REPORT NO. FRA/ORD-81/33 PB 81-179483

A METALLURGICAL EVALUATION OF TWO AAR M-128 STEEL TANK CAR HEAD PLATES USED IN SWITCHYARD IMPACT TESTS

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WASHINGTON, DC 20545

APRIL 1981

FINAL REPORT

Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL RAILROAD ADMINISTRATION

Office of Research and Development

Washington, D.C. 20590

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FRA/ORD-81/33		

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code / 8. Performing Organization Report No.
A METALLURGICAL EVALUATION OF TWO AAR M128 STEEL TANK CAR HEAD PLATES USED IN SWITCHYARD IMPACT TESTS	5. April 1981 6. 8. NBSIR 80-2039
7. Author(s): J. G. Early, C. G. Interrante	
9. Performing Organization Name and Address: National Bureau of Standards Washington, DC	10. Work Unit No. (TRAIS) 11. Contract or Grant No.: AR-40008
12. Sponsoring Agency Name and Address: Federal Railroad Administration Department of Transportation Washington, DC 20234	13. Type of Report and Period Covered: Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The National Bureau of Standards correlated the mechanical properties and metallurgical characteristics of two steel head plate samples taken from tank cars subjected to switchyard impact tests. This metallurgical evaluation included determining whether the samples conformed with the appropriate specifications and to determine the impact test behavior of both plate samples. The results of check chemical analyses and ambient-temperature tensile tests indicated that both plates met the chemical, tensile strength, and tensile ductility requirements of AAR M128 steel. The results of metallographic analyses of both plates revealed extensive banding with alternate layers of ferrite and peralite, typical of carbon-manganese steel in the hot-rolled condition. One sample also contained a microstructural anomaly near the inside plate surface, possible related to prior thermo/mechanical processing of the plate. The nil-ductility transition temperatures were determined to be -20F and -40F for the plates, similar to the lowest values reported for a group of tank car plate samples. The results of Charpy V-notch tests established that the transition temperatures of these two plates are similar to one another, and are among the lowest of those measured for all other tank car plates tested at NBS. The comparatively low impact transition temperatures for both plates are related to the high manganese-to-carbon ratio and relatively fine ferrite grain size observed in the microstructures.

17. Key Words	18. Distribution Statement
Impact Properties Rail Tank Car Tensile Properties	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	58	

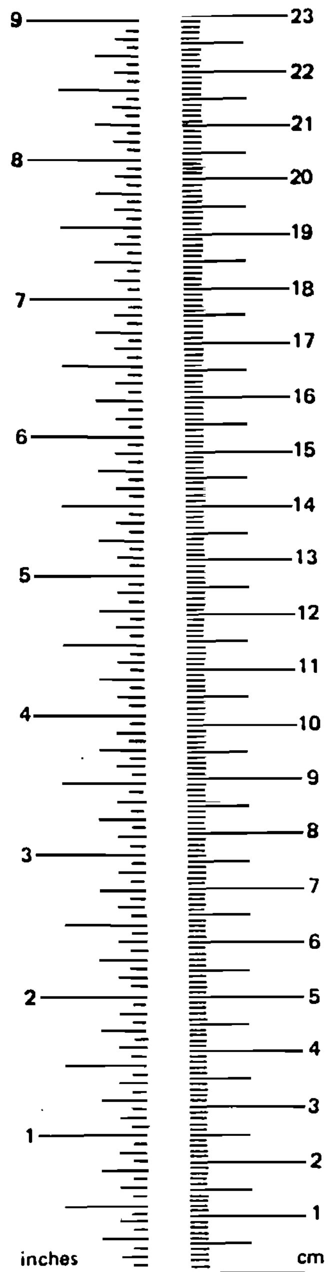
Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

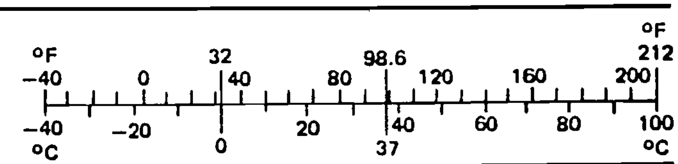
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

The National Bureau of Standards (NBS) was requested by the Federal Railroad Administration, Department of Transportation (FRA-DOT) to conduct metallurgical evaluations of two steel plate samples taken from two railroad tank cars. These tank cars, identified as GATX 93412 and UTLX 38498, were reportedly involved in two simulated switchyard impact tests as part of the Phase 15 test program carried out in 1976 at the DOT test facility at Pueblo, Colorado.(1)[a]

Both the GATX and UTLX tank cars were filled with water and pressurized to 100 psig. The temperature of the water in tank car UTLX 38498 was reported to be 74 F (23 C), and unknown in tank car GATX 93412.

In each of these two tests, it was reported (1) that a moving tank car impacted a stationary hopper car which subsequently impacted a stationary tank car coupled to five hopper cars. At the start of both tests, the stationary hopper car was separated from the stationary tank car by a distance of two and one-half feet.

In the test involving UTLX 38498, neither the stationary tank car (UTLX 38498) nor the moving tank car were equipped with head shields. It was reported (1) that at impact, the stationary hopper car was lifted off its trucks, overrode the draft sill of the stationary UTLX 38498 and struck the A-head of the tank car. The hopper-car coupler dented and punctured the A-head of UTLX 38498 at the weld joint between the head plate and the head-plate reinforcing pad. The head-plate sample removed and sent to NBS for evaluation contained both the dent and puncture.

In the test involving GATX 93412, both the moving tank car (GATX 93412) and the stationary tank car were equipped with head shields. It was reported (1) that after the impacted hopper car struck the stationary tank car, the hopper car continued to rise upwards and subsequently struck the moving tank car in the upper half of the A-head. The hopper car coupler overrode the top of the head shield and punctured the A-head of GATX 93412 just above the head shield. The head-plate sample removed from GATX 93412 and sent to NBS for evaluation did not contain the region of impact, and therefore the exact location of this plate sample on the head plate is unknown.

The two head plates from which samples were taken for this metallurgical evaluation are presumed to be in the hot-rolled, hot-formed, and stress-relieved condition. Details concerning the exact thermo/ mechanical condition of these two head plates were not reported to NBS.

Very little if any evidence of cold work was observed to be present in the GATX plate sample as a result of the puncture of the head plate. The observations and properties reported for the GATX sample are therefore believed to be relevant to the A-head of this tank car in service.

(a) The isolated numbers in parentheses refer to references listed at the end of this report.

The UTLX plate sample, however, exhibited substantial evidence of cold work since it contained the dented and punctured region of the A-head plate. Due to this severe deformation, all test specimens were taken from the region with the least amount of cold work. Although some deformation from the denting and puncture of the head plate may be present, results indicate that there does not appear to have been any significant effect of the deformation on the properties measured for this sample.

2. PURPOSE

The purpose of this metallurgical evaluation was to correlate the mechanical properties and metallurgical characteristics of two head plate samples taken from tank cars GATX 93412 and UTLX 38498. This evaluation included determining whether the samples conformed with the chemical-composition and tensile-property requirements of AAR M128, a specification for high strength carbon manganese steel plates for tank cars (AAR TC128-69), as well as a determination of the impact behavior of these plate samples.

3. EXPERIMENTAL PROCEDURE

Chemical analyses and tensile properties were determined and compared with the requirements of AAR M128-69. In addition to these required tests, standard Charpy V-notch impact tests, drop-weight nil-ductility transition-temperature tests, inclusion content ratings and a hardness survey were performed, and macroscopic and microscopic observations were made. Longitudinal and transverse specimens were prepared for the tensile tests and Charpy tests.

The principal rolling direction of each of the GATX and UTLX head-plate samples had to be determined prior to the preparation of test specimens. Head plates, as a result of their method of fabrication, lack reference features that identify the principal rolling direction. Thus, it was necessary to use studies of inclusion morphology and Charpy V-notch impact test results from specifically oriented specimens to identify the principal rolling direction.

Results of pre-cracked Charpy V-notch impact tests and dynamic-tear tests, currently being conducted on these two plate samples, will be reported in subsequent reports.

3.1 Macroscopic Observations and Rolling Direction Determination

The plate samples taken from tank cars GATX 93412 and UTLX 38498 were macroscopically examined for evidence of deformation resulting from the switchyard impact tests. The principal rolling direction was determined by testing a series of Charpy V-notch specimens oriented at fixed angles with respect to an arbitrary reference line scribed on the plate surface (Figures 1 and 2). A plot of energy absorption versus reference angle revealed either a maximum or a minimum, which identifies respectively the principal rolling direction (longitudinal) or the perpendicular (transverse) direction. The locations and orientations of test specimens taken from each of the two head plates are shown in Figure 3.

3.2 Chemical Analysis

Check chemical analyses (by combustion-conductometric and emission spectroscopic methods) were conducted by a commercial testing laboratory at the quarter-thickness location of the chemistry samples (Figures 1 and 2) from each plate to determine if the composition satisfied the requirements of AAR M128-69 steel.

3.3 Tensile Testing

Longitudinal and transverse tension test specimens, 0.250 inches in diameter with a 1-inch-gage length, were taken as closely as possible from the quarter thickness position in each plate and tested in accordance with ASTM A370-73,[b] Mechanical Testing of Steel Products.

(b) The General Conditions for Delivery section of the specification for AAR M128-69 tank-car steel requires that materials furnished to these specifications conform to the applicable requirements of ASTM Specification A20-65. Specification A20-67 requires, for plates 1-1/2 inch and under in thickness, tension test specimens shall be Standard Rectangular Tension Test Specimens with 8-inch-gage length and for plates over 1-1/2 inches in thickness, tension test specimens shall be Standard Round Tension Test Specimens with 2-inch-gage length, 0.505 inches in diameter. However, ASTM A20-67 requires the tests be conducted in accordance with the ASTM Methods and Definitions A370, for the Mechanical Testing of Steel Products. ASTM A370-73 allows Standard Round Tension Test Specimens and Small Size Specimens proportional to the Standard Round Specimen to be used when it is necessary to test material from which the Standard Rectangular Test Specimens of 8-inch- and 2-inch-gage length cannot be prepared. Because the amount of plate material available for machining test samples was limited, it would not have been feasible to prepare the Standard Rectangular Tension Specimens. The Standard Round Tension Test Specimen, 0.505 inches in diameter, has a 2-inch-gage length, thus allowing direct comparison between test result and specification; however, the threaded end section requires a diameter of 3/4 inches and due to the head-plate curvature the plate thickness was insufficient. Thus, for test consistency and to facilitate comparison with previous results (2-7), the tensile test specimens were machined to standard 0.250-inch-diameter round test specimens with a 1-inch-gage length.

3.4 Impact Testing

The results of two types of impact tests are discussed in this report: drop-weight nil-ductility transition temperature (NDTT) tests, carried out in accordance with ASTM E208-69, and standard Charpy V-notch (CVN) tests, carried out in accordance with ASTM E23-72. Specimens for the NDTT tests were full-plate-thickness type specimens with length and width dimensions of 5 inches and 2 inches, respectively, and a saw-cut notch located on a weld bead on the outside plate surface. The Charpy specimens were standard size and were machined as closely as possible from the quarter-thickness location of the plate, nearest the outside plate surface. The Charpy data were analysed by methods described earlier.(2-8)

The drop-weight test was originally developed to study the initiation of brittle fractures in low- and intermediate-strength structural steels. This test is used to measure the nil-ductility transition (NDT) temperature (the temperature above which many steels undergo a transition from brittle to ductile fracture behavior) and permits the evaluation of the ability of a steel to resist crack propagation. The NDTT, according to ASTM E208-69, is independent of the specimen orientation with respect to the plate rolling direction.

The orientation of Charpy specimens used in this study are the standard longitudinal (LT) and transverse (TL) orientations used in previous reports (2-8). For all sets of impact specimens, tests were conducted over a temperature range selected to demonstrate the transition from ductile to brittle fracture behavior.

3.5 Metallographic Studies and Hardness Testing

Representative photomicrographs, oriented as shown in Figure 4, were obtained on metallographic samples located as shown in Figures 1 and 2. Metallographic observations were made on selected polished and etched areas of longitudinal C planes and transverse B planes. The ferrite grain size was measured in accordance with the circular intercept method from ASTM E112-74, Intercept Method.

Rockwell B hardness measurements were taken on specimens adjacent to the metallographic specimens and correlated with the microstructure of each plate sample.

The inclusion content was determined on longitudinal C planes by a Quantitative Television Microscope (QTM) method which rates the inclusion content as an area percent of the section being rated. The area percentage measurements were made at two quarter thickness locations and at the mid-thickness. In addition, the worst field and the number of fields with inclusion area greater than 0.5 percent, were tabulated. The QTM methods used in this study are described in previous reports (2-6) and in the literature (9).

4. RESULTS AND DISCUSSION

4.1 Chemical Composition

The chemical compositions, as determined by check chemical analysis of the two plate samples, are given in Table I, along with the chemical requirements for AAR M128-69 steel, Grades A and B, and one producer's ladle analysis. The results of the laboratory check analyses and the producer's ladle analysis (where available) are in good agreement and indicate that the composition of both plate samples satisfies the chemical requirements for AAR M128-69 steel. The carbon levels in both samples are close to the maximum level allowed. The manganese level of the GATX plate is 0.20 percent by weight below the maximum level allowed and that for the UTLX plate is only 0.11 percent by weight below the maximum allowed. The vanadium content of the GATX sample is 0.026 weight percent and thus meets the specified minimum content of 0.02 for AAR M128, Grade A steel. The UTLX plate satisfies the chemical requirements for AAR M128, Grade B steel.

Specification AAR M128-69 requires the steel to be made to fine-grain practice and the presence of aluminum in the UTLX sample, and aluminum and vanadium in the GATX sample indicates that a fine-grain steelmaking practice was followed.

4.2 Macroscopic Observations

The plate samples from tank cars GATX 93412 and UTLX 38498 had been flame cut from the impacted head plates. The GATX sample had a number of small surface scratches and gouges but did not appear to have experienced any significant amount of plastic deformation (Figure 2) as a result of the switchyard impact test. The specimen layout (Figure 3a) was chosen to avoid most of the gouged areas, and therefore the results for the GATX plate sample are believed to represent the as-fabricated head plate.

Visual examination of the UTLX plate sample revealed extensive deformation and reforming over much of the sample. This apparently resulted from the switchyard impact test. The plate sample appeared to be centered about the principal impact site on the head plate and contained numerous surface gouges, a puncture at the weld joint between the head plate and head-plate reinforcing pad, and an extensive concave dent (Figure 1). The portion of the plate sample adjoining the flame-cut edge contained the least visible evidence of deformation. Therefore, the specimen layout (Figure 3b) was selected so that all of the test specimens used for mechanical property measurements were taken from this region of minimum deformation. The results for the UTLX plate sample are believed to be representative of the as-fabricated head plate even though a small amount of deformation from the switchyard test may have been present in the areas selected. This possible level of deformation appeared to have no significant effect on the mechanical properties measured for this plate.

4.3 Metallographic Analyses

Representative photomicrographs taken at low magnification on longitudinal C planes and transverse B planes for the GATX sample and on longitudinal C planes for the UTLX sample are shown in the unetched condition in Figure 5. A comparison at a magnification of X100 was made of the inclusions in these two plate samples with those of the Winder sample (6), an ASTM A212 steel head plate studied previously. For the Winder sample, a substantial difference in the inclusion lengths on the longitudinal and transverse planes was observed as compared to the GATX and UTLX samples (shown in Figure 5a for the GATX plate sample). This difference in inclusion length was greater for the Winder sample compared to the UTLX and GATX samples and could result from differences in thermo/mechanical processing procedure.

The method employed initially to identify the principal plate rolling direction for the GATX and UTLX head plate samples, used successfully on the Winder and other head plate samples, measured the change in average inclusion length as a function of specimen orientation about an arbitrary reference line. The effectiveness of this technique is therefore reduced as the difference in inclusion length between the longitudinal and transverse directions decreases. The principal plate rolling directions in the GATX and UTLX samples could not be established through examination of inclusion morphology due to the inability to consistently distinguish between the longitudinal and transverse directions as a result of the small difference in inclusion length in these two directions. Therefore, the principal plate rolling direction was finally determined by the testing of Charpy V-notch specimens oriented about an arbitrary reference line.

Representative microstructures of both plate samples are shown in the etched condition in Figures 6 through 10. The microstructures are typical of carbon-manganese steel in the hot-rolled condition and consist of a mixture of proeutectoid ferrite and pearlite. Montages of the longitudinal plane microstructures from the outside surface to the inside surface of the GATX and UTLX plates (Figures 6 and 7) show the existance of extensive banding with alternate layers (parallel to the plate surfaces) of ferrite and pearlite. The degree of banding observed in these two head-plate samples is similar to that reported (5) for other AAR M128 head-plate samples studied at NBS. However, no quantitative measure of the degree of banding was carried out.

The estimates of ferrite grain size of the GATX and UTLX plate samples are ASTM Nos. 10 1/2 and 11 respectively. Ferrite grain size and pearlite colony size are strongly influenced by the prior austenite grain size and by the cooling rate through the transformation temperature, and are therefore affected by deoxidation practice and by finishing temperature. The fine ferrite grain size observed in both plate samples is consistent with the conclusion (based on the check chemical analyses) that both steels were produced to fine-grain practice. A fine ferrite grain size is one of the factors which promote low impact transition temperatures.

The microstructure of the UTLX sample (Figure 8) shows that the banded structure exhibits a high degree of regularity with generally continuous layers of the lighter etching proeutectoid ferrite phase separating the darker etching pearlite phase. The microstructure in this region of the plate (Figure 1) does not show any effects of deformation resulting from the impact that punctured this head plate.

The cross-sectional montage of the GATX sample (Figure 7) reveals the presence of a microstructural anomaly near the inside plate surface. In this region, the regularity of the banded structure (Figures 9a and 10a) has been disrupted resulting in local areas consisting of large pearlite colonies and large proeutectoid ferrite grains (Figures 9b and 10b). This microstructural anomaly is probably related to thermal and mechanical effects resulting from processing of the plate, such as too high a forming temperature, since the prior austenite grain size and cooling rate can affect the grain sizes and distributions of ferrite and pearlite in these low-carbon steels.(10) This microstructure is similar to that reported earlier (4) for the Callao K-1 plate, a head plate believed to have been improperly hot formed. The nonuniformity through the cross-section of the GATX sample (Figure 7) is not as severe as that of Callao K-1.

4.4 Hardness Measurements

The results of hardness measurements on the plate cross-section are given for the UTLX and GATX plate samples in Figures 6 and 7 respectively. The Rockwell B hardness profiles for both plates are quite similar and very uniform across most of the cross-section and can be correlated with the microstructure. The region of the GATX plate containing the microstructural anomaly has an average hardness of almost HRB 90 compared to HRB 86 1/2 for the remainder of the plate. The higher hardness observed in this region near the inside plate surface is associated with the presence of large pearlite colonies and a somewhat higher fraction of the relatively harder pearlite phase.

4.5 Tensile Properties

The measured tensile properties of both the GATX and UTLX samples are given in Table II along with the requirements of AAR M128-69. The results of the longitudinal and transverse specimens indicate that both head-plate samples are within the allowed range of ultimate tensile strength, 81 ksi to 101 ksi, and both samples meet the minimum yield-strength and elongation requirements of 50 ksi and 19 percent, respectively..

The average values of longitudinal and transverse ultimate tensile strength for the GATX plate were 84.4 ksi and 90.2 ksi, respectively, while the average 0.2 percent offset yield-strength values were 55.2 ksi and 56.4 ksi, respectively. For the UTLX plate, the average ultimate tensile strength values of longitudinal, transverse, and 45° specimens were 88.6 ksi, 88.2 ksi, and 88.3 ksi, respectively, while the average 0.2 percent offset yield-strength values were 58.5 ksi, 52.8 ksi, and 55.2 ksi, respectively. These results indicate that there was no significant anistropy in the strength of the two plates in the plane of the rolling direction; a finding consistent with earlier results on both head and shell plates of ASTM A217 and AAR M128 steel.(5,6,11)

The yielding behavior of a plate sample can provide evidence as to whether its mechanical properties have been affected by cold work. The cold work sustained by the head plates in the switchyard impact tests could lead to the elimination of a sharp yield point, increases in yield strength, and increases in the ductile-to-brittle transition temperature, as measured by Charpy V-notch impact tests. In tensile tests of these plates, the presence of a sharp yield point is an indication that significant cold work of the plate had not occurred since the tank car tank was stress relieved after fabrication. Further, unusually high yield-strength values are another indication of significant cold work. In contrast to this observation, both plate samples have yield-strength values within the specification requirements of AAR M128 and these values are consistent with the carbon and manganese levels determined by the check chemical analyses. In addition, a sharp yield point was observed in eight of the ten tensile test specimens (Table II) tested. These results suggest that the plastic deformation received by these two plate samples as a result of the switchyard tests was insufficient to significantly affect the mechanical properties in regions of the plates from which test specimens were taken.

The average tensile ductility values, as measured by percent elongation, were 31.7 percent and 26.9 percent respectively for longitudinal and transverse specimens taken from the GATX plate sample. The longitudinal elongation values were approximately 18 percent higher than the transverse values. This finding is in agreement with the general observation that the tensile ductility of rolled steel plates tends to be greater in the longitudinal direction than in the transverse direction.

The average tensile ductility values of the UTLX plate sample, measured by percent elongation, were 31.4 percent, 33.9 percent, and 30.6 percent respectively for the longitudinal, transverse, and 45 degree specimens. The transverse elongation value was about eight percent higher than the longitudinal value, but only single test values are available for each orientation. The average percent elongation (four specimens) for the 45 degree orientation was about three percent smaller than the longitudinal value. These results are contrary to the behavior of the GATX sample and can be interpreted as: (i) a reflection of the variability of the properties within this plate, and (ii) an indication that this plate was more extensively cross-rolled.

Reduction-in-area requirements are not specified in AAR M128, but they provide a useful check of the elongation results since percent reduction-in-area measurements are independent of the gage length of the test specimen. The results for the GATX sample (Table II) show that the percent reduction-in-area values were 63.2 percent and 57.4 percent, respectively, for the longitudinal and transverse specimens. The longitudinal value is approximately ten percent higher than the transverse value and the trend is similar to that observed for the GATX elongation data. The UTLX sample exhibited isotropic behavior with reduction-in-area values of 61.0 percent, 61.0 percent, and 60.6 percent respectively for the longitudinal, transverse and 45 degree specimens and this behavior is similar to that shown by the UTLX elongation data.

Previous studies at NBS (5), with both head-plate and shell-plate samples of AAR M128 steel, revealed that: (i) there was little difference between the average ultimate tensile strength and yield strength values of longitudinal and transverse specimens; (ii) the average longitudinal tensile ductility, measured by percent elongation, was approximately ten percent higher than the transverse ductility; and (iii) the anisotropy of tensile ductility was attributed to the rolling operation used in the fabrication the steel plates. The greater longitudinal tensile ductility observed in the GATX sample indicates that this plate experienced less cross-rolling than the previous AAR M128 samples studied. Conversely, the lack of definite anisotropy in tensile ductility properties found for the UTLX sample suggests that this plate experienced greater cross-rolling than either the GATX sample or any of the other AAR M128 plates studied.

The ultimate-tensile-strength data can be compared with the hardness measurements and the results of the metallographic analyses. Using an empirical relationship between hardness and tensile strength (12), the measured hardness range of HRB 86 to 90 for the GATX sample and HRB 86 1/2 to 89 for the UTLX sample correspond to ultimate-tensile-strength ranges of 81 ksi to 89 ksi and of 83 ksi to 87 ksi, respectively. The measured average ultimate tensile strength of slightly more than 87 ksi for both longitudinal and transverse specimens of the GATX plate is within the predicted range. For the UTLX plate, the average ultimate tensile strength of somewhat more than 88 ksi is slightly above its predicted strength range. This general agreement between the measured hardness data and the empirically derived strength data is as good as can be expected for this type of correlation and the small discrepancy in the UTLX comparison is not believed to be significant.

4.6 Inclusion Content

The results of the inclusion content rating of both the GATX and UTLX samples are given in Table III. The QTM area-percentage rating at an effective magnification[c] of X100 indicates an overall average inclusion content (based on 100 fields) for the GATX and UTLX samples of 0.21 area percent and 0.27 area percent, respectively. There were no fields found with an inclusion area equal to or greater than 0.5 percent.

The results of earlier QTM inclusion analyses[d] of one head and two shell plates of AAR M128 steel (3,4) showed higher average overall inclusion contents of 0.35, 0.33, and 0.45 area percent respectively. The observed number of fields with inclusion areas equal to or greater than 0.5 percent were 21, 15, and 34 respectively, for the head and shell plates. Thus, the results of inclusion content ratings indicate

(c) The effective magnification of the QTM system represents the actual magnification of the image used by the internal electronic measuring scale of the instrument. The image magnification or apparent magnification, as measured on the visual display monitor, has no meaning because the monitor is not part of the measuring system.

(d) These QTM measurements were reported for an apparent magnification of X338. This is equivalent to an effective magnification of X120 for the particular instrument used.

that the GATX and UTLX samples of AAR M128 steel were similar to each other and cleaner than the other AAR M128 steels studied to date at NBS. Further, these results indicate that the cleanliness of the GATX and UTLX samples are similar to NBS test results previously reported for ASTM A212-B steel.(5,6)

A further comparison can be drawn between the GATX and UTLX results and data reported[e] for production heats of steels with a broad range of composition and strength levels.(9) These production heats of steel were not produced to cleanliness specifications but were taken from regular production heats of basic oxygen or open-hearth steel. The average inclusion area percent range reported was 0.10 to 0.38 and the reported range for number of fields with inclusion area equal to or greater than 0.5 percent was 1 to 28. The results for the GATX and UTLX plate samples lie towards the low end of this ranges and indicates that the cleanliness of these two samples compares favorably with that attained in production heats of other steels.

4.7 Impact Properties

The results of drop-weight tests and Charpy V-notch (CVN) tests for these two AAR M128 steel head plates lead to the following observations: (i) these two plates have very similar impact properties; only minor differences are observed; (ii) the nil-ductility transition temperature (NDTT) for each plate is close to the lowest NDTT values recently reported (13) for steels produced according to AAR M128; (iii) in comparison with other head-plate steels tested at NBS, these two plates have low (generally desirable) transition temperatures and their upper-shelf energy-absorption levels are comparable with those of steels produced according to AAR M128; (iv) like other head plates tested at NBS, these plates were produced with extensive cross rolling as compared to shell plates; and (v) a lamellar fracture appearance observed on broken Charpy specimens from both the GATX and UTLX plates and on other tank-car plate steels appears to be associated with a banded microstructure of alternate layers of ferrite and pearlite, while the fracture surfaces of two plates that do not appear lamellar do not have banded microstructures.

4.7.1 Nil-Ductility Transition Temperature

The results of the drop-weight tests are given for both the GATX and UTLX samples in Table IV. Inspection of the drop-weight test specimens taken from the GATX plate (pictured in Figure 11a) shows that in both specimens tested at -10 F the weld starter crack did not propagate to either edge of the specimen surface. At -20 F and below, the weld starter crack propagated to at least one edge of the surface. Inspection of the UTLX plate test specimens (pictured in Figure 11b) shows that in both specimens tested at -30 F, the starter crack did not propagate to either edge of the specimen surface. At -40 F and below the starter crack propagated to at least one edge of the surface. Thus, according to the test criteria of ASTM E 208-69, the nil-ductility transition temperature (NDTT) values for the GATX and UTLX samples are -20 F and -40 F, respectively.

(e) The reported data were obtained at an apparent magnification of X350 which was equivalent to an effective magnification of X100.

The NDTT values for these two plates compare favorably with those given in a recent review (13) of fracture toughness properties of samples of steels of several grades of plate materials currently and formerly specified for use in tank cars. This review reported a broad NDTT range of from -60 F to +30 F for 17 plates representative of plates in various conditions of heat treatment and fabrication and of plates from tank cars involved in accidents.

For the AAR M128 steels, this range is -60 F to +20 F for all eight plates tested. The individual NDTT values are: -60 F for an as-rolled, normalized and stress-relieved (A-N-S) shell plate; -20 F for an as-rolled and normalized (A-N) head plate; 0 F for each of three as-rolled and stress-relieved (A-S) shell plates; +20 F for an as-rolled, hot-formed and stress-relieved (A-H-S) head plate; and -10 F and +20 F for two shell plates taken from accidents. In general, AAR M128 plates that were normalized have NDTT values that are lower than those for plates that were not normalized. The NDTT values for the GATX and UTLX plates are -20 F and -40 F, respectively, and these values are within the range reported for the A-N-S and A-N plates tested. They are lower than the one A-H-S plate tested, and are at the low end of the range of all AAR M128 plates tested. Thus, the NDTT values for the GATX and UTLX plates appear to be generally similar to those reported for the group of plates that had been normalized but they are lower than the value for the head plate reported to have been hot-formed (A-H-S).

4.7.2 Charpy V-notch (CVN) Tests

The results of Charpy V-notch (CVN) impact tests are given for the UTLX plate in Figures 12a, 12b, and 12c, and for the GATX plate in Figures 12d, 12e, and 12f, with each figure representing one of the three fracture criteria. These criteria, respectively, are energy absorption, lateral expansion, and shear fracture appearance (SFA). In the figures, observed values and calculated curves are shown, for both the longitudinal (LT) specimens and the transverse (TL) specimens. In addition, raw data and results of calculations associated with these figures are given in separate tables in Appendix A: Tables A1 through A6 represent the GATX plate and Tables A7 through A12 represent the UTLX plate.

The figures reinforce some of the findings of previous investigations (6,8) of head-plate steels taken from failed tank cars. For each of the three fracture criteria, the transition zone for a given plate begins and ends over approximately the same range of temperatures. Further, the magnitude of the values of energy absorption and those for lateral expansion, are nearly proportional to the percent SFA, and the transition regions, as measured by SFA, are independent of specimen orientation. Further discussion of the lateral expansion is omitted below because of the similarity in trends between lateral expansion data and energy absorption data.

4.7.3 CVN Transition Behavior

The transition region is the range of temperatures over which a transition from brittle to ductile fracture is observed. Brittle fracture is observed at temperatures below the lowest temperature of the transition;

the fracture mode is described as cleavage (or quasi-cleavage) fracture. Ductile fracture is observed above the highest temperature of the transition region; the fracture mode is described as shear fracture. The transition regions for the GATX and UTLX plates are similar. This is shown in the SFA plots of Figures 12c and 12f, which also show that the SFA is independent of specimen orientation. The CVN transition of the UTLX plate extends from -80 F to about 60 F, and that of the GATX plate extends from -80 F to about 30 F, a slightly narrower range of temperatures.

A transition temperature is a temperature, normally within the transition region, at which an arbitrary level of a fracture criterion is met. The CVN transition temperatures for longitudinal and transverse specimens for the six head plates tested to date at NBS (6,8) are given in Table V for three commonly reported fracture criteria: 15 ft-lb energy absorption, 15 mil lateral expansion, and 50% SFA.

In the table, it is seen that of the six head plate samples tested at NBS, three AAR M128 samples (the GATX, UTLX, and Belle plates) had comparatively low transition temperatures. A fourth plate of AAR M128 steel is Callao K-1, which is believed to have been improperly heat treated during fabrication (4). This plate, K-1, and the remaining two plates, both of which were produced to ASTM A-212-B specification, have transition temperatures that are more than 80 F above those of the three head plate samples of AAR M128 steel with the comparatively low transition temperatures.(f) Thus, the GATX and UTLX plates have very favorable transition temperatures, when compared with all head plates tested at NBS, and these transition temperatures are similar with those observed for the Belle head plate, an AAR M128 steel.

The 50 percent SFA transition temperature is given here to generally characterize the transition temperatures of head plates tested at NBS. The average of longitudinal and transverse results for this CVN transition criterion are the average 50% SFA value is -2 F, -23 F, and -16 F for the UTLX, GATX, and Belle plates, respectively. Thus, transition temperatures of these three steel plates are similar to one another and are significantly more favorable (lower) transition temperatures than the values of 92 F, 105 F, and 140 F, which represent the other three head plates tested at NBS.

(f) The less favorable (higher) transition temperature of the ASTM A212-B steel plates is a result primarily of their larger ferrite grain size and lower manganese-to-carbon (Mn/C) ratio. For the A212-B steels, the ratios are less than three, whereas the ratios for the AAR M128 steels are higher, about five. In general, the transition temperature decreases as the ferrite grain size decreases and the Mn/C ratio increases. Another important factor influencing the transition temperature is the effect of heat treatment. Although the Callao, K-1, plate had a high Mn/C ratio, its ferrite grain size was large and within the range seen in the A212-B plates. This is probably a result of improper heat treatment and it has resulted in the increased transition temperature of this plate to the comparatively higher levels observed in the A212-B plates.

In comparison with these transition temperatures for the UTLX and GATX plates, the NDTT values of -40 F and 20 F, as given earlier in this report, are observed to be approximately 20 F lower than the 50 percent SFA values for these steels. Further, the data in Appendix A indicate that on average, 46 percent of the upper-shelf values of energy absorption, lateral expansion, and percent SFA is available at the NDTT for these two steels.

4.7.4 Upper-Shelf Energy Absorption

On the upper shelf, the fracture appearance is 100% shear fracture. For specimens of all orientations taken parallel to the rolling plane of the plate, the minimum Charpy V-notch upper-shelf energy-absorption is measured using specimens of the transverse (TL) orientation. As seen in Table VI, the transverse upper-shelf energy-absorption values for both the GATX and the UTLX plates, 38 ft-lbs and 37 ft-lbs respectively, are similar to values obtained for the other AAR M128 plates tested, 38 to 40 ft-lbs. The maximum CVN upper-shelf values are measured using longitudinal (LT) specimens. The longitudinal results for these two plates also overlap the range of values observed for the two previously tested AAR M128 head plates. The upper-shelf energy absorption values for the four AAR M128 steel plates, for longitudinal and transverse specimens, are less than those of the two ASTM A212-B plates. Thus, the results of CVN tests of two orientations show that the upper-shelf behavior of the four AAR M128 head-plate steels tested at NBS are similar, and that two ASTM A212-B steels previously tested have comparatively higher upper-shelf values for both longitudinal and transverse specimens.

The upper-shelf energy-absorption values of longitudinal (LT) specimens obtained for these two AAR M128 steels (GATX and UTLX) and an ASTM A212-B steel (6) are generally supportive of earlier findings reported (8) for head plates and shell plates of other tank-car steels produced to these same specifications. These findings are shown, Figure 15, in a plot of upper-shelf energy absorption as a function of yield strength for longitudinal specimens of all nine steels tested. In addition to the data and trend line for these tank-car steels, there is shown a trend line taken from the literature (14) representing the behavior of a wide variety of steels, including ferritic-pearlitic steels, as discussed earlier (8). A linear fit for the tank-car steels is shown by the solid line and that for the literature values is given by the dotted line. A comparison of these two lines, representing upper-shelf energy absorption values, indicates that at all levels of yield strength, the tank-car steels generally absorbed less energy than that reported in the literature trend line.

The four tank-car plates with the highest shelf-energy values do not contain vanadium and these data are close to the literature trend line. All three of the ASTM A212-B plates previously tested are part of this group along with one M128 plate which apparently was not produced to fine-grain practice. Using an arbitrary inclusion ranking system described in a previous report (5) (Rank 1 - lowest inclusion content observed, Rank 3 - highest inclusion content observed), these four plates include a head plate (Crescent City, A212-B) and a shell plate (Crescent City, A212-B) of Rank 1, and a shell plate (Callao, M128) and a head plate (Winder, A212-B) of Rank 2.

The five tank-car plates with the lowest shelf-energy values are AAR M128 steels and four of the five plates contain vanadium. The four plates with vanadium include a head plate (Belle) and a shell plate (South Byron) of Rank 3, a head plate (Callao, K-1) of Rank 2, and a head plate (GATX) of Rank 1. The last plate in this group, a head plate (UTLX) without vanadium, has an inclusion content of Rank 2. Thus, on the basis of results for all nine steels, it appears that in general, higher inclusion content levels and the presence of vanadium are associated with lower levels of upper-shelf energy absorption values, and is supportive of earlier reported (8) findings.

4.7.5 Plate Anisotropy

Plate anisotropy, as measured by an anisotropy index (8), has been used as a measure of the extent of cross rolling. This index is the ratio of the transverse to longitudinal energy absorption on the upper shelf. It has a value of one for an isotropic material, and the value decreases with increasing plate anisotropy. As the amount of cross rolling increases, the difference between longitudinal and transverse upper-shelf energy absorption decreases (15), and this index approaches a value of one.

Anisotropy index values, as determined from CVN tests of the six head-plate steels tested to date at NBS, are given in Table VI. This index is 0.79 for the UTLX plate, 0.63 for the GATX plate, and for the other four head plates it ranges from 0.59 to 0.70. Compared with the four other head plates tested at NBS, the UTLX plate is the most isotropic of this group of plates and the GATX plate is one of the least isotropic. Shell plates, however, are given less cross rolling and the anisotropy indices for CVN tests of three shell plates tested at NBS (5) varied from 0.46 to 0.54. As expected, the shell plates are observed to be considerably less isotropic than the head plates.

4.7.6 Fracture Appearance

Photographs of selected fractured Charpy specimens are shown in Figure 13 and 14, respectively for the UTLX and GATX plates. At temperatures above -50 F and -60 F respectively for the UTLX and GATX plates, where the shear fracture appearance was above 15 percent, the fracture surfaces of both longitudinal and transverse specimens were similar, and contained regions of cleavage fracture, fiberous fracture, and shear lips. At the highest test temperatures they contained only regions of fiberous fracture and shear lips. Generally, the size of the shear lips increased with increasing test temperature, and at a fixed temperature, were larger for longitudinal specimens than for transverse specimens.

Previously reported studies (2,3) of shear fracture appearance from broken Charpy specimens of shell plates, taken from an ASTM A212-B plate (Crescent City (2)) and an AAR M128 plate (South Byron (3)) revealed large scale lamellar fracture on both longitudinal and transverse specimens, with the lamellae oriented parallel to the rolling plane of the plate. A lamellar fracture appearance was not observed in specimens of either orientation from two previously reported ASTM A212-B head plates (Crescent City (2) and Widner (6)). These two head plates do not exhibit microstructural banding. Other previously reported steels showing microstructural banding include the AAR M128 head plates Belle (7) and Callao K-1 (4), and an AAR M128 shell plate, Callao K-5 (4). Examination of the fracture surfaces of broken Charpy specimens revealed a lamellar fracture appearance in each of these three plates. In the present study of two AAR M128 steel head plate samples, GATX and UTLX, a lamellar fracture appearance was observed in fractured Charpy specimens of both orientations. However, the extensiveness of these lamellae was not quantified for any of the seven plates studied at NBS. Thus, it is observed that all seven steels, including three shell plates and four head plates, that exhibit microstructural banding [(g)] show some degree of lamellar fracture appearance and two head-plate steels that did not have microstructural banding did not show a lamellar fracture appearance.

4.8 General Discussion

The purpose of this metallurgical evaluation was to correlate the mechanical properties and metallurgical characteristics of two head plate samples taken from tank cars GATX 93412 and UTLX 38498, involved in simulated switchyard impact tests. This evaluation included a determination as to whether these plates conformed to the chemical composition and tensile property requirements of specification AAR M128 for railroad tank car steel, to which the plates were produced, and to investigate the impact behavior of the plates.

The results of check chemical analyses indicated that both plate samples met the chemical composition requirements of AAR M128-69. The results further show a strong compositional similarity between the two plates with the following exceptions: (i) the presence of vanadium in the GATX plate and the absence of vanadium in the UTLX plate; (ii) a lower manganese content in the GATX plate; and (iii) a higher silicon level in the UTLX plate.

Generally, the strength properties of ferritic-pearlitic steels such as AAR M128 are governed by both the carbon and manganese contents and by the thermo/mechanical history. The average ultimate tensile strength and yield strength values for the two plates (averaging all orientations) are 87.3 ksi and 55.8 ksi respectively for the GATX plate and 88.4 ksi and 55.5 ksi respectively for the UTLX plate, indicating very little difference in the overall average strength values between the two plates. Thus, any effect on strength properties as a result of differences in chemistry or thermo/ mechanical history between these two plates is minimal.

The observation that both the GATX and UTLX samples satisfied all of the strength and tensile ductility requirements is in agreement with the results of the check chemical analyses. The measured hardness profiles for both plates are consistent with their respective microstructures and correlate reasonably well with the measured ultimate tensile strength values. The tensile strength of the UTLX plate as predicted from the hardness data is lower than the actual measured strength values, but is

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(g) It should be noted that steels with microstructural banding were shown (4,8) to have very favorable resistance to fracture in the through-thickness direction in tests conducted with CVN specimens of the LS and TS orientations.

of an acceptable level for this type of correlation. The yielding behavior for both the GATX and UTLX plates supports the conclusion that the mechanical properties of these two samples have not been significantly affected by the extsent of damage received by the plates during the switchyard impact tests.

The Charpy V-notch ductile-to-brittle transition temperature of carbon steels, often characterized by the 15 ft-lb transition temperature or the 50 percent shear-fracture-appearance transition temperature, is primarily controlled by the steel chemistry and ferrite grain size. Increasing the ferrite grain size raises the transition temperature. Carbon and manganese affect the transition temperature of these tank car steels primarily from their effects on the ferrite grain size and pearlite content. Increasing the carbon level raises the transition temperature by increasing the fraction of pearlite while increasing the manganese level lowers the transition temperature through refinement of the ferrite grain size. Although vanadium is added to these steels primarily to strengthen the ferrite phase through precipitation hardening by vanadium carbides and nitrides, the transition temperature can also be increased (15) due to these strengthening effects.

A comparison of the four AAR M128 head plate samples tested to date at NBS revealed a large variation in their ferrite grain sizes (Table VII), from a relatively coarse ASTM No. 7 for the Callao plate to a much finer ASTM No. 11 for the UTLX plate. This large difference in ferrite grain size was observed in spite of the fact that the four head plates were produced to fine-grain practice, and the difference is believed to reflect primarily differences in plate forming practice.

In this group of six head plates, the Crescent City plate with the largest ferrite grain size and highest carbon content had the highest transition temperature. The Belle, GATX, and UTLX plates with the smallest ferrite grain sizes, higher manganese contents and lower carbon contents, had the lowest transition temperatures. Thus the data indicate that for head plates produced to the ASTM A212-B and AAR M128 specifications, the manganese-to-carbon ratio and the ferrite grain size are the most important factors influencing the Charpy V-notch transition temperature behavior.

The NDTT values of -40 F and -20 F measured for the UTLX and GATX plates respectively, occur at the temperatures at which 40 percent SFA and about 50 percent of the upper-shelf values of energy absorption and lateral expansion, based on the average of both plates and both orientations, are observed in CVN tests results from these two plates. These results suggest that the NDTT is a slightly less conservative measure of the ductile to brittle transition than is the 50 percent SFA criterion and that the NDTT is more conservative than either the 15 ft-lb energy absorption or the 15 mils lateral expansion fracture criteria.

5. CONCLUSIONS

1. The chemical composition of the GATX and UTLX plate samples, as determined by check chemical analyses, satisfied the chemical requirements

of specification AAR M128. A strong compositional similarity was found between the two plates with the exception that the GATX plate contained vanadium and a lower manganese content than the UTLX plate.

2. The tensile strength properties and tensile ductility properties of both the GATX and UTLX plates satisfied the requirements of specification AAR M128. Very little difference in the overall average strength values was observed between the two plates.

3. Ultimate-tensile-strength and yield-strength values for both plates indicate little anisotropy in the strength of the plate in the plane of the rolling direction. Tensile-ductility values, measured by both percent elongation and reduction-in-area, indicated that longitudinal ductility was greater than transverse ductility for the GATX plate, while no significant difference between longitudinal and transverse tensile ductility was observed in the UTLX plate.

4. The results of Charpy V-notch impact tests of the GATX and UTLX plates indicated that:

a. The transition from ductile to brittle fracture mode for each of these two plates, as measured by percent shear fracture appearance (SFA), occurs over a range of 120-140 F, from +30 F to -80 F for the GATX plate and from +60 F to -80 F for the UTLX plate.

b. The transition temperatures of these two plates, for three commonly used criteria, are similar to one another, and their transition temperatures are among the lowest of those measured for all other tank-car plates tested to date at NBS.

c. Based on an average for the two steel plates, two specimen orientations, and the three CVN fracture criteria, the NDTT is determined to be the temperature at which 46 percent of the upper-shelf values for these criteria is obtained.

d. The comparatively low impact transition temperatures for both plates are related to the high manganese-to-carbon ratio and relatively fine ferrite grain size.

e. All seven steel plates, including three shell plates and four head plates, that exhibit microstructural banding show some degree of lamellar fracture appearance, and two head-plate steels that did not show microstructural banding did not exhibit a lamellar fracture appearance.

6. ACKNOWLEDGEMENT

The authors wish to express thanks to Mr. D. E. Harne for his excellent contributions to the metallographic, photographing and mechanical testing portions of this report. Special thanks to Mr. S. R. Low for his assistance in conducting the impact tests and in the impact data analysis. Thanks to Mr. C. H. Brady for the grain size measurements.

CONVERSION FACTORS

1 ksi = 6.89 MPa

1 ft-lb = 1.36 Joules

1 mil = 0.025 mm

$$t_c^o = \frac{(t_f^o - 32)}{1.8}$$

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Table I Chemical Composition of Head Plate Samples From Tank Cars GATX 93412 and UTLX 38498

Percent by Weight

Element	Specification AAR M128-69 Ladle Analysis		Tank Car GATX 93412 Check Analysis[a]	Tank Car UTLX 38498[d]
	Grade A	Grade B		
Carbon	0.25 max		0.23	0.24
Manganese	1.35 max		1.15	1.24
Phosphorus	0.04 max		0.01	0.01
Sulfur	0.05 max		0.017	0.014
Silicon	0.30 max		0.19	0.28
Copper	(b)	0.35 max	0.02	0.06
Nickel	(b)	0.25 max	0.20	0.15
Chromium	(b)	0.25 max	0.09	0.06
Molybdenum	(b)	0.08 max	0.05	0.01
Vanadium	0.02 min	(c)	0.026	<0.01
Aluminum	(c)		0.02	0.025

(a) Carbon was determined by combustion-conductometric analysis; all other elements were determined by emission spectroscopy.

(b) Element not specified.

(c) Element not specified, fine grain practice is required.

(d) Producers Report: UTLX 38498 plate sample is reported to be Kawasaki heat number 91-7850, AAR M128-B, with the ladle analysis of 0.25 carbon, 1.30 manganese, 0.0015 phosphorus, 0.0019 sulfur, 0.29 silicon, 0.08 copper, 0.15 nickel, 0.05 chromium, and 0.0015 molybdenum; all weight percent.

Table II Tensile Properties of Head Plate Samples From Tank Cars GATX 93412 and UTLX 38498

Tank Car Identification	Specimen Orientation[a] and Code	Tensile Strength ksi	Yield Strength 0.2% Offset ksi	Yield Point ksi	Elongation Percent in one inch[b]	Reduction of Area Percent	Yield Point Observed
GATX 93412	Longitudinal - GL1	84.6	55.1	58.4	29.7	63.0	Yes, Large
GATX 93412	Longitudinal - GL2	84.1	55.4	58.1	33.7	63.5	Yes, Large
	Average	84.4	55.2	58.3	31.7	63.2	
GATX 93412	Transverse - GT1	90.5	56.5	57.3	26.8	57.3	Yes, Small
GATX 93412	Transverse - GT2	90.0	56.2	57.3	27.0	57.6	Yes, Small
	Average	90.2	56.4	57.3	26.9	57.4	
UTLX 38498	Longitudinal - UL	88.6	58.5	60.0	31.4	61.0	Yes, Large
UTLX 38498	Transverse - UT	88.2	52.8	N.A.	33.9	61.0	No
UTLX 38498	45° - U1	88.8	57.9	61.4	30.6	61.0	Yes, Large
UTLX 38498	45° - U2	88.5	56.7	60.2	31.7	60.8	Yes, Large
UTLX 38498	45° - U3	87.9	54.4	55.4	30.1	61.0	Yes, Small
UTLX 38498	45° - U4	88.1	51.9	N.A.	30.1	59.8	No
	Average	88.4	55.2	59.5	32.0	60.9	
Specification AAR M128-69		101.0 max 81.0 min	(c)	50.0 min	19	(c)	

(a) Although the specification AAR M128-69 does not specify test specimen orientation, ASTM A370-73 does specify that wrought steel products are usually tested in the longitudinal direction but that where size permits and service justifies it, transverse testing is done.

(b) A comparison of elongation data obtained from different sizes of specimens of the same material can be made provided the ratio of the gage length to cross-sectional dimensions is held constant. Since the ratio of the square root of the cross-sectional area to the gage length is the same for the specimen with a 0.500-inch-diameter with a 2-inch-gage and for the specimen with a 0.250-inch-diameter with a 1-inch-gage length, the elongation data from the 1-inch-gage length specimen can be directly compared to the specification requirement based on a 2-inch-gage length.

(c) Not specified.

Table III QTM Inclusion Content Rating of Head Plate Samples From Tank Cars GATX 93412 and UTLX 38498

QTM Ratings, Inclusion Area Percent

Head Plate Identification	Effective Magnification	1/4 Thickness Position (25 Fields)	Mid-Thickness Position (50 Fields)	3/4 Thickness Position (25 Fields)	Number of Fields With Inclusion Area ≥ 0.5*	Worst Field** Quarter Thickness	Worst Field** Mid-Thickness
GATX 93412	X100	0.17	0.22	0.24	0	0.40	0.46
UTLX 38498	X100	0.29	0.24	0.28	0	0.44	0.36

* Per 100 Fields

** Per 50 Fields

Table IV Drop-Weight Test Behavior of Head Plate Samples From Tank Cars GATX 93412 and UTLX 38498

AAR M128 Steel

Tank Car GATX 93412

Specimen Code	Test Temperature, F	Comments
GN5	-50	Starter crack propagated to both edges of specimen.
GN2	-30	Starter crack propagated to both edges of specimen.
GN3	-20	Starter crack propagated to both edges of specimen.
GN1	-10	Starter crack did not propagate to either edge of specimen.
GN7	-10	Starter crack did not propagate to either edge of specimen.

Nil-Ductility Transition Temperature = -20 F

Tank Car UTLX 38498

Specimen Code	Test Temperature, F	Comments
UN6	-70	Starter crack propagated to both edges of specimen.
UN2	-60	Starter crack propagated to both edges of specimen.
UN7	-40	Starter crack propagated to both edges of specimen.
UN8	-30	Starter crack did not propagate to either edge of specimen.
UN4	-30	Starter crack did not propagate to either edge of specimen.

Nil-Ductility Transition Temperature = -40 F

Table V Charpy V-notch Impact Transition Temperatures For Six Head Plate Steels Tested at NBS

Steel Type	Plate Identity	Specimen Orientation	Transition Temperature, F: 15 ft-lbs Energy Absorption	15 mil Lateral Expansion	50 percent Shear Fracture
AAR M128-A[a]	GATX 93412	Long. (LT)	-58	-64	-30
		Trans. (TL)	-46	-50	-17
AAR M128-B	UTLX 38498	Long. (LT)	-47	-46	- 7
		Trans. (TL)	-42	-46	+ 4
AAR M128-A	Belle[b]	Long. (LT)	-47	-43	-11
		Trans. (TL)	-49	-50	-21
AAR M128-A[a]	Callao[b] K-1	Long. (LT)	56	41	86
		Trans. (TL)	72	64	98
A212-B	Winder[c] SOEX 3033	Long. (LT)	66	50	111
		Trans. (TL)	67	44	100
A212-B	Crescent City[b] FRA-2	Long. (LT)	92	72	137
		Trans. (TL)	84	69	143

[a] Designation of Grade A is based on NBS check chemical analysis.

[b] Reference (8)

[c] Reference (6)

Table VI Comparison of Charpy V-notch Upper-Shelf Behavior of Six Head Plates Tested at NBS

Steel Type	Plate Code	Upper Shelf Energy Absorption, ft-lbs Longitudinal (LT)	Transverse (TL)	Anisotropy Index $\frac{\text{TL Upper Shelf Energy}}{\text{LT Upper Shelf Energy}}$
A212-B	Winder	72	45	0.63
A212-B	Crescent City	81	55	0.68[a]
AAR M128-A[b]	Callao, K-1	54	38	0.70
AAR M128-A	Belle	68	40	0.59[a]
AAR M128-A[b]	GATX 93412	59	37	0.63
AAR M128-B	UTLX 38498	48	38	0.79

(a) The orientation of specimens from the Belle and Crescent City head plates may deviate from the true longitudinal and transverse directions. Any deviation would tend to decrease the LT upper shelf energy and increase the TL upper shelf energy, thereby resulting in an artificially higher value of the anisotropy index.

(b) Designation of Grade A is based on NBS check chemical analysis.

Table VII Comparison of Selected Results From Check Chemical Analyses of Four Head Plates Tested at NBS.

Plate Code	Steel Type	Ferrite Grain Size	Weight Percent Carbon	Manganese	Vanadium	Aluminum
Crescent City	A212-B	6	0.29	0.81	<0.02	<0.002
Winder	A212-B	7	0.24	0.73	<0.01	<0.01
Callao, K-1	M128-A[a]	7	0.26	1.25	0.035	0.026
Belle	M128-A	8 1/2	0.26	1.20	0.04	(b)
GATX 93412	M128-A[a]	10 1/2	0.23	1.15	0.026	0.02
UTLX 38498	M128-B	11	0.24	1.24	<0.01	0.025

(a) Designation of Grade A is based on NBS check chemical analysis

(b) Not determined

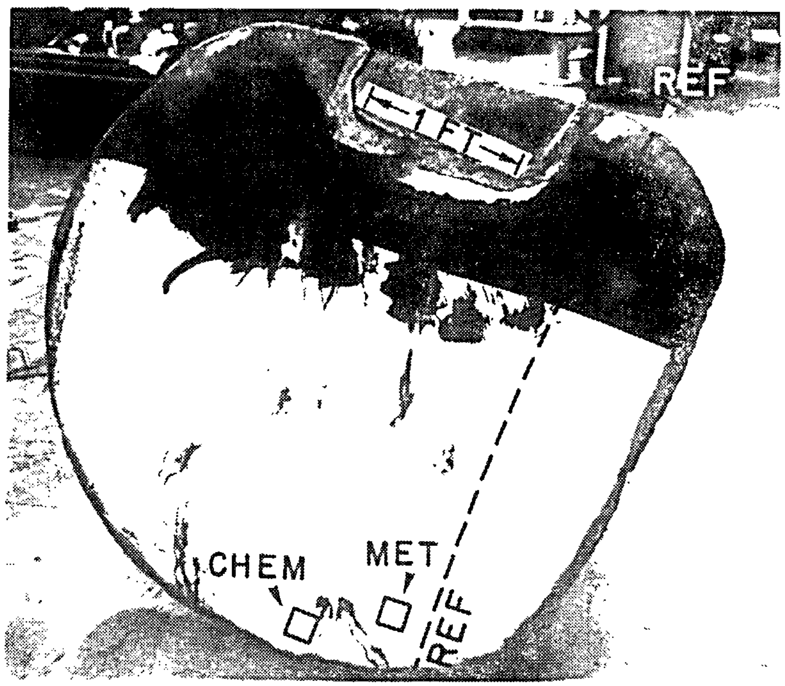


Figure 1. Plate Sample Taken from Tank Car UTLX 38498

Principal plate rolling direction determined with respect to an arbitrary reference line scribed on the plate surface, marked REF. Chemistry and metallographic samples were taken from locations marked CHEM and MET, respectively.

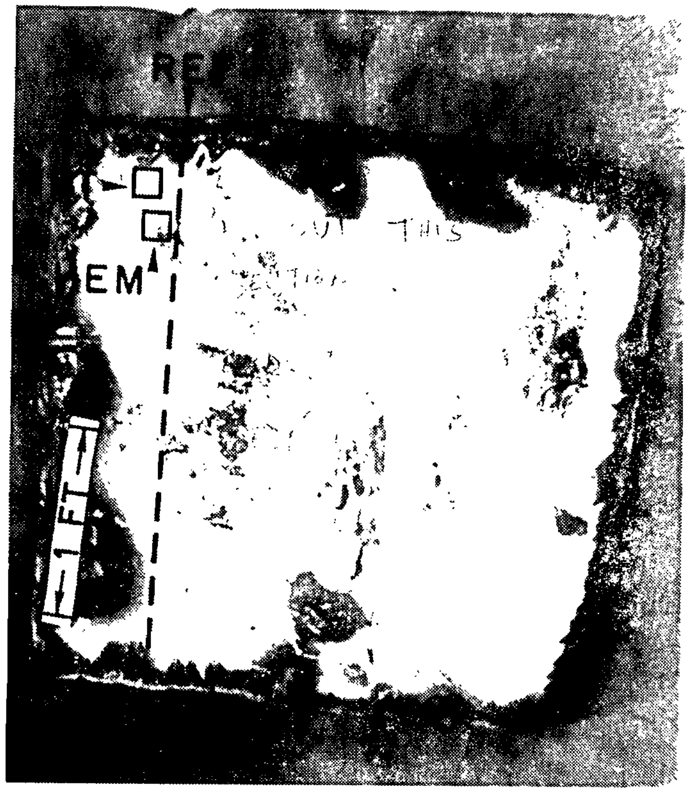
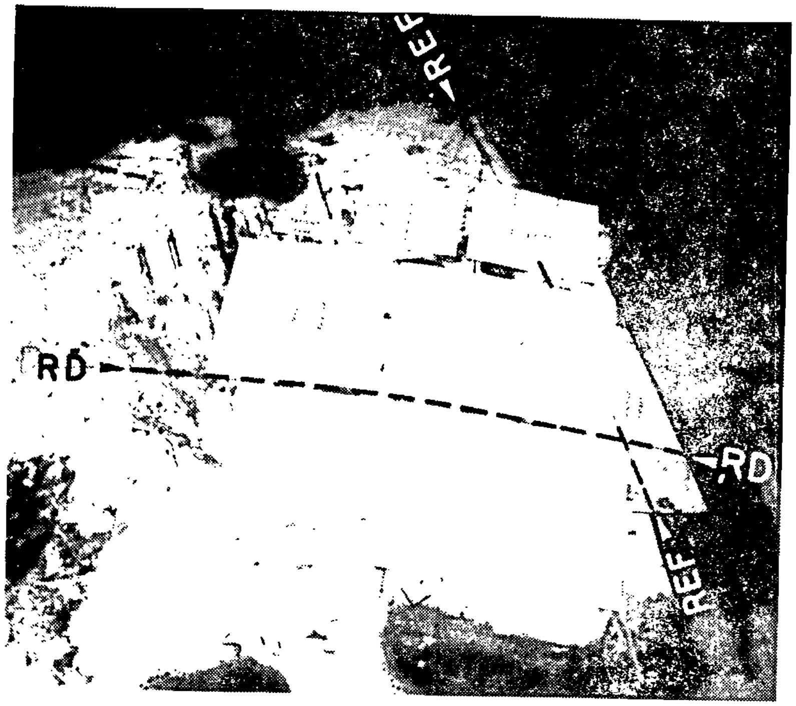
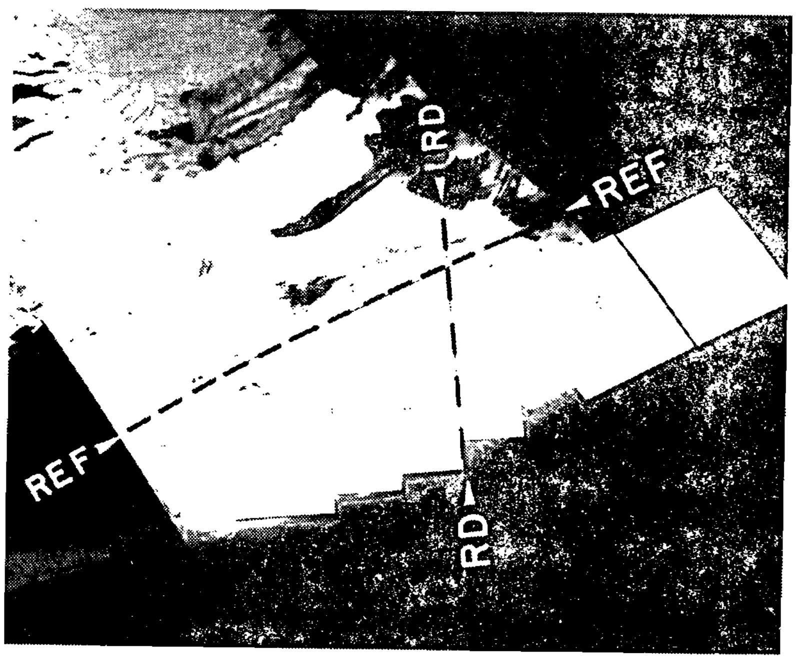


Figure 2. Plate Sample Taken From Tank Car GATX 93412

Principal plate rolling direction determined with respect to an arbitrary reference line scribed on the plate surface, marked REF. Chemistry and metallographic samples were taken from locations marked CHEM and MET, respectively.



a.



b.

Figure 3. Plate Samples Showing Location and Orientation of Test Specimens

Principal rolling direction and arbitrary reference line are shown marked as RD and REF, respectively.

a. Tank Car GATX 93412
b. Tank Car UTLX 38498

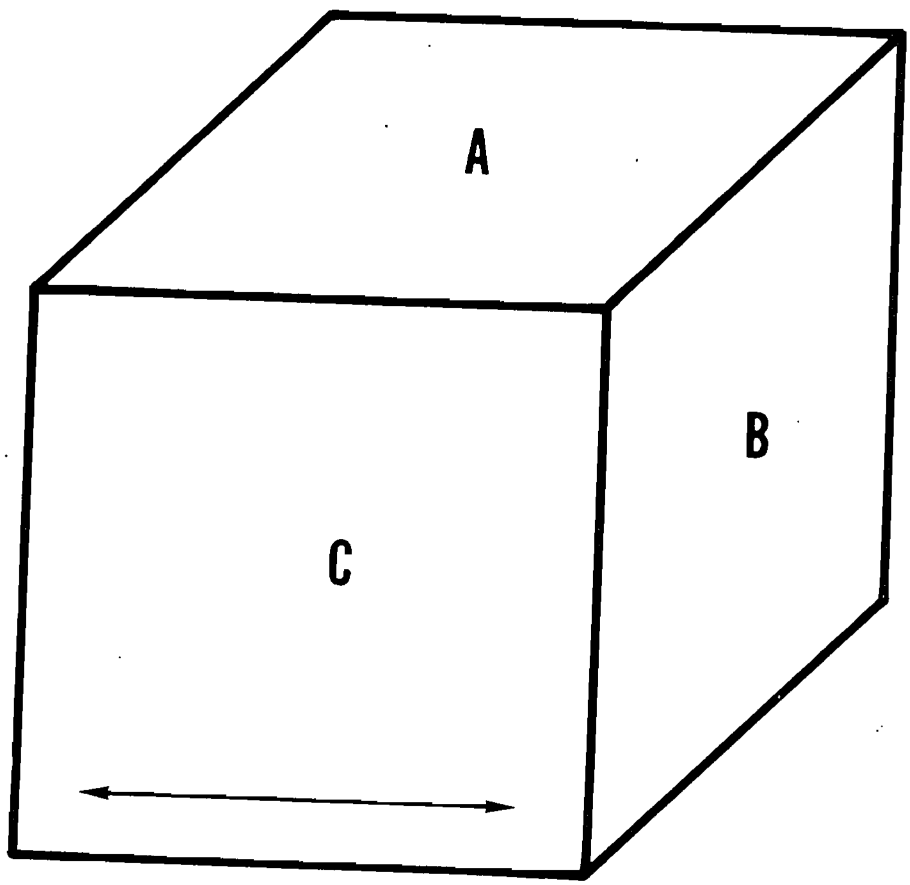
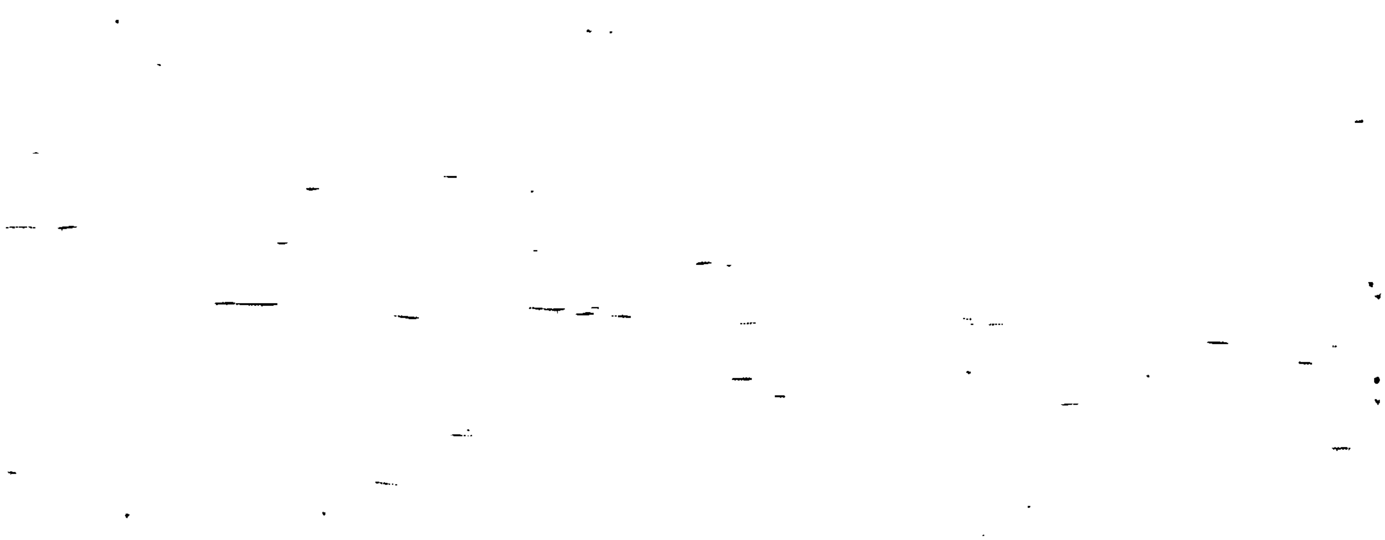


Figure 4. Schematic Showing the Three Mutually Perpendicular Planes Associated with the Rolling Direction in a Plate

The A plane is parallel to the plate surface. The C plane contains an arrow which indicates the plate rolling direction or longitudinal direction.



Longitudinal Transverse

a.

Longitudinal

b.

Figure 5. Representative Photomicrographs of Inclusions on Longitudinal and Transverse Planes

a. Tank Car GATX 93412
b. Tank Car UTLX 38498

Unetched Mag. X 100

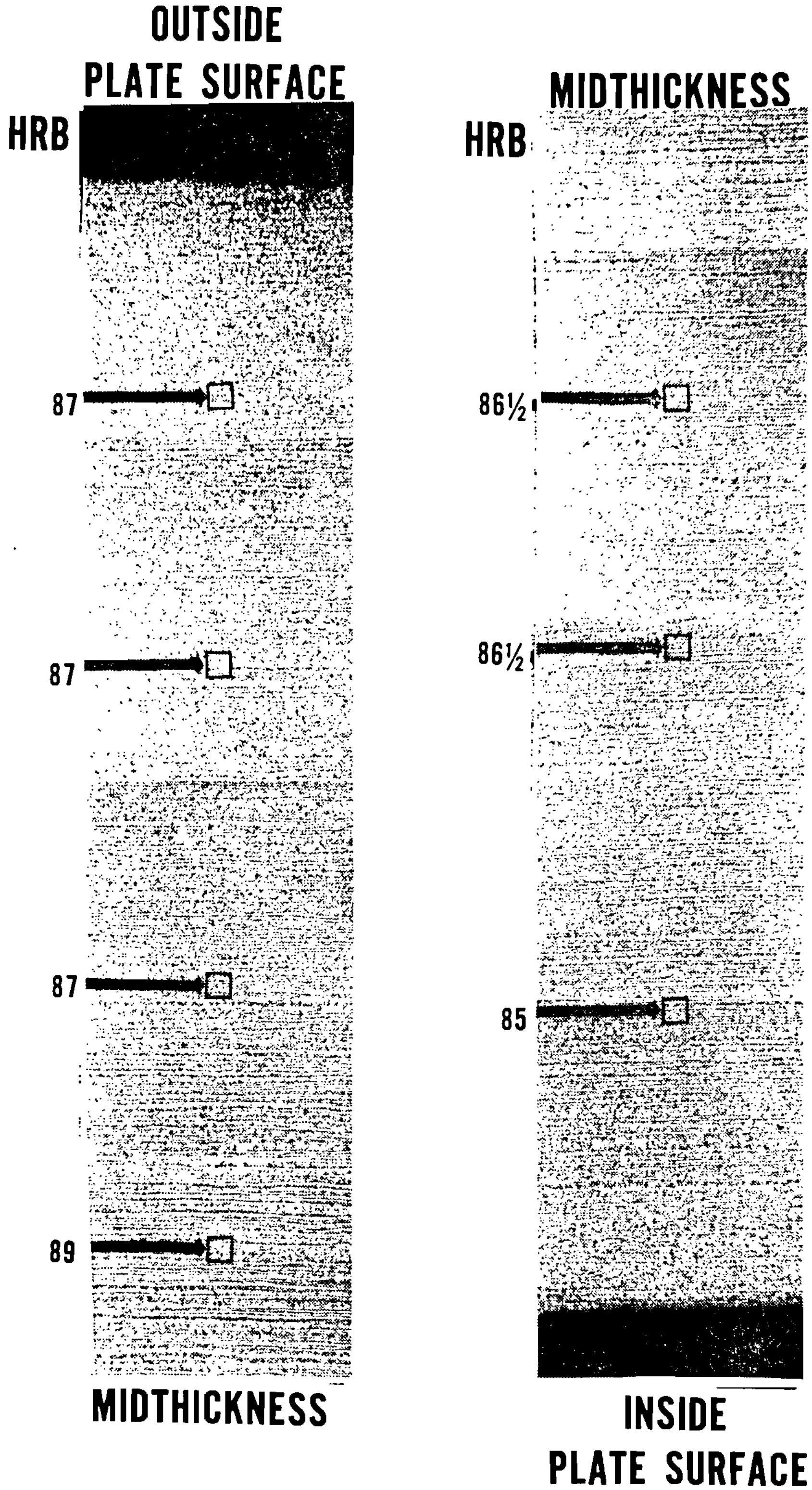


Figure 6. Montage of Microstructure Through Cross-Section of the Plate Sample from Tank Car UTLX 38498

Hardness values are representative of the locations shown.

Etch: 1% Nital Original Micrographs Mag. X 40

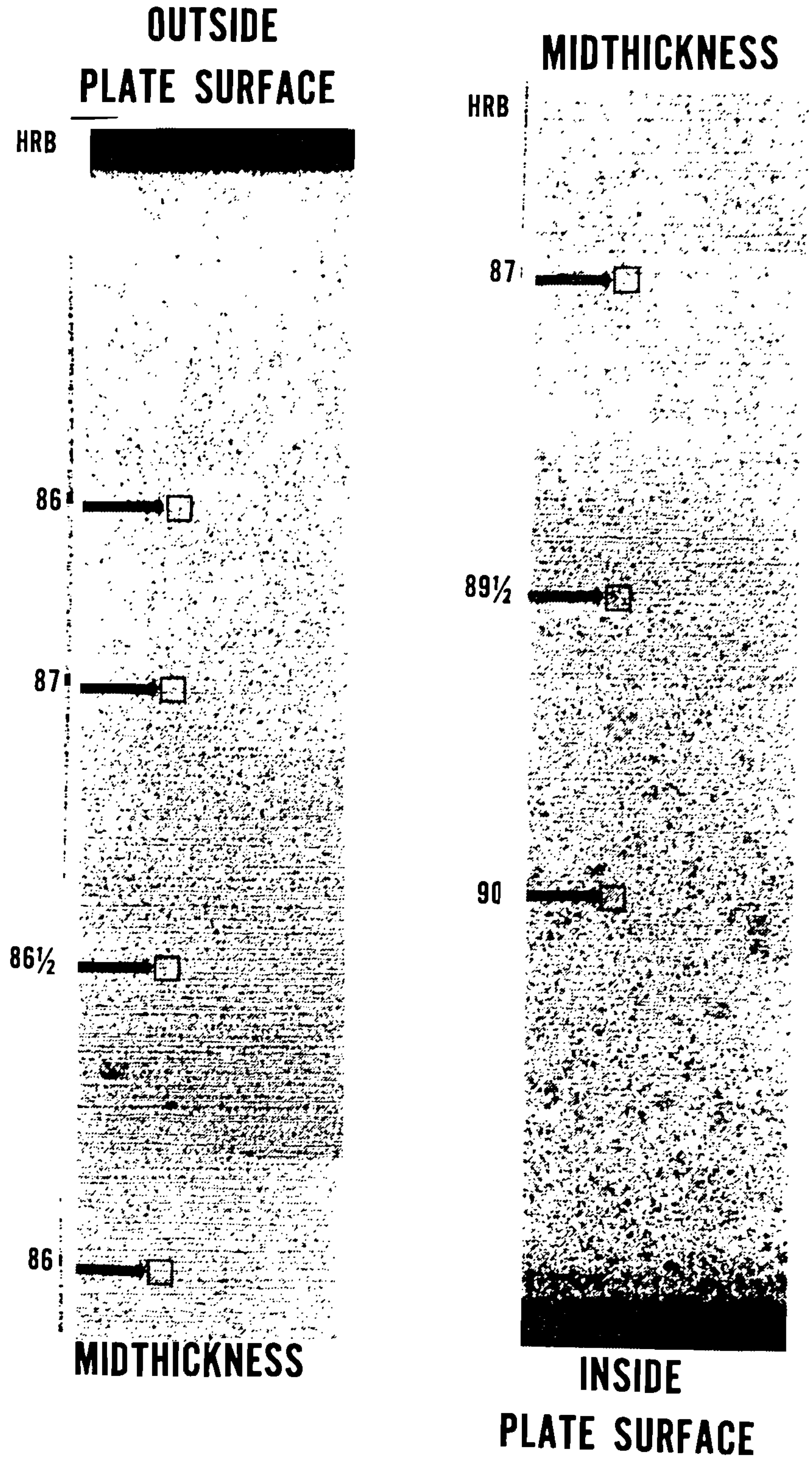
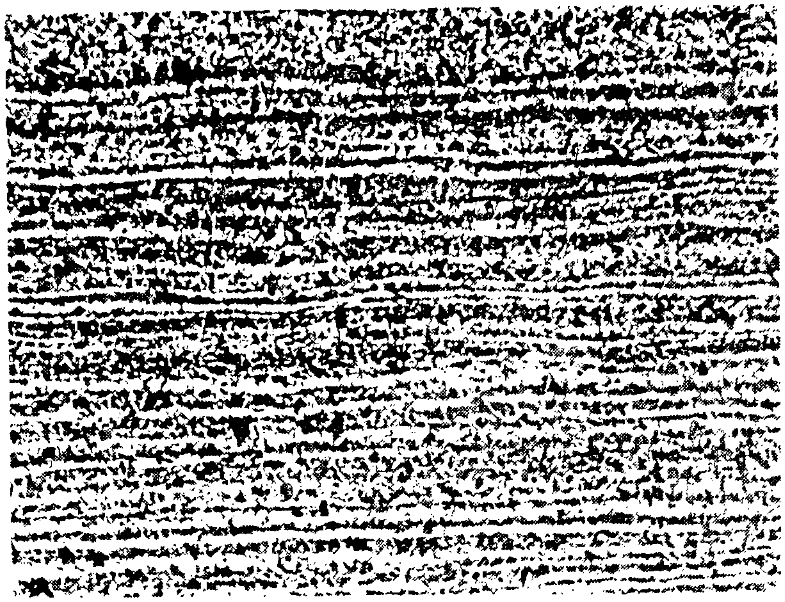


Figure 7. Montage of Microstructure Through Cross-Section of the Plate Sample from Tank Car GATX 93412

Hardness values are representative of the locations shown.

Etch: 1% Nital   Original Micrographs Mag. X 40



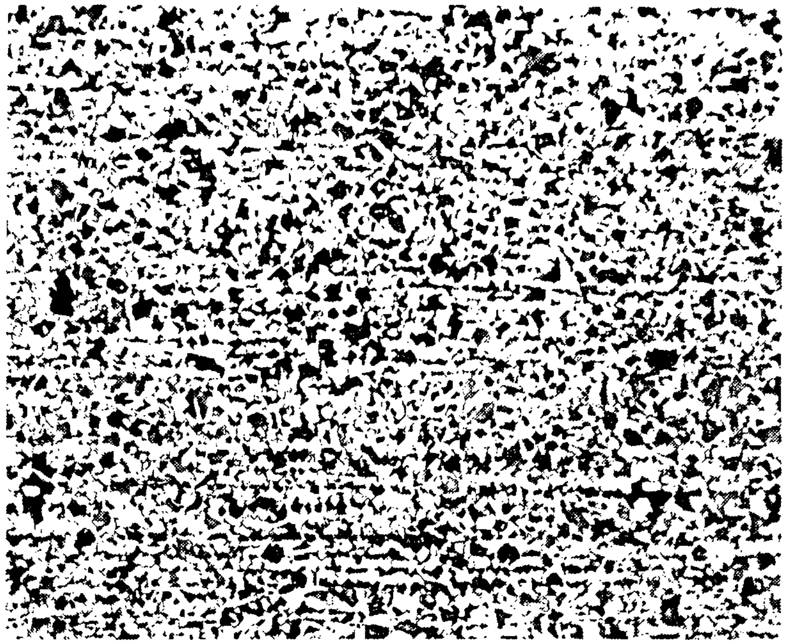
a.

b.

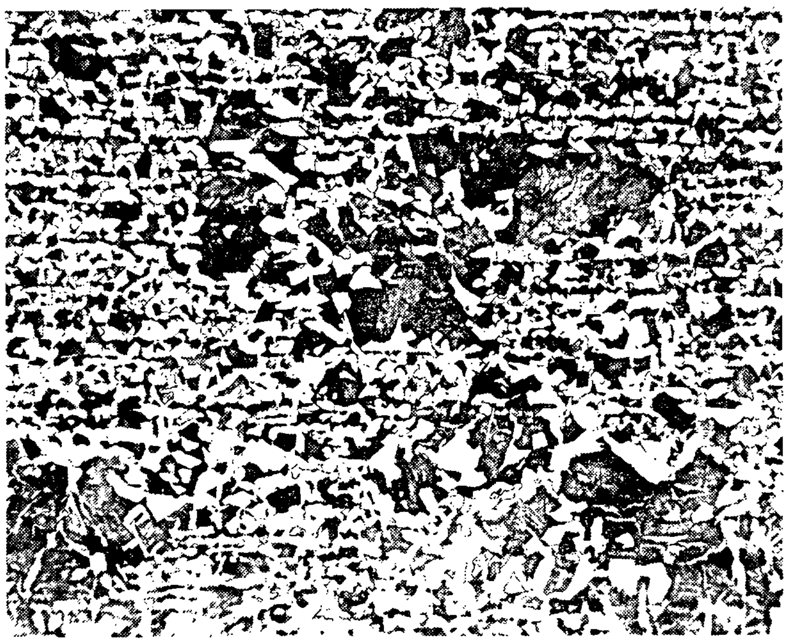
Figure 8. Photomicrographs of Typical Microstructure on Longitudinal Plane from Tank Car UTLX 38498

a. Mag. X 100
b. Mag. X 400

Etch: 4% Picral



a.

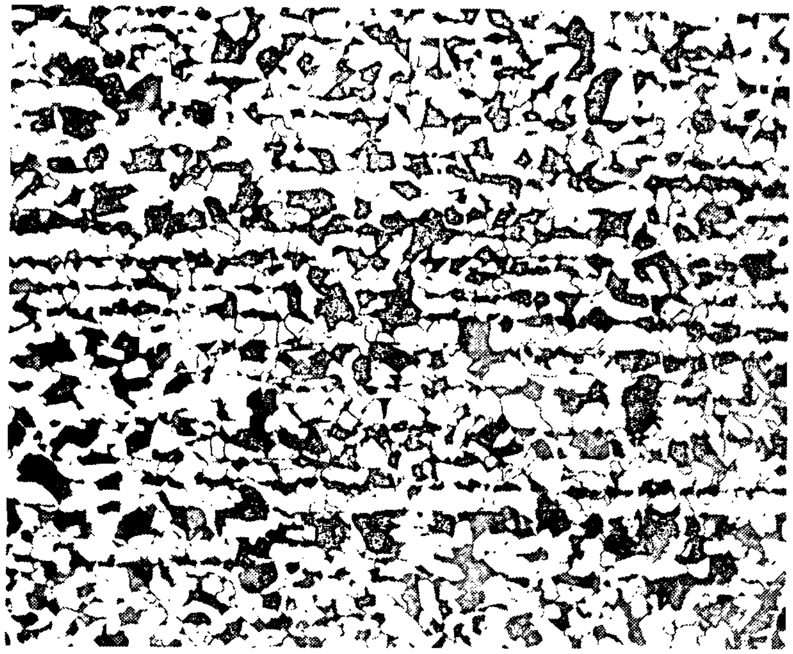


b.

Figure 9. Photomicrographs of Typical Microstructure on Longitudinal Planes from Tank Car GATX 93412

a. near outside plate surface, Mag. X 100
b. near inside plate surface, Mag. X 100

Etch: 4% Picral



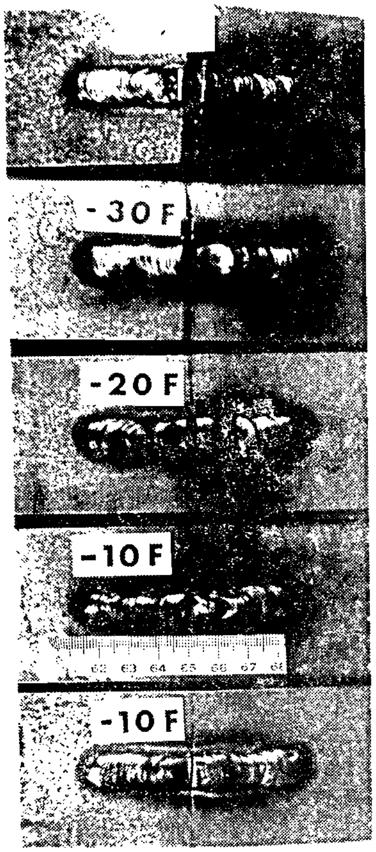
a.

b.

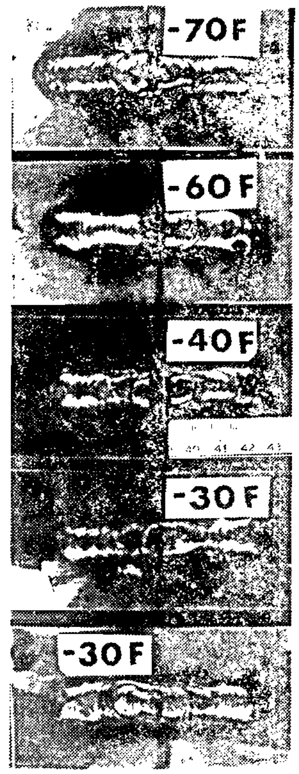
Figure 10. Photomicrographs of Typical Microstructure on Longitudinal Planes from Tank Car GATX 93412

a. near outside plate surface, Mag. X 200
b. near inside plate surface, Mag. X 200

Etch: 4% Picral



a.



b.

Figure 11. Drop-Weight Test Specimens

a. Tank Car GATX 93412, Nil-Ductility Transition Temperature = -20 F

b. Tank Car UTLX 38498, Nil-Ductility Transition Temperature = -40 F

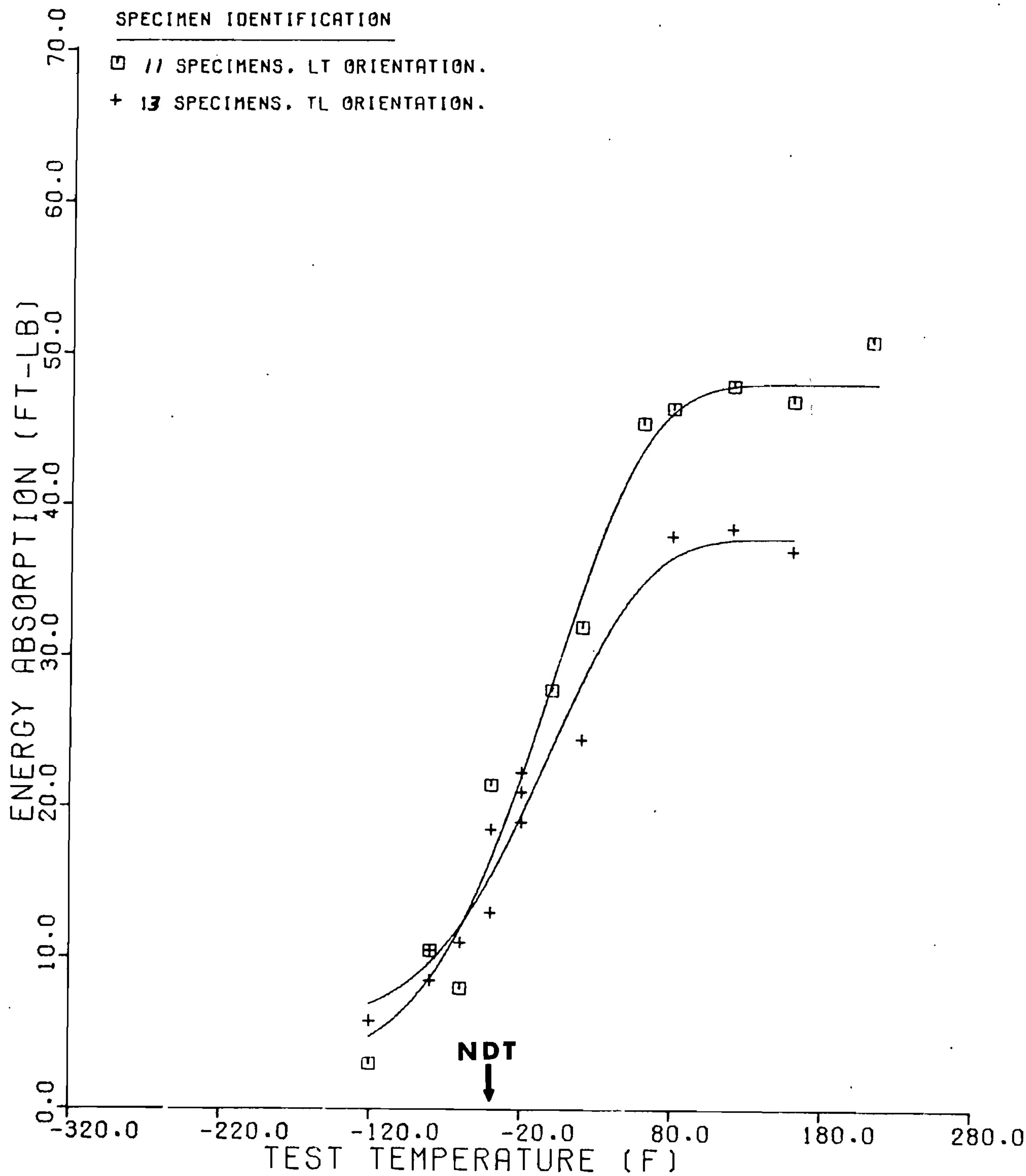


Figure 12a CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS TAKEN FROM AAR TC128 STEEL PLATE U

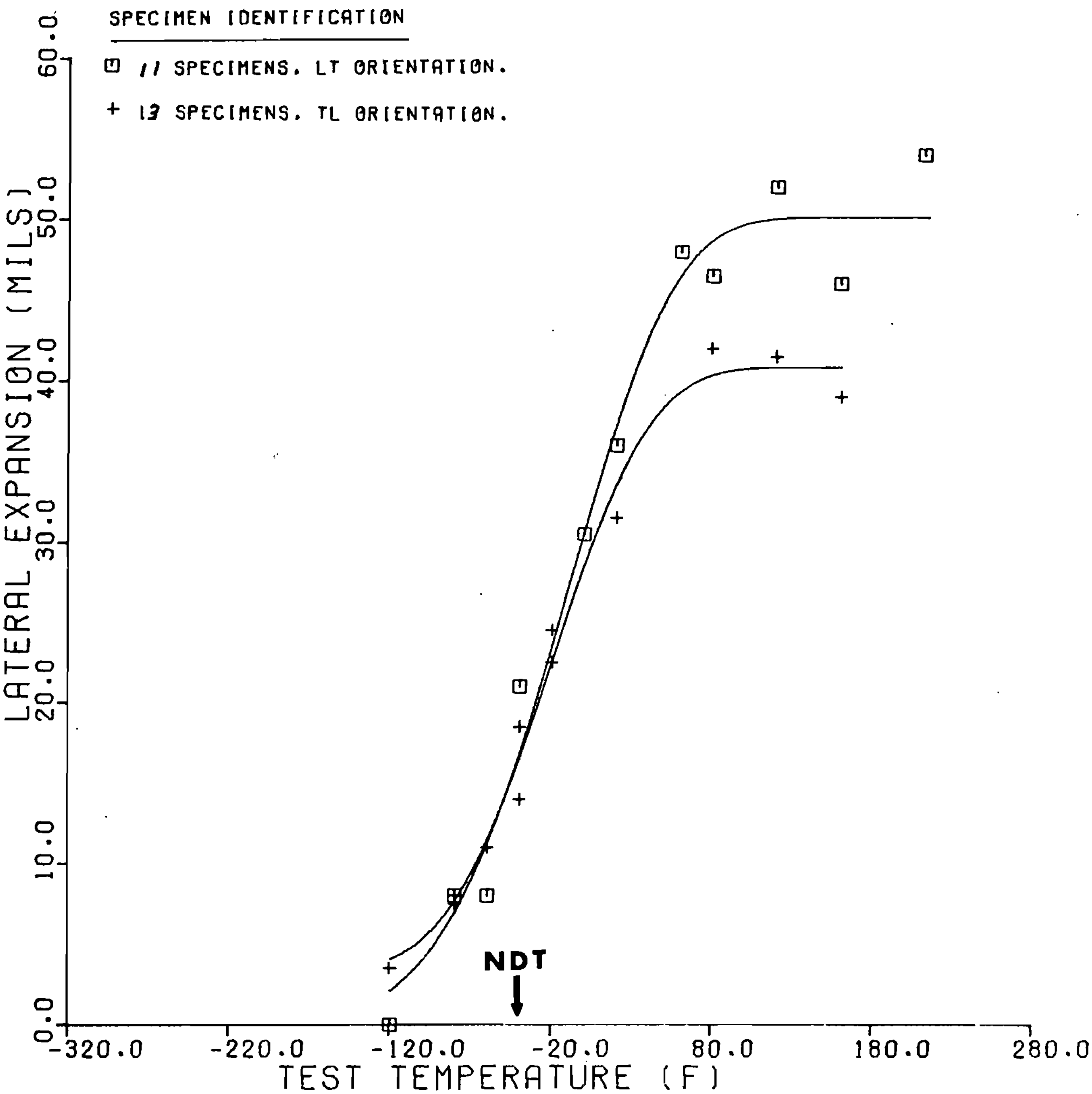


Figure 12b CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS TAKEN FROM AAR TC128 STEEL PLATE U

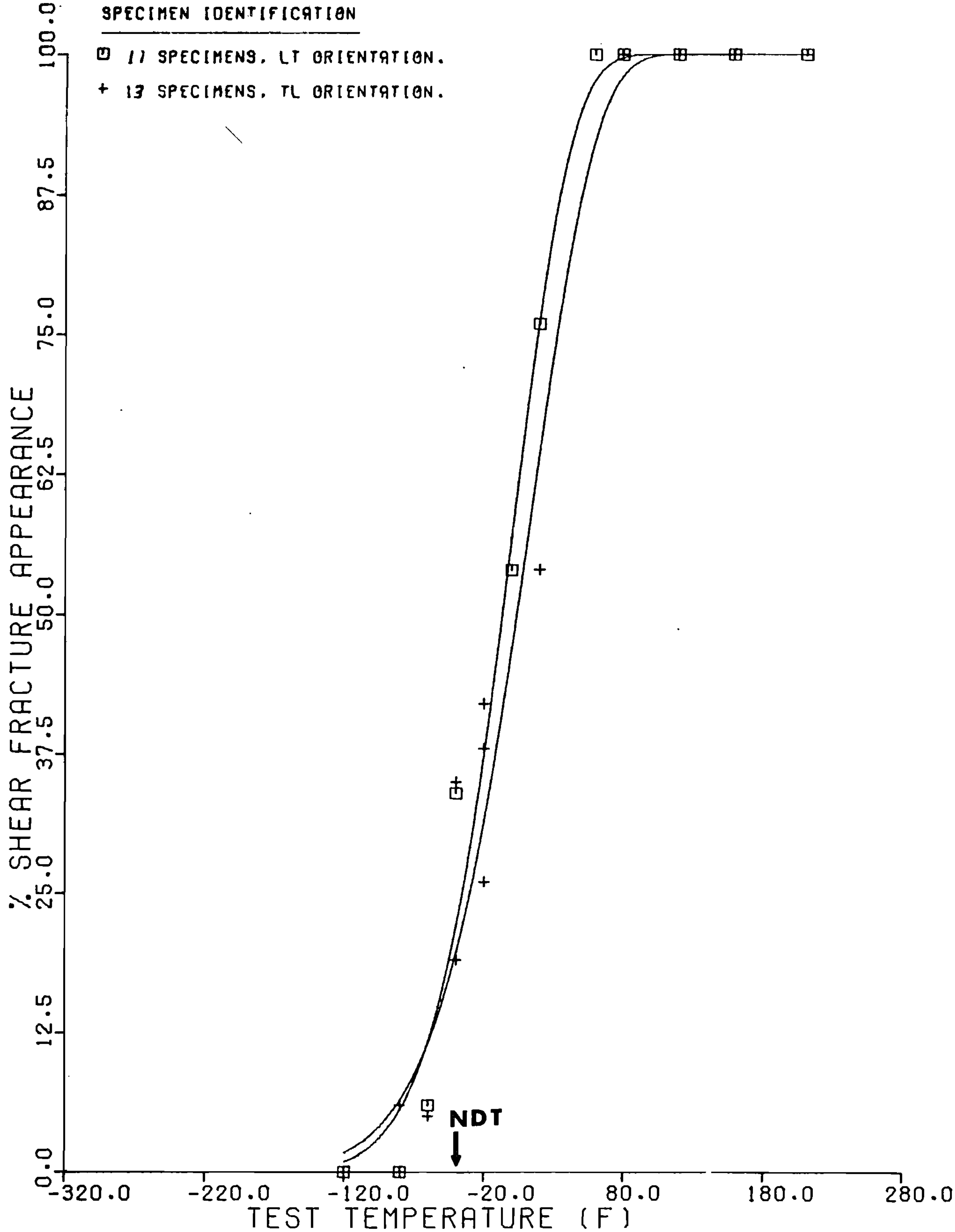


Figure 12c CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS TAKEN FROM AAR TC128 STEEL PLATE U

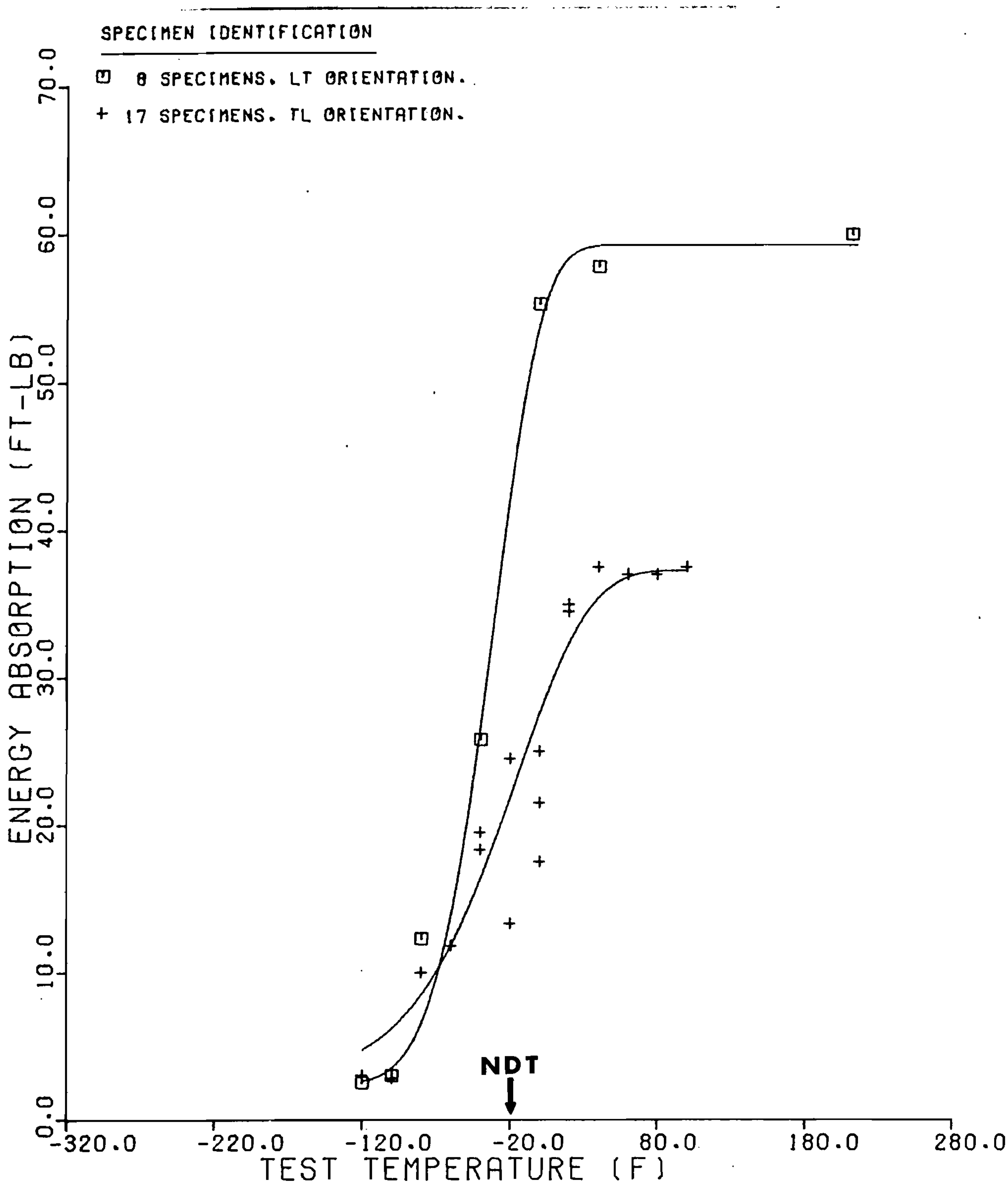


Figure 12d CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS TAKEN FROM AAR TC128 STEEL PLATE G

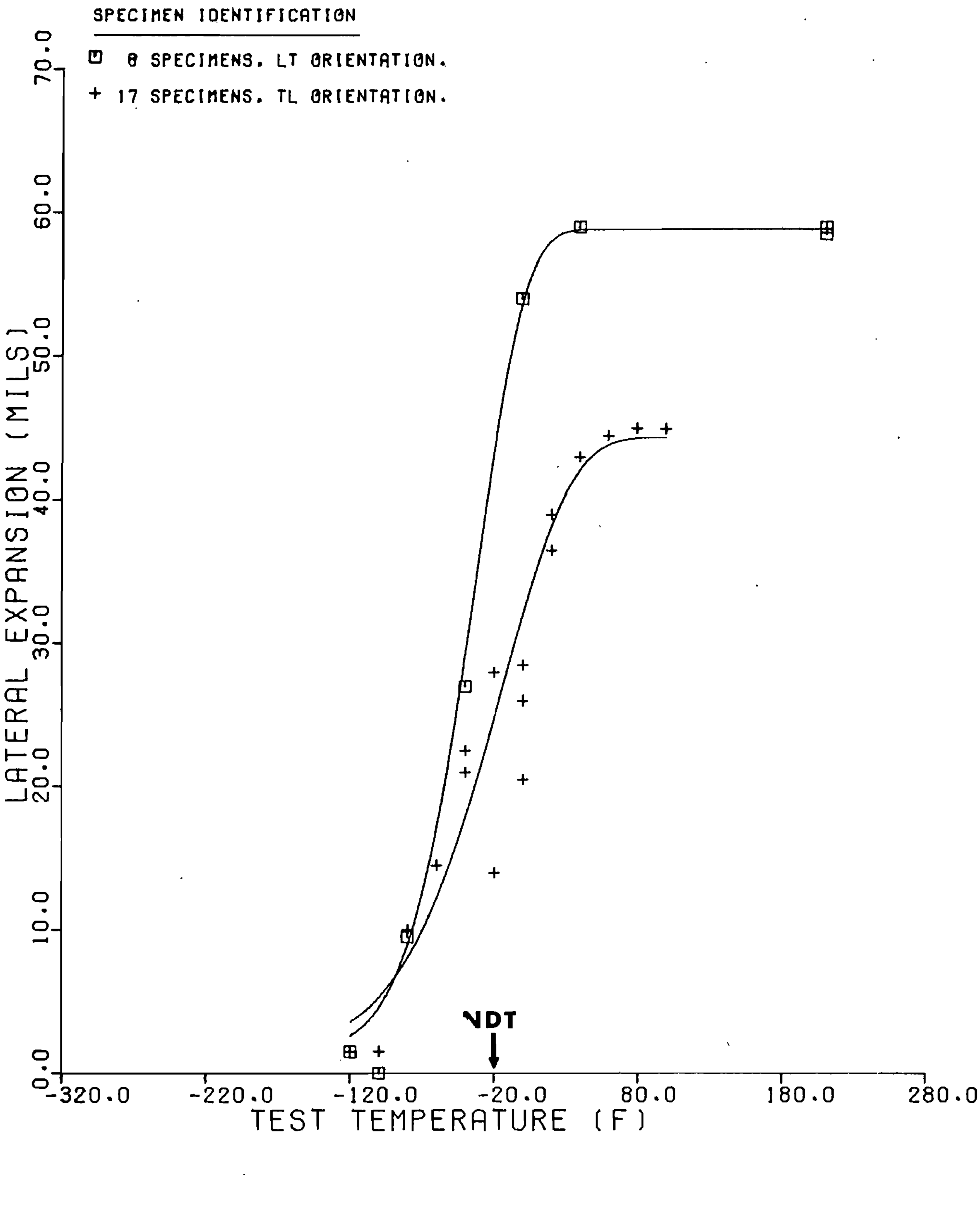


Figure 12e CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS TAKEN FROM AAR TC128 STEEL PLATE G

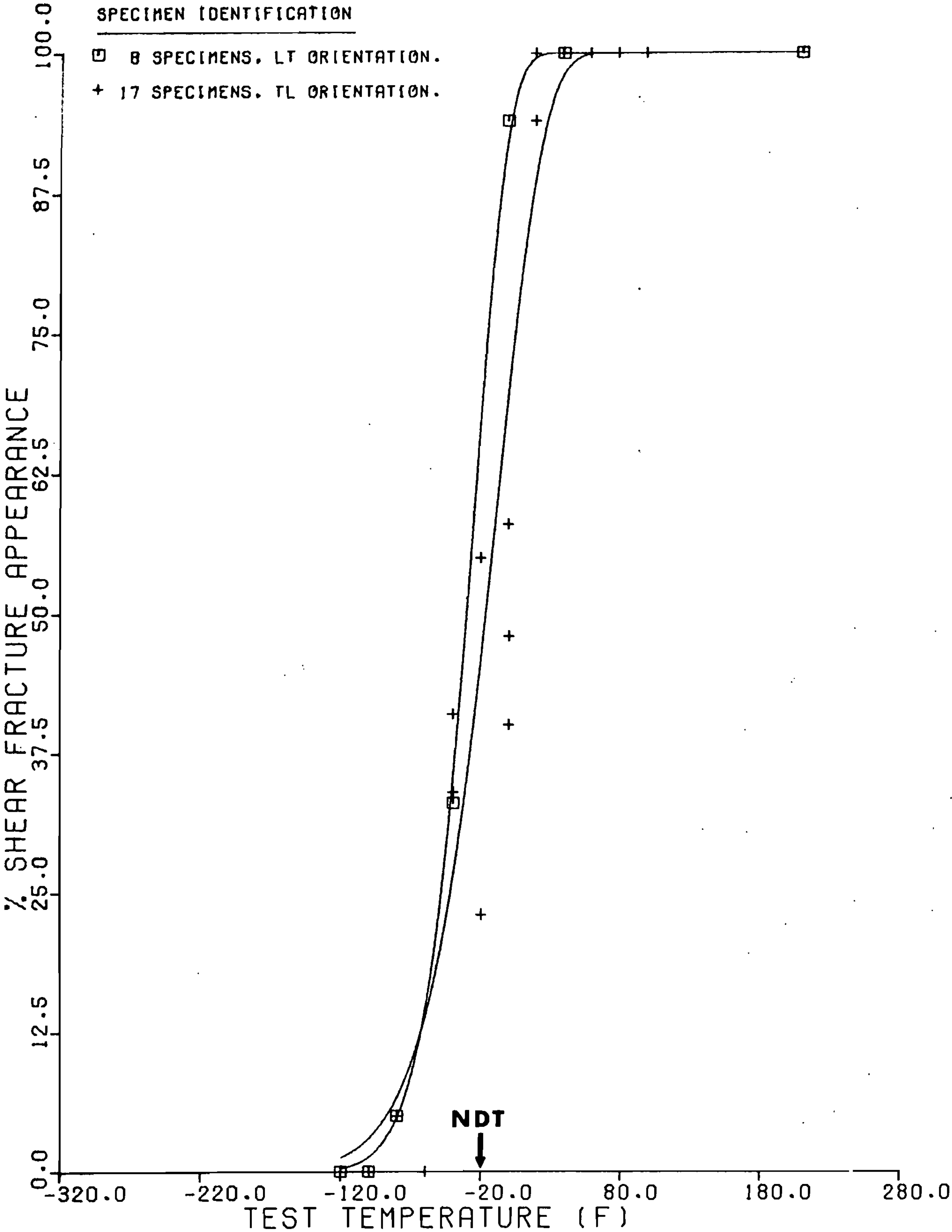
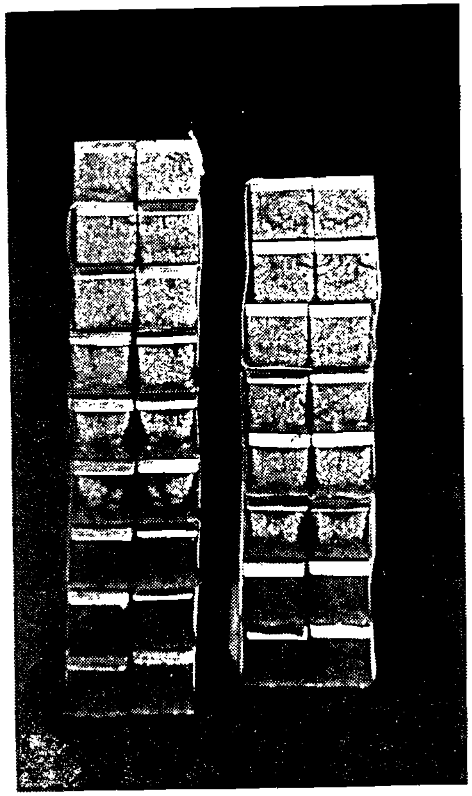


Figure 12f CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS TAKEN FROM AAR TC128 STEEL PLATE G

Sample No.	Energy Abs. (ft-lb)	Test Temperature
UL13	3	-120 F
UL6	10 1/2	- 80 F
UL5	8	- 60 F
UL10	21 1/2	- 40 F
UL3	28	0 F
UL1	32	20 F
UL2	45 1/2	60 F
UL16	48	120 F
UL60	51	212 F

Longitudinal Transverse

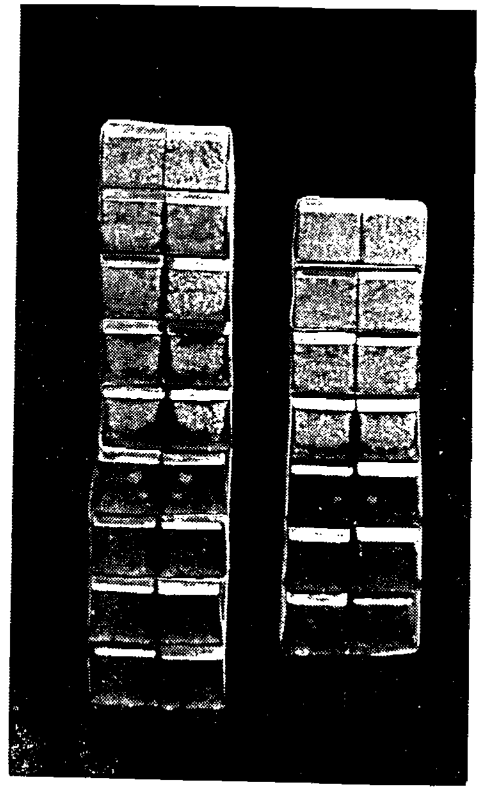


Test emperature	Energy Abs. (ft-lb)	Sample No.
-120 F	6	UT26
- 80 F	10 1/2	UT35
- 60 F	11	UT25
- 40 F	18 1/2	UT29
- 20 F	22	UT21
20 F	24 1/2	UT43
80 F	38	UT41
160	37	UT39

Figure 13. Fracture Appearance of Selected Charpy Specimens Taken From Tank Car UTLX 38498.

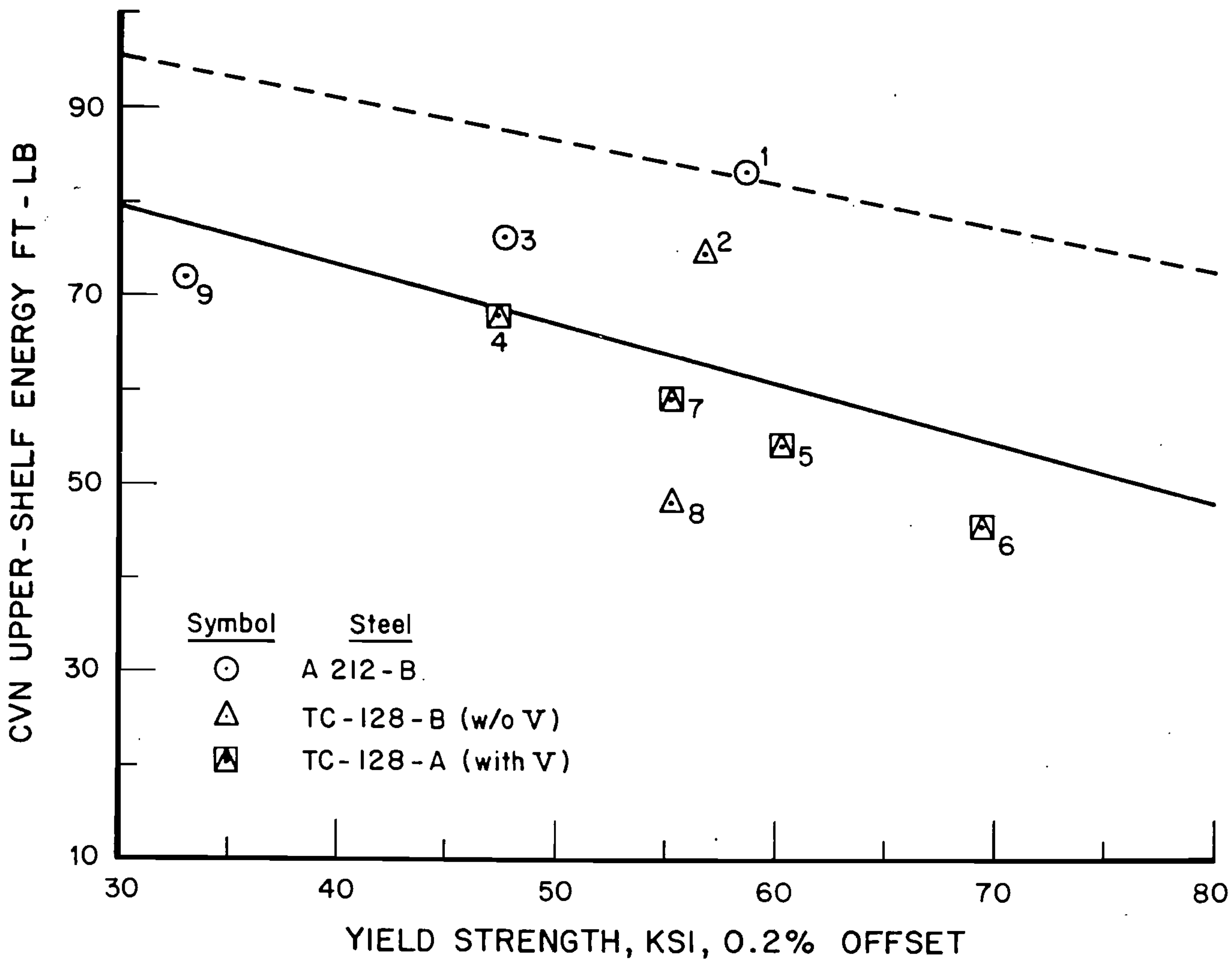
Transverse Longitudinal

Sample No.	Energy Abs. (ft-lb)	Test Temperature
GT27	3	-120 F
GT32	10	- 80 F
GT33	12	- 60 F
GT1	19 1/2	- 40 F
GT15	25	0 F
GT35	34 1/2	20 F
GT10	37 1/2	40 F
GT11	37	80 F
GT6	37 1/2	100 F



Test mperature	Energy Abs. (ft-lb)	Sample No.
-120 F	2 1/2	GL13
-100 F	3	GL9
- 80 F	12 1/2	GL12
- 40 F	27	GL7
0 F	55	GL10
40 F	58	GL3
212 F	60	GL60

Figure 14. Fracture Appearance of Selected Charpy Specimens Taken from Tank Car GATX 93412.



SUBSCRIPTS ON THE SYMBOLS REPRESENT THE FOLLOWING SAMPLES

1. C.CITY A-HEAD A212-B, w/o AL INCLUSION RANK 1
2. CALLAO K-5 TC-128-B, w/o AL INCLUSION RANK 1
3. C.CITY SHELL A212-B, FINE GRAIN INCLUSION RANK 3
4. BELLE B-HEAD TC-128-A INCLUSION RANK 3
5. CALLAO A-HEAD TC-128-A INCLUSION RANK 2
6. S.BYRON SHELL TC-128-A INCLUSION RANK 3
7. GATX HEAD TC-128-A INCLUSION RANK 1
8. UTLX HEAD TC-128-B INCLUSION RANK 2
9. WIDNER HEAD A212-B INCLUSION RANK 2

Figure 15. Longitudinal CVN Upper-Shelf-Energy Absorption for Nine Tank Car Steels of Various Yield Strength Levels.

CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS
TAKEN FROM AAR TC128 STEEL PLATE U
CALCULATIONS FOR ENERGY ABSORPTION DATA OF
11 SPECIMENS, LT ORIENTATION.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
UL13	-120.0	3.00	4.8
UL6	-80.0	10.50	8.7
UL5	-60.0	8.00	12.1
UL10	-40.0	21.50	16.6
UL3	.0	27.80	28.3
UL1	20.0	32.00	34.4
UL2	60.0	45.50	43.8
UL7-19	80.0	46.50	46.2
UL1-16	120.0	48.00	48.0
UL7-20	160.0	47.00	48.1
60	212.0	51.00	48.1

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	-117.1	/	-110.0	5.5
10.0	-71.6	/	-105.0	5.9
15.0	-46.6	/	-100.0	6.3
20.0	-27.3	/	-95.0	6.9
25.0	-10.5	/	-90.0	7.4
30.0	5.6	/	-85.0	8.0
35.0	22.1	/	-80.0	8.7
40.0	41.1	/	-75.0	9.5
45.0	68.6	/	-70.0	10.3
		/	-65.0	11.1
		/	-60.0	12.1
		/	-55.0	13.1
		/	-50.0	14.2
		/	-45.0	15.4
		/	-40.0	16.6
		/	-35.0	17.9
		/	-30.0	19.3
		/	-25.0	20.7
		/	-20.0	22.1
		/	-15.0	23.6

CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS
TAKEN FROM AAR TC128 STEEL PLATE U
CALCULATIONS FOR ENERGY ABSORPTION DATA OF
13 SPECIMENS. TL ORIENTATION.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
UT26	-120.0	5.80	6.9
UT33	-80.0	8.50	9.7
UT35	-80.0	10.50	9.7
UT25	-60.0	11.00	12.1
UT23	-40.0	13.00	15.4
UT29	-40.0	18.50	15.4
UT18	-20.0	21.00	19.5
UT21	-20.0	22.30	19.5
UT6-40	-20.0	19.00	19.5
UT2-43	20.0	24.50	28.3
UT5-41	80.0	38.00	36.6
UT2-44	120.0	38.50	37.7
UT6-39	160.0	37.00	37.8

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
10.0	-76.9	/	-70.0	10.8
15.0	-42.3	/	-65.0	11.4
20.0	-17.5	/	-60.0	12.1
25.0	4.9	/	-55.0	12.9
30.0	28.5	/	-50.0	13.7
35.0	61.3	/	-45.0	14.5
		/	-40.0	15.4
		/	-35.0	16.4
		/	-30.0	17.4
		/	-25.0	18.4
		/	-20.0	19.5
		/	-15.0	20.5
		/	-10.0	21.7
		/	-5.0	22.8
		/	.0	23.9
		/	5.0	25.0
		/	10.0	26.1
		/	15.0	27.2
		/	20.0	28.3
		/	25.0	29.3

CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS
TAKEN FROM AAR TC128 STEEL PLATE U
CALCULATIONS FOR LATERAL EXPANSION DATA OF
11 SPECIMENS, LT ORIENTATION.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
UL13	-120.0	.00	2.1
UL6	-80.0	8.00	7.0
UL5	-60.0	8.00	11.3
UL10	-40.0	21.00	16.8
UL3	.0	30.50	30.5
UL1	20.0	36.00	37.2
UL2	60.0	48.00	46.5
UL7-19	80.0	46.50	48.7
UL1-16	120.0	52.00	50.0
UL7-20	160.0	46.00	50.1
60	212.0	54.00	50.1

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	-92.3	/	-90.0	5.3
10.0	-65.3	/	-80.0	7.0
15.0	-46.1	/	-70.0	9.0
20.0	-30.1	/	-60.0	11.3
25.0	-15.6	/	-50.0	13.9
30.0	-1.5	/	-40.0	16.8
35.0	13.0	/	-30.0	20.0
40.0	29.4	/	-20.0	23.5
45.0	50.9	/	-10.0	27.0
50.0	117.9	/	.0	30.5
		/	10.0	34.0
		/	20.0	37.2
		/	30.0	40.2
		/	40.0	42.7
		/	50.0	44.8
		/	60.0	46.5
		/	70.0	47.8
		/	80.0	48.7
		/	90.0	49.3

CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS
TAKEN FROM AAR TC128 STEEL PLATE U
CALCULATIONS FOR LATERAL EXPANSION DATA OF
13 SPECIMENS. TL ORIENTATION.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
UT26	-120.0	3.50	4.1
UT33	-80.0	8.00	7.7
UT35	-80.0	7.50	7.7
UT25	-60.0	11.00	11.5
UT23	-40.0	14.00	16.6
UT29	-40.0	18.50	16.6
UT18	-20.0	22.50	22.5
UT21	-20.0	24.50	22.5
UT6-40	-20.0	22.50	22.5
UT2-43	20.0	31.50	33.6
UT5-41	80.0	42.00	40.3
UT2-44	120.0	41.50	40.8
UT6-39	160.0	39.00	40.8

TRANSITION REGION. CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	-103.5	/	-100.0	5.3
10.0	-66.9	/	-95.0	5.8
15.0	-45.8	/	-90.0	6.3
20.0	-28.4	/	-85.0	7.0
25.0	-11.9	/	-80.0	7.7
30.0	5.5	/	-75.0	8.5
35.0	26.9	/	-70.0	9.4
40.0	71.6	/	-65.0	10.4
		/	-60.0	11.5
		/	-55.0	12.6
		/	-50.0	13.9
		/	-45.0	15.2
		/	-40.0	16.6
		/	-35.0	18.0
		/	-30.0	19.5
		/	-25.0	21.0
		/	-20.0	22.5
		/	-15.0	24.1
		/	-10.0	25.6
		/	-5.0	27.1

Appendix A, Table A5

CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS
TAKEN FROM AAR TC128 STEEL PLATE U
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
11 SPECIMENS, LT ORIENTATION.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
UL13	-120.0	.00	.9
UL6	-80.0	.00	5.6
UL5	-60.0	6.00	11.7
UL10	-40.0	34.00	22.1
UL3	.0	54.00	56.9
UL1	20.0	76.00	76.3
UL2	60.0	100.00	97.7
UL7-19	80.0	100.00	99.7
UL1-16	120.0	100.00	100.0
UL7-20	160.0	100.00	100.0
60	212.0	100.00	100.0

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	-103.9	/	-100.0	2.4
5.0	-82.8	/	-95.0	3.0
10.0	-64.5	/	-90.0	3.7
15.0	-52.5	/	-85.0	4.6
50.0	-6.8	/	-80.0	5.6
85.0	30.9	/	-75.0	6.8
90.0	38.7	/	-70.0	8.2
95.0	49.8	/	-65.0	9.8
98.0	61.4	/	-60.0	11.7
		/	-55.0	13.8
		/	-50.0	16.3
		/	-45.0	19.0
		/	-40.0	22.1
		/	-35.0	25.4
		/	-30.0	29.2
		/	-25.0	33.2
		/	-20.0	37.5
		/	-15.0	42.1
		/	-10.0	46.9
		/	-5.0	51.8

CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS
TAKEN FROM AAR TC128 STEEL PLATE U
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
13 SPECIMENS, TL ORIENTATION.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
UT26	-120.0	.00	1.7
UT33	-80.0	6.00	6.4
UT35	-80.0	.00	6.4
UT25	-60.0	5.00	11.6
UT23	-40.0	35.00	19.7
UT29	-40.0	19.00	19.7
UT18	-20.0	42.00	31.5
UT21	-20.0	38.00	31.5
UT6-40	-20.0	26.00	31.5
UT2-43	20.0	54.00	31.5
UT5-41	80.0	100.00	64.4
UT2-44	120.0	100.00	98.0
UT6-39	160.0	100.00	100.0

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)
2.0	-115.4
5.0	-88.1
10.0	-65.2
15.0	-50.5
50.0	3.6
85.0	46.3
90.0	55.0
95.0	67.2
98.0	79.8

TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
-110.0	2.4
-105.0	2.9
-100.0	3.4
-95.0	4.0
-90.0	4.7
-85.0	5.5
-80.0	6.4
-75.0	7.5
-70.0	8.7
-65.0	10.1
-60.0	11.6
-55.0	13.3
-50.0	15.2
-45.0	17.3
-40.0	19.7
-35.0	22.3
-30.0	25.1
-25.0	28.2
-20.0	31.5
-15.0	35.0

CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS
TAKEN FROM AAR TC128 STEEL PLATE G
CALCULATIONS FOR ENERGY ABSORPTION DATA OF
8 SPECIMENS. LT ORIENTATION.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
GL13	-120.0	2.50	2.6
GL9	-100.0	3.00	3.5
GL12	-80.0	12.30	6.6
GL7	-40.0	25.80	26.9
GL10	.0	55.30	53.9
GL3	40.0	57.80	59.2
60	212.0	60.00	59.3
70	212.0	60.00	59.3

TRANSITION REGION. CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	-87.8	/	-80.0	6.6
10.0	-69.0	/	-75.0	8.0
15.0	-58.1	/	-70.0	9.6
20.0	-49.8	/	-65.0	11.7
25.0	-42.6	/	-60.0	14.0
30.0	-36.0	/	-55.0	16.8
35.0	-29.6	/	-50.0	19.9
40.0	-23.2	/	-45.0	23.3
45.0	-16.2	/	-40.0	26.9
50.0	-8.2	/	-35.0	30.8
55.0	3.1	/	-30.0	34.7
		/	-25.0	38.6
		/	-20.0	42.4
		/	-15.0	45.8
		/	-10.0	49.0
		/	-5.0	51.7
		/	.0	53.9
		/	5.0	55.6
		/	10.0	56.9
		/	15.0	57.8

CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS
TAKEN FROM AAR TC128 STEEL PLATE G
CALCULATIONS FOR ENERGY ABSORPTION DATA OF
17 SPECIMENS, TL ORIENTATION.

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
GT27	-120.0	3.00	4.8
GT25	-100.0	2.80	6.2
GT32	-80.0	10.00	8.5
GT33	-60.0	11.80	11.9
GT1	-40.0	19.50	16.4
GT18	-40.0	18.30	16.4
GT26	-20.0	13.30	21.9
GT19	-20.0	24.50	21.9
GT31	.0	21.50	27.6
GT15	.0	25.00	27.6
GT28	.0	17.50	27.6
GT22	20.0	35.00	32.3
GT35	20.0	34.50	32.3
GT10	40.0	37.50	35.4
GT34	60.0	37.00	36.8
GT11	80.0	37.00	37.2
GT6	100.0	37.50	37.2

TRANSITION REGION, CALCULATED VALUES

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
5.0	-115.8	/	-110.0	5.4
10.0	-70.1	/	-105.0	5.8
15.0	-45.7	/	-100.0	6.2
20.0	-26.7	/	-95.0	6.7
25.0	-9.2	/	-90.0	7.2
30.0	9.5	/	-85.0	7.8
35.0	36.4	/	-80.0	8.5
		/	-75.0	9.2
		/	-70.0	10.0
		/	-65.0	10.9
		/	-60.0	11.9
		/	-55.0	12.9
		/	-50.0	14.0
		/	-45.0	15.2
		/	-40.0	16.4
		/	-35.0	17.7
		/	-30.0	19.1
		/	-25.0	20.5
		/	-20.0	21.9
		/	-15.0	23.3

CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS
TAKEN FROM AAR TC128 STEEL PLATE G
CALCULATIONS FOR LATERAL EXPANSION DATA OF
8 SPECIMENS. LT ORIENTATION.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
GL13	-120.0	1.50	2.6
GL9	-100.0	.00	4.6
GL12	-80.0	9.50	9.0
GL7	-40.0	27.00	29.5
GL10	.0	54.00	53.7
GL3	40.0	59.00	58.8
60	212.0	58.50	58.8
70	212.0	59.00	58.8

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	-97.3	/	-90.0	6.4
10.0	-76.8	/	-85.0	7.6
15.0	-64.4	/	-80.0	9.0
20.0	-54.8	/	-75.0	10.6
25.0	-46.7	/	-70.0	12.5
30.0	-39.2	/	-65.0	14.7
35.0	-32.1	/	-60.0	17.2
40.0	-25.0	/	-55.0	19.9
45.0	-17.4	/	-50.0	22.9
50.0	-8.6	/	-45.0	26.1
55.0	3.8	/	-40.0	29.5
		/	-35.0	33.0
		/	-30.0	36.5
		/	-25.0	40.0
		/	-20.0	43.3
		/	-15.0	46.5
		/	-10.0	49.3
		/	-5.0	51.7
		/	.0	53.7
		/	5.0	55.3

CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS
TAKEN FROM AAR TC128 STEEL PLATE G
CALCULATIONS FOR LATERAL EXPANSION DATA OF
17 SPECIMENS, TL ORIENTATION.

SPECIMEN	TEMPERATURE(F)	OBSERVED LATERAL EXPANSION (MILS)	CALCULATED LATERAL EXPANSION (MILS)
GT27	-120.0	1.50	3.6
GT25	-100.0	1.50	5.3
GT32	-80.0	10.00	8.1
GT33	-60.0	14.50	12.2
GT1	-40.0	22.50	17.9
GT18	-40.0	21.00	17.9
GT26	-20.0	14.00	24.8
GT19	-20.0	28.00	24.8
GT31	.0	26.00	32.1
GT15	.0	28.50	32.1
GT28	.0	20.50	32.1
GT22	20.0	36.50	38.2
GT35	20.0	39.00	38.2
GT10	40.0	43.00	42.1
GT34	60.0	44.50	43.8
GT11	80.0	45.00	44.3
GT6	100.0	45.00	44.4

TRANSITION REGION, CALCULATED VALUES

LATERAL EXPANSION(MILS)	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED LATERAL EXPANSION(MILS)
5.0	-102.6	/	-100.0	5.3
10.0	-69.7	/	-95.0	5.9
15.0	-49.5	/	-90.0	6.5
20.0	-33.7	/	-85.0	7.2
25.0	-19.5	/	-80.0	8.1
30.0	-5.8	/	-75.0	9.0
35.0	8.9	/	-70.0	9.9
40.0	27.8	/	-65.0	11.0
		/	-60.0	12.2
		/	-55.0	13.5
		/	-50.0	14.9
		/	-45.0	16.3
		/	-40.0	17.9
		/	-35.0	19.5
		/	-30.0	21.3
		/	-25.0	23.0
		/	-20.0	24.8
		/	-15.0	26.7
		/	-10.0	28.5
		/	-5.0	30.3

Appendix A, Table All

CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS
TAKEN FROM AAR TC128 STEEL PLATE G
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
8 SPECIMENS, LT ORIENTATION.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
GL13	-120.0	.00	.3
GL9	-100.0	.00	1.3
GL12	-80.0	5.00	4.8
GL7	-40.0	33.00	35.7
GL10	.0	94.00	92.2
GL3	40.0	100.00	100.0
60	212.0	100.00	100.0
70	212.0	100.00	100.0

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	-93.9	/	-90.0	2.6
5.0	-79.5	/	-85.0	3.6
10.0	-67.3	/	-80.0	4.8
15.0	-59.5	/	-75.0	6.5
50.0	-30.4	/	-70.0	8.6
85.0	-7.3	/	-65.0	11.3
90.0	-2.5	/	-60.0	14.6
95.0	4.1	/	-55.0	18.7
98.0	11.0	/	-50.0	23.5
		/	-45.0	29.2
		/	-40.0	35.7
		/	-35.0	42.9
		/	-30.0	50.7
		/	-25.0	58.8
		/	-20.0	66.9
		/	-15.0	74.7
		/	-10.0	81.7
		/	-5.0	87.6
		/	.0	92.2
		/	5.0	95.5

CHARPY IMPACT TEST RESULTS FOR HEAD PLATE SPECIMENS
TAKEN FROM AAR TC128 STEEL PLATE G
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF
17 SPECIMENS, TL ORIENTATION.

SPECIMEN	TEMPERATURE(F)	OBSERVED SHEAR FRACTURE (%)	CALCULATED SHEAR FRACTURE (%)
GT27	-120.0	.00	1.2
GT25	-100.0	.00	3.0
GT32	-80.0	5.00	6.7
GT33	-60.0	.00	13.9
GT1	-40.0	41.00	26.7
GT18	-40.0	34.00	26.7
GT26	-20.0	23.00	46.0
GT19	-20.0	55.00	46.0
GT31	.0	48.00	69.3
GT15	.0	58.00	69.3
GT28	.0	40.00	69.3
GT22	20.0	100.00	88.8
GT35	20.0	94.00	88.8
GT10	40.0	100.00	98.1
GT34	60.0	100.00	99.9
GT11	80.0	100.00	100.0
GT6	100.0	100.00	100.0

TRANSITION REGION, CALCULATED VALUES

% SHEAR FRACTURE	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED SHEAR FRACTURE(%)
2.0	-109.3	/	-100.0	3.0
5.0	-87.4	/	-95.0	3.7
10.0	-69.3	/	-90.0	4.5
15.0	-57.8	/	-85.0	5.5
50.0	-16.5	/	-80.0	6.7
85.0	15.3	/	-75.0	8.1
90.0	21.7	/	-70.0	9.7
95.0	30.5	/	-65.0	11.7
98.0	39.7	/	-60.0	13.9
		/	-55.0	16.5
		/	-50.0	19.5
		/	-45.0	22.9
		/	-40.0	26.7
		/	-35.0	30.9
		/	-30.0	35.6
		/	-25.0	40.6
		/	-20.0	46.0
		/	-15.0	51.7
		/	-10.0	57.6
		/	-5.0	63.5