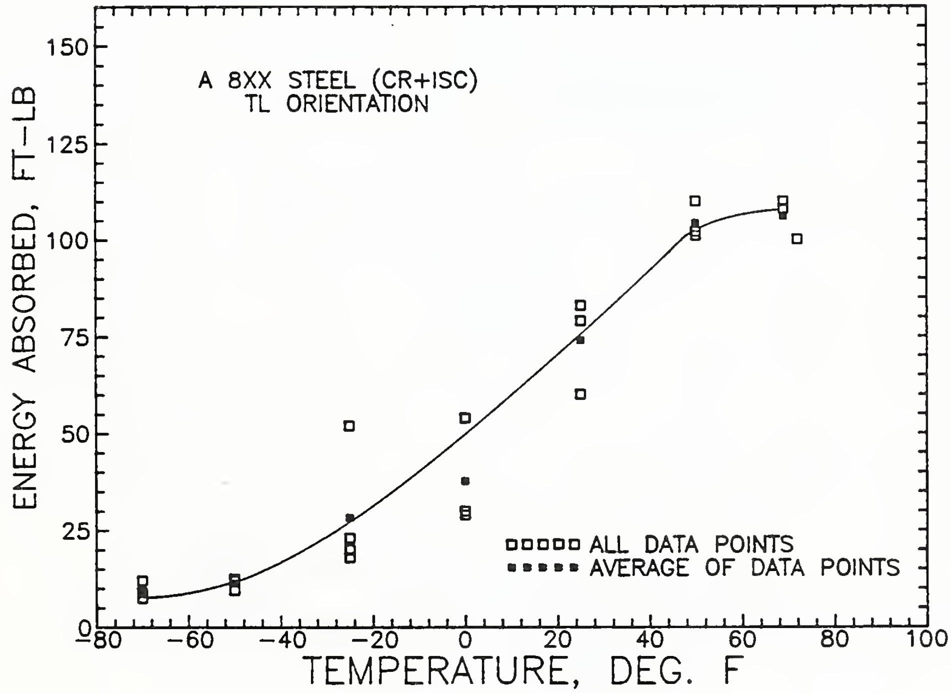
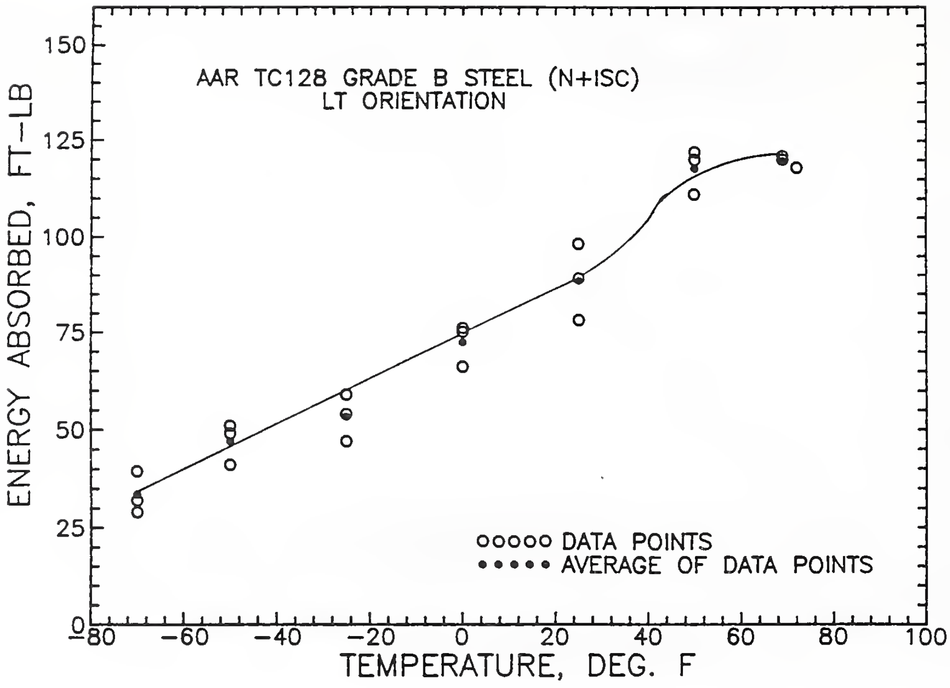


Figure 4. Energy absorbed versus test temperature for the A 8XX grade B steel tested in both the LT and TL orientations. All data points are used, and the plot is an average of the data points at each test temperature.



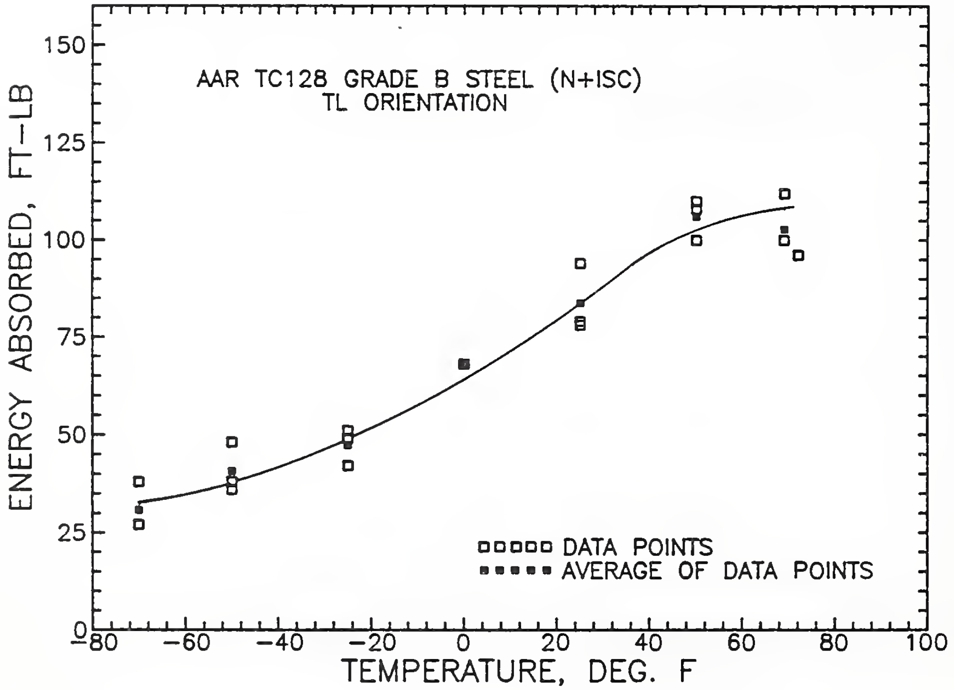
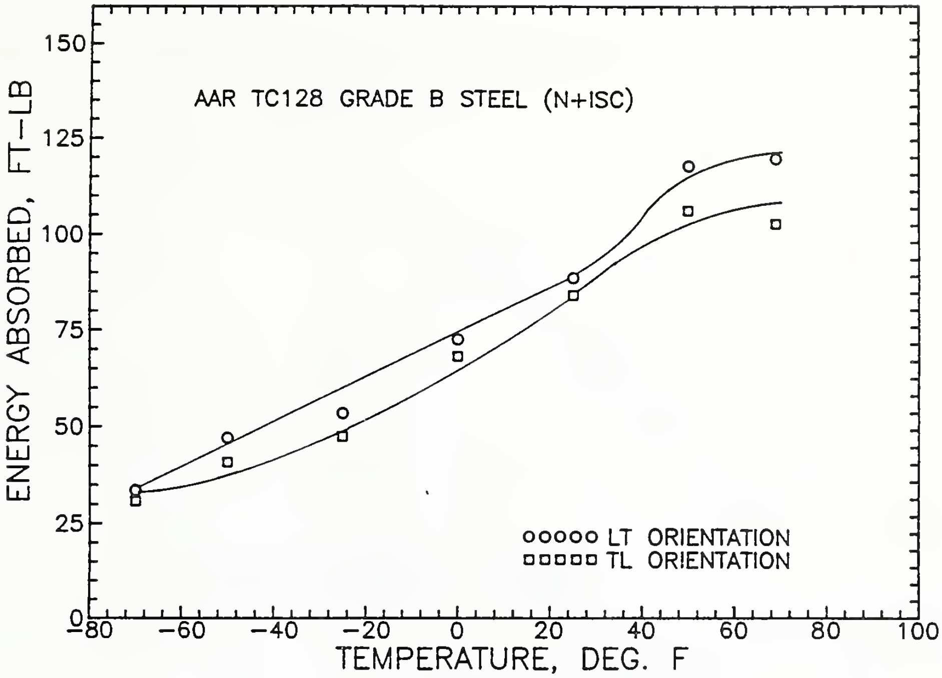
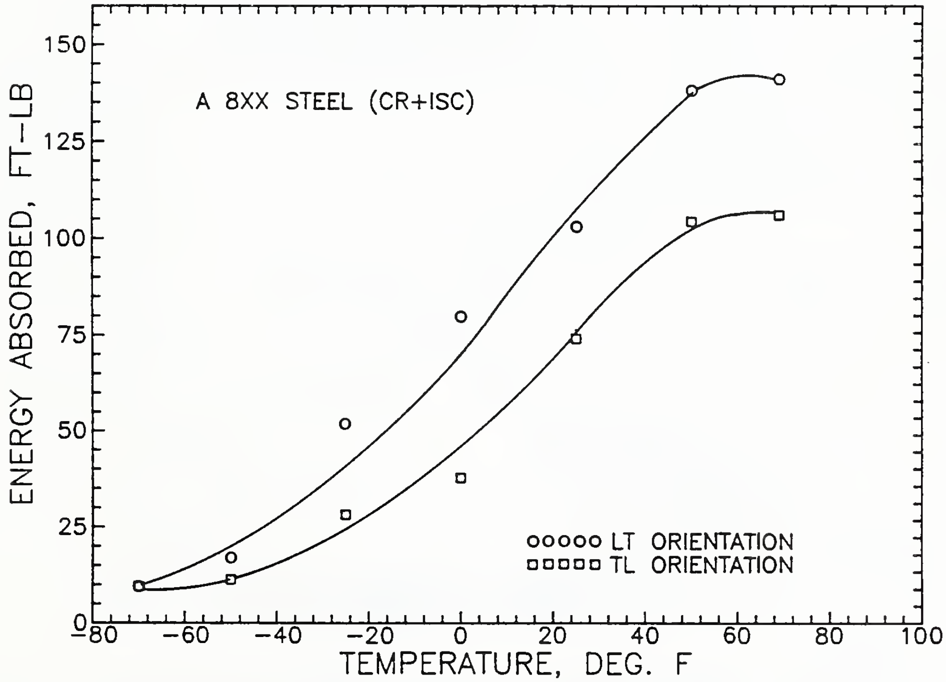


Figure 5. Energy absorbed versus test temperature for the AAR TC128 grade B steel tested in both the LT and TL orientations. All data points are used, and the plot is an average of the data points at each test temperature.

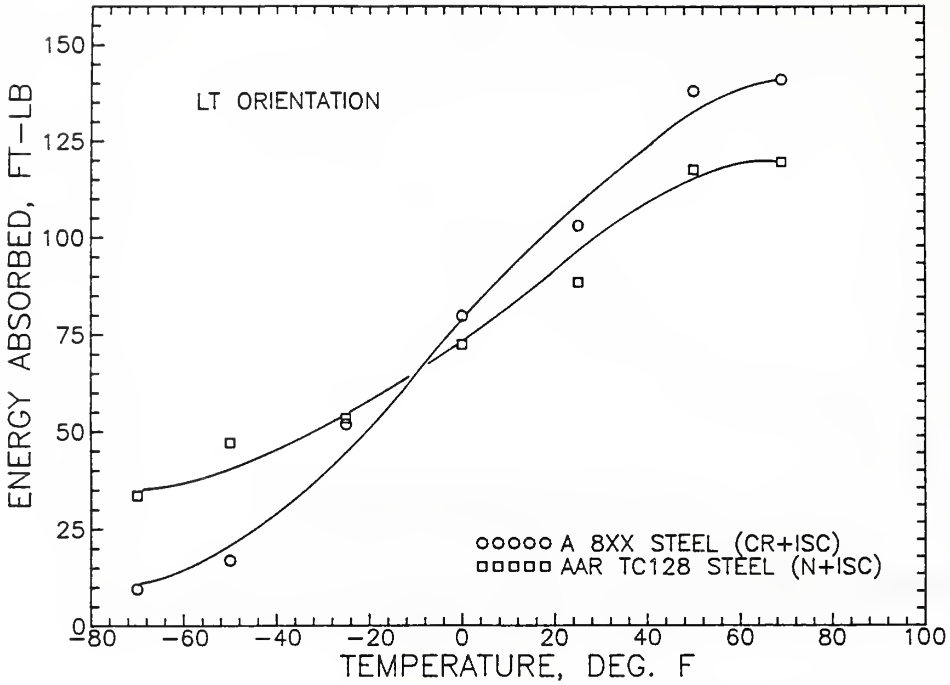


(a)



(b)

Figure 6. Energy absorbed versus test temperature for both steels. Graph (a) shows a comparison of the energy absorbed for both the LT and TL orientations for the AAR TC128 grade B steel. Graph (b) shows a similar comparison for the A 8XX grade B steel.



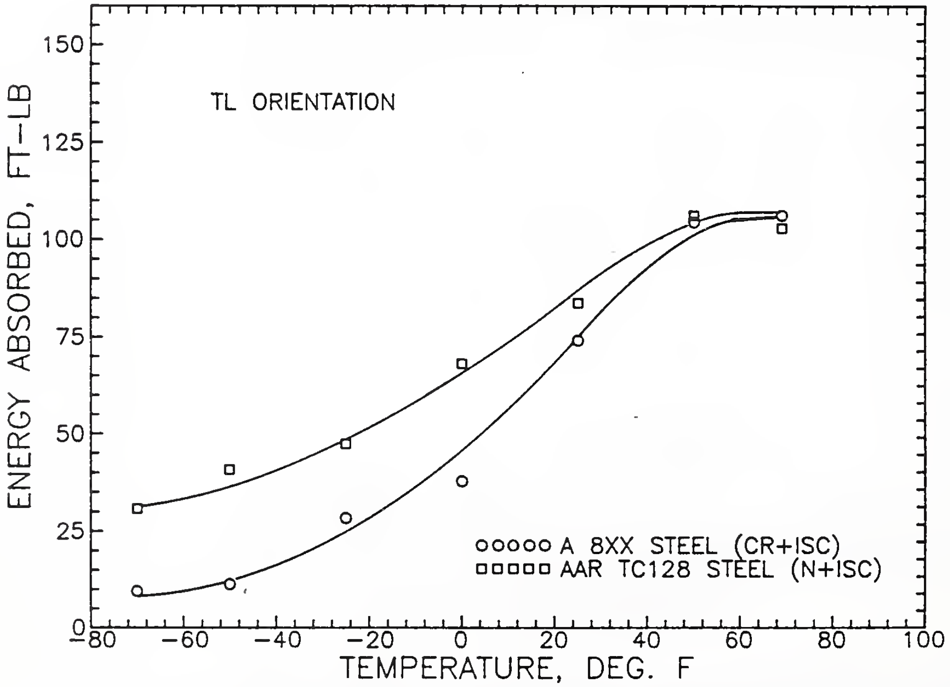


Figure 7. A comparison of the energy absorbed versus test temperature for both steels as a function of orientation.

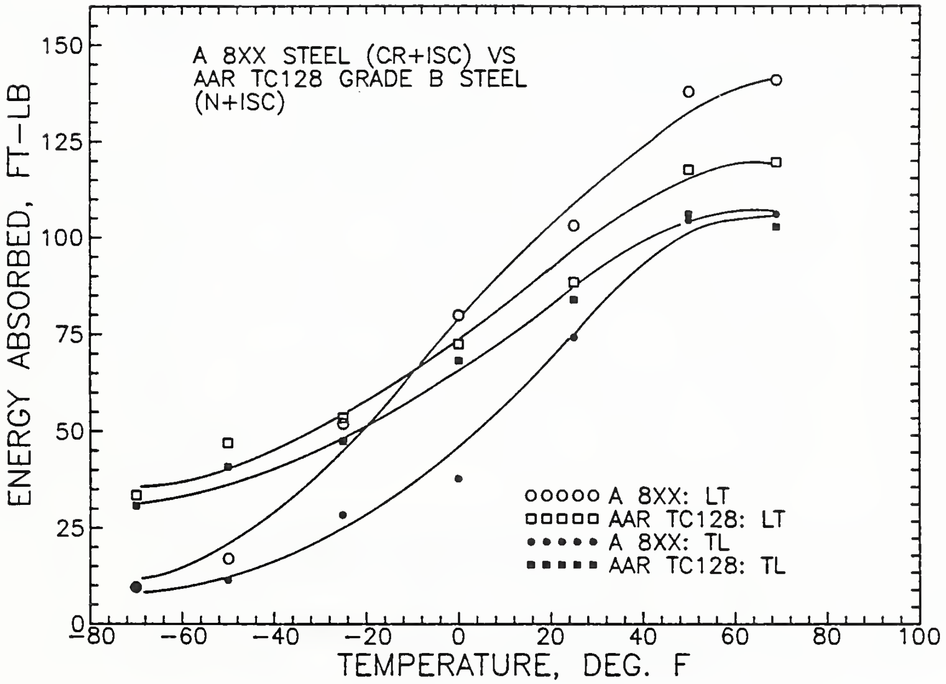


Figure 8. Summary graph showing a comparison of the energy absorbed as a function of temperature and orientation for both steels.

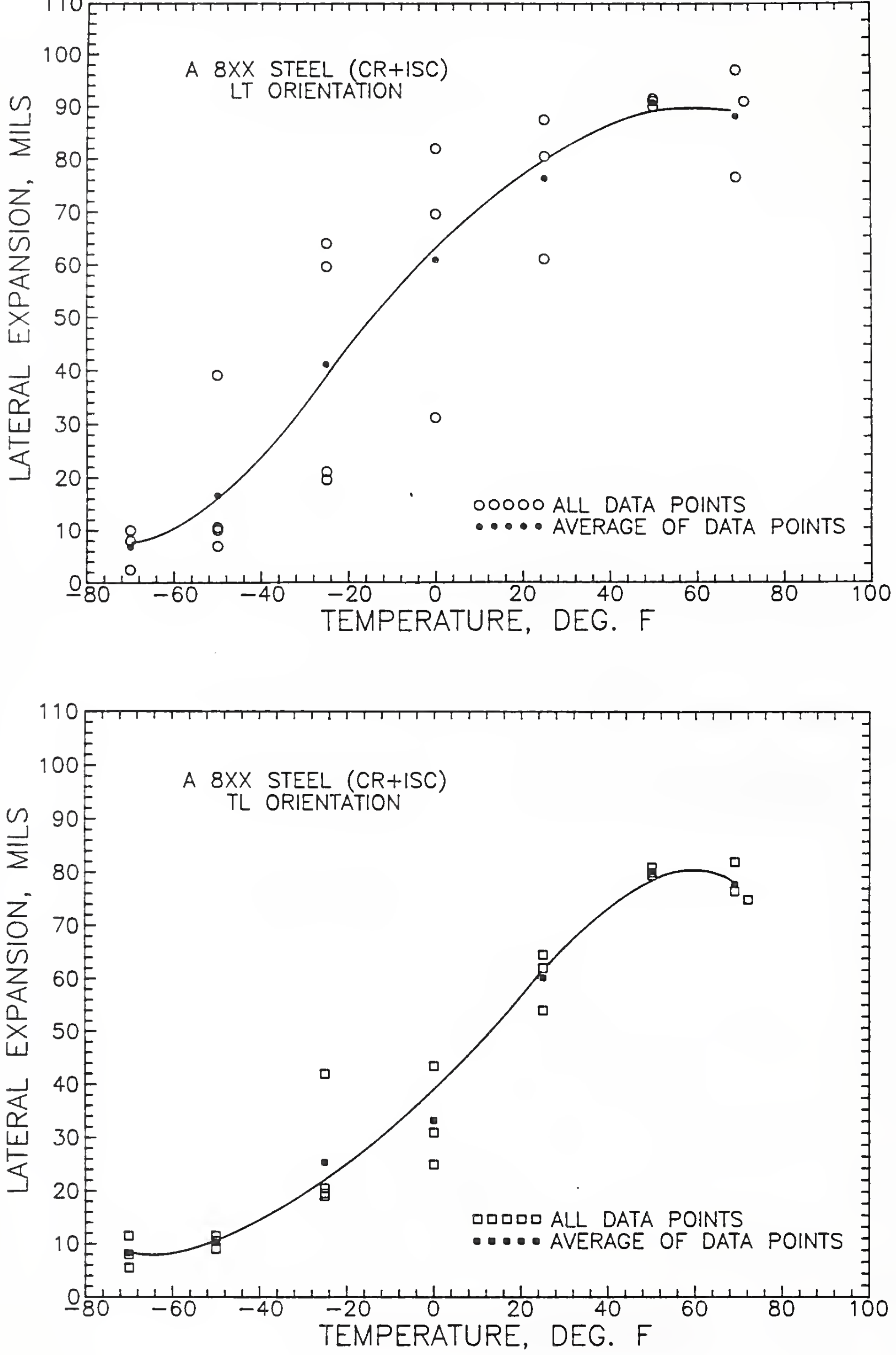
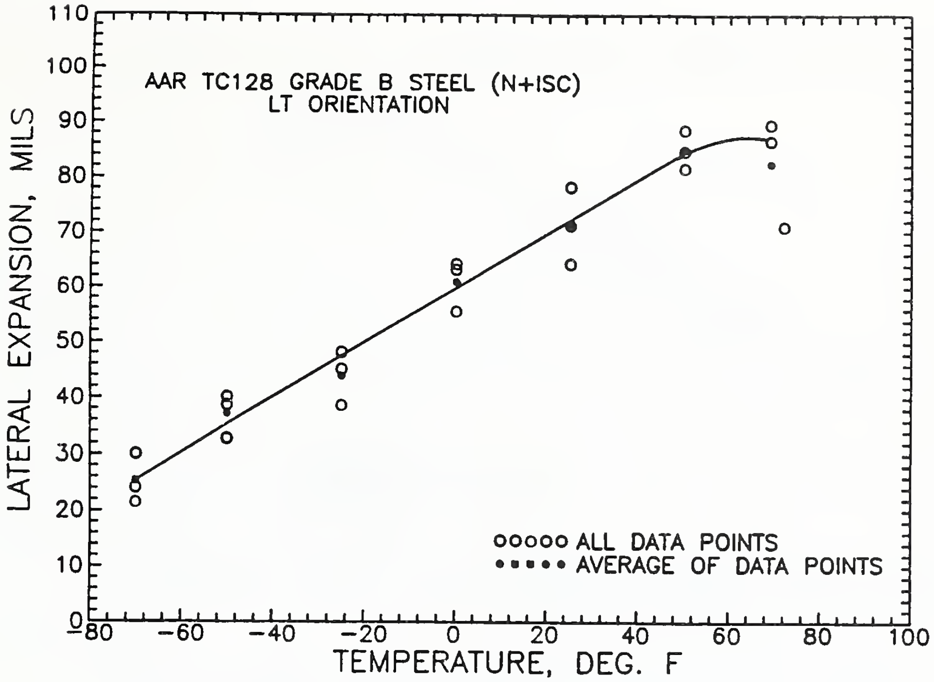


Figure 9. Lateral expansion versus test temperature for the A 8XX grade B steel tested in both the LT and TL orientations. All data points are used, and the plot is an average of the data points at each test temperature.



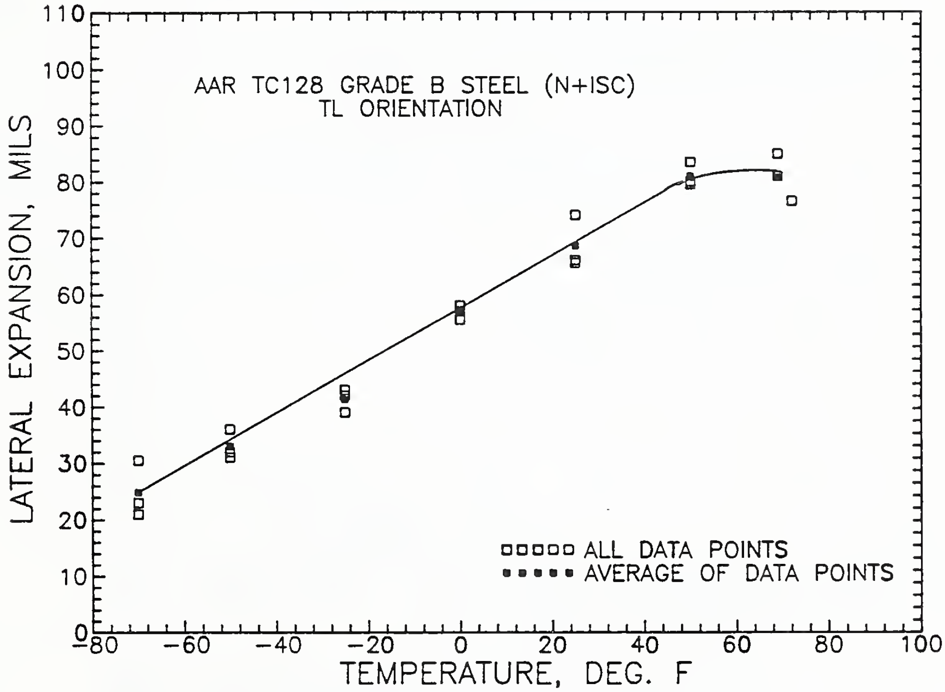


Figure 10. Lateral expansion versus test temperature for the AAR TC128 grade B steel tested in both the LT and TL orientations. All data points are used, and the plot is an average of the data points at each test temperature.

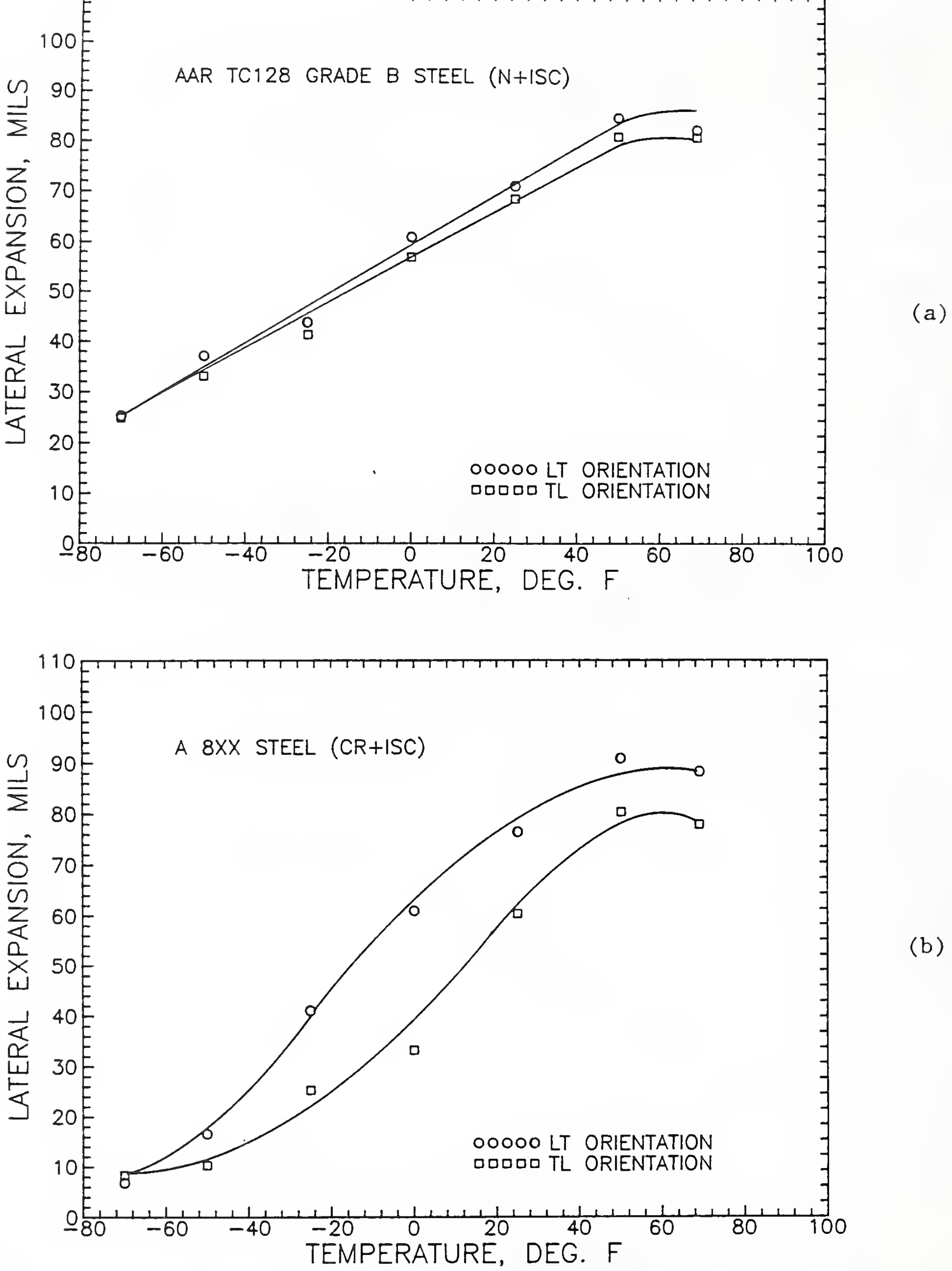


Figure 11. Lateral expansion versus test temperature for both steels. Graph (a) shows a comparison of the lateral expansion for both the LT and TL orientations for the AAR TC128 grade B steel. Graph (b) shows a similar comparison for the A 8XX grade B steel.

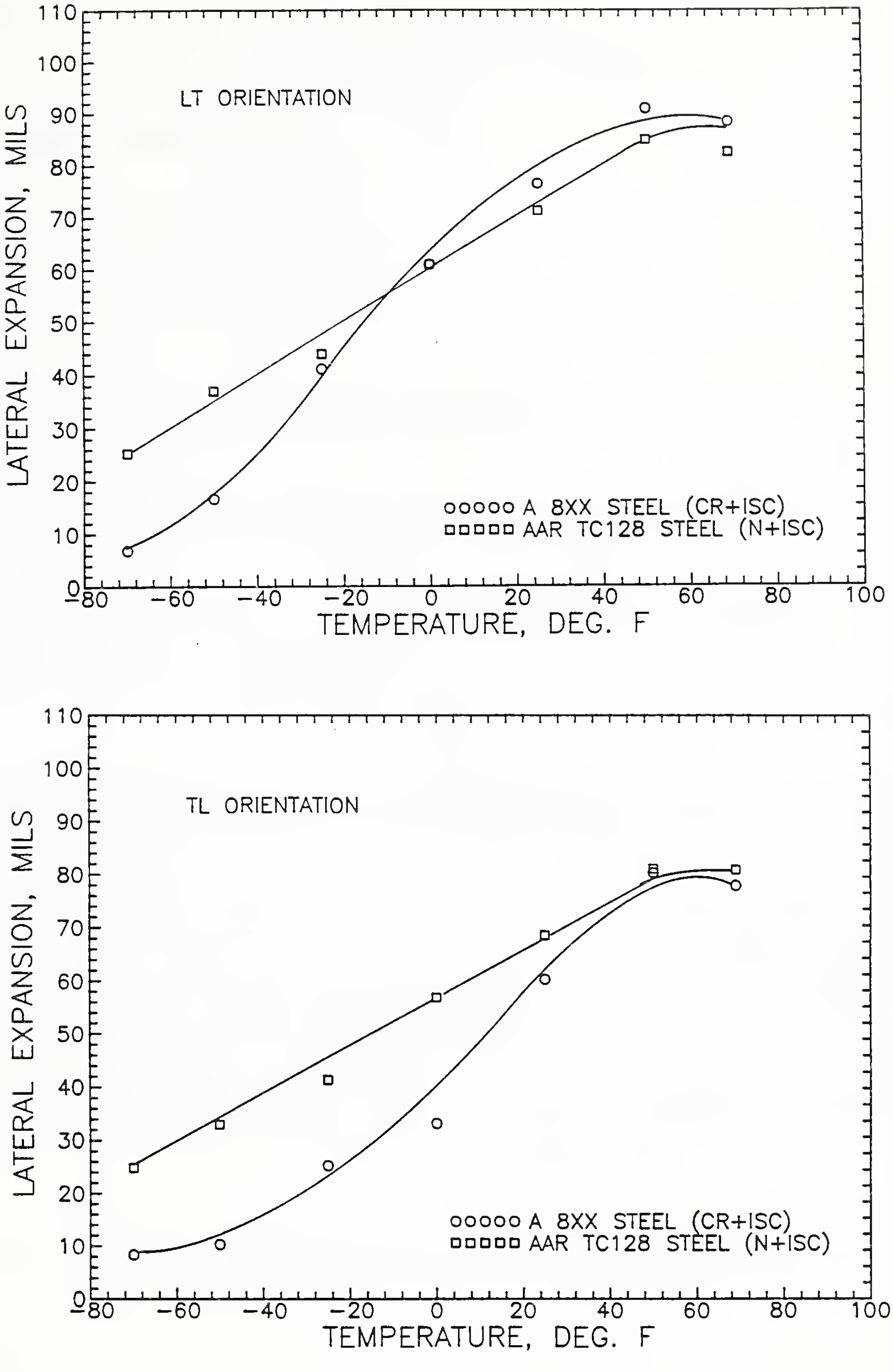


Figure 12. A comparison of the lateral expansion versus test temperature for both steels as a function of orientation.

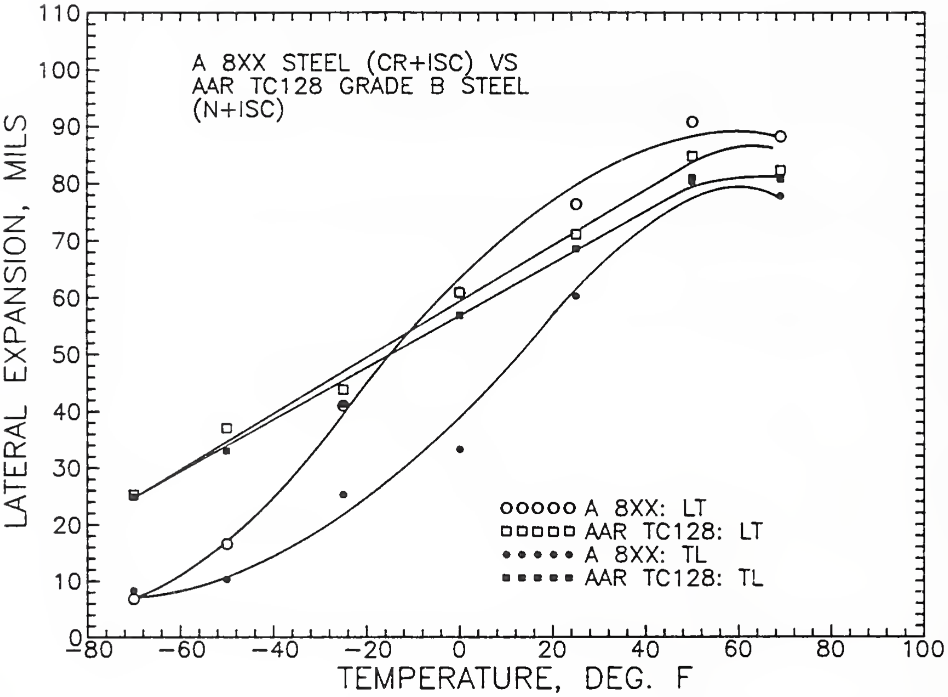


Figure 13. Summary graph showing a comparison of the lateral expansion as a function of temperature and orientation for both steels.

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☐ DOCUMENT DESCRIBES A COMPUTER PROGRAM; SF-185, FIPS SOFTWARE SUMMARY, IS ATTACHED.

11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

Charpy V-notch impact tests and the nil-ductility transition (NDT) temperature were redetermined for two steels. The two steels examined were normalized and inclusion shape controlled AAR TC128 grade B steel and control-rolled and inclusion shape controlled A 8XX grade B steel. The notch toughness, as determined by Charpy V-notch impact test, and the NDT temperature of the AAR TC128 grade B steel was found again to be better than that of the A8XX grade B steel. Metallographic investigations showed that the ferrite/pearlite grain size of the AAR TC128 grade B steel was more uniform and finer than that of the A 8XX grade B steel. Charpy V-notch impact results and NDT temperatures, presented in an earlier report were confirmed. Plate chemistry and test specimen orientation were also confirmed.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

Charpy V-notch impact, ferrite/pearlite grain size, nil-ductility transition temperature, steel.

13. AVAILABILITY

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