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A METALLURGICAL ANALYSIS OF FIVE STEEL PLATES TAKEN FROM A TANK CAR ACCIDENT NEAR CRESCENT CITY, ILLINOIS

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FINAL REPORT

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16. Abstract A metallurgical analysis of five steel samples (numbered FRA-1 through FRA-5) was requested by the Bureau of Railroad Safety, Federal Railroad Administration, Department of Transportation. These steel samples were taken from two tank cars (numbered SOEX 3037 and SOEX 3219) which had been involved in an accident near Crescent City, Illinois. Samples FRA-1, FRA-4, and FRA-5 were reported to be shell plates and sample FRA-3, a head plate. Sample FRA-2 was a welded sample of head plate and shell plate and it was used for most of the mechanical properties determinations in this report. An investigation was conducted at the National Bureau of Standards to determine if the samples conformed with the appropriate specifications for tank car materials and to gather information pertinent to the question of the suitability of these steels for use as plate materials of tank cars. Samples FRA-1, -2, and -5 were reportedly produced to the specification for ASTM A 212-65 Grade B, flange quality steel (A 212-B); and FRA-3 and -4 were reportedly produced to specification AAR M128 Grade B, flange quality steel (M128-B).			
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SUMMARY AND CONCLUSIONS

1. The Crescent City samples investigated in this report include two M128-B steels numbered FRA-3, and -4; and four A 212-B steels, numbered FRA-1, -2 shell, -2 head, and -5.
2. The chemical compositions of the four samples of A 212-B steels and one of the M128-B steels met the chemical requirements for their respective grades of steel. However, the other M128-B steel (FRA-3) contains carbon at a level that is high for M128-B steel, but the amount by which it exceeds the specified maximum plus tolerance is marginal. In addition, the producer's ladle analysis for this steel does not agree with the NBS check analyses for carbon and manganese.
3. The results of tensile tests conducted on sample FRA-2 indicated that the head plate, the shell plate and the weld met the tensile requirements for A 212-B steel, and that the weld joint efficiency is 1.
4. The results of bend tests conducted on sample FRA-2 indicated that this A 212-B steel shell plate passed the bend requirements for plates and the weldment passed the guided-bend test for welds.
5. The results of thickness measurements and observations of the fracture mode of the five failed plates indicated that substantial plate thinning occurred near the fracture surfaces of samples that failed with a shear failure mode, FRA-2, FRA-4, and FRA-5; whereas in samples FRA-1 and FRA-3 substantial plate thinning did not occur near the fracture surfaces and the profile views of FRA-1 and FRA-3 respectively showed that fracture occurred either on a plane perpendicular to the plate surfaces or in a step-like shear mode.
6. A region of high hardness was observed near the plate surface of a sample of head plate (M128-B) steel taken from FRA-3. This region is believed to be an improperly stress-relieved heat-affected-zone of a weldment.

7. The results of Charpy V-notch impact tests conducted on the A 212-B steel samples of head and shell plate contained in sample FRA-2 indicated that:
 - a. The shell plate is anisotropic with a ratio of longitudinal to transverse energy absorption values of about 2, indicating that this plate did not receive substantial cross-rolling.
 - b. The head plate is also not isotropic, but it may be more isotropic than the shell plate of FRA-2.
 - c. The transition temperatures for the shell plate are above 34 F and for the head plate are above 70 F, by any of three arbitrarily selected criteria.
 - d. The upper-shelf energy absorption values for the shell and head plates are near the expected values for steels of their respective strength levels. This observation was consistent with other observations and data given on these steels in this report.

Appendix A Specifications

AAR M128-65, -69 and -70; ASTM A212-65

JANUARY 1, 1969
AAR APPENDIX M

M-2

M128.00 Specification for high strength carbon manganese steel plates for tank cars - AAR TC128-69.

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 procedures 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 A300-63, Class 1, except that impact specimens shall be Type A Charpy V-Notch as shown in ASTM Specification A370-67 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 A20-67 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 $\frac{1}{4}$ " and under in thickness		1.35	1.35
For plates over $\frac{1}{4}$ " 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 $\frac{1}{4}$ " and under in thickness		0.30	0.30
For plates over $\frac{1}{4}$ " to 1" incl. in thickness		0.50	0.50
Vanadium	Min.	0.02	—
Copper *	Max.	—	0.35
Nickel *	Max.	—	0.25
Chromium *	Max.	—	0.25
Molybdenum *	Max.	—	0.08

* 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	50,000
Elongation in 8 inches	
percent Min.	16.0 *
Elongation in 2 inches	
percent Min.	19.0

* For material under $\frac{1}{4}$ inch thick a reduction from the specified percent of elongation of 1.25 percent shall be made for each decrease of $\frac{1}{16}$ inch of thickness below $\frac{1}{4}$ inch. For material over $\frac{1}{4}$ inch thick a reduction from the specified percent elongation of 0.5 percent shall be made for each increase of $\frac{1}{16}$ inch of the thickness above $\frac{1}{4}$ 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.

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 A Specifications

AAR M128-65, -69 and -70; ASTM A212-65

APPROVED BY THE
AMERICAN SOCIETY OF MECHANICAL ENGINEERS
ON BEHALF OF THE AMERICAN BOILER AND SHIPBUILDING SOCIETY
SPECIFICATIONS FOR
STEEL BOILERS AND PRESSURE VESSELS
Code Book No. 1964, Sixth Edition, For Public Viewing

Standard Specification for HIGH TENSILE STRENGTH CARBON-SILICON STEEL PLATES FOR BOILERS AND OTHER PRESSURE VESSELS



ASTM Designation: A 212 - 65

November, 1964, Revisions, 1963*

This Standard of the American Society for Testing and Materials is based on the first designation A 212; the last number indicates the year of original adoption or, in the case of revision, the year of last revision.

See 1

1. This specification covers carbon-silicon steel plates in two high tensile strength ranges, designated as grades A and B, of flange and flange qualities; for use in locomotive boiler shells, boilers for stationary service, and other pressure vessels. The minimum thickness of flange

quality plates to be specified under this specification shall be 2 in., and for flange quality, 8 in. This material is intended for fusion welding. Welding technique is of fundamental importance and it is presupposed that welding procedure will be in accordance with approved methods.

General Conditions for Delivery

2. Material furnished under this specification 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 Flange Qualities (ASTM Designation: A 30).¹

Process

3. The steel shall be made by one or more of the following processes: open-hearth, basic-oxygen, or electric-furnace.

Heat Treatment

4. (a) Plates over 2 in. in thickness shall be treated to produce grain refinement in this publication.

* Applies to this publication.

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TABLE I.—CHEMICAL REQUIREMENTS¹

	Grade A	Grade B
Carbon, max., per cent:	0.25	0.31
For plates 1 in. and under in thickness:	0.21	0.27
For plates over 1 in. to 8 in. in thickness:	0.26	0.32
For plates over 8 in. to 24 in. in thickness:	0.31	0.37
Manganese, max., per cent:	0.01	0.02
Phosphorus, max., per cent:	0.015	0.025
Sulfur, max., per cent:	0.03	0.04
Fluorine:	0.01	0.01
Silicon, per cent:	0.15 to 0.20	0.15 to 0.20
Lead analysis:	0.10	0.10
Chemical analysis:	0.10 to 0.15	0.10 to 0.15

¹ See Section (6) and (7).

² When steel plates are furnished under this specification to meet the impact requirements of the Specification for Steel Plates for Pressure Vessels (ASTM Designation: A 515), the minimum impact energy shall be 40 ft.-lb. for temperatures below 0°F. and shall be 60 ft.-lb. for temperatures below 0°F. and above 0°F.

When specified, the maximum mechanical properties shall be as follows: yield strength, 60,000 psi; tensile strength, 70,000 psi; elongation in 2 in., 22%; elongation in 8 in., 18%; reduction of area, 40%; Charpy impact, 40 ft.-lb. for temperatures below 0°F. and above 0°F. When specified, the steel shall be normalized and shall be furnished in accordance with the Methods for Determining the Gross Size of Plate (ASTM Designation: E 132), and in Plate IV, by conforming to 1260 F. for 8 in.

When specified, the steel shall be normalized either by normalizing or heating uniformly for hot forming. If the required treatment is to be obtained in conjunction with the hot-forming operation, the temperature to which the plates are heated for hot forming shall be equivalent to and shall not significantly exceed the normalizing temperature. If the treatment of the plates is not specified to be done at the plate manufacturer's plant, the testing shall be carried out in accordance with Paragraph (6).

(6) When a fabricator is equipped and elects to perform the required normalizing or fabricating by hot forming as provided in Paragraph (5), the plates shall be accepted on the basis of mill tests performed in accordance with Paragraph 2.

Tensile Properties

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

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TABLE III.—BEND DILUTION

Thickness of Material, in.	Bend Dilution, %	
	Grade A	Grade B
1 and under	15	2
Over 1 to 1/2 in.	15	2
Over 1 1/2 to 2 in.	15	2
Over 2 to 3 in.	15	2
Over 3 to 4 in.	15	2
Over 4 1/2 to 8 in.	15	2

(b) Tensile strength only need be determined on the tension test specimens taken from the top of flange plates, and shall not exceed 79,000 psi for grade A, and 87,000 psi for grade B.

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

(d) For material over 1/8 in. 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 1/8 in. of the specified thickness above 1/8 in. This deduction shall not exceed 3 per cent.

(e) For material over 1/4 in. in thickness, a deduction from the percentage of elongation in 2 in. specified in Table II of 0.5 per cent shall be made for each increase of 1/4 in. of the specified thickness above 1/4 in. This deduction shall not exceed 3 per cent.

Bending Properties

7. The bend test specimens shall stand being bent cold through 180 deg without cracking on the outside of the bent portion.

shall 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.

Test Specimens

8. (a) For plates 2 in. and under in thickness the test specimens shall be prepared for testing from the material in its rolled condition.

(b) For plates over 2 in. in thickness the test specimens shall be prepared from the material in its heat-treated condition, or from full thickness samples similarly and simultaneously treated (See Section 1).

(c) When so specified in the purchase order with the mill, test specimens representing the plates shall be stress relieved by gradually and uniformly heating them to a temperature between 1100 and 1200 F. for a temperature range of 100 F. between the manufacturer and the fabricator, holding at temperature for at least 1 hr per inch of thickness and cooling in still atmosphere to a temperature not exceeding 600 F.

Number of Tests

9. Tensile tests, one bend test and one homogeneity test shall be made from each flange steel plate as rolled. One tension test and one bend test shall be made from each flange steel plate as rolled.

Note.—The term "plate as rolled" means here and there the plate as rolled from a slab or strip before any heat treatment in the heat treatment of the specimen; not to its condition as rolled.

PLATES FOR FUSION-WELDED PRESSURE VESSELS (A 515)

required in accordance with ASTM Methods E 112, of Estimating the Average Grain Size of Metals, by carburizing at 1700 F for 8 hr.
4. Heat Treatment
4.1 Plates over 2 in. in thickness, and when specified by the purchaser, plates 2 in. and under shall be treated to produce grain refinement either by normalizing or heating uniformly for hot forming. If the required treatment is to be obtained in conjunction with the hot-forming operation, the temperature to treatment of the plates.

TABLE 1.—CHEMICAL REQUIREMENTS.

Table with 5 columns: Property, Grade 53, Grade 56, Grade 58, Grade 70. Rows include Carbon, max, per cent; Manganese, max, per cent; Phosphorus, max, per cent; Sulfur, max, per cent; Silicon, max, per cent; and Char analysis.

4.4 When the plates are to be normalized at the plate manufacturer's plant, the mechanical properties shall be determined on specimens simultaneously treated with the plates.
4.5 Plates 2 in. and under in thickness shall be tested and supplied in the as-rolled condition, except when agreed upon between the manufacturer and the purchaser, plates 2 in. and under shall be furnished stress-relieved, normalized, or normalized and stress-relieved.
4.6 When plates are to be supplied in the as-rolled condition, the manufacturer, at his option may heat treat the plates by normalizing, or stress relieving, or normalizing and stress relieving, in accordance with 4.2 and 8.3.

PLATES FOR FUSION-WELDED PRESSURE VESSELS (A 515)

liering to meet the mechanical properties.
5. Chemical Composition
5.1 The steel shall conform to the requirements as to chemical composition prescribed in Table 1.
6. Tensile Properties
6.1 The material as represented by the tension test specimens shall conform to the requirements as to tensile properties prescribed in Table 2.
6.2 For material under 1/2 in. in thickness, a deduction of 1.25 per cent from the percentage of elongation in 8 in. inside diameter which shall have the thickness above 1/2 in. This deduction shall not exceed 3 per cent.
6.4 For material over 3/4 in. in thickness, a deduction of 0.5 per cent from the percentage of elongation in 2 in. specified in Table 2 shall be made for each increase of 1/4 in. of the specified thickness above 3/4 in. This deduction shall not exceed 3 per cent.
7. Bending Properties
7.1 The bend test specimen shall stand being bent cold (room temperature) through 180 deg without cracking on the outside of the bent portion through an inside diameter of 8 in. This deduction shall have the

TABLE 2.—TENSILE REQUIREMENTS.

Table with 5 columns: Tensile strength, psi; Yield point, min, psi; Elongation in 8 in., min, per cent; Elongation in 2 in., min, per cent; Grade 53; Grade 56; Grade 58; Grade 70.

TABLE 3.—BEND DIAMETERS.

Table with 2 columns: Thickness, in.; Bend Diameter in Specimen Thickness. Rows include 1 and under, Over 1 to 2 in., Over 2 to 4 in., Over 4 to 8 in., Over 8 to 12 in.

relation to the thickness of the specimens prescribed in Table 3. When the test is made on a specimen reduced in thickness, the rolled surface shall be on the outer curve of the bend.
8. Test Specimens
8.1 For plates 2 in. and under in thickness, the test specimens shall be prepared for testing from the material in the condition it is furnished except as provided in 4.2 and 8.3.
8.2 For plates over 2 in. in thickness, the test specimens shall be prepared from the material in its heat-treated condition, or from full-thickness samples similarly and simultaneously treated in accordance with 4.2 except as provided otherwise in 4.2 and 8.3.

Standard Specification for CARBON STEEL PLATES FOR PRESSURE VESSELS FOR INTERMEDIATE AND HIGHER TEMPERATURE SERVICE



ASTM Designation: A 515 - 70

This Standard of the American Society for Testing and Materials is hereby adopted as a standard for use in the United States and in other countries where the standard adoption is standard or, in the case of revision, the year of last revision.

1. Scope

1.1 This specification covers carbon-silicon steel plates in four tensile strength ranges, designated Grades 53, 60, 65, and 70, intended primarily for intermediate or high temperature service in boilers and other pressure vessels. It is expected that plates will be manufactured in accordance with coarse grain practice. The maximum thickness plates of Grade 53 shall be 12 in.; and of Grade 60, 65, and 70 shall be 8 in.

2. General Conditions for Delivery

2.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of ASTM Specification A 70, for General Requirements for Delivery of Steel Plates for Pressure Vessels.

3. Process

3.1 The steel shall be made by one or more of the following processes: open-hearth, basic-oxygen, or electric-furnace. A list of committee members may be found in the ASTM Year-Book.
3.2 When specified, the steel shall be coarse grained, having a carburized austenitic grain size of 1 to 5 as determined by the method specified in Section II of that Code.

1 Annual Book of ASTM Standards, Part 4.

SPECIFICATION FOR PLATES FOR FUSION-WELDED PRESSURE VESSELS (A 516) 617

9. Test Specimens
 9.1 For plates 1½ in. and under in thickness, the test specimens shall be prepared from material in the condition it is furnished except as provided otherwise in Sections 4.2 and 9.3.
 9.2 For plates 1½ in. and under in thickness requiring heat treatment, or for plates over 1½ in. in thickness, the test specimens shall be prepared from the material in its heat-treated condition, or from full thickness samples similarly and simultaneously treated, except as noted in 4.2 and 9.3.
 9.3 When so specified in the purchase order, test specimens representing the plates shall be stress-relieved by gradually and uniformly heating them to a temperature between 1100 and 1200 F (or a temperature range otherwise agreed upon between the manufacturer and the purchaser), holding at temperature for at least 1 hr per inch of thickness and cooling in still atmosphere to a temperature not exceeding 600 F.

SUPPLEMENTARY REQUIREMENT

The following supplementary requirement shall not apply unless specified in the purchase order.
 A list of standardized supplementary requirements for use at the option of the purchaser is included in Specification A 20. Those which are considered suitable for use with this specification are given below. Others enumerated in Specification A 20 may be used with this specification subject to agreement by the supplier.

- S1. Vacuum Treatment**
 S1.1 The steel shall be made by a process which includes vacuum degassing while molten. Unless otherwise agreed upon with the purchaser, it is the responsibility of the manufacturer to select suitable process procedures.
- S2. Product Analysis**
 S2.1 A product analysis shall be made of each plate as rolled. The specimens for analysis shall be taken adjacent to or from a broken tension test specimen.
- S3. Simulated Post-Weld Heat Treatment of Mechanical Test Coupons**
 S3.1 The test specimens representing the plate shall be thermally treated after the final heat treatment for mechanical properties to simulate heat treatments below the critical temperature which the plate may receive during fabrication after heat treatment for mechanical properties. The temperature range, time and cooling rates shall be as specified in the order.
- S4. Additional Tension Test**
 S4.1 *Other Than Quenched and Tempered Plates*—In addition to the required single tension test, a second tension test shall be made on a specimen taken from a corner of the plate as rolled on the end opposite the single specimen and in a direction parallel to the single specimen. The results obtained on testing this second specimen shall conform to the requirements of the specification.
- S5. Charpy V-Notch Impact Test**
 S5.1 Charpy V-notch impact tests shall be conducted in accordance with ASTM Specification A 593, for Charpy V-Notch Testing Requirements for Steel Plates for Pressure Vessels, except that orientation of the test bars (whether transverse or longitudinal to the direction of final rolling), the test temperature, and the required acceptance criteria, shall be

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as agreed upon between the purchaser and the manufacturer. The recorded results shall include both absorbed energy and lateral expansion at the base of the notch in accordance with the procedures provided in Methods A 370.

- S6. Drop-Weight Test (for Plates 0.625 in. (15.8 mm) and Over in Thickness)**
 S6.1 Drop-weight tests shall be made in accordance with the requirements of ASTM F 208, for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels. The specimens shall be taken from the same location with respect to plate pattern as is specified for the tension tests and shall present the plates in the final condition of heat treatment. Agreement shall be reached between the purchaser and the manufacturer as to the number of plates to be tested and whether a maximum NDT temperature is mandatory or if the test results are for information only.
- S7. High-Temperature Tension Tests**
 S7.1 A short-time elevated-temperature tension test as specified by the purchaser shall be made to represent each plate or each heat of steel as indicated by the purchaser. The material for testing shall be obtained as required for the room temperature tension tests specified in this specification. The hot tests shall be made in accordance with ASTM Recommended Practice E 21, Short-Time, Elevated-Temperature Tension Tests of Materials. Mandatory conformance with specified properties shall be a matter for agreement between the manufacturer and purchaser.
- S8. Ultrasonic Examination**
 S8.1 All plates shall be ultrasonically examined in accordance with the requirements of ASTM Method A 435, for Longitudinal-Wave Ultrasonic Inspection of Steel Plates for Pressure Vessels.
 S8.2 All plates shall be ultrasonically examined in accordance with the requirements of ASTM Specification A 578, for Longitudinal-Wave Ultrasonic Inspection of Plain and Clad Steel Plates for Special Applications. The acceptance level shall be as specified on the order.
 S8.3 All plates shall be ultrasonically examined in accordance with the requirements of ASTM Specification A 577, for Ultrasonic, Angle-Beam Examination of Steel Plates.
- S9. Magnetic Particle Examination**
 S9.1 All plate edges shall be examined by magnetic particles in accordance with the procedures covered in ASTM Method E 109, for Dry Powder Magnetic Particle Inspection. The acceptability of defects revealed by this examination shall be judged in accordance with the requirements for quality in 7.3 of Specification A 20.

Standard Specification for CARBON STEEL PLATES FOR PRESSURE VESSELS FOR MODERATE AND LOWER TEMPERATURE SERVICE.



ASTM Designation: A 516 - 70a

This Standard of the American Society for Testing and Materials is issued under the designation A 516; the final number indicates the year of original adoption as standard or, in the case of revision, the year of last revision.

1. Scope

1.1 This specification covers carbon-manganese-silbon steel plates in four tensile strength levels, designated Grades 55, 60, 65, and 70, intended primarily for service at temperatures in pressure vessels where improved notch toughness is important. The maximum thickness of plates of Grades 55, 60, 65, and 70 shall be 8 in. 1.2 This material is intended for fusion welding. Welding technique is of fundamental importance and it is presupposed that welding procedure will be in accordance with approved methods.

2.1 Material furnished under this specification shall conform to the applicable provisions of the Specification for Delivery of Steel, and to the chemical composition, mechanical properties, and testing procedures found in the ASTM Specification for Carbon-Manganese-Silbon Steel Plates for Pressure Vessels (ASTM Designation: A 593).
2.2 General Conditions for Delivery shall conform to the applicable provisions of the Specification for Delivery of Steel, and to the chemical composition, mechanical properties, and testing procedures found in the ASTM Specification for Carbon-Manganese-Silbon Steel Plates for Pressure Vessels (ASTM Designation: A 593).

3. Process
3.1 The steel shall be made by one or more of the following processes: open-hearth, basic-oxygen, or electric-furnace.
3.2 The steel shall be made to fine grain practice.
3.3 All plates in Grades 55, 60, 65, and 70 shall be fine grained having a carbonized austenitic grain size of 5 or finer as determined in accordance with ASTM Method E 112, for Estimating the Average Grain Size of Metals, Specimenally, Plate IV, by carburizing at 1700 F for 8 hr.

3.4 When specified by the purchaser, plates shall be furnished under this specification to meet the impact requirements of the Specification for Charpy V-Notch Testing Requirements for Steel Plates for Pressure Vessels (ASTM Designation: A 593).
3.5 The provisions of 3.3 above need not apply to plates in Grades 55, 60, 65, and 70.

4. Heat Treatment
4.1 Plates over 1 1/2 in. in thickness, and when specified by the purchaser, plates 1 1/2 in. and under shall be heat treated to produce grain refinement either by normalizing or heating uniformly for hot forming. If the required treatment is to be obtained in conjunction with hot forming, the temperature to which the plates are heated for hot-forming shall be equivalent to and shall not significantly exceed the normalizing temperature. If the treatment of the plates is not specified to be done at the plate manufacturer's plant, the testing shall be carried out in accordance with 4.2.

4.2 Heat Treatment
4.1 Plates over 1 1/2 in. in thickness, and when specified by the purchaser, plates 1 1/2 in. and under shall be heat treated to produce grain refinement either by normalizing or heating uniformly for hot forming. If the required treatment is to be obtained in conjunction with hot forming, the temperature to which the plates are heated for hot-forming shall be equivalent to and shall not significantly exceed the normalizing temperature. If the treatment of the plates is not specified to be done at the plate manufacturer's plant, the testing shall be carried out in accordance with 4.2.

4.3 The purchaser shall indicate in his order whether the plate manufacturer or the fabricator shall perform the treatment of the plates.
4.4 When the plates are to be normalized at the plate manufacturer's plant, the mechanical properties shall be determined on specimens simultaneously treated with the plates.
4.5 Plates 1.5 in. and under in thickness under conditions he considers appropriate for grain refinement, and to meet the test requirements. The plate manufacturer shall inform the purchaser of the procedure followed in treating the specimens at the mill.
4.6 The purchaser shall indicate in his order whether the plate manufacturer or the fabricator shall perform the treatment of the plates.

4.7 When the plates are to be normalized at the plate manufacturer's plant, the mechanical properties shall be determined on specimens simultaneously treated with the plates.
4.8 Plates 1.5 in. and under in thickness under conditions he considers appropriate for grain refinement, and to meet the test requirements. The plate manufacturer shall inform the purchaser of the procedure followed in treating the specimens at the mill.
4.9 The purchaser shall indicate in his order whether the plate manufacturer or the fabricator shall perform the treatment of the plates.

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not apply when notch toughness tests are performed to meet the Specification for Notch Toughness Requirements for Normalized Steel Plates for Pressure Vessels (ASTM Designation: A 300). The Specification for Charpy V-Notch Testing Requirements for Steel Plates for Pressure Vessels (ASTM Designation: A 593), or other recognized specifications.
4.2 When a fabricator elects to perform the required normalizing or fabricating by hot forming as provided in 4.1, the plates shall be accepted on the basis of mill tests made on full-thickness specimens heat treated in accordance with the purchaser's order requirements. If the heat treatment temperatures are not indicated on the purchase order, the plate manufacturer shall heat treat the

TABLE 1.—CHEMICAL REQUIREMENTS.

	Grade 55	Grade 60	Grade 65	Grade 70
Carbon, max. per cent:	0.18	0.21	0.24	0.27
1/2 in. and under, incl.	0.20	0.23	0.26	0.28
Over 1/2 to 4 in., incl.	0.22	0.25	0.28	0.30
Over 4 to 8 in., incl.	0.24	0.27	0.30	0.31
Over 8 to 12 in., incl.	0.26	0.29	0.32	0.33
Manganese, per cent:	0.28 to 0.40	0.30 to 0.40	0.30 to 0.45	0.30 to 0.45
1/2 in. and under:	0.28 to 0.40	0.30 to 0.40	0.30 to 0.45	0.30 to 0.45
Over 1/2 to 12 in., incl.:	0.28 to 0.40	0.30 to 0.40	0.30 to 0.45	0.30 to 0.45
Phosphorus, max. per cent:	0.035	0.035	0.035	0.035
Sulfur, max. per cent:	0.04	0.04	0.04	0.04
Lead:	0.15 to 0.20	0.15 to 0.20	0.15 to 0.20	0.15 to 0.20
Over 1/2 to 12 in., incl.:	0.15 to 0.20	0.15 to 0.20	0.15 to 0.20	0.15 to 0.20

a Grade 60 plates 1/2 in. and under in thickness may be specified to have 0.55 to 1.20 per cent manganese.

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ness shall be tested and supplied in the as-rolled condition except, when agreed upon between the manufacturer and the purchaser, plates 1.5 in. and under may be furnished stress relieved, normalized, or normalized and stress relieved.
4.6 When plates are to be supplied in the as-rolled condition, the manufacturer at his option may heat treat the plates by normalizing, or stress relieving, shall not exceed 3 per cent.

TABLE 2.—TENSILE REQUIREMENTS.

	Grade 55	Grade 60	Grade 65	Grade 70
Tensile strength, psi:	43 000 to 48 000	49 000 to 53 000	53 000 to 57 000	57 000 to 64 000
Yield point, min. psi:	20 000	23 000	26 000	28 000
Elongation in 8 in., min. per cent:	23	21	19	17
Elongation in 2 in., min. per cent:	27	26	23	20

TABLE 3.—BEND DIAMETERS.

Thickness, in.	Ratio of Bend Diameter to Thickness of Specimen	
	Grade 55	Grade 60 to 70
1 and under	1 1/4	1 1/4
Over 1 to 2, incl.	1 1/4	1 1/4
Over 2 to 4, incl.	1 1/2	1 1/2
Over 4 to 8, incl.	1 3/4	1 3/4
Over 8 to 12, incl.	2 1/4	2 1/4

6.4 For material over 3/4 in. in thickness, a deduction of 0.5 per cent from the percentage of elongation in 2 in. specified in Table 2 shall be made for each increase of 1/4 in. of the specified thickness above 3/4 in. This deduction shall not exceed 3 per cent.

7. Bending Properties

7.1 The bend test specimen shall stand being bent cold through 180 deg 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 3. When the test is made on a specimen reduced in thickness, the rolled surface shall be on the outer curve of the bend.

8. Notch Toughness

8.1 When improved notch toughness is required for plates 1 1/2 in. and under in thickness, heat treatment may be specified by the purchaser in accordance with 4. Heat Treatment

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8.3 When so specified in the purchase order with the mill, test specimens representing the plates shall be stress-relieved by gradually and uniformly heating them to a temperature between 1100 and 1200 F. (or a temperature not exceeding 600 F.

SUPPLEMENTARY REQUIREMENT

The following supplementary requirement shall apply only when specified in the purchase order. A list of standardized supplementary requirements for use at the option of the purchaser is included in Specification A 20. Those which are considered suitable for use with this specification are given below. Others enumerated in Specification A 20 may be used with this specification subject to agreement by the supplier.

81. Vacuum Treatment S1.1 The steel shall be made by a process which includes vacuum degassing while molten. Unless otherwise agreed upon with the purchaser, it is the responsibility of the manufacturer to select suitable process procedures.

82. Product Analysis S2.1 A product analysis shall be made of each plate as rolled. The specimens for analysis shall be taken adjacent to or from a broken tension test specimen.

83. Simulated Post-Weld Heat Treatment of Mechanical Test Coupons S3.1 The test specimens representing the plate shall be thermally treated after the final heat treatment for mechanical properties to simulate heat treatments below the critical temperature which the plate may receive during fabrication after heat treatment for mechanical properties. The temperature range, time and cooling rates shall be as specified in the order.

84. Additional Tension Test S4.1 Other Than Quenched and Tempered Plates—In addition to the required single tension test, a second tension test shall be made on a specimen taken from a corner of the plate as rolled

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taken from the same locations with respect to plate pattern as is specified for the tension tests and shall represent the plates in the final condition of heat treatment. Agreement shall be reached between the purchaser and the manufacturer as to the number of plates to be tested and whether a maximum NDT temperature is mandatory or if the test results are for information only.

S7. High-Temperature Tension Tests S7.1 A short-time elevated-temperature tension test as specified by the purchaser shall be made to represent each plate or each heat of steel as indicated by the purchaser. The material for testing shall be obtained as required for the room temperature tension tests specified in this specification. The hot tests shall be made in accordance with ASTM Recommended Practice E 21, Short-Time, Elevated-Temperature Tension Tests of Materials. Mandatory conformance with specified properties shall be a matter for agreement between the manufacturer and purchaser.

S8. Ultrasonic Examination S8.1 All plates shall be ultrasonically examined in accordance with the requirements of ASTM Specification A 578, for Longitudinal-Wave Ultrasonic Inspection of Plain and Clad Steel Plates for Special Applications. The acceptance level shall be as specified on the order. S8.2 All plates shall be ultrasonically examined in accordance with the requirements of ASTM Specification A 577, for Ultrasonic, Angle-Beam Examination of Steel Plates.

S9. Magnetic Particle Examination S9.1 All plate edges shall be examined by magnetic particles in accordance with the procedures covered in ASTM Method E 109, for Dry Powder Magnetic Particle Inspection. The acceptability of defects revealed by this examination shall be judged in accordance with the requirements for quality in 7.3 of Specification A 20.