Designation: A841/A841M – 13

Standard Specification for Steel Plates for Pressure Vessels, Produced by Thermo-Mechanical Control Process (TMCP)[1]

This standard is issued under the fixed designation A841/A841M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification[2] covers steel plates produced by the thermo-mechanical control process (TMCP). The plates are intended primarily for use in welded pressure vessels. A description of the TMCP method is given in Appendix X1.

1.2 Due to the inherent characteristics of the TMCP method, the plates cannot be formed at elevated temperatures without sustaining significant losses in strength and toughness. Except for Grade G, the plates may be formed and post-weld heat-treated at temperatures not exceeding 1200°F [650°C], providing the requirements of 6.1 are met. Grade G plates may be formed at temperatures not exceeding 985°F [530°C] provided the requirements of 6.1 are met.

1.3 The maximum permitted nominal thickness of plates furnished to this specification is 4 in. [100 mm] for Grades A, B, and C; 1.5 in. [40 mm] for Grades D,[3] E, and F; and 2 in. [50 mm] for Grade G.

1.4 Grade G is susceptible to magnetization. Use of magnets in handling after heat treatment should be avoided if residual magnetism would be detrimental to subsequent fabrication or service.

1.5 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents. Therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with this specification.

2. Referenced Documents

2.1 *ASTM Standards:*[4]

A20/A20M Specification for General Requirements for Steel Plates for Pressure Vessels

A435/A435M Specification for Straight-Beam Ultrasonic Examination of Steel Plates

A577/A577M Specification for Ultrasonic Angle-Beam Examination of Steel Plates

A578/A578M Specification for Straight-Beam Ultrasonic Examination of Rolled Steel Plates for Special Applications

3. General Requirements and Ordering Information

3.1 Plates supplied to this product specification shall conform to Specification A20/A20M, which outlines the testing and retesting methods and procedures, permissible variations in dimensions, quality and repair of defects, marking, loading, etc.

3.2 Specification A20/A20M also establishes the rules for ordering information that should be complied with when purchasing plates to this specification.

3.2.1 If the plates are to be subjected to warm forming or post-weld heat treatment, the order must indicate the temperatures and times-at-temperature that will be utilized in such operations. (See 6.1 and Specification A20/A20M, Supplementary Requirement S3.)

3.3 In addition to the basic requirements of this specification, certain supplementary requirements are available when additional control, testing, or examination is required to meet end use requirements. These include:

3.3.1 Vacuum treatment,

3.3.2 Additional or special tension testing,

3.3.3 Additional or special impact testing, and

3.3.4 Nondestructive examination.

3.4 The purchaser is referred to the listed supplementary requirements in this specification and to the detailed requirements in Specification A20/A20M.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.11 on Steel Plates for Boilers and Pressure Vessels.

Current edition approved Oct. 1, 2013. Published November 2013. Originally approved in 1985. Last previous edition approved in 2007 as A841/A841M – 03a (2007). DOI: 10.1520/A0841_A0841M-13.

[2] For ASME Boiler and Pressure Vessel Code applications, see related Specification SA-841/SA-841M in Section II of that Code.

[3] ExxonMobil Upstream Research Company has patents pending concerning the use of chemistry ranges in ASTM A841 Grade D, in combination with specific TMCP routes and/or specific microstructural features. Interested parties are invited to submit information regarding identification of alternatives to these patented items to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[4] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

3.5 If the requirements of this specification are in conflict with the requirements of Specification A20/A20M, the requirements of this specification shall prevail.

4. Manufacture

4.1 *Steelmaking Practice*—The steel shall be killed and shall conform to the fine austenitic grain size requirement of Specification A20/A20M.

4.2 The plates shall be produced by the thermo-mechanical control process.

5. Chemical Composition

5.1 The chemical composition on heat analysis shall conform to the requirements given in Table 1, except as otherwise provided in Supplementary Requirement S17 of Specification A20/A20M when that requirement is involved.

5.2 If a product analysis is made on a sample taken from the standard location (see Specification A20/A20M), the results of the analysis shall not deviate from the limits for the heat analysis by more than the values given in Table 2.

6. Mechanical Requirements

6.1 If the plates are to be subjected to warm forming or post-weld heat treatment, the test coupons shall be subjected to heat treatment to simulate such fabrication operations. (See 3.2.1 and Specification A20/A20M, Supplementary Requirement S3.)

6.2 *Tension Test Requirements*—The plates as represented by the tension-test specimens shall conform to the requirements given in Table 3.

6.2.1 *Number and Location of Test Coupons*—Two tension tests shall be made from each plate-as-rolled. One test coupon shall be taken from a corner of the plate on each end.

6.3 *Notch Toughness Test Requirements:*

6.3.1 Except for Grade G, longitudinal Charpy V-notch tests shall be made in accordance with Specification A20/A20M.

6.3.2 For Grades A, B and C, unless the test temperature and absorbed energy requirements are specified in the purchase order, the tests shall be conducted at –40°F [–40°C] and the average absorbed energy for each set of three full size specimens shall be 15 ft·lb [20J] or more.

6.3.3 For Grade D, unless the test temperature and the lateral expansion requirements are specified in the purchase order, the tests shall be conducted at –40°F [–40°C] and the lateral expansion for each specimen shall be 0.015 in. [0.4 mm] or more.

6.3.4 For Grades E and F, unless the test temperature and absorbed energy requirements are specified in the purchase order, the tests shall be conducted at –40°F [–40°C] and the average absorbed energy for each set of three full size specimens shall be 20 ft·lb [27 J] or more.

6.3.5 For Grade G, transverse Charpy V-notch tests shall be made in accordance with Specification A20/A20M. Unless the test temperature is specified in the purchase order, the tests shall be conducted at –320°F [–195°C]. Each specimen shall have a lateral expansion opposite the notch of not less than 0.015 in. [0.38 mm], up to a plate thickness of 1.25 in. [31.75 mm] inclusive; and 0.019 in. [0.48 mm] at a plate thickness of 2.0 in. [50 mm]. Values of lateral expansion for plate thicknesses between 1.25 in. [31.75 mm] and 2.0 in. [50 mm] shall be determined by linear interpolation.

7. Marking

7.1 In addition to the marking required in Specification A20/A20M, each plate shall be legibly stamped with the letters “TMC” following the stamped specification designation.

8. Keywords

8.1 pressure containing parts; pressure vessel steel; steel plates; steel plates for pressure vessel applications

TABLE 1 Chemical Requirements[A]

Element	Composition, %						
	Grade A	Grade B	Grade C	Grade D	Grade E	Grade F	Grade G
Carbon	0.20	0.15	0.10	0.09	0.07	0.10[B]	0.13
Manganese							
t ≤ 1.5 in. [40 mm]	0.70–1.35[C]	0.70–1.35[C]	0.70–1.60	1.00–2.00	0.70–1.60	1.10–1.70[B]	0.60–1.20
t > 1.5 in. [40 mm]	1.00–1.60	1.00–1.60	1.00–1.60	[D]	[D]	[D]	0.60–1.20
Phosphorus	0.030	0.030	0.030	0.010	0.015	0.020	0.015
Sulfur	0.030	0.025	0.015	0.005	0.005	0.008	0.015
Silicon	0.15–0.50	0.15–0.50	0.15–0.50	0.05–0.25	0.05–0.30	0.10–0.45	0.04–0.15[E]
Copper	0.35	0.35	0.35	0.50	0.35	0.40	. . .
Nickel	0.25	0.60	0.25	1.0–5.0	0.60	0.85	6.0–7.5
Chromium	0.25	0.25	0.25	0.30	0.30	0.30	0.30–1.00
Molybdenum	0.08	0.30	0.08	0.40	0.30	0.50	0.30
Columbium	0.03	0.03	0.06	0.05	0.08	0.10	. . .
Vanadium	0.06	0.06	0.06	0.02	0.06	0.09	. . .
Titanium	[F]	[F]	0.006–0.02	0.006–0.03	[F]	[G]	. . .
Boron	...	...	...	0.0005–0.002	0.0007	0.0007	. . .
Aluminum, min	0.020 total or 0.015 acid soluble[F]	0.020 total or 0.015 acid soluble[F]	...	...	0.020 total or 0.015 acid soluble[F]	0.020 total or 0.015 acid soluble[G]	[E] 0.008 acid soluble

[A] Values are maximums unless a minimum or a range is indicated. Where ellipses appear in this table, there is no requirement.
[B] For each reduction of 0.01 percentage point below the specified maximum for carbon, an increase of 0.06 percentage points above the specified maximum for manganese is permitted, up to a maximum of 1.85 %.
[C] Manganese may exceed 1.35 % on heat analysis, up to a maximum of 1.60 %, provided that the carbon equivalent on heat analysis does not exceed 0.47 %, or the value specified in Supplementary Requirement S77 when that requirement is invoked, when based on the following formula:

$$CE = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15\,\%$$

When this option is exercised, the manganese content on product analysis shall not exceed the heat analysis content by more than 0.12 percentage points.

[D] Not applicable.
[E] Silicon may be less than 0.04 %, provided that total aluminum is 0.030 % or over, or provided acid soluble aluminum is 0.025 % or over.
[F] By agreement, the steel may be produced with titanium, in which case the minimum aluminum content shall not apply. When this option is exercised, the titanium content, by heat analysis, shall be 0.006 % to 0.02 %, and the actual titanium content shall be reported on the test report.
[G] By agreement, the steel may be produced with titanium, in which case the minimum aluminum content shall not apply. When this option is exercised, the titanium content, by heat analysis, shall be 0.006 % to 0.03 %, and the actual titanium content shall be reported on the test report.

TABLE 2 Product Analysis Tolerances

Element	Specified Limit, %	Tolerances, %	
		Under Minimum Limit	Over Maximum Limit
Carbon	to 0.15, incl	0.02	0.03
	over 0.15	0.03	0.04
Manganese	to 0.60, incl	0.05	0.06
	over 0.60 to 0.90, incl	0.06	0.08
	over 0.90 to 1.20, incl	0.08	0.10
	over 1.20 to 1.35, incl	0.09	0.11
	over 1.35 to 1.65, incl	0.09	0.12
	over 1.65	0.11	0.14
Phosphorus	to 0.020, incl	...	0.005
	over 0.020	...	0.010
Sulfur	to 0.020, incl	...	0.005
	over 0.020	...	0.010
Silicon	to 0.30, incl	0.02	0.03
	over 0.30 to 0.40, incl	0.05	0.05
	over 0.40	0.06	0.06
Nickel	to 1.00, incl	0.03	0.03
	over 1.0 to 2.0, incl	0.05	0.05
	over 2.0 to 3.8, incl	0.07	0.07
	over 3.8	0.08	0.08
Chromium	to 0.90, incl	0.04	0.04
Molybdenum	to 0.20, incl	0.01	0.01
	over 0.20	0.03	0.03
Copper	to 1.00, incl	0.03	0.03
Vanadium	to 0.10, incl	0.01	0.01
Columbium	to 0.10, incl	0.01	0.01
Aluminum	to 0.15, incl	0.005	0.01
Titanium	to 0.010, incl	0.002	0.01
	over 0.010	0.01	0.01
Boron	any	[A]	[A]

[A] Product analysis is not applicable for this element.

TABLE 3 Tensile Requirements

	Grades A, B, and C		Grade D	Grade E		Grade F			Grade G	
	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10
Yield strength, min, ksi [MPa]										
to 1.5 in. [40 mm] incl	50 [345]	60 [415]	100 [690]	70 [485]	75 [515]	70 [485]	75 [515]	80 [550]	85 [585]	90 [620]
over 1.5 in. [40 mm] to 2.0 in. [50 mm]	[A]	[A]	[A]	[A]	[A]	[A]	[A]	[A]	85 [585]	90 [620]
over 1.5 in. [40 mm] to 2.5 in. [to 65 mm]	50 [345]	60 [415]	[A]	[A]	[A]	[A]	[A]	[A]	[A]	[A]
over 2.5 in. [over 65 mm]	45 [310]	55 [380]	[A]	[A]	[A]	[A]	[A]	[A]	[A]	[A]
Tensile strength, ksi [MPa]										
to 1.5 in. [40 mm] incl	70–90 [485–620]	80–100 [550–690]	145–170 [1000–1170]	84–104 [580–715]	88–108 [605–745]	82–102 [565–705]	86–106 [590–730]	90–110 [620–760]	100–120 [690–825]	109–129 [750–885]
over 1.5 in. [40 mm] to 2.0 in. [50 mm]	[A]	[A]	[A]	[A]	[A]	[A]	[A]	[A]	100–120 [690–825]	109–129 [750–885]
over 1.5 in. [40 mm] to 2.5 in. [to 65 mm]	70–90 [485–620]	80–100 [550–690]	[A]	[A]	[A]	[A]	[A]	[A]	[A]	[A]
over 2.5 in. [over 65 mm]	65–85 [450–585]	75–95 [515–655]	[A]	[A]	[A]	[A]	[A]	[A]	[A]	[A]
Elongation in 2 in. [50 mm], min, %[B]										
to 1.5 in. [40 mm] incl	22	22	13	20	19	20	19	18	20	20
over 1.5 in. [40 mm] to 2.0 in. [50 mm]	[A]	[A]	[A]	[A]	[A]	[A]	[A]	[A]	20	20
over 1.5 in. [40 mm] to 2.5 in. [to 65 mm]	22	22	[A]	[A]	[A]	[A]	[A]	[A]	[A]	[A]
over 2.5 in. [over 65 mm]	22	22	[A]	[A]	[A]	[A]	[A]	[A]	[A]	[A]
Elongation in 8 in. [200 mm], min, %[B]										
to 1.5 in. [40 mm] incl	18	...	...	16	15	16	15	14	[A]	[A]
over 1.5 in. [40 mm] to 2.5 in. [to 65 mm]	18	....	[A]	[A]	[A]	[A]	[A]	[A]	[A]	[A]
over 2.5 in. [over 65 mm]	18	...	[A]	[A]	[A]	[A]	[A]	[A]	[A]	[A]

[A] Not applicable.
[B] See Specification A20/A20M for elongation requirement adjustments.

SUPPLEMENTARY REQUIREMENTS

Supplementary requirements shall not apply unless specified in the order.

A list of standardized supplementary requirements for use at the option of the purchaser are included in Specification A20/A20M. Several of those that are considered suitable for use with this specification are listed in this section by title. Other tests may be performed by agreement between the supplier and the purchaser.

S1. Vacuum Treatment,
S2. Product Analysis,
S3. Simulated Post-Weld Heat Treatment of Mechanical Test Coupons,
S5. Charpy V-Notch Impact Test,
S6. Drop Weight Test (for Material 0.625 in. [16 mm] and Over in Thickness),
S7. High-Temperature Tension Test,
S8. Ultrasonic Examination in accordance with Specification A435/A435M,
S9. Magnetic Particle Examination,
S10. Charpy V-Notch Test Curve,
S11. Ultrasonic Examination in accordance with Specification A577/A577M,
S12. Ultrasonic Examination in accordance with Specification A578/A578M,
S13. NDT Temperature Determination,
S17. Vacuum Carbon-Deoxidized Steel,
S18. Unspecified Elements, and
S19. Restricted Chemical Requirements.

ADDITIONAL SUPPLEMENTARY REQUIREMENTS

Also listed are additional supplementary requirements suitable for use with this specification.

S55. Longitudinal Charpy Impact Energy Absorption Requirement

S55.1 Longitudinal Charpy V-notch tests shall be made in accordance with Specification A20/A20M. Unless the test temperature is specified in the purchase order, the tests shall be conducted at –320°F [–195°C] and the average absorbed energy for each set of three full size specimens shall be 25 ft-lb [34 J] or more, and the individual test value of not more than one specimen may be below 25 ft-lb [34 J], but in no case below 20 ft-lb [27 J].

S56. Transverse Charpy Impact Energy Absorption Requirement

S56.1 Transverse Charpy V-notch tests shall be made in accordance with Specification A20/A20M. Unless the test temperature is specified in the purchase order, the tests shall be conducted at –320°F [–195°C] and the average absorbed energy for each set of three full size specimens shall be 20 ft-lb [27 J] or more, and the individual test value of not more than one specimen may be below 20 ft-lb [27 J], but in no case below 15 ft-lb [20 J].

S64. Heat Treatment Parameters for Grad G

S64.1 Except for the TMR-I-T process, the plates shall be cooled directly after rolling without being allowed to cool below 1025°F [550°C]. Quenching hardening shall be initiated from a temperature within the range from 1025 to 1490°F [550 to 810°C].

S64.2 Subsequent to quenching, the plates shall be tempered within the range from 1030 to 1155°F [555 to 625°C], holding at that temperature for a minimum of 30 min/in. [1.2 min/mm] of thickness but for not less than 15 min, and then cooling at a rate of not less than 300°F/h [165°C/h], either in air or by quenching in water, to ambient temperature.

S64.3 Prior to the tempering treatment, the plates may be subjected to an intermediate heat treatment (Note S64.1) consisting of heating to a temperature in the range from 1185 to 1310°F [640 to 710°C], holding at that temperature for a minimum of 1 hr/in. [2.4 min/mm] of thickness, but in no case less than 15 min, and then water-quenching to below 300°F [150°C] in the case of plate thicknesses of more than ⅝ in. [16 mm]; or cooling in air or water-quenching in the case of plate thickness of ⅝ in. [16 mm] and under.

NOTE S64.1—The intermediate heat treatment is for the purpose of enhancing elongation and notch-toughness and for reducing susceptibility to strain-aging embrittlement and temper embrittlement. It may be performed at the option of the material manufacturer or may be specified by the purchaser.

S64.4 Heat treatment temperatures and times shall be reported in accordance with Section 19 of Specification A20/A20M.

S77. Carbon Equivalent Limit

S77.1 The carbon equivalent, on heat analysis, shall not exceed the limits listed in this section when based on the following equation:

$$CE = C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15\ \%$$

[Grade A]	
t = 2 in. [50 mm] and under in thickness	0.40%
t > 2 in. [50 mm] in thickness	0.45%
[Grade B]	
t = 2 in. [50 mm] and under in thickness	0.45%
t > 2 in. [50 mm] in thickness	0.50%

S78. Low Sulfur Treatment

S78.1 Restricted sulfur content shall be specified on the order. In the absence of such a specification the maximum sulfur furnished under this supplementary requirement shall be 0.003 % on heat analysis.

NOTE S78.1—The low sulfur treatment is for the purpose of enhancing the HIC (Hydrogen Induced Cracking) and SSC (Sulfide Stress Cracking) resistance.

S79. Carbon Equivalent Limit

S79.1 The carbon equivalent, on heat analysis, shall not exceed 0.27 %, or a lower value as specified in the purchase order, when based on the following equation:

$$P_{CM} = C + \frac{Si}{30} + \frac{Mn + Cu + Cr}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + 5B\ \%$$

APPENDIX

(Nonmandatory Information)

X1. THERMO-MECHANICAL CONTROLLED PROCESSING (TMCP)

X1.1 *Introduction* —The Thermo-Mechanical Controlled Processing, commonly referred to as "TMCP," has evolved from the "controlled rolling" (CR) processes, which have been known and used for a number of years. TMCP produces fine-grained steel by a combination of chemical composition and integrated controls of manufacturing processes from slab reheating to post-rolling cooling, thereby achieving the specified mechanical properties in the required plate thicknesses. TMCP requires accurate control of both the steel temperature and rolling reductions, and does not involve coiling after the post- cooling.

X1.2 *Outline of TMCP As May Be applied to Grades A through F*—As shown in Fig. X1.1, TMCP for those grades may incorporate three processes, as follows:

X1.2.1 *Thermo-Mechanical Rolling (TMR)*—Steels of fine grain size are produced by rolling in the recrystallization and the nonrecrystallization regions of austenite, and sometimes in the dual-phase temperature region of austenite and ferrite. Generally, a high proportion of the rolling reduction is performed close to, or below, the temperature at which austenite begins to transform to ferrite during cooling (Ar3) and may involve rolling in the lower portion of the temperature range of the intercritical dual-phase region.

X1.2.2 *Accelerated Cooling (AC)*—Steels meeting the specified requirements are produced by controlled cooling (accelerated cooling and air cooling) through the dual-phase temperature region immediately after final controlled rolling (CR) or TMR operation.

X1.2.3 *Direct Quenched and Tempered (DQT)*—Steels meeting the specified requirements are produced by promoting grain refinement and increasing hardness through direct quenching immediately after final controlled rolling (CR) or TMR operations. Subsequent to direct quenching the plates are tempered.

X1.2.4 The selection, from the above, of the method to be used is made by the plate producer depending upon the chemical composition, the plate thickness, and the required properties.

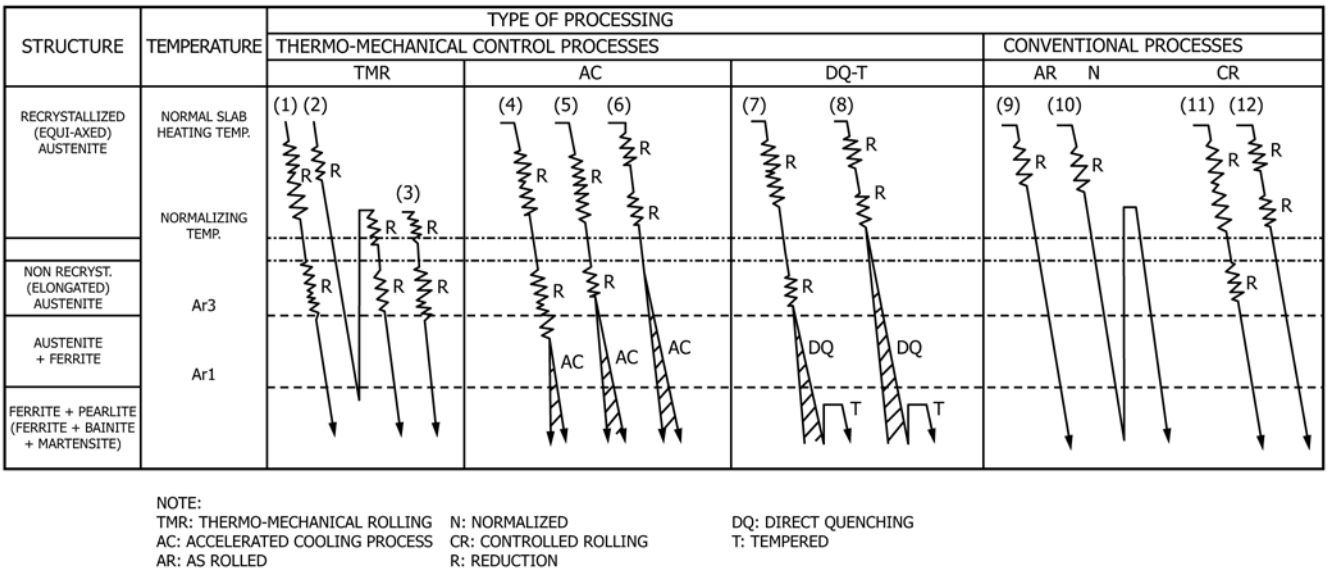


FIG. X1.1 Schematic Diagrams of Thermo-Mechanical Control and Conventional Process of Steel Plate as may be Applied to Grades A through F

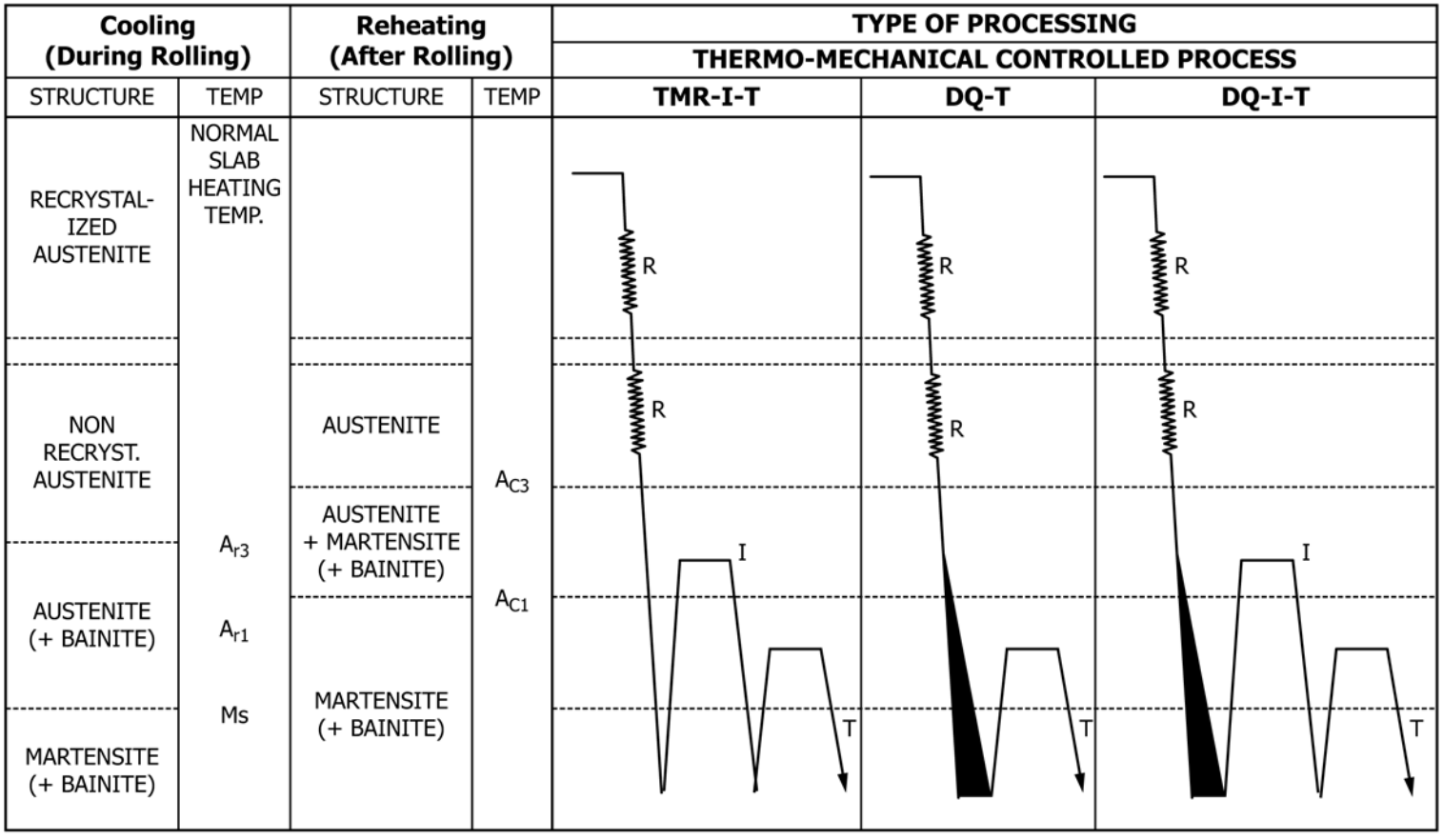
X1.3 *Outline of TMCP As May Be Applied to Grade G*—As shown in Fig. X1.2, TMCP for this grade may incorporate three processes, as follows:

X1.3.1 *Thermo-Mechanical Rolling and Intermediately Heat Treated and Tempered (TMR-I-T);*—Subsequent to TMR as described in X1.2.1, the plate may be tempered, except that prior to tempering after TMR, the plate may be subjected to an intermediate heat treatment consisting of heating to a temperature in the range from A_{C1} to A_{C3}.

X1.3.2 *Direct Quenched and Tempered (DQ-T)*—As described in X1.2.3.

X1.3.3 *Direct Quenched and Intermediately Heat Treated and Tempered (DQ-I-T)*—Similar to DQT, as described in X1.2.3, except that prior to the tempering treatment and after DQ, the plate may be subjected to an intermediate heat treatment consisting of heating to a temperature in the range from A_{C1} to A_{C3}.

X1.3.4 The selection, from the above, of the method to be used is made by the plate producer depending upon the chemical composition, the plate thickness, and the required properties.



NOTE:
TMR: THERMO-MECHANICAL ROLLING DQ: DIRECT QUENCHING
I: INTERMEDIATE HEAT TREATMENT T: TEMPERING
R: REDUCTION

FIG. X1.2 Schematic Diagrams of Thermo-Mechanical Control Processes of Steel Plate as may be Applied to Grade G

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since the last issue (A841/A841M – 03a (2007)) that may impact the use of this standard. (Approved Oct. 1, 2013.)

(1) Deleted 1.2 and renumbered subsequent subsections according.
(2) Revised 1.2, 1.3, Table 1, Table 3, and Appendix X1.
(3) Added Additional Supplementary Requirements S55, S56, and S64 and Fig. X1.2.