PB-250 063

REPORT NO. FRA-OR&D 75-47

METALLURGICAL ANALYSIS OF A STEEL SHELL PLATE TAKEN FROM A TANK CAR ACCIDENT NEAR SOUTH BYRON, NEW YORK

C. G. Interrante
G. E. Hicho

OCTOBER 1971
FINAL REPORT

Prepared For
DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Research and Development
Washington, D.C. 20590

Technical Report Documentation Page

1. Report No. FRA-OR&D 75-47	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle METALLURGICAL ANALYSIS OF A STEEL SHELL PLATE TAKEN FROM A TANK CAR ACCIDENT NEAR SOUTH BYRON, N.Y.		5. Report Date October 1971
		6. Performing Organization Code
		8. Performing Organization Report No. 312.01/35
7. Author(s) C.G. Interrante, G.E. Hicho		
9. Performing Organization Name and Address National Bureau of Standards Washington, D.C. 20234		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DOT-AR-10023
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Railroad Administration Office of Research and Development Washington, D.C. 20590		13. Type of Report and Period Covered FINAL REPORT
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

A metallurgical analysis of a steel plate sample (the South Byron sample) was requested by the Federal Railroad Administration. The steel sample was taken from a tank car (number PPGX9990) which had been involved in an accident near South Byron, New York. This sample was reported to have been produced to specification AAR-M-128-65-DTD-1966-Flange Quality-Grade B, and it was reportedly taken from the second course of shell plate of car number PPGX9990. The fracture in this course circumscribed the tank car and resulted in the division of the car into two sections.

An investigation was conducted at the National Bureau of Standards to determine if the plate sample conformed with the above Association of American Railroads (AAR) Specifications for Tank Cars and to gather information pertinent to the question of the suitability of this type of steel for use as the shell plate of tank cars.

17. Key Words Metallurgy, Tank Cars	18. Distribution Statement Documents is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 57	22. Price

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

TABLE OF CONTENTS

Tables

Figures

Figures (continued)

Report No. 2

Metallurgical Analysis Of a Steel Shell Plate Taken From a Tank Car Accident Near South Byron, New York

INTRODUCTION

A metallurgical analysis on a steel plate sample (the South Byron sample) was requested by the Bureau of Railroad Safety, Federal Railroad Administration, Department of Transportation. The South Byron sample was reported [1]* to have been taken from a tank car (number PPGX9990) being used to transport vinyl chloride monomer when it was involved in an accident near South Byron, New York at about 7:15 a.m. on August 27, 1970. The car exploded, presumably after being subjected to heat from a fire caused by the burning of the spilled contents (vinyl chloride monomer) of a nearby tank car (number PPGX9948). Apparently [1], the explosion of car number PPGX9990 propelled a large section of this car a distance of almost 175 feet. This section, shown in Figure 1, contained the South Byron sample submitted to NBS for metallurgical analysis.

The South Byron sample was reported [1] to have been cut from the "nine o'clock" position in the second course of the car's shell plate, as shown in Figure 2, which was prepared from an AAR report [1]. This figure also shows that one of the edges of the sample contains a segment of the fracture line that progressed around the entire circumference of course number 2. This circumferential-type of fracture separated this car into two sections and led to the propulsion of one of them. It was reported to us that this type of fracture is not uncommon in accidents involving tank car explosions, and the unguided propulsion of large sections of metal is a potential hazard to life and property. Therefore, circumferential fractures are considered to be important in analyses of tank car failures.

The ambient temperature at the accident site was estimated to have been about 68°F. This estimate was based on U.S. Weather Bureau reports for that day for the nearby town of Batavia, New York (high of 83°F and low of 62°F) and for Buffalo, New York, about 30 miles west of Batavia, (66°F at 7:00 a.m.).

---

* Figures in brackets indicate the literature reference at the end of this report.

The shell plate material used in the fabrication of the second course of the tank car was reported [2] to be a 5/8 inch-thick, fine-grained steel plate in the as-rolled condition. It was produced [2] to specification AAR-M-128-65-DTD-1966-Flange Quality-Grade B, by U.S. Steel Corporation, Homestead District Works, as part of Heat Number 75E812, Slab Number 283838.

It should be noted that in AAR-M-128, mechanical properties are specified for plates in the as-rolled condition, and, of course, the test specimens taken from the South Byron sample for this investigation were in the as-rolled, cold-worked, and stress-relieved condition, with the cold work resulting mainly from the original forming for fabrication of the tank car and possibly from some indeterminate amount of reforming during the explosion of the tank car. However, the general shape of the South Byron sample indicated that only a minor amount of reforming occurred in this sample. It is therefore believed that the observations and properties reported in this metallurgical analysis of the shell plate sample are germane to the shell plate in the tank car in service, except, of course, where the contrary has been indicated in the report.

PURPOSE

The principal purpose of this metallurgical analysis was to determine if the shell plate sample taken from tank car PPGX9990 (the South Byron sample) conformed with the above specifications for high-tensile-strength, carbon-manganese steel plates for tank cars*. Another objective of the investigation was to gather information pertinent to the question of the suitability of this type of steel for use as the shell plate of tank cars.

EXPERIMENTAL WORK

Chemical analysis, tensile and bend properties were determined and compared with the requirements of AAR-M-128-65 and -70. However, more than the required single bend specimen and single tensile specimen were tested. In addition to the required tests, impact tests, inclusion content ratings, a hardness survey, and thickness measurements were performed and macroscopic and microscopic observations were made.

---

* For reference, these specifications and the current specifications M128-70 are given in Appendix A.

Before the South Byron sample was sectioned for the preparation of test specimens, the orientation of the fracture line with respect to the original rolling direction of the plate was determined by examining the length of inclusions on planes parallel and perpendicular to the principal direction of fracture.

Macroscopic Observations and Thickness Measurements

The South Byron sample was macroscopically examined before it was sectioned. As shown in Figure 3, the specimens were oriented in longitudinal and transverse directions with respect to the fracture line. This line was estimated to be approximately parallel with the rolling direction of the plate. The fracture surface extends along the line from C1 through C10. At several locations along this line, thickness measurements were taken at various distances from the fracture to determine if plate thinning occurred in regions near the fracture.

Chemical Analysis

Check chemical analyses (spectrometric and combustion-thermoconductivity) were conducted on the chemistry sample (Figure 3) at the quarterthickness position to determine if the composition satisfied the requirements of the AAR-M-128-65 and -70 Grade B Specifications. This work was done by the Analytical Chemistry Division, NBS.

Tensile Testing

Three longitudinal and two transverse 0.250 inch diameter tension-test specimens*, taken (as nearly as possible) from the quarterthickness location of the plate, were prepared and tested in accordance with ASTM Methods and Definitions A 370-71.

---

* The AAR-M-128 Requirements give minimum elongation values for gage lengths of 8 inches (1970 and 1965 Specifications) and 2 inches (1970 Specification). The overall size of the South Byron sample precluded the use of the standard tension-test specimens which are commonly used to obtain elongation in 2- and 8-inch gage lengths. Therefore, 0.250 inch diameter specimens were used with a 1-inch gage length so as to provide elongation values that are directly comparable with the values specified for the 0.500 inch specimens with 2-inch gage lengths [3,4].

Bend Testing

Four longitudinal and four transverse bend-test specimens were prepared with dimensions* of 3/8 x 1-1/2 x 6 inches and with the outside surface of the tank car being the outer curve of the bend. In accordance with the AAR-M-128-65 and -70 Specifications, and the ASTM A 370-68 Standard Methods and Definitions, specimens were bent through an inside diameter of 3/4 inches, so as to provide the required bend ratio of bend diameter (d) to thickness (t) equal to 2. However, two of the longitudinal specimens were inadvertantly bent to a d/t ratio slightly less than 2 and so the bending strain in these specimens was greater than the strain obtained in the required test.

In addition, duplicate longitudinal and duplicate transverse plate specimens were prepared and tested under conditions less severe than the AAR bend requirements for plates. The outer surfaces on these bend specimens had several-thousandths of an inch removed to eliminate surface effects. In addition, a less severe bend ratio of 4 was used to provide test conditions given in the methods of ASTM E-190-64 for the guided bend test for ductility of welds.

Impact Testing

Sets of 19 transverse and 19 longitudinal standard-width Charpy V-notch impact-test specimens were obtained from the quarterthickness location of the South Byron sample. Specimens were oriented with respect to the direction of crack propagation, as shown in Figure 3. Also shown is the orientation of the V-notch (see Impacts A for transverse specimens and Impacts B for longitudinal specimens).

---

* Although the width of the bend specimens is not specified in AAR-M-128-65 and -70, specimen width affects the severity of the test. It has been shown [5] that the ductility, in terms of the bend angle before cracking occurs in a material in bending, decreases with increasing values of the ratio of width to thickness (w/t) until a terminal level is achieved at a w/t ratio of about 8. Therefore, bend tests were conducted at an intermediate severity, with w/t equal to 4 for the 1-1/2 inch wide by 3/8-inch thick specimens. This is the specimen size specified in AAR-W5-1970 for weld-root and weld-face bend tests.

The impact specimens were tested over a temperature range selected to show the transition from ductile to brittle fracture. Test methods were in accordance with ASTM Designation E23-66. The experimental data were analyzed by a computer method (to be published) that calculated the least squares (best fit) curves for the available data, and then plotted the calculated curve and the experimental data with an incremental digital plotter.

Metallographic Studies and Hardness Testing

Metallographic observations and hardness measurements were made on three mutually perpendicular planes in the plate material as shown in Figure 4: Plane A is parallel to the plate surface, Plane B is a transverse plane perpendicular to the line of the fracture on the South Byron sample, and Plane C is a longitudinal plane parallel to the fracture line. Rockwell B hardness measurements were taken on three samples taken from various plate locations, metallographic samples A and B and sample T5. On metallographic sample A, Rockwell B measurements were taken at random locations at about an 0.010 inch depth from the plate surface, and on B and C planes along straight lines between the plate surfaces. Brinell hardness measurements were also taken on this sample on the A plane

The metallographic observations were made on selected polished areas in both the etched and unetched steel. Etched samples were used to observe the general microstructure and to measure the ferrite grain size. Unetched samples taken from locations C2, C4, C6, C8 and C10, as shown in Figure 3, were used to rate the inclusion content of the steel. The inclusion contents were rated on longitudinal (C) planes located about 1/2 inch from the fracture line. Two methods were used in this rating: (1) ASTM E-45-63 Method A, which provides for rating the field number of the worst field for four different types of inclusions observed in an area of 0.25 square inches, and (2) a method using quantitative television microscope (QTM) determinations of the area percentage of inclusions. Five specimens were rated at magnifications of X1300 and X338 with the QTM area percentage method. At the X1300 magnification, a total of 50 fields was observed on each specimen, with 25 fields being taken at the center of the plate thickness and the remaining 25 being taken at the two quarterthickness locations. At the X338 magnification, a similar procedure was used but the number of fields was 100 per specimen. In general, the QTM methods described in the literature [6] were used.

RESULTS AND DISCUSSION

Chemical Composition

The chemical composition, as determined by the NBS laboratory check analysis of the South Byron sample, is given in Table I, along with the producer's ladle analysis and the chemical requirements for M-128-65 and -70 Grade B Steel. The results of the laboratory check analysis and the producers ladle analysis are in good agreement and they indicate that the composition of the South Byron sample meets the chemical requirements for M-128 Grade B Steel. Although the values of 0.26 percent carbon and 1.36 percent manganese obtained in the check analysis are greater than the maximum contents of 0.25 percent carbon and 1.35 percent manganese permitted for ladle analyses, these compositions are within the expected variability for plates within a heat. However, it should be noted that both the carbon and the manganese contents of this plate were at the top of the range permitted for this grade of steel and the sulfur content, 0.04 percent, was near the maximum permitted for this steel.

Metallographic Analysis

The microstructure of an unetched steel sample, as observed on three orthogonal planes, is shown at magnification of X100 in Figure 4. The figure shows that inclusions in the C planes are much longer than inclusions in the B planes. This was observed to be the case for most areas on the metallographic sample, indicating that the direction of crack propagation on the South Byron sample was roughly the longitudinal (principal or rolling) direction of the plate. This indication was further confirmed by examinations of inclusion length on planes perpendicular to the plate surfaces but inclined +15° and -15° from the B plane. Inclusions on both of these planes were longer than or the same length as inclusions on the B plane, indicating that the B plane was nearly perpendicular to the rolling direction and that specimens aligned with respect to the direction of crack propagation would be approximately aligned with respect to the plate rolling direction. Therefore, longitudinal specimens were aligned with their axes in the direction of crack propagation and transverse specimens were aligned perpendicular to this direction.

It should be noted that some long inclusions were also observed in the B plane, indicating that the plate may have received some cross rolling.

The etched steel sample, as observed on three orthogonal planes, is shown at magnifications of X100 and X240 in Figure 5. The microstructure shown is not unexpected for a carbon-manganese steel in the as-rolled condition and produced in accordance with the M-128 specifications. It is a mixture of ferrite and pearlite and is moderately banded with alternate layers of ferrite of ASTM Grain Size No. 8.0 and pearlite, some of which is unresolvable and some of which is blocky.

Tensile Properties

The tensile properties of the South Byron sample are given in Table II. The results of both the longitudinal and the transverse specimens indicate that the steel meets the AAR requirements of 19.0 percent minimum elongation and 50,000 psi minimum yield point. Based on the average values for each orientation, the tensile strength for the longitudinal and transverse directions exceeded the specified maximum tensile strength by amounts of 1500 psi and 950 psi, respectively.

The relatively high strength of this plate is consistent with the high levels of carbon and manganese present in combination with the 0.04 percent vanadium. In addition, at the levels present, the elements copper, nickel, chromium, and molybdenum also contribute slightly to the strength.

All of the tensile specimens had a lower yield point, i.e. a decrease in stress at strain values slightly greater than the yield point strain.

The strength levels of the longitudinal and transverse specimens are similar. However, the ductility of the steel, as measured by the reduction-of-area and the elongation, is anisotropic, with the ductility for longitudinal specimens being greater than for transverse specimens. The poorer ductility of the transverse tensile specimens is manifest, on the fracture faces, as a flat lamellar-type fracture, as shown in Figure 6. The appearance of the fracture faces of the longitudinal specimens is also layered, but a large shear lip (indicative of higher ductility) is seen around half of the periphery of each of the fracture faces. For comparison with these layered fracture faces, also shown in Figure 6 is a cup-and-cone fracture obtained from a 1/4-inch diameter rod of 1018 steel. This fracture has a flat, unlayered central region.

Bend Behavior

The results of the bend tests are given in Table III. For the shell plate specimens tested in accordance with bend test requirements for plates, all of the longitudinal and transverse specimens failed to meet the AAR-M-128-65 requirements. Failure of the two longitudinal specimens*, B11 and B12, was evidenced (Figure 7) by surface crazing in the region of maximum strain. The longest cracks on these surfaces were about 0.2 inch in length, except for one thin, 0.5 inch long crack in specimen B12. Failure of the transverse specimens was much more pronounced. All four specimens tested failed at small bend angles of less than 90 degrees (Figure 8). Two of these specimens, B7 and B8, were completely fractured at bend angles of 90 and 85 degrees, respectively. The photographs of the fracture surfaces of these bend specimens show a somewhat lamellar appearance. The other two specimens B9 and B10, failed with extensive cracks at bend angles of 90 and 75 degrees, respectively and so they were not tested beyond these relatively small bend angles. These results indicate that this steel does not have adequate bend ductility as defined by the AAR requirements (bend ratio = 2). However, it is important to note that these tests were conducted under the "three-point loading" conditions permitted by the ASTM Standard Methods but in the mills, where the steel is produced, the bend test is conducted by an acceptable "wrap around" method which is apparently less severe. If this steel passed the "wrap-around" test in the mill and failed the "three-point loading" test in our laboratory (it appears as though this is the case), perhaps this indicates that there is a need for standardization of the test method for the AAR bend requirements.

---

* The failures of specimens B5 and B6, which were inadvertantly bent to a bend ratio of d/t equal to 1.7, were not considered significant, because this bend ratio is less than the required bend ratio.

When the shell plate was tested in accordance with the less severe (bend ratio = 4) requirements on the quided-bend test for welds, all specimens (B1, B2, B3, B4) passed. No cracks were observable with the unaided eye, as shown in Figure 9. These tests indicate that with an as-ground surface, this steel has a moderately good ductility in bending.

Macroscopic Observations

The South Byron sample was macroscopically examined before it was cut into test specimens. This examination revealed that the outer surface of the tank car was almost completely covered with a protective paint. The paint was blistered, as shown in Figure 10, but there was very little or no evidence of charring of the paint. The best available estimate* of the characteristics of this paint indicate that charring would occur at roughly 400 F to 450 F, and the paint would burn clean from the surface at about 600 F. Based on this estimate, it appears that the steel at the surface of the South Byron sample could not have exceeded 450 F in the fire that apparently led to the explosion of tank car PPGX9990. Thus, it was estimated that the bulk of the steel of the South Byron sample was at some temperature between 400 F and the ambient temperature of 68 F, and it probably was much closer to 68 F, perhaps at about 100 F.

The fracture surface on the South Byron sample was rusted when received at NBS. On this surface, the failure mode varied from one end of the fracture line to the other end. At the end marked C9, Figure 3, much of the fracture face was nearly perpendicular to the plane of the plate surface, whereas, at the end marked C1 the fracture plane made an angle of about 45 degrees with the surfaces of the plate. Near location C6 was a region of transition. This region contained both the perpendicular mode of fracture observed at C9 and the shear mode observed at C1. These failure modes are illustrated in Figure 11 which gives

---

* A telephone conversation on 7-6-71 between Q. Banks (FRA) Washington, D. C. and C. Graves (GATX) Sharon, Pa. provided this estimate. In addition, Graves indicated to Banks that the paint manufacturer (PPG) is planning to conduct tests on the charring characteristics of this paint (PPG-No. UC 33873 paint and PPG No. UC 36611 primer).

profile views of the fracture along the B planes at locations C1, C6, and C9. In the region at which perpendicular fracture mode predominated, the fracture surface is a series of steps, but in the regions at which the shear-fracture mode predominated, the fracture surface is either much more continuous with fewer and shorter steps or it is pure shear with no visible steps.

Thickness Measurements

The results of the thickness measurements given in Table IV indicate that plate thinning occurred near the fracture surfaces. Plate thickness was observed to increase with distance from the fracture surface. This observation was made at many locations along the fracture edge, but measurements are reported for three locations only: near location C2, near location C6, and between location C8 and C10. As would be expected, the plate thickness is least at the location with the greatest amount of shear fracture (near C1). These thickness measurements and the appearances of the profile views of the South Byron sample indicate that the fracture of the plate occurred with through-thickness yielding which was greater at locations with a greater percent shear failure.

Hardness Measurements

The results of hardness measurements are given in Table V. The Rockwell B hardness was relatively uniform on metallographic sample A which was surveyed on each of three mutually perpendicular planes, and it varied from 91.0 to 99.0 over 30 readings taken on a total of three specimens. The overall average hardness was Rockwell B 94.0. The Brinell hardness of 196.4, taken on a A plane on metallographic sample A, was in good agreement with the Rockwell hardness of 92.1 taken at this same location. These hardness values are consistent [7] with the hardness expected in a steel at the strength level specified by the M-128-65 requirements. The observed variability in Rockwell B hardness values is somewhat expected in an as-rolled steel, because steels in the as-rolled condition are less homogeneous than steels that have been recrystallized by heat treatment after rolling.

Inclusion Content

The results of the inclusion content ratings are given in Table VI. The results of the QTM area percentage ratings indicated that at a magnification of X1300, the South Byron sample had an overall average inclusion content of about 0.44 area percent, whereas at a magnification of X338 the average content was 0.40 area percent. The lower average area percent value is expected to be lower at the lower magnification [6], because the resolving power of the QTM decreases with decreasing magnification and at the lower magnification many of the thin inclusions are not resolvable. The observed number of fields (per 100 fields) with an inclusion area percent equal to or greater than 0.5, as determined at magnification levels of X1300 and X338, were 32 and 29, respectively.

The literature gives very little information on the inclusion area percent expected in steel plate. However, for a rough comparison, the values recently reported [6] for 4x4-in. billet specimens over a broad range of strength levels (including the strength of TC128) may be used. The range of average inclusion area percent reported for production heats of various steel compositions is 0.10 to 0.38. The range reported for the number of fields with inclusion area equal to or greater than 0.5 percent was 1 to 28. Because these reported values were obtained at a magnification of X350 and by the QTM methods used in this report, the most direct comparison would be made with the results for magnification X338. When this is done it becomes apparent that the inclusion content of the South Byron sample is at the top of the expected range of area percent inclusion.

The results of the ASTM E-45, Method A rating indicate that manganese sulfides (Type A in Table VI) are the principal type of inclusions in the South Byron sample. This finding was verified by electron-microprobe analyses which showed that manganese sulfides and iron-manganese sulfides were by far the most prevalent type of inclusions in two samples analyzed in the microprobe.

Impact Properties

The results of the Charpy V-notch impact tests are given for three fracture criteria in Figure 12A, 12B, and 12C, which present the observed data and calculated curves for percent shear fracture appearance, energy absorption, and lateral expansion, respectively. On each figure, two plots are given, one for longitudinal specimens and one for transverse specimens. The raw data and the results of calculations for these six plots are given in Appendix B as Tables B-1 through B-6.

In all six plots, the data show that in the range of temperatures from 212 F to about 80 F, there was very little variation in the observed behavior of a given set of test specimens. In this region, called the upper shelf, the percent shear fracture appearance, the energy absorption, and the lateral expansion values are at a maximum for both longitudinal and transverse specimens. However, for transverse specimens the energy absorption (Figure 12B) at the upper shelf is only half as great as the corresponding value for longitudinal specimens: 25 ft-lb compared with 46 ft-lb. The smaller capacity for energy absorption of transverse specimens is also evidenced (Figure 12C) as a decreased amount of lateral expansion at the base of the Charpy specimen where lateral expansion is measured (27 mils for transverse compared with 47 mils for longitudinal specimens). The shelf energy of transverse specimens is expected to be smaller than that for longitudinal specimens because inclusion length is greater in longitudinal planes and these are fracture planes in transverse specimens.

With decreasing temperatures below the upper shelf, fracture of Charpy specimens is associated with decreasing amounts of energy absorption, lateral expansion, and shear fracture appearance, and at some lower temperature each of these fracture criteria approaches a minimum value called the lower shelf.

At temperatures between the upper shelf and the lower shelf, there is a transition zone. The results indicated that for both the longitudinal and the transverse specimens this transition zone occurred in about the same range of temperatures, roughly -10 to 80 F. At temperatures below about 10 F, the behavior of longitudinal and transverse specimens was very similar, but at all higher test temperatures (up to about 212 F) the energy absorption and lateral expansion values were greater for the longitudinal specimens.

At temperatures above 0°F at which shear fracture appearance was about 10 percent or more, the fracture surfaces of the Charpy specimens had a lamellar appearance. A photograph of several fractured Charpy specimens, given as Figure 13, shows that the fracture surfaces have large spaces between even larger lamellae and the edges of the lamellae extend outward as tongues of shear fracture. In general, the size of these shear lips and the surface roughness on these specimens increased with increasing test temperatures, and at a given temperature, were greater for longitudinal specimens than for transverse specimens. Thus, for Charpy specimens with a lamellar fracture appearance, the energy absorption was generally greater when larger shear lips formed on the lamellae.

However, the longitudinal shelf energy value of the South Byron sample, which represents the specimens with the largest of the shear lips observed in the specimens tested, was relatively low when compared with other conventionally melted steels at the same strength level. Figure 14, taken from a recent publication [8], gives a plot of longitudinal Charpy V-Notch Shelf Energy Absorption as a function of Yield Strength. At the 70 ksi yield strength level, the conventionally melted steels would be expected to have shelf energy values of about 75 to 80 ft-lb, whereas the South Byron sample had only 46 ft-lb. It is concluded that lamellar tearing did not enhance the capacity for energy absorption in this ferrite-pearlite steel.

Thus, the South Byron sample is believed to have relatively small upper shelf energy values when compared with other steels of the same strength level. This is related to (1) the laminated fracture appearances [9,10] the relatively high sulfur level of the steel [9,11-13] the relatively large number of long inclusions [10, 12-14] the pearlite-ferrite microstructure [13], and the banding of the pearlite and ferrite [9,10,14].

The minimum impact properties required for steels in a specific application may be specified as a maximum "transition temperature" for one or more of the three fracture criteria. Table VII gives Charpy V-notch impact transition temperatures for longitudinal and transverse specimens taken from the South Byron sample. Transition temperatures are given for several of the commonly used criteria: 15 mils lateral expansion, 15 ft-lb energy absorption, and 50 percent shear fracture appearance. Calculational results for many other criteria are given in Appendix B, Tables B1-B6.

General Discussion

The observations of plate thinning near the fracture edge and of shear failure on the fracture surface on the South Byron sample were interpreted as being indications that the steel plate was fractured at a temperature at which the resistance to crack propagation was near the maximum for this steel, i.e. at upper-shelf temperatures. This interpretation was supported by the estimate of the failure temperature (near 100 F), and by the results of impact tests which indicated that the lowest temperature of the upper shelf for Charpy V-notch specimens was near 80 F*.

Two distinguishing features were observed on fractures produced in laboratory specimens tested at temperatures high enough to produce shear failure in the Charpy V-notch tests. These features were observed in tests of tensile, impact and bend properties. First, the fracture appearances were lamellar, indicating that the fractures were produced as a series of failures of individual lamella. The fracture face of the South Byron sample also had this lamellar fracture appearance. Second, when compared with the longitudinal specimens, transverse specimens had consistently poorer properties of bend ductility in bend tests, reduction-of-area and elongation in tension tests, and energy absorption and lateral expansion in impact tests. Thus, these mechanical properties are anisotropic in this steel.

It is believed that the anisotropy of mechanical properties may have governed the direction of crack propagation in the tank car and led to the propagation of a crack around the circumference of the car. The fracture plane of transverse specimens is a longitudinal plane in the plate from which the specimens were taken. The results of Charpy impact tests indicated that the resistance to crack propagation in the longitudinal planes was only about half that in the transverse planes. Cracks in longitudinal planes propagate in the longitudinal (or principal rolling) direction of the plate, and in the tank car the shell plate

---

* However, this temperature would be higher in tests that more closely simulated the section size and load distribution of a shell plate in a tank car under service conditions.

is aligned so that the longitudinal direction of the plate is the hoop or circumferential direction of the car. Thus, the hoop direction is the plate rolling direction and the direction shown to have lower resistance to crack propagation. It is worthwhile to note that in the shell plate of the South Byron sample, the crack circumscribed the car (thereby separating the car into two sections) and this occurred despite the fact that, in normal service, the tensile stress from pressure inside the tank car is about twice as great in the hoop direction as in the axial direction. The hoop direction stress would promote crack propagation along the length of the tank car.

Anisotropy of mechanical properties of steels has been associated with both banding [14-16] and sulfide inclusions [9-17]. Heat treatments which remove the microstructural banding may improve both the longitudinal and the transverse impact properties [12,14,15], probably because the manganese sulfides coagulate only slightly after such heat treatments [11,12]. The spread in Charpy values between longitudinal and transverse specimens is proportional to the amount of cross rolling [12].

It is concluded that (1) the anisotropy of mechanical properties observed in the South Byron sample is due to the combined effects of banding and inclusions in the steel, (2) anisotropy would remain even in a heat-treated steel at the strength level of the South Byron sample or even in an unbanded steel of lower strength, and (3) only substantial cross rolling would further lessen the anisotropy of mechanical properties. However, the application of substantial cross-rolling usually limits the dimensions of the plates and alters the production rate requirements.

RECOMMENDATION

It is recommended that if the possibility of circumferential type of fracture is to be minimized in tank cars, then the design of the tank cars should be reviewed in detail to explore various approaches for making allowances for the expected anisotropy of mechanical properties of the plates specified for use in the fabrication of the cars.

CONCLUSIONS

1. The chemical composition of the South Byron sample met the chemical requirements for AAR-TC128-65 Grade B Steel.

2. The results of bend tests indicated that the steel failed the bend requirements for plates.

3. The results of tensile tests indicated that the steel meets the minimum yield point and minimum elongation requirements, but slightly exceeds the specified maximum tensile strength.

4. The results of Charpy V-notch impact tests indicated that the observed upper shelf values of energy absorption for the South Byron sample are relatively low when compared with other conventionally melted steels at the same strength level.

5. These shelf energy values were related to the laminated fracture appearances, the sulfur level, the length of inclusions, and the microstructure of the steel.

6. The steel was determined to be anisotropic in mechanical properties, with ductility and notch toughness being lower in the transverse specimens than in longitudinal specimens.

7. The fracture of the shell plate from which the South Bryon sample was taken, was believed to have circumscribed the tank car because the shell plate was anisotropic with lower resistance to crack propagation in the circumferential direction of the tank car, which was the rolling direction of the plate.

8. The anisotropy in mechanical properties was believed to be related to the inclusion content, the banded structure of the steel and the rolling practice.

REFERENCES

1. RA-03-2-4, Phase 03, "Report on Metallographic Examination of Specimens Removed from a Section of Tank Car in South Byron, New York Derailment", March 10, 1971.

2. U.S. Steel Corporation, Homestead District Works, Metallurgical Report dated November 21, 1969.

3. George E. Dieter, "Introduction to Ductility", Ductility, ASM, Metals Park, Ohio, 1968.

4. The Making, Shaping and Treating of Steel, U.S. Steel, Seventh Edition, 1957, p. 892.

5. George E. Dieter, Mechanical Metallurgy, McGraw-Hill Book Co., New York City, 1961, pp. 557-562.

6. R. A. Rege, W. D. Forgeng, Jr., D. H. Stone, and J. V. Alger, "Microcleanliness of Steel - A New Quantitative TV Rating Method", Applications of Modern Metallographic Techniques, ASTM STP 480, American Society for Testing and Materials, 1970, pp. 249-272.

7. Metals Handbook, 8th Edition, V2, ASM, Metals Park, Ohio, p. 671.

8. J. H. Gross, "The Effective Utilization of Yield Strength", Journal of Engineering for Industry, 1971, ASME Paper No. 71-PVP-11.

9. W. Dahl, H. Hengstenberg, and C. Düren, "Verhalten der Verschiedenen Sulfidformen bei der Verformung" Stahl Eisen. 1966, 86, pp. 796-817.

10. A Brownrigg and F. M. Chambers, "Effect of Inclusions on Impact Properties",JISI, 1970 (12), p. 1078.

11. H. A. Vogels, W. Dahl, H. Hengstenberg, und F. Brüning, "Verformungsbedingungen, Seigerungen und Einschlüssen in ihrem Einflub auf die an Längsund Querproben ermittelten Eigenschaften von Grobblechen", Arch. Eisenh., 1962, 33, pp. 649-659.

12. J. M. Hodge, R. H. Frazier, and F. W. Boulger, "The Effect of Sulfur on the Notch Toughness of Heat-Treated Steels", Trans. AIME, 1959, 215, p. 745.

13. A. G. Franklin and W. J. Tegart, "Effect of Desulfurization on the Impact Properties of Some Low-Alloy Steels", JISI, 1964, 202, pp. 588-600.

14. R. A. Grange, "Effect of Microstructural Banding in Steels", Metallurgical Transactions, 1971, 2, pp. 417-426.

15. W. S. Owen, M. Cohen and B. L. Averbach, "The Influence of Ferrite Banding on the Impact Properties of Mild Steel", Welding J., 1958, 37, p. 368.

16. C. F. Jatckzak, D. J. Girardi and E. S. Rowland, "On Banding in Steel", Trans. ASM, 1956, 48, pp. 279-305.

17. A. T. English, "Influence of Mechanical Fibering on Anisotropy of Strength and Ductility", J'nl of Metals, 1965 (4), p. 395.

Table I. Chemical Composition of the South Byron Sample

		Percent by Weight			
Element		Specification AAR-M-128-Grade B Ladle Analysis		NBS Laboratory Check Analysis	Producer's Ladle Analysis*
		1965	1970		
Carbon	Max	0.25	0.25	.26**	0.24
Manganese	Max	1.35	1.35	1.36	1.32
Phosphorus	Max	0.040	0.040	0.013	0.011
Sulfur	Max	0.050	0.050	0.04	0.029
Silicon	Max	0.30	0.30	0.25	0.25
Vanadium	Max	(+)	0.08	0.04	0.05
Copper	Max	0.35	0.35	0.04	0.04
Nickel	Max	0.25	0.25	0.16	0.20
Chromium	Max	0.25	0.25	0.08	0.06
Molybdenum	Max	0.08	0.08	< 0.05	0.06
Aluminum	(+)	(+)	(+)	0.018	(+)
Columbium	(+)	(+)	(+)	< 0.05	(+)
Zirconium	(+)	(+)	(+)	< 0.05	(+)
Titanium	(+)	(+)	(+)	< 0.05	(+)

* Producer's heat number for this shell plate is 75E812.

** This value is a combustion-thermoconductivity analysis. The others are optical emission spectrometric analysis.

(+) Not specified or not determined.

Table II. Tensile Properties of the South Byron Sample

Code	Orientation	Yield Point (psi)	Lower Yield Strength (psi)	Yield Strength, 0.2% Offset (psi)	Tensile Strength (psi)	Reduction of Area (percent	Elongation (percent)
T3	Longitudinal	72,200	69,000	69,400	102,100	55.1	23.1
T4	Longitudinal	70,200	69,200	69,200	102,600	55.3	23.8
T5	Longitudinal	69,300	68,900	69,500	102,800	55.3	18.3
Average	Longitudinal	70,600	69,000	69,400	102,500	55.2	21.7
T1	Transverse	70,100	69,600	72,100	101,900	46.1	20.8
T2	Transverse	71,400	70,300	71,400	102,000	42.3	20.8
Average	Transverse	70,750	69,950	71,750	101,950	44.2	20.8
Producer's report (c)		-	-	62,380	90,690	-	23.0(c)
M-128-65 Specification	(a)	(a)	(a)	51,000 minimum	101,000max. 81,000min.	(a)	19.0 minimum (b)

(a) Not specified.

(b) M-128-65 specifies elongation in 8 inches only. However, M-128-70 specifies values for both 2 inches and 8 inches, with the 2 inch value representing the standard 0.500 inch diameter round specimens. Values were obtained in these tests with 0.250 inch-diameter specimens and the gage length was adjusted to 1-inch so as to give results that are directly comparable with specified elongation requirements.

(c) Production Department, Homestead District Works, U.S. Steel Corporation. Test report of plate Number 283838, heat Number 75E812. Results are given for duplicate plate-type tension specimens with 8-inch gage length.

Table III. Bend Behavior of South Byron Sample

Orientation	Sample Number	Ratio of Bend Diameter to Thickness	Angle of Bend*	Length** of Longest Crack (in.)	Comments
Shell Plate Specimens Tested in Accordance with Bend Test Requirements for Plates					
Longitudinal	B5	1.7	180°	0.4	Failed, but specimens were inadvertantly bent to (d/t) more severe than the (d/t) required in M-128, so failure is not significant.
Longitudinal	B6	1.7	180°	0.7	
Longitudinal	B11	2.0	180°	0.1	Failed, crazed surface.
Longitudinal	B12	2.0	180°	0.5	Failed, crazed surface.
Transverse	B7	2.0	90°	1.5	Failed, specimens completely fractured.
Transverse	B8	2.0	85°	1.5	
Transverse	B9	2.0	90°	1.5	Failed.
Transverse	B10	2.0	75°	0.9	Failed.
Shell Plate Specimens Tested in Accordance with Requirements of Guided-Bend Test of Welds					
Longitudinal	B1	4.0	175°	None	Passed.
Longitudinal	B2	4.0	175°	None	Passed.
Transverse	B3	4.0	175°	None	Passed.
Transverse	B4	4.0	170°	None	Passed.

* Less than the required 180 degree bend was used in the plate test only for selected specimens that failed at low values of bend angle. Angles given for guided-bend tests were measured on the specimens after the completion of Procedure 5.2 of ASTM Designation E 190-64.

** Based on observations made either with the unaided eye or with an X5 magnification.

Table IV. Thickness Measurements Taken Near the Fracture Line on the South Byron Sample

Distance from the Fracture Surface (in.)	Plate Thickness (in.)		
	Near Location C2*	Near Location C6*	Between Locations C8* and C10*
0.1	0.588	0.602	0.613
0.2	0.596	0.611	0.618
0.3	0.604	0.615	0.619
0.4	0.606	0.620	0.623
0.5	0.608	0.625	0.625
0.6	0.615	0.627	0.627
0.7	0.615		0.632
0.8	0.618		0.632
0.9	0.618		
1.0	0.618		
1.1	0.618		
1.2	0.619		
1.3	0.624		
1.4	0.625		

* See Figure 3.

Table V. Results of Hardness Surveys taken on the South Byron Sample

Specimen*	Location**	Hardness Rockwell B	Average
Met. Sample A	A plane (0.010 in below plate surface)	92.5, 92.0, 92.0, 92.0	92.1
Met. Sample A	B plane	93.5, 92.0, 92.5, 92.0	92.5
Chem. Sample B	B plane	91.0, 93.0, 96.0, 94.5, 93.0, 93.0, 92.0	93.2
Met. Sample A	C plane	93.5, 92.5, 91.5, 92.0	92.4
Met. Sample C	C plane	97.0, 97.5, 99.0, 98.5, 97.0	97.8
Tensile Sample T5	unknown	95.0, 95.0, 95.5, 95.5, 95.0, 95.0	95.2
		Overall Average = R_B 94.0	
		Hardness Brinell (3000 Kg load)	
Met. Sample A	A plane (0.010 in below plate surface)	195, 197, 198, 193, 198, 198, 196	196.4

* See Figure 3.

** See Figure 4.

Table VI. Inclusion Content Ratings by a QTM Method and by ASTM E-45, Method A

QTM Ratings (in inclusion area percent)

Specimen Number	1/4 Thickness Position	Midthickness Position	3/4 Thickness Position	Number of Fields with Inclusion Area ≥ 0.5*	Worst Field	
					Quarter-thickness	Mid-thickness
A: Magnification X1300						
2	0.25	0.56	0.78	40	1.96	2.16
4	0.51	0.58	0.60	38	2.30	3.0
6	0.35	0.44	0.31	26	1.16	3.0
8	0.24	0.24	0.46	22	1.44	1.24
10	0.29	0.53	0.39	32	1.10	2.94
Averages	0.33	0.47	0.51	32		
B: Magnification X338						
2	0.52	0.35	0.31	28	1.4	0.94
4	0.57	0.59	0.74	49	1.78	2.0
6	0.36	0.45	0.43	33	1.1	1.8
8	0.42	0.34	0.28	23	1.2	0.94
10	0.22	0.29	0.15	12	0.74	1.40
Averages	0.42	0.40	0.38	29		

* Per 100 fields.

Based on a total of 125 quarterthickness, and 125 midthickness inclusion determinations observed at X1300, the average inclusion content of the South Byron sample is 0.44 percent. At a magnification of X338, the overall inclusion content is 0.40 percent. This percentage is based on a total of 250 quarterthickness and 250 midthickness determinations.

ASTM E-45 Method A Ratings
(Based on worst field in 0.25 sq. in. per specimen)

Specimen Number	Type A		Type B		Type C		Type D	
	thin	heavy	thin	heavy	thin	heavy	thin	heavy
2	5.0	0	3.0	0	2.0	0	3.0	2.0
4	3.0	0	1.0	0	3.5	0	1.0	0
6	4.0	0	1.5	0	3.0	2.0	1.5	0
8	4.0	1.0	1.0	0	1.0	0	1.0	0
10	3.5	0	1.5	0	3.0	0	3.0	2.0

Table VII. Charpy V-notch Impact Transition Temperatures for the South Byron Sample

	Transition Temperature, F		
	15 ft-lb Energy Absorption	15 mil Lateral Expansion	50 percent Shear Fracture
Longitudinal specimens	17.8	13.8	36.3
Transverse specimens	26.3	20.6	28.0

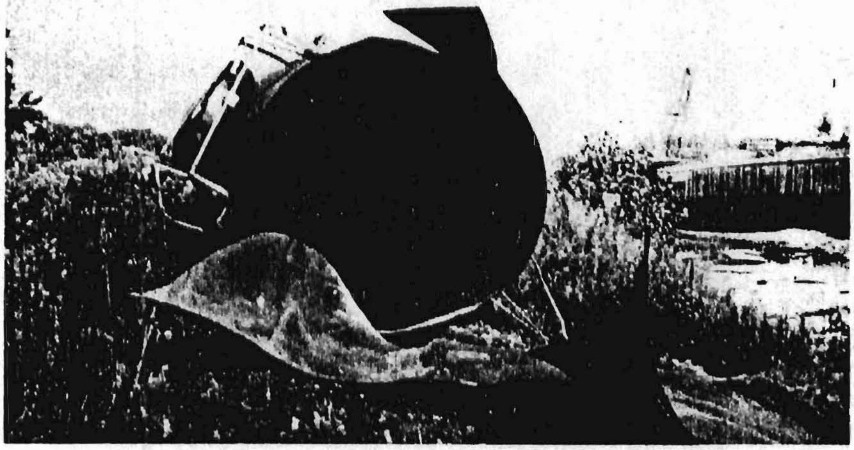


Figure 1. Photograph of the Section of Tank Car PPGX9990 from which the South Byron Sample was Taken.

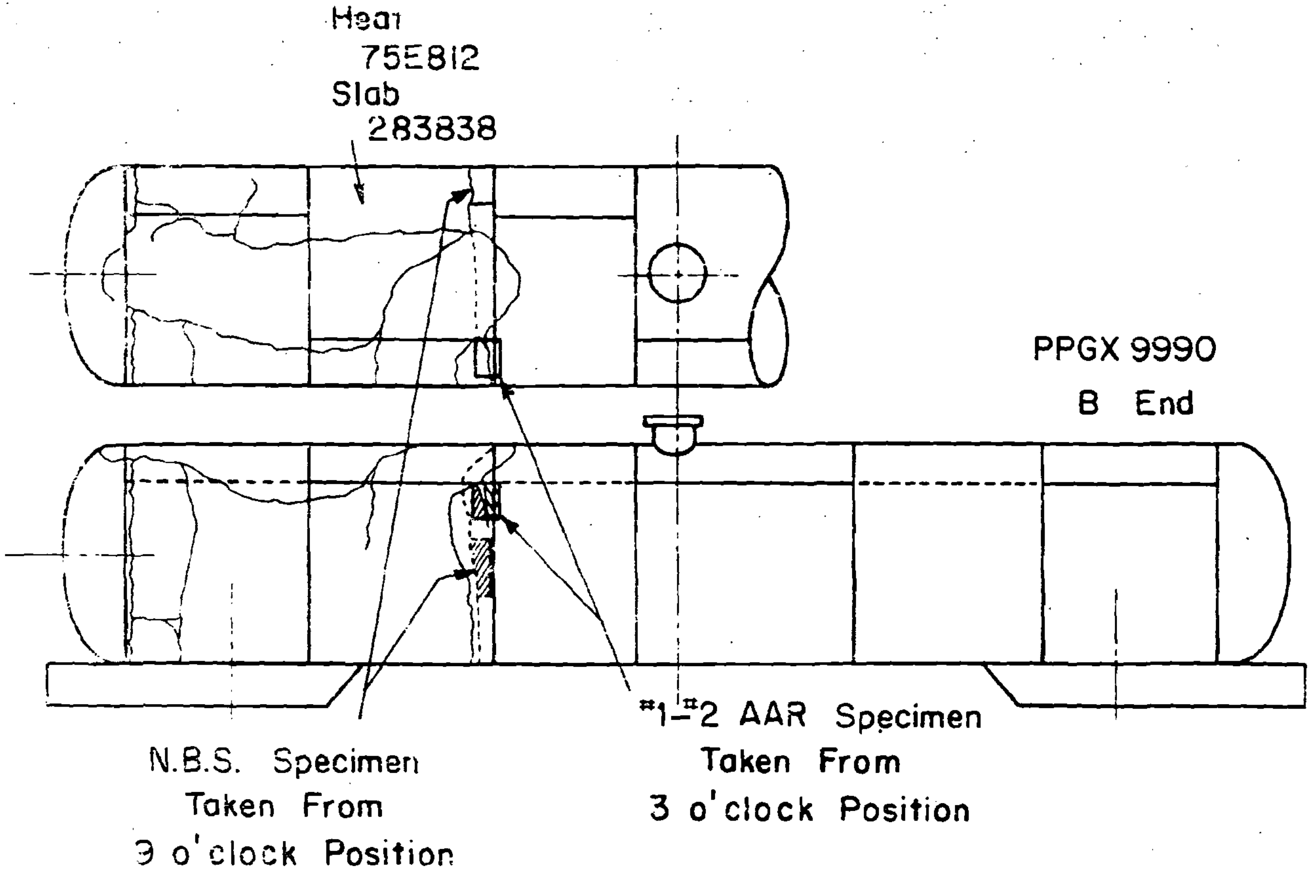


Figure 2. Schematic Diagram Showing the Fracture Lines on Tank Car PPGX9990 and the Location of the South Byron Sample.

A diagram in an AAR report[1] was used to prepare this diagram.

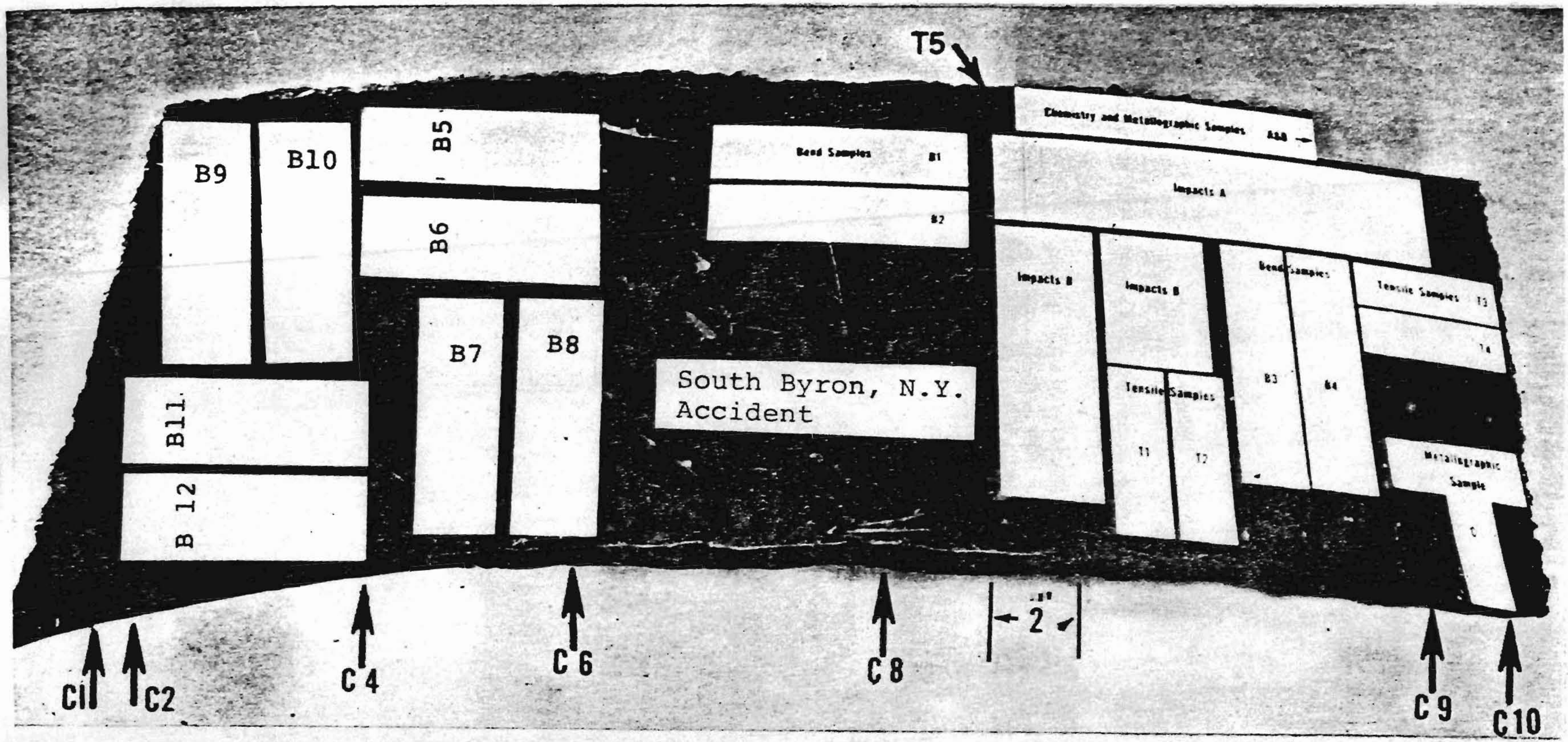


Figure 3. Locations of Specimens on the South Bryon Sample.

The fracture surface extends along the line from C1 to C10. Areas marked C1 through C10 were used for metallographic investigations. Areas B1 through B12 were bend specimens.

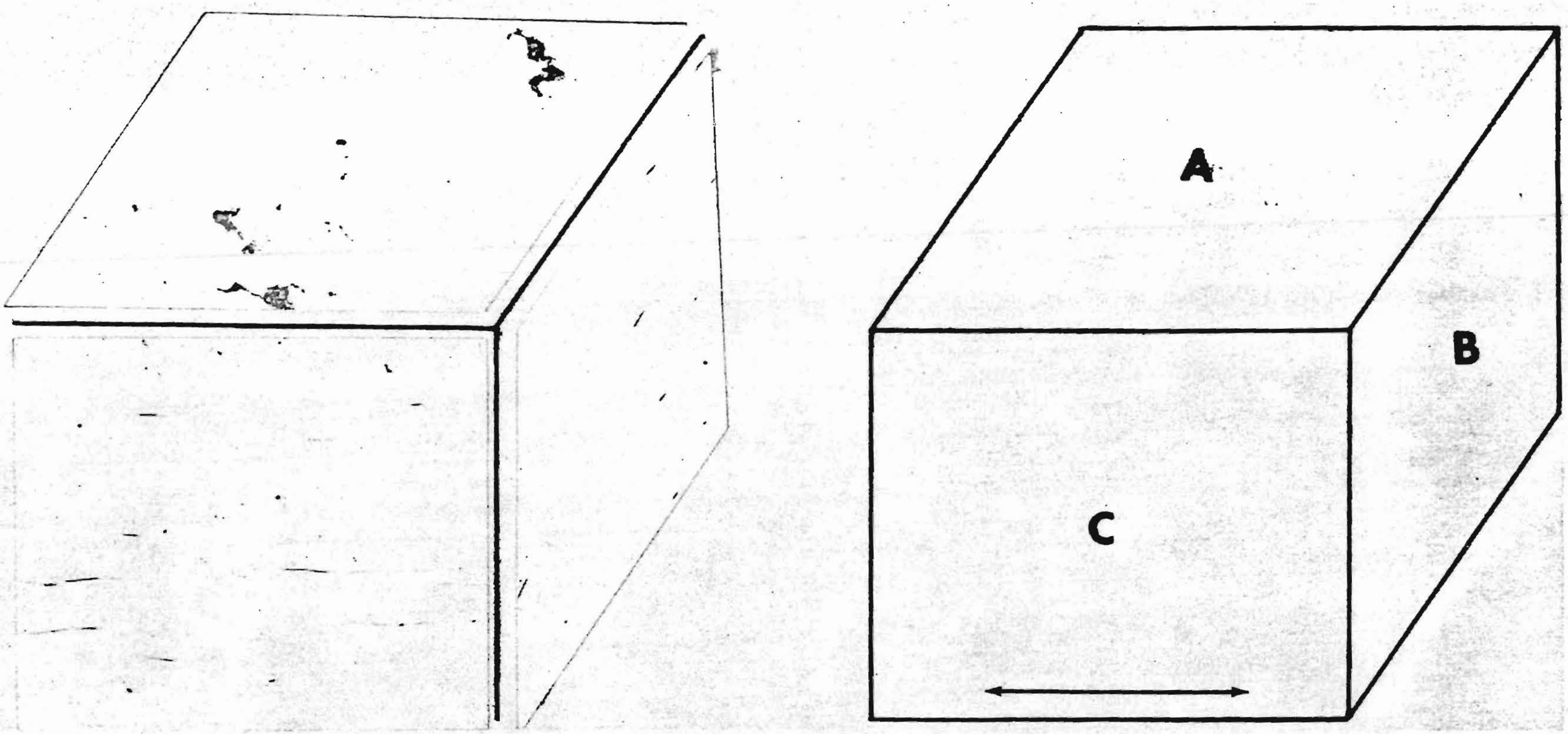
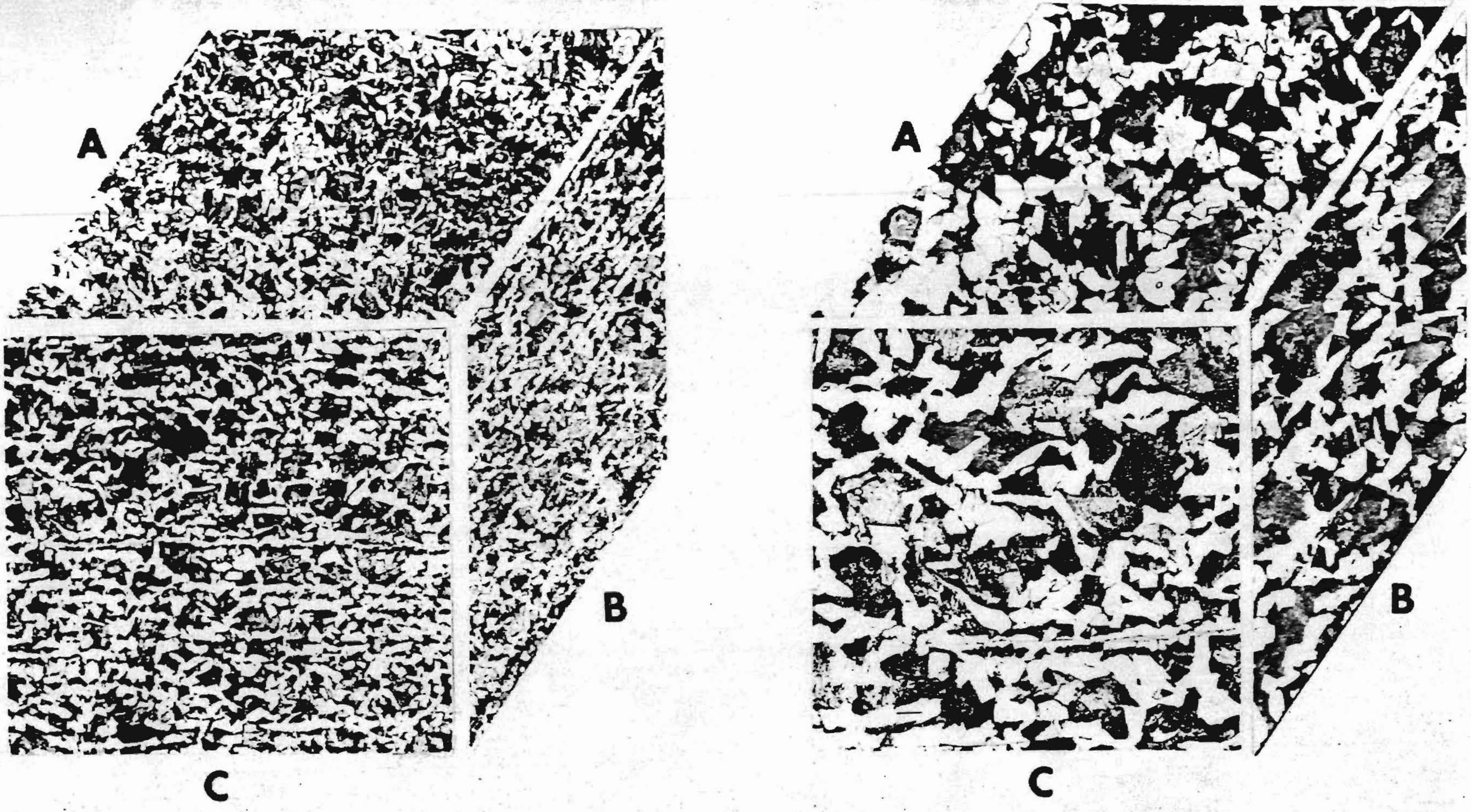


Figure 4. Inclusions on Three Mutually Perpendicular Planes.

The A plane is parallel to the plate surface. The B plane and C plane are approximately perpendicular and parallel, respectively, to the edge of the South Byron sample that contained the fracture. The arrow indicates the direction of crack propagation, which is approximately parallel to the rolling direction (longitudinal) of the shell plate. Unetched. X 100



X 100

X 240

Figure 5. Microstructure of the South Byron Sample, as Observed on Three Mutually Perpendicular Planes.

The A, B, and C planes are oriented as in Figure 4. Etched with Picral.

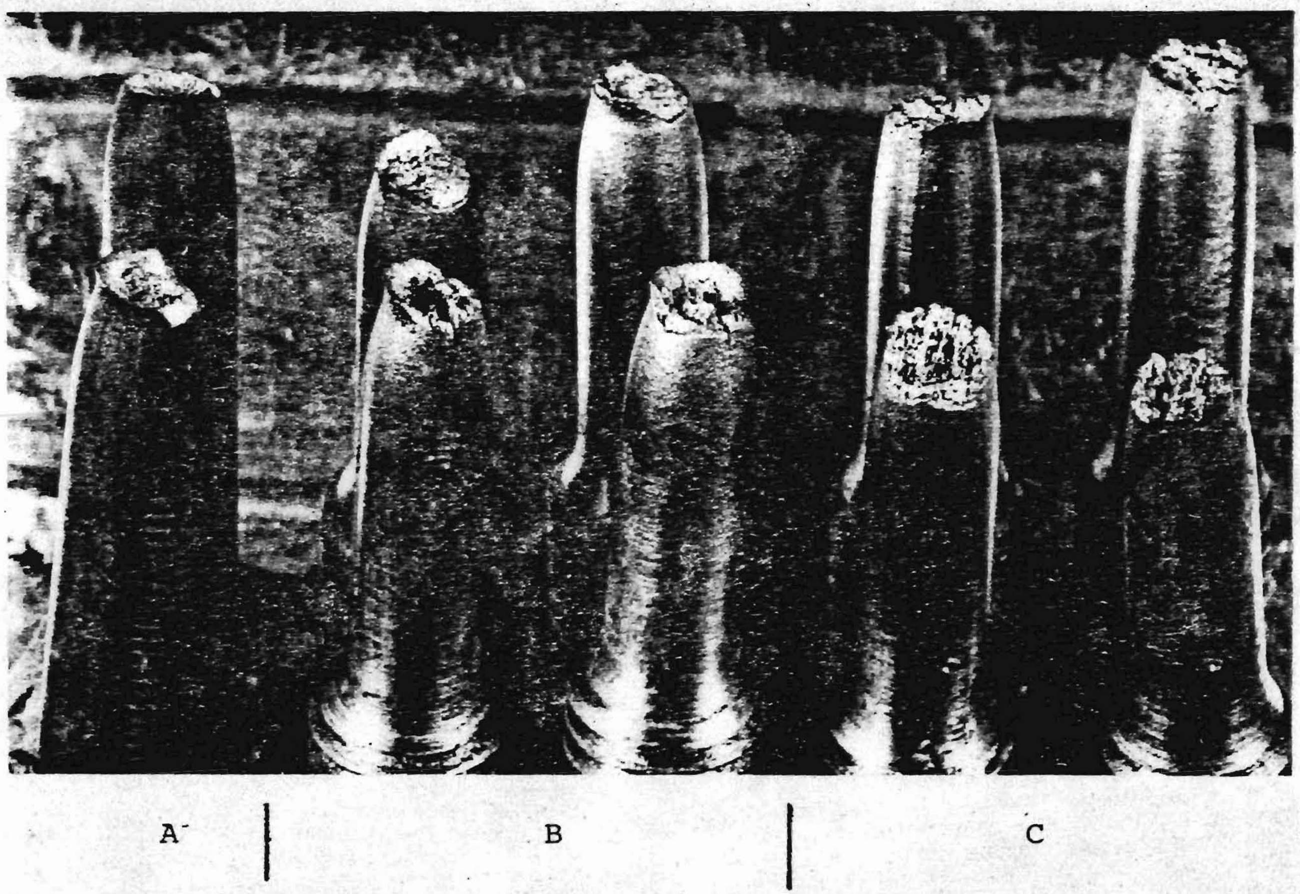
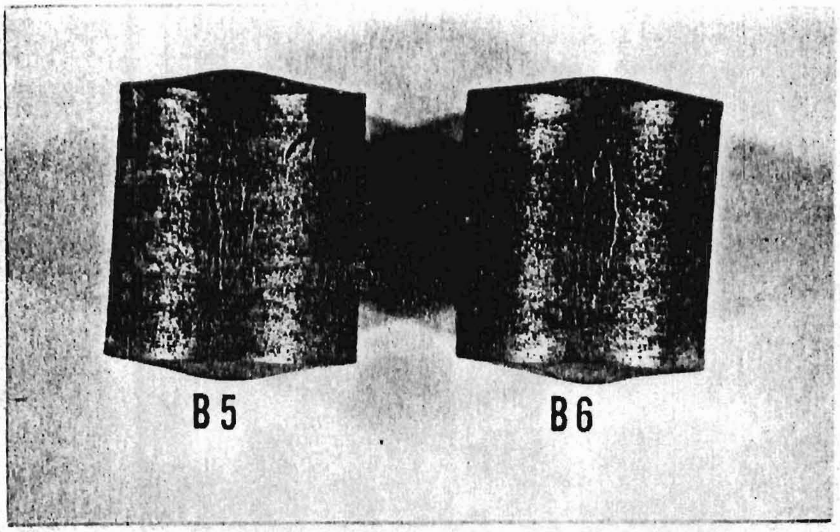


Figure 6. Fracture Appearances of Tension Specimens.

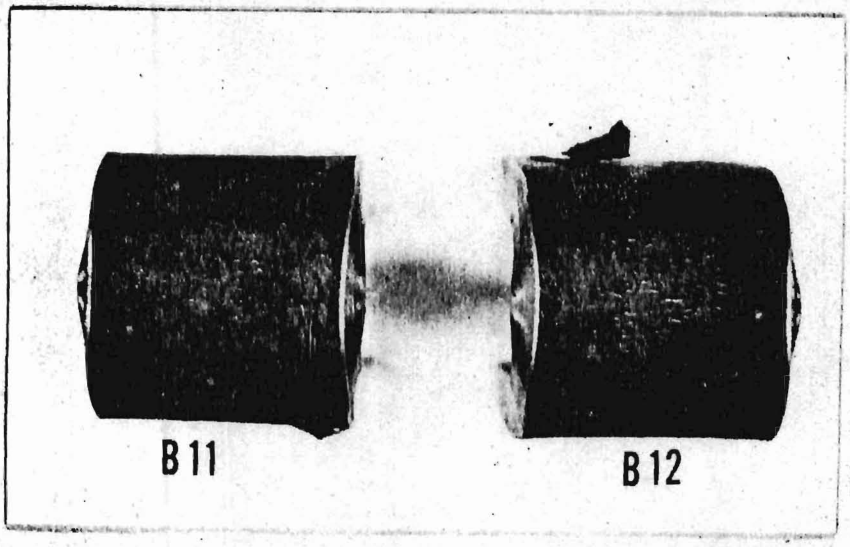
A. Cup-and cone fracture of a 1018 steel round.

B. Cup-and-cone fracture with flat, layered central region - shell plate longitudinal specimens, T3, T4.

C. Flat, layered fracture - shell plate transverse specimens, T1, T2.



Bend diameter equals 1.7 x thickness of specimen.

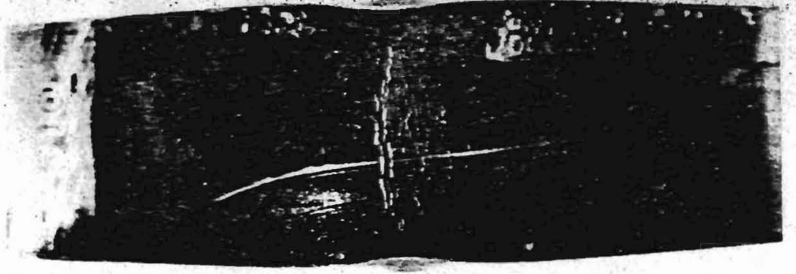


Bend diameter equals 2.0 x thickness of specimen.

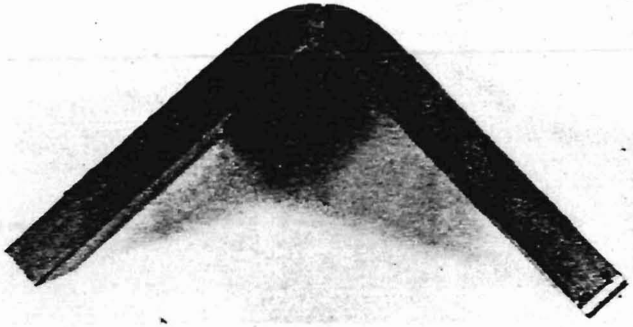
Figure 7. Longitudinal Bend Test Specimens Showing Failure Evidence by Cracking in B5 and B6 and by Crazing in B5, B6, B11, B12, after 180° Bend.

The difference in surface appearances is due to a difference in the lighting used for the photographs. Mag. ~ X 1.

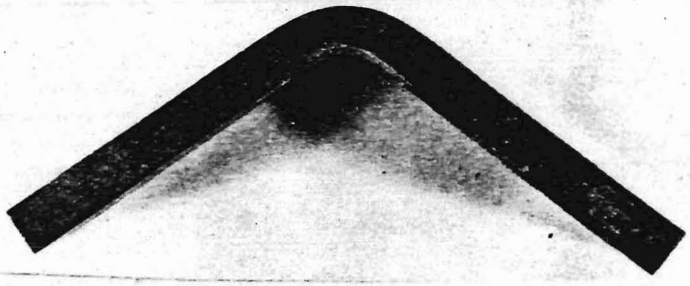
B9 (90° bend) Mag. ~ X 1



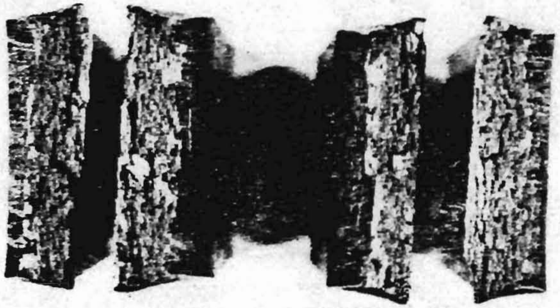
B10 (75° bend) Mag. ~ X 1



B9 (90° bend) Mag. ~ X 3/4



B10 (75° bend) Mag. ~ X 3/4



B7 (90° bend) B8 (85° bend) Mag. ~ X 1

Figure 8. Transverse Bend Test Specimens Showing Failure Evidence by Extensive Cracking and Complete Fracture at Relatively Low Angles of Bend.

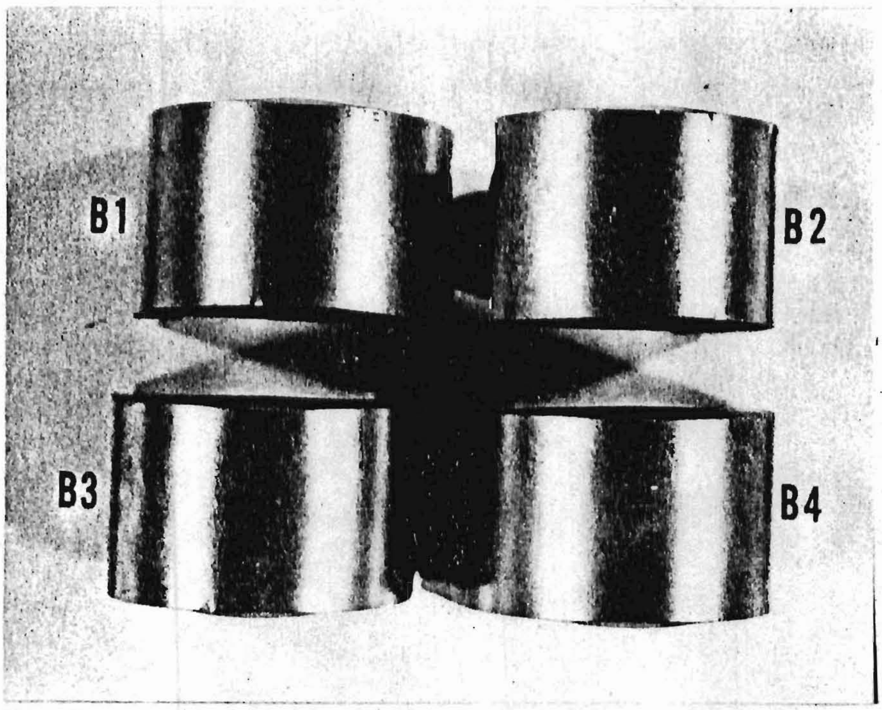
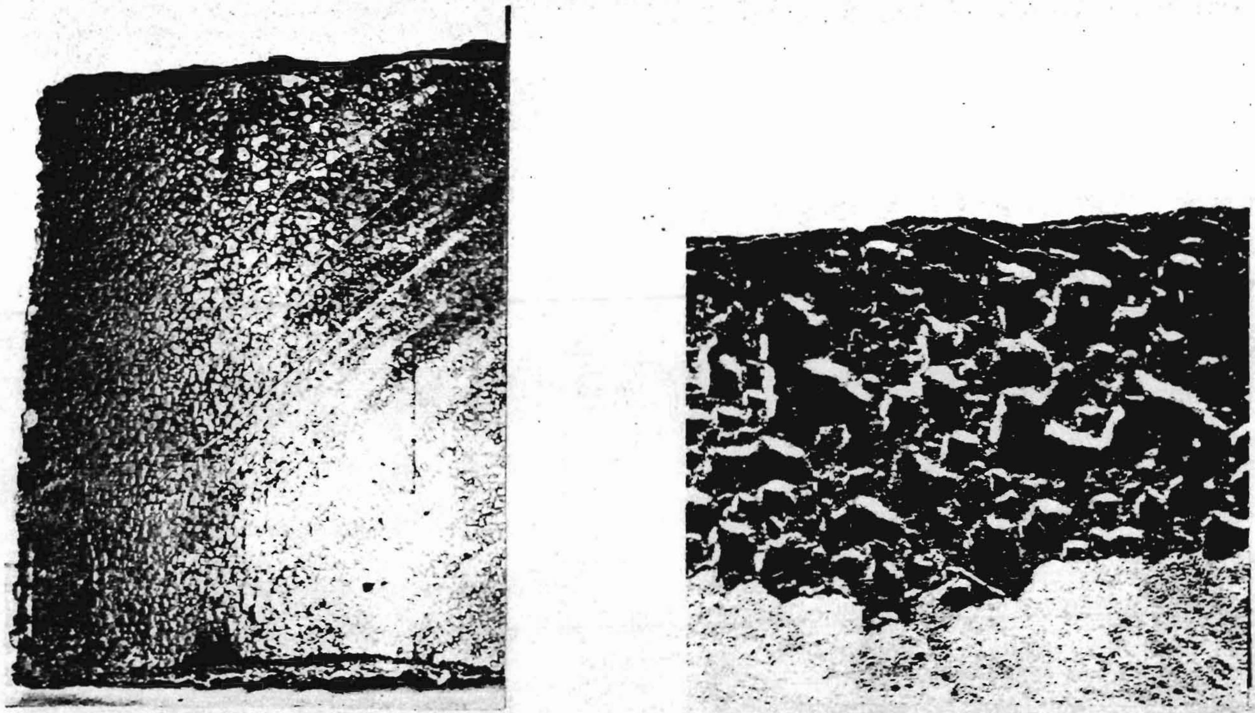


Figure 9. Transverse (B1, B2) and Longitudinal (B3, B4) Surface Ground Bend Specimens of Shell Plate Steel after Testing in Accordance with Guided-Bend Tests of Welds with the Bend Diameter Equal to 4 x Thickness of Specimen. Mag. ~ X 3/4.



Mag. ~ X 1/3

Mag. ~ X 2

Figure 10. Photographs Showing Blistered Paint on the Surface of the South Byron Sample.

Differences in appearance are principally due to lighting effects.

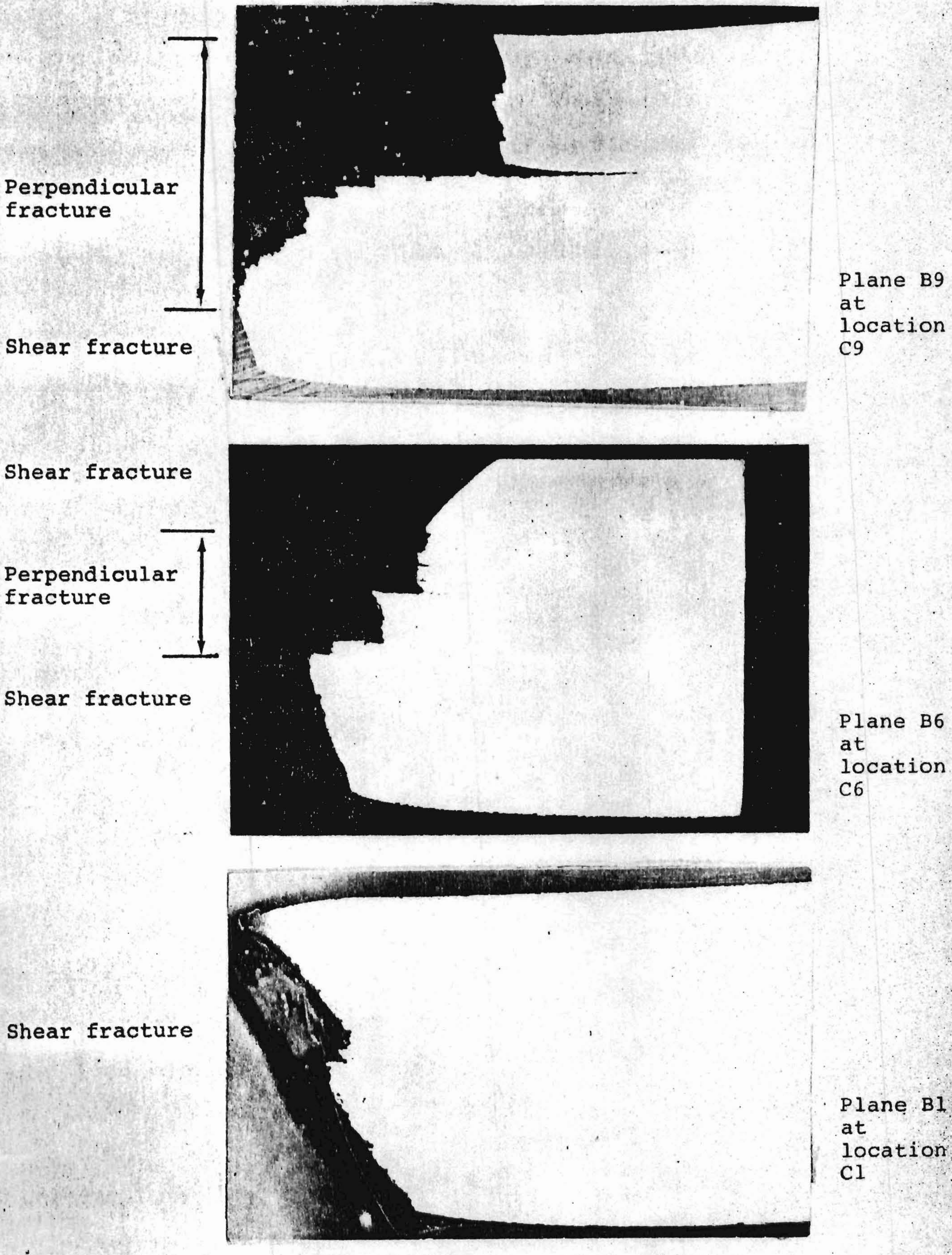


Figure 11. Profile views of the fracture at locations C1, C6, and C9. Mag. ~ X 4.

Figure 12. Charpy V-Notch Impact Test Results.

Longitudinal specimens are oriented parallel to the direction of crack propagation.

Figure 12A

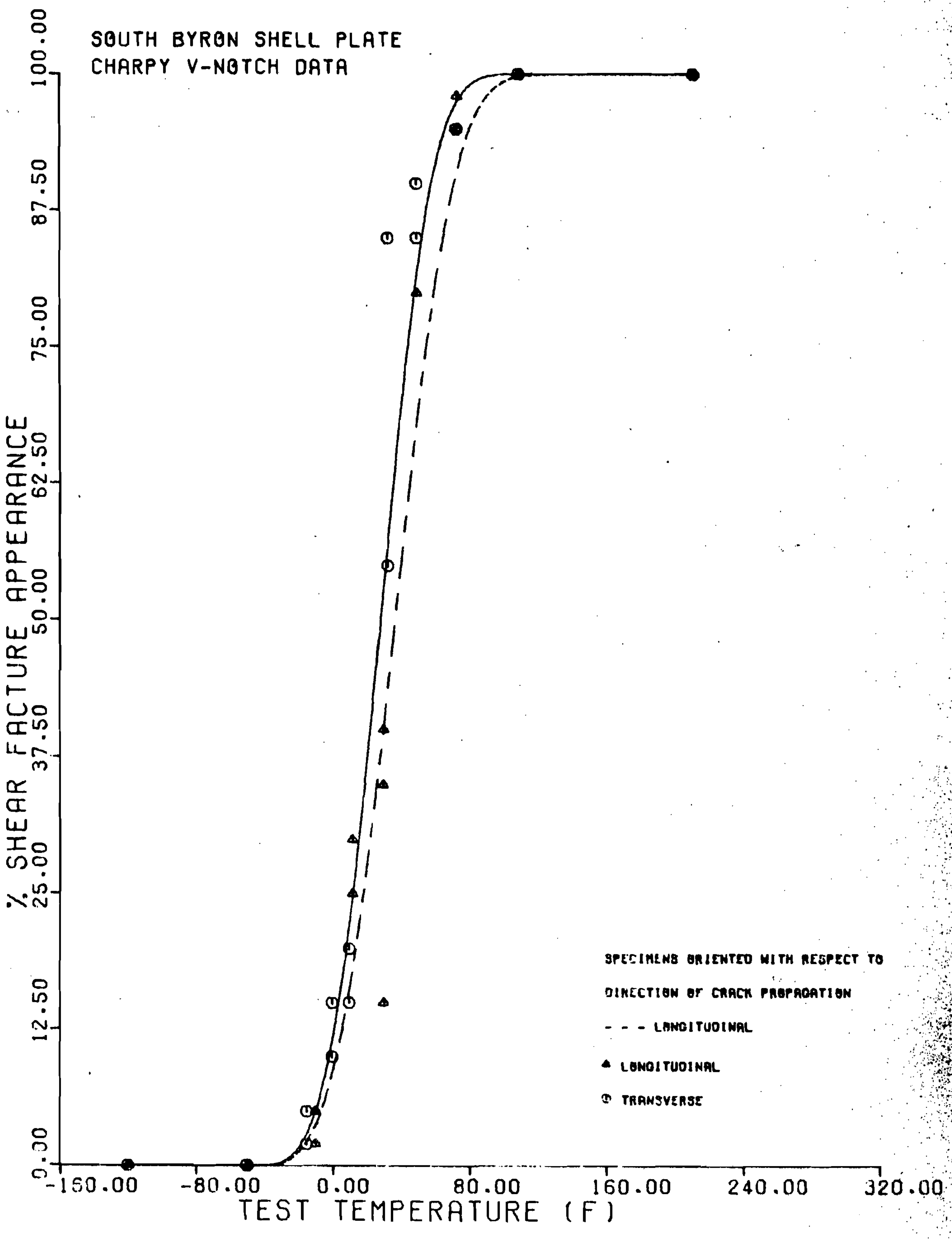

SOUTH BYRON SHELL PLATE
CHARPY V-NOTCH DATA
% SHEAR FACTURE APPEARANCE
0.00
12.50
25.00
37.50
50.00
62.50
75.00
87.50
100.00
TEST TEMPERATURE (F)
-160.00
-80.00
0.00
80.00
160.00
240.00
320.00
SPECIMENS ORIENTED WITH RESPECT TO
DIRECTION OF CRACK PROPAGATION
- - - LONGITUDINAL
▲ LONGITUDINAL
⊕ TRANSVERSE

Figure 12B

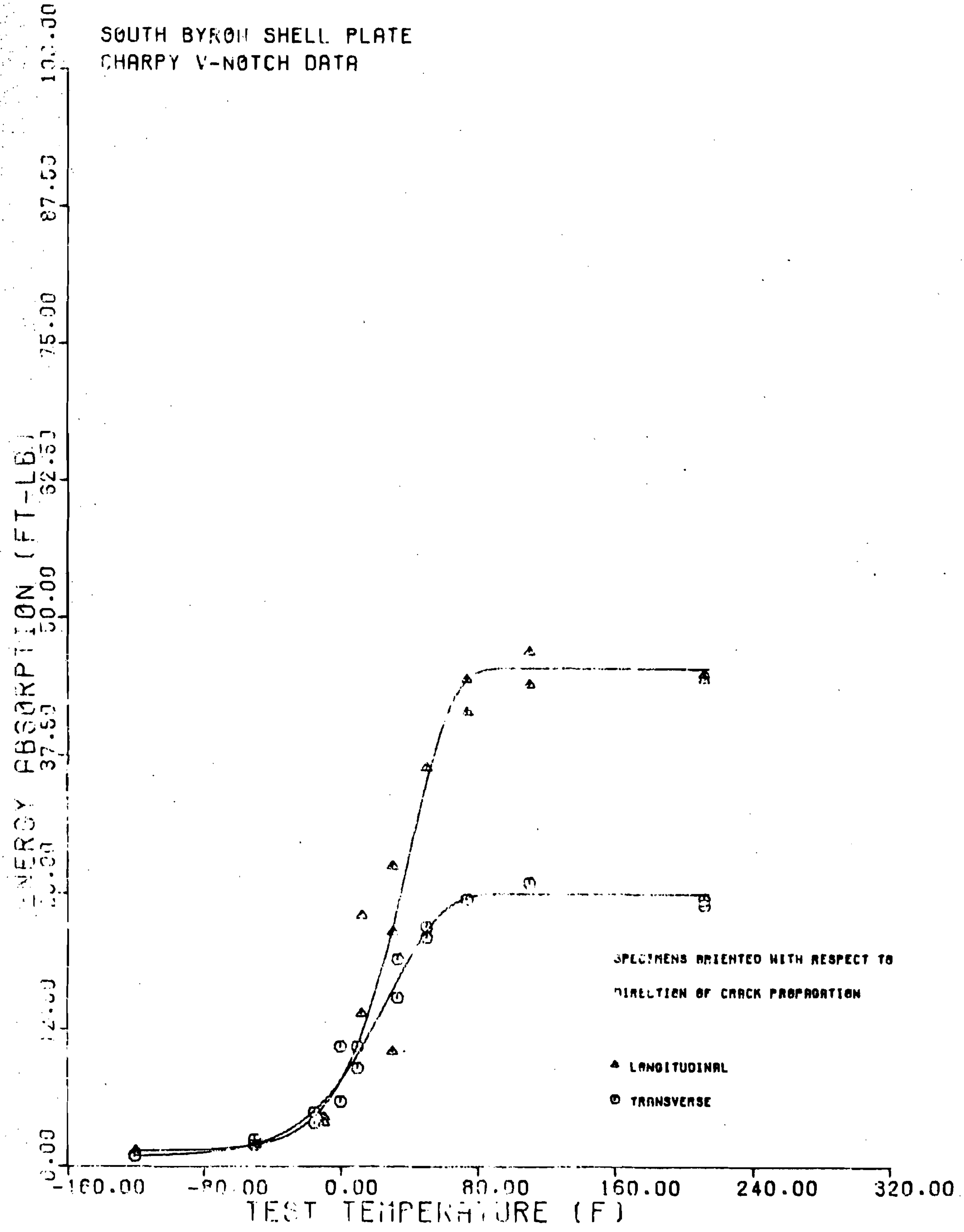
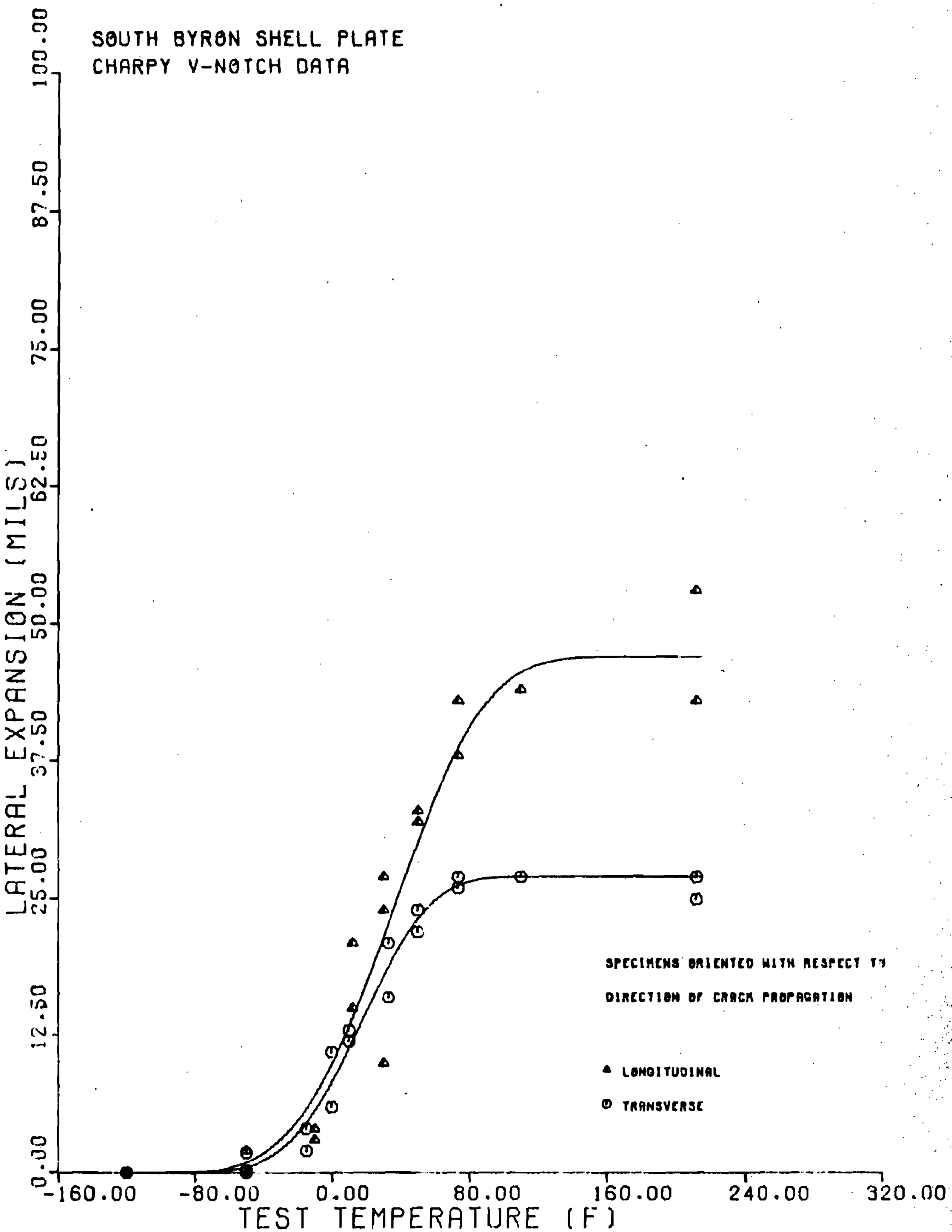
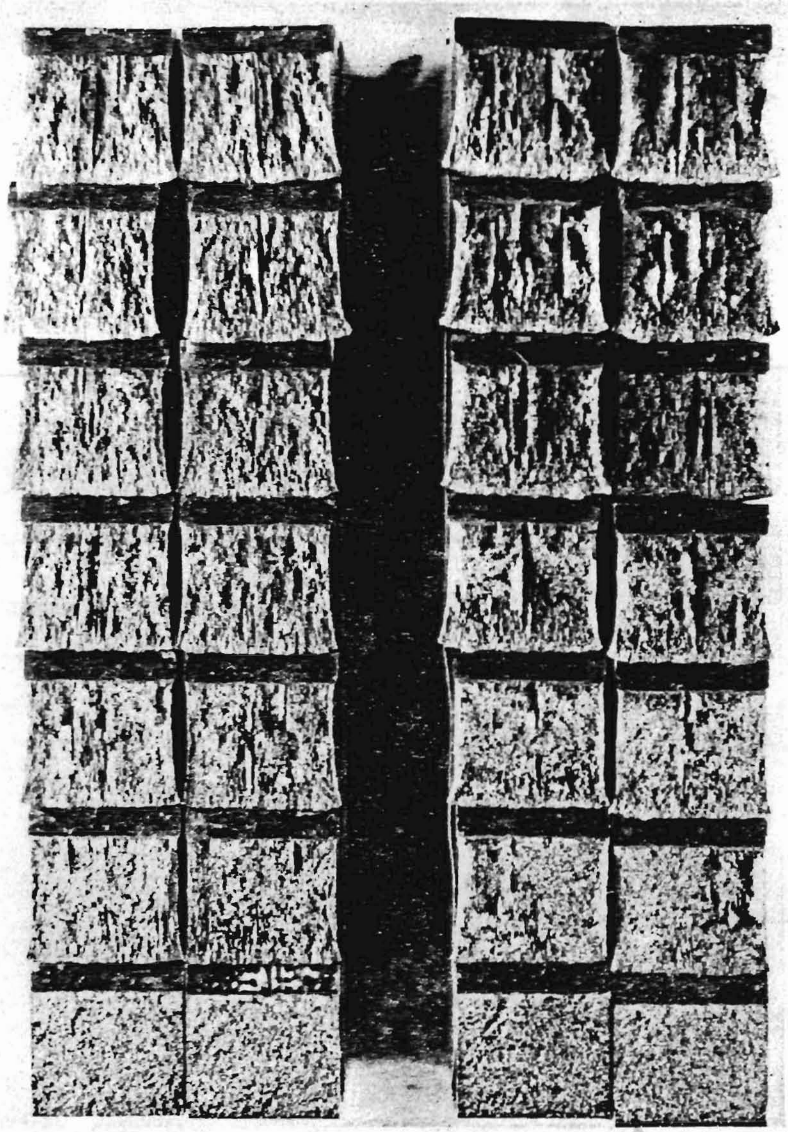

SOUTH BYRON SHELL PLATE
CHARPY V-NOTCH DATA
ENERGY ABSORPTION (FT-LB)
0.00
12.50
25.00
37.50
50.00
62.50
75.00
87.50
100.00
TEST TEMPERATURE (F)
-160.00
-80.00
0.00
80.00
160.00
240.00
320.00
SPECIMENS ORIENTED WITH RESPECT TO
DIRECTION OF CRACK PROPAGATION
LONGITUDINAL
TRANSVERSE

Figure 12C


SOUTH BYRON SHELL PLATE
CHARPY V-NOTCH DATA
LATERAL EXPANSION (MILS)
0.00
12.50
25.00
37.50
50.00
62.50
75.00
87.50
100.00
-160.00
-80.00
0.00
80.00
160.00
240.00
320.00
TEST TEMPERATURE (F)
SPECIMENS ORIENTED WITH RESPECT TO
DIRECTION OF CRACK PROPAGATION
▲ LONGITUDINAL
⊙ TRANSVERSE



Sample No.	Energy Abs. (ft-lb)	Test Temp. (F)	Test Temp. (F)	Energy Abs. (ft-lb)	Sample No.
B29	24.5	+212	+212	44.5	B9
B40	26.0	+110	+110	47.0	B18
B25	24.5	+ 73.5	+ 73.5	44.5	B5
B38	22.0	+ 50	+ 50	36.5	B15
B27	19.0	+ 33	+ 30	21.5	B19
B32	11.0	+ 10	+ 12	14.0	B6
B24	2.0	- 50	- 50	2.0	B1

Figure 13. Fracture Appearances of Selected Charpy Specimens Taken from the South Byron Sample.

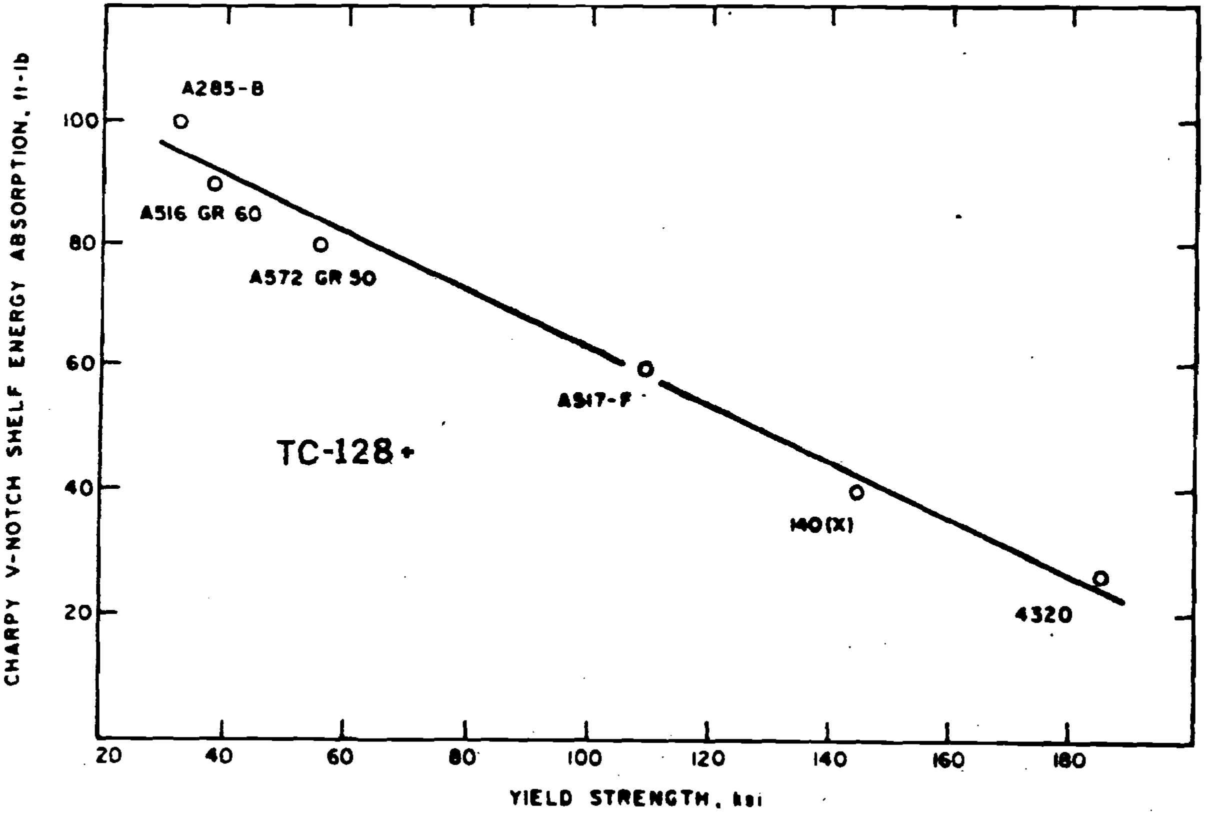


Figure 14. Comparison of the Shelf Energy Absorption of TC128 Steel and Other Conventionally Melted Steels of Various Yield Strength Levels. Reference No. 8.

+ represents the longitudinal shelf energy of the South Byron sample.

Appendix A

American Association of Railroads Specifications M-128-65 and M-128-70

ASSOCIATION OF AMERICAN RAILROADS

OPERATIONS AND MAINTENANCE DEPARTMENT

MECHANICAL DIVISION

SPECIFICATIONS

M-128-65

HIGH TENSILE STRENGTH CARBON-MANGANESE STEEL PLATES FOR TANK CAR TANKS AND OTHER PRESSURE VESSELS

ADOPTED, 1964; REVISED, 1965

1. **Scope.**—This specification covers two grades of high strength carbon-manganese steel plate of flange quality. The maximum thickness shall be 1 inch. Moderately high manganese content, together with small amounts of other elements, provide for high tensile strength with limited carbon content. The steel shall be made to fine grain practice.

Welding technique is of fundamental importance, and it is pre-supposed that welding procedures will be in accordance with good practice.

2. **General Conditions for Delivery.**—Material furnished under these specifications shall conform to the applicable requirements of the current edition of the Specification for General Requirements for Delivery of Rolled Steel Plates of Flange and Firebox Qualities (A.S.T.M. Designation: A-20).

3. **Process.**—The steel shall be made by one or more of the following processes: Open hearth, electric furnace or basic oxygen.

4. **Chemical Composition.**—The steel shall conform to the requirements as to chemical composition prescribed in Table I.

TABLE I. CHEMICAL REQUIREMENTS
(LADLE ANALYSIS)

	Grade A	Grade B
Carbon, max. per cent	0.25	0.25
Manganese, max. per cent		
For plates ¾" and under in thickness	1.35	1.35
For plates over ¾" to 1" incl. in thickness	1.50	1.50
Phosphorus, max. per cent	0.040	0.040
Sulphur, max. per cent	0.050	0.050
Silicon, max. per cent		
For plates ¾" and under in thickness	0.30	0.30
For plates over ¾" to 1" incl. in thickness	0.50	0.50
Vanadium, min. per cent	0.02	—

Grade B will contain small amounts of other elements not exceeding the following percentages:

Copper	0.35%
Nickel	0.25
Chromium	0.25
Molybdenum	0.08

These elements will be reported when requested by the purchaser.

TABLE II. TENSILE REQUIREMENTS

	Grade A Grade B
Tensile strength, psi	81,000 to 101,000
Yieldpoint, min. psi	50,000
Elongation in 8 inches, min. per cent	18.0 (b, c)

5. **Tensile Properties.**—(a) The material as represented by the test specimens shall conform to the requirements as to tensile properties prescribed In Table II.

(b) For material under 5/16 inch in thickness, a deduction from the percentage of elongation in 8 inches specified in Table II of 1.25 per cent shall be made for each decrease of 1/32 inch of the specified thickness below 5/16 inch.

(c) For material over ¾ inch in thickness a deduction from the percentage of elongation in 8 in. specified in Table II of 0.5 per cent shall be made for each increase of ⅛ in. of the specified thickness above ¾ inch. This deduction shall not exceed 3 per cent.

6. **Bending Properties.**—The bend test specimen shall stand being bent cold through 180° without cracking on the outside of the bent portion through an inside diameter which shall have the relation to the thickness of the specimen prescribed in Table III. When the test is made on a specimen reduced in thickness, the rolled surface shall be on the outer curve of the bend.

TABLE III. BEND DIAMETERS

Thickness of Material, in.	Ratio of Bend Diameter to Thickness of Specimen
1 and under	2

7. **Test Specimens.**—Test specimens shall be prepared from the material in the as-rolled condition.

8. **Number of Tests.**—One tension test and one bend test shall be made from each plate as-rolled.

9. **Inspection.**—(a) The inspector representing the purchaser shall have free entry, at all times while the work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the material ordered. The manufacturer shall afford the inspector, free of charge, all reasonable facilities and necessary assistance to satisfy him that the material is being furnished in accordance with these specifications. Tests and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified.

(b) The purchaser may make tests to cover the acceptance or rejection of the material in his own laboratory or elsewhere. Such tests shall be made at the expense of the purchaser.

10. **Rejection.**—(a) Material represented by samples which fail to conform to the requirements of these specifications will be rejected.

(b) Material which shows injurious defects subsequent to its original inspection and acceptance at the manufacturer's works, or elsewhere, will be rejected, and the manufacturer shall be notified.

11. **Rehearing.**—Samples tested in accordance with these specifications which represent rejected material, shall be held for a period of fourteen, (14) days from date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

M128.00 SPECIFICATION FOR HIGH STRENGTH CARBON MANGANESE STEEL PLATES FOR TANK CARS – AAR TC128-70.

M128.01 SCOPE

(a) This specification covers two grades of high strength carbon-manganese steel plate of flange quality. The maximum thickness shall be 1 inch. Moderately high manganese content, together with small amounts of other elements provide for high strength with limited carbon content. The steel shall be made to fine grain practice. Welding technique is of fundamental importance, and it is presupposed that welding procedure will be in accordance with good practice.

(b) The material shall be furnished in the as-rolled condition. When specified for low temperature service the material shall be furnished normalized to meet requirements of ASTM Specification A300-68, Class 1, except that impact specimens shall be Type A Charpy V-Notch as shown in ASTM Specification A370-68 and meet impact requirements at the temperature specified in the tank car specification.

M128.02 GENERAL CONDITIONS FOR DELIVERY

(a) Material furnished under this specification shall conform to the applicable requirements of ASTM Specification A20-69a titled, "General Requirements for Delivery of Steel Plates for Pressure Vessels."

(b) See M128.01(b).

M128.03 PROCESS

(a) The steel shall be made by one or more of the following processes:

(1) Open-hearth,
(2) Electric furnace, or
(3) Basic oxygen.

M128.04 CHEMICAL COMPOSITION

(a) The steel shall conform to the requirements as to chemical composition prescribed in Table M128.04(a).

TABLE M128.04(a) CHEMICAL REQUIREMENTS

Element		Ladle Analysis, Percent	
		Grade A	Grade B
Carbon	Max.	0.25	0.25
Manganese,	Max.		
For plates 3/4" and under in thickness		1.35	1.35
For plates over 3/4" to 1" incl. in thickness		1.50	1.50
Phosphorus	Max.	0.040	0.040
Sulfur	Max.	0.050	0.050
Silicon	Max.		
For plates 3/4" and under in thickness		0.30	0.30
For plates over 3/4" to 1" incl. in thickness		0.50	0.50
Vanadium a/		0.02 Min.	0.08 Max.
Copper a/	Max.	...	0.35
Nickel a/	Max.	...	0.25
Chromium a/	Max.	...	0.25
Molybdenum a/	Max.	...	0.08

a/ These elements will be reported when requested by the purchaser.

M128.05 TENSILE PROPERTIES

(a) The material as represented by the test specimens shall conform to the requirements as to tensile properties prescribed in Table M128.05(a).

TABLE M128.05(a) TENSILE REQUIREMENTS

Property		Grade A and Grade B
Tensile strength, psi		81,000 to 101,000
Yield point, psi	Min.	50,000
Elongation in 8 inches percent	Min.	16.0 a/
Elongation in 2 inches percent	Min.	19.0

a/ For material under 5/16 inch thick a reduction from the specified percent of elongation of 1.25 percent shall be made for each decrease of 1/32 inch of thickness below 5/16 inch. For material over 3/4 inch thick a reduction from the specified percent elongation of 0.5 percent shall be made for each increase of 1/8 inch of the thickness above 3/4 inch; this deduction shall not exceed 3 percent.

M128.06 BENDING PROPERTIES

(a) The bend test specimens shall stand being bent cold through 180° without cracking on the outside of the bent portion through an inside diameter which shall have the relation to the thickness of the specimen prescribed in Table M128.06(a). When the test is made on a specimen reduced in thickness, the rolled surface shall be on the outer curve of the bend.

TABLE M128.06(a) BEND DIAMETERS

Thickness of Material, Inches	Ratio of Bend Diameter to Thickness of Specimen
1 and under	2

M128.07 TEST SPECIMENS

(a) Test specimens shall be prepared from the material in the as-rolled condition.

M128.08 NUMBER OF TESTS

(a) One tension test and one bend test shall be made from each plate as rolled.

Note: The term "plate as rolled" used here refers to the unit plate rolled from a slab or directly from an ingot in its relation to the location and number of specimens, not to its condition.

M128.09 INSPECTION

(a) The inspector representing the purchaser shall have free entry, at all times while the work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the material ordered. The manufacturer shall afford the inspector, free of charge, all reasonable facilities and necessary assistance to satisfy him that the material is being furnished in accordance with these specifications. Tests and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified.

(b) The purchaser may make tests to cover the acceptance or rejection of the material in his own laboratory or elsewhere. Such tests shall be made at the expense of the purchaser.

M128.10 REJECTION

(a) Material represented by samples which fail to conform to the requirements of these specifications will be rejected.

(b) Material which shows injurious defects subsequent to its original inspection and acceptance at the manufacturer's works, or elsewhere, will be rejected, and the manufacturer shall be notified.

M128.11 REHEARING

(a) Samples tested in accordance with these specifications which represent rejected material, shall be held for a period of fourteen days from date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

Appendix B

Experimental and Calculational Results of Charpy V-Notch Impact Tests

Appendix B

Table B1

```
SOUTH BYRON SHELL PLATE
CHARPY V-NOTCH DATA
SPECIMENS ORIENTED WITH RESPECT TO DIRECTION OF CRACK PROPAGATION
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF LONGITUDINAL SPECIMENS

SPECIMEN TEMPERATURE(F) OBSERVED SHEAR       CALCULATED SHEAR
                        FRACTURE (%)         FRACTURE (%)
B14        -120.0               .0                .0
B2          -50.0               .0                .0
B3          -50.0               .0                .0
B1          -50.0               .0                .0
B11         -10.0              5.0               3.9
B10         -10.0              2.0               3.9
B7           12.0             25.0              18.8
B6           12.0             30.0              18.8
B13          30.0             35.0              40.9
B12          30.0             15.0              40.9
B19          30.0             40.0              40.9
B16          50.0             80.0              69.0
B15          50.0             80.0              69.0
B4           73.5             95.0              91.6
B5           73.5             90.0              91.6
B18         110.0            100.0              99.8
B17         110.0            100.0              99.8
B8          212.0            100.0             100.0
B9          212.0            100.0             100.0

% SHEAR          CALCULATED          /   TEMPERATURE      CALCULATED SHEAR
FRACTURE         TEMPERATURE(F)      /       (F)          FRACTURE(%)
     2.0             -16.4           /      10.0              16.6
     5.0              -7.3           /      20.0              27.7
    10.0               1.6           /      30.0              40.9
    15.0               8.0           /      40.0              55.3
    50.0              36.3           /      50.0              69.0
    85.0              64.5           /      60.0              80.7
    90.0              71.0           /      70.0              89.3
    95.0              80.4           /
    98.0              90.6           /
```

Appendix B (Continued)

Table B2

```
SOUTH BYRON SHELL PLATE
CHARPY V-NOTCH DATA
SPECIMENS ORIENTED WITH RESPECT TO DIRECTION OF CRACK PROPAGATION
CALCULATIONS FOR SHEAR FRACTURE APPEARANCE DATA OF TRANSVERSE SPECIMENS

SPECIMEN TEMPERATURE(F) OBSERVED SHEAR      CALCULATED SHEAR
                        FRACTURE (%)        FRACTURE (%)
B37         -120.0                .0                 .0
B23          -50.0                .0                 .0
B24          -50.0                .0                 .0
B22          -50.0                .0                 .0
B36          -15.0               2.0                3.1
B35          -15.0               5.0                3.1
B34             .0              10.0               12.1
B33             .0              15.0               12.1
B32           10.0              20.0               22.8
B31           10.0              15.0               22.8
B28           33.0              55.0               58.2
B27           33.0              85.0               58.2
B38           50.0              90.0               82.3
B39           50.0              85.0               82.3
B26           73.5              95.0               97.6
B25           73.5              95.0               97.6
B40          110.0             100.0              100.0
B29          212.0             100.0              100.0
B30          212.0             100.0              100.0

% SHEAR         CALCULATED        /  TEMPERATURE     CALCULATED SHEAR
FRACTURE        TEMPERATURE(F)    /      (F)         FRACTURE(%)
     2.0           -18.6          /         .0           12.1
     5.0           -10.5          /       10.0           22.8
    10.0            -2.6          /       20.0           37.1
    15.0             3.1          /       30.0           53.3
    50.0            28.0          /       40.0           69.1
    85.0            52.6          /       50.0           82.3
    90.0            58.2          /
    95.0            66.3          /
    98.0            75.2          /
```

Appendix B (Continued)

Table B3

```
SOUTH BYRON SHELL PLATE
CHARPY V-NOTCH DATA
SPECIMEN ORIENTATION WITH RESPECT TO DIRECTION OF CRACK PROPAGATION
CALCULATIONS FOR ENERGY ABSORPTION DATA OF LONGITUDINAL SPECIMENS

SPECIMEN TEMPERATURE(F)  OBSERVED ENERGY      CALCULATED ENERGY
                          ABSORPTION(FT-LB)   ABSORPTION(FT-LB)
B14        -120.0              1.5                  1.5
B2          -50.0              2.0                  2.0
B3          -50.0              2.0                  2.0
B1          -50.0              2.0                  2.0
B11         -10.0              4.5                  5.5
B10         -10.0              4.0                  5.5
B7           12.0             23.0                 12.3
B6           12.0             14.0                 12.3
B13          30.0             27.5                 22.1
B12          30.0             19.5                 22.1
B19          30.0             21.5                 22.1
B16          50.0             36.5                 35.4
B15          50.0             36.5                 35.4
B4           73.5             41.5                 44.4
B5           73.5             44.5                 44.4
B18         110.0             47.0                 45.5
B17         110.0             44.0                 45.5
B8          212.0             45.0                 45.5
B9          212.0             44.5                 45.5

ENERGY           CALCULATED        /  TEMPERATURE     CALCULATED ENERGY
ABSORPTION       TEMPERATURE(F)    /      (F)         ABSORPTION(FT-LB)
    10.0              6.3          /      10.0              11.4
    15.0             17.8          /      20.0              16.2
    20.0             26.7          /      30.0              22.1
    25.0             34.4          /      40.0              28.8
    30.0             41.7          /      50.0              35.4
    35.0             49.4          /      60.0              40.6
    40.0             58.7          /      70.0              43.8
    45.0             78.6          /      80.0              45.1
                                   /      90.0              45.5
                                   /     100.0              45.5
```

Appendix B (Continued)

Table B4

SOUTH BYRON SHELL PLATE
CHARPY V-NOTCH DATA
SPECIMEN ORIENTATION WITH RESPECT TO DIRECTION OF CRACK PROPAGATION
CALCULATIONS FOR ENERGY ABSORPTION DATA OF TRANSVERSE SPECIMENS

SPECIMEN	TEMPERATURE(F)	OBSERVED ENERGY ABSORPTION(FT-LB)	CALCULATED ENERGY ABSORPTION(FT-LB)
B37	-120.0	1.0	1.0
B23	-50.0	2.5	2.1
B24	-50.0	2.0	2.1
B22	-50.0	2.0	2.1
B36	-15.0	4.0	5.2
B35	-15.0	5.0	5.2
B34	.0	6.0	7.9
B33	.0	11.0	7.9
B32	10.0	11.0	10.3
B31	10.0	9.0	10.3
B28	33.0	15.5	17.1
B27	33.0	19.0	17.1
B38	50.0	22.0	21.6
B39	50.0	21.0	21.6
B26	73.5	24.5	24.6
B25	73.5	24.5	24.6
B40	110.0	26.0	25.0
B29	212.0	24.5	25.0
B30	212.0	24.0	25.0

ENERGY ABSORPTION	CALCULATED TEMPERATURE(F)	/	TEMPERATURE (F)	CALCULATED ENERGY ABSORPTION(FT-LB)
10.0	8.9	/	10.0	10.3
15.0	26.3	/	20.0	13.1
20.0	43.3	/	30.0	16.1
25.0	212.0	/	40.0	19.1
		/	50.0	21.6
		/	60.0	23.4
		/	70.0	24.4
		/	80.0	24.8
		/	90.0	25.0
		/	100.0	25.0

Appendix B (Continued)

Table B5

```
SOUTH BYRON SHELL PLATE
CHARPY V-NOTCH DATA
SPECIMEN ORIENTATION WITH RESPECT TO DIRECTION OF CRACK PROPAGATIO
CALCULATIONS FOR LATERAL EXPANSION DATA OF LONGITUDINAL SPECIMENS

SPECIMEN TEMPERATURE(F) OBSERVED LATERAL   CALCULATED LATERAL
                        EXPANSION (MILS)   EXPANSION (MILS)
B14        -120.0                 .0                  .0
B2          -50.0                2.0                  .9
B3          -50.0                 .0                  .9
B1          -50.0                 .0                  .9
B11         -10.0                4.0                 7.2
B10         -10.0                3.0                 7.2
B7           12.0               21.0                14.3
B6           12.0               15.0                14.3
B13          30.0               27.0                21.7
B12          30.0               10.0                21.7
B19          30.0               24.0                21.7
B16          50.0               32.0                30.3
B15          50.0               33.0                30.3
B4           73.5               38.0                38.8
B5           73.5               43.0                38.8
B18         110.0               44.0                45.5
B17         110.0               44.0                45.5
B8          212.0               53.0                47.0
B9          212.0               43.0                47.0

LATERAL           CALCULATED      /  TEMPERATURE      CALCULATED LATERAL
EXPANSION(MILS) TEMPERATURE(F)    /      (F)          EXPANSION(MILS)
      10.0            -.3         /         .0              10.1
      15.0           13.8         /       10.0              13.6
      20.0           26.0         /       20.0              17.5
      25.0           37.5         /       30.0              21.7
      30.0           49.2         /       40.0              26.1
      35.0           62.0         /       50.0              30.3
      40.0           77.7         /       60.0              34.3
      45.0          104.6         /       70.0              37.7
                                  /       80.0              40.6
                                  /       90.0              42.6
                                  /      100.0              44.4
                                  /      110.0              45.5
                                  /      120.0              46.2
                                  /      130.0              46.6
                                  /      140.0              46.8
                                  /      150.0              46.9
                                  /      160.0              47.0
                                  /      170.0              47.0
                                  /      180.0              47.0
```

Appendix B (Continued)

Table B6

```
SOUTH BYRON SHELL PLATE
CHARPY V-NOTCH DATA
SPECIMEN ORIENTATION WITH RESPECT TO DIRECTION OF CRACK PROPAGATIO
CALCULATIONS FOR LATERAL EXPANSION DATA OF TRANSVERSE SPECIMENS

SPECIMEN TEMPERATURE(F) OBSERVED LATERAL   CALCULATED LATERAL
                        EXPANSION (MILS)   EXPANSION (MILS)
B37         -120.0                .0                .0
B23          -50.0               1.8                .5
B24          -50.0                .0                .5
B22          -50.0                .2                .5
B36          -15.0               2.0               4.6
B35          -15.0               4.0               4.6
B34             .0               6.0               8.4
B33             .0              11.0               8.4
B32           10.0              12.0              11.5
B31           10.0              13.0              11.5
B28           33.0              16.0              18.9
B27           33.0              21.0              18.9
B38           50.0              24.0              23.2
B39           50.0              22.0              23.2
B26           73.5              27.0              26.2
B25           73.5              26.0              26.2
B40          110.0              27.0              27.0
B29          212.0              25.0              27.0
B30          212.0              27.0              27.0

LATERAL           CALCULATED      /  TEMPERATURE     CALCULATED LATERAL
EXPANSION(MILS)   TEMPERATURE(F)  /      (F)         EXPANSION(MILS)
     10.0              5.3        /      10.0             11.5
     15.0             20.6        /      20.0             14.8
     20.0             36.7        /      30.0             18.0
     25.0             60.8        /      40.0             20.9
                                  /      50.0             23.2
                                  /      60.0             24.9
                                  /      70.0             26.0
                                  /      80.0             26.5
                                  /      90.0             26.8
                                  /     100.0             26.9
                                  /     110.0             27.0
                                  /     120.0             27.0
```