Designation: B 661 – 03

Standard Practice for Heat Treatment of Magnesium Alloys[1]

This standard is issued under the fixed designation B 661; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This practice is intended as an aid in establishing a suitable procedure for the heat treatment of magnesium alloys to assure proper physical and mechanical properties.

1.2 Times and temperatures are typical for various forms, sizes, and manufacturing methods and may not exactly describe the optimum heat treatment for a specific item. Consequently, it is not intended that this practice be used as a substitute for a detailed production process or procedure.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B 557 Test Methods of Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products[2]

E 21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials[3]

E 44 Definitions of Terms Relating to Heat Treatment of Metals[4]

E 527 Practice for Numbering Metals and Alloys (UNS)[5]

3. Terminology

3.1 *Definitions:*

3.1.1 The definitions relating to heat treatment of metals appearing in Definitions E 44 are considered as applying to this practice.

4. Apparatus

4.1 Furnaces used for the heat treatment of magnesium are usually of the air chamber type and may be electrically heated or oil- or gas-fired. Because of the atmospheres used for solution heat treatment, furnaces must be gas tight and contain suitable equipment for the introduction of protective atmospheres, and means for control of those atmospheres. In order to promote uniformity of temperature, furnaces should be equipped with a high-velocity fan or comparable means for circulating the atmosphere. In the design of the furnace it is desirable that there be no direct radiation from the heating elements or impingement of the flame on the magnesium.

4.2 Automatic recording and control equipment to control the temperature of the furnaces, which must be capable of maintaining temperature in the working zone to within ±10°F (±6°C) of the specified temperature.

4.3 There must be a separate manual reset safety cutout which will turn off the heat source in the event of any malfunctioning or failure of the regular control equipment. These safety cutouts shall be set as closely as practicable above the maximum temperature for the alloy being heat treated. This will be above the variation expected, but shall not be more than 10°F (6°C) above the maximum solution heat treating temperature for the alloy being heat treated. Protective devices shall also be installed to turn off the heat source in case of stoppage of circulation of air, and they shall be interconnected with a manual reset control.

4.4 The furnaces or ovens used for aging treatments may be heated by means of electricity, gas, or oil. The temperature at any point in the working zone, for any charge, shall be maintained within ±10°F (±6°C) of the desired aging temperature after the furnace has been brought up to the aging temperature.

4.5 *Quenching*:

4.5.1 Normally magnesium work loads are cooled in air. This should be by fan cooling the furnace charge after removal from the furnace in such a way that the cooling is uniform on various parts of the furnace charge.

4.5.2 Some alloys (notably EQ21A and QE22A) are quenched in water or other suitable media from the solution heat treating temperature. Quench tanks should be situated near the heat treatment furnaces. If required, means of heating the quench medium should be provided. Handling equipment shall be such that it is possible to quench heat treatment loads within 30 s after the opening of the furnace door.

[1] This practice is under the jurisdiction of ASTM Committee B07 on Light Metals and Alloys and is the direct responsibility of Subcommittee B07.04 on Magnesium Alloy Cast and Wrought Products.

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[2] *Annual Book of ASTM Standards,* Vol 02.02.

[3] *Annual Book of ASTM Standards,* Vol 03.01.

[4] Discontinued; Replaced by Terminology A 941, see *Annual Book of ASTM Standards*, Vol 01.01.

[5] *Annual Book of ASTM Standards*, Vol 01.01.

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

4.6 In the case of ZE63A alloy, a special heat treatment apparatus is required to enable heat treatment to take place in a hydrogen atmosphere.

5. Calibration and Standardization

5.1 *Calibration of Equipment*:

5.1.1 *Surveys*:

5.1.1.1 Perform a temperature survey, to ensure compliance with the applicable recommendations presented herein for each furnace.

5.1.1.2 Make a new temperature survey after any changes in the furnace that may affect operational characteristics.

5.1.2 *Furnace Calibration*:

5.1.2.1 Make the initial temperature survey at the maximum and minimum temperature of solution heat treatments and aging heat treatment for which each furnace is to be used. There shall be at least one test location for each 25 ft^3 (0.7 m^3) of air furnace volume up to a maximum of 40 test locations with a minimum of nine test locations.

5.1.2.2 After the initial survey, survey each furnace monthly, except as provided in 5.1.2.7. The monthly survey shall be at one operating temperature for solution heat treatment and one for aging heat treatment.

5.1.2.3 For the monthly surveys there shall be at least one test location for each 40 ft^3 (1.13 m^3) load volume.

5.1.2.4 For furnaces of 10 ft^3 (0.28 m^3) or less the temperature survey may be made with a minimum of three thermocouples located at front, center, and rear, or at top, center, and bottom of the furnace.

5.1.2.5 Perform the surveys in such manner as to reflect the normal operating characteristics of the furnace. If the furnace is normally charged after being stabilized at the correct operating temperature, similarly charge the temperature-sensing elements. If the furnace is normally charged cold, charge the temperature-sensing elements cold. After insertion of the temperature-sensing elements, readings should be taken frequently enough to determine when the temperature of the hottest region of the furnace approaches the bottom of the temperature range being surveyed. From that time until thermal equilibrium is reached, the temperature of all test locations should be determined at 2-min intervals in order to detect any overshooting. After thermal equilibrium is reached, readings should be taken at 5-min intervals for sufficient time to determine the recurrent temperature pattern, but for not less than 30 min. Before thermal equilibrium is reached, none of the temperature readings should exceed the maximum temperature of the range being surveyed. After thermal equilibrium is reached, the maximum temperature variation of all elements (both load and furnace thermocouples) shall not exceed 20°F (11°C) and shall not vary outside the range being surveyed.

5.1.2.6 For furnaces used only for treatments other than solution heat treatment, after the initial temperature uniformity survey as outlined in 5.1.2.5, surveys need not be made more often than at each 6-month interval, provided that (*a*) test specimens from each lot are tested and meet applicable material specifications requirements, (*b*) the furnace is equipped with a multipoint recorder, or (*c*) one or more separate load thermocouples are employed to measure and record actual metal temperatures.

5.1.2.7 Monthly surveys for batch furnaces are not necessary when the furnace is equipped with a permanent multipoint recording system with at least two sensing thermocouples in each working zone, or when one or more separate load thermocouples are employed to measure actual metal temperature, providing that uniformity surveys show a history of satisfactory performance for a period of at least 6 months. The sensing thermocouples shall be installed so as to record the temperature of the heated air or actual metal temperatures. However, periodic surveys shall also be made at 6-month intervals in accordance with the procedures outlined for the monthly survey.

5.1.2.8 Do not use furnace control temperature-measuring instruments to read the temperature of the test temperature-sensing elements.

5.1.3 *Temperature-Measuring System Check*—Check the accuracy of temperature-measuring system under operating conditions weekly. Check should be made by inserting a calibrated test temperature-sensing element adjacent to the furnace temperature-sensing element and reading the test temperature-sensing element with a calibrated test potentiometer. When the furnace is equipped with dual potentiometer measuring systems, which are checked daily against each other, the above checks may be conducted every three months rather than every week. Calibrate the test temperature-sensing element, potentiometer, and cold junction compensation combination against National Institute of Standards and Technology primary or secondary certified temperature-sensing elements, within the previous three months, to an accuracy of ±2°F (1.1°C).

5.1.4 *Records*—Maintain records for each furnace for at least 7 years to show compliance with this standard. These records shall include the following: furnace number or description; size; temperature range of usage; whether used for solution heat treatment or aging heat treatment, or both; temperature(s) at which uniformity was surveyed; dates of each survey; number and locations of thermocouples used; and dates of major repairs or alterations.

5.2 *Test and Verification of Equipment*:

5.2.1 *Test Requirements*:

5.2.1.1 *Heat-Treating Equipment*, operated in accordance with documented procedures, shall have a demonstrated capability of producing material and components meeting the mechanical and physical properties specified for each heat-treated alloy.

5.2.1.2 *Use of Production Test Results*—In all cases, the results of tests made to determine conformance of heat-treated material to the requirements of the respective material specifications are acceptable as evidence of the properties being obtained with the equipment and procedure employed.

5.2.2 *Mechanical Properties*—The heat treated (or reheat treated) test specimen shall have tensile strength, yield strength, and elongation properties not less than those specified in the applicable material specification or detail drawings. The required tests for alloys shall be in accordance with the requirements of the respective specifications and shall conform to Methods B 557 or Test Methods E 21, or both.

5.2.2.1 *Microscopical Examination*—The tensile test may be supplemented by a microscopical examination of the test bars or selected castings at the discretion of the procuring activity. Take a single representative sample for each of the specified tests if the furnace selected for routine inspection contains a load that is homogeneous as to alloy, form, and size of part. Select two specimens to represent the least massive and the most massive portions of the charge. In the event of nonhomogeneity as to alloy and when the recommended heat treatments for the respective alloys differ, prepare additional samples.

5.2.2.2 *Eutectic Melting and High Temperature Oxidation of Castings*—Section, mount, and prepare specimens from the heat treated samples for microscopical examination. Examine the unetched surface at a 500-diameter magnification with a metallurgical microscope. The presence of eutectic melting or high temperature oxidation shall be considered evidence of improper heat treatment.

5.3 *Interpretation of Results*:

5.3.1 Test specimens prepared in accordance with 5.2.1 and treated in accordance with the applicable parts of Section 6 shall meet the requirements specified below. Failure to meet the specified mechanical or physical requirements is reason to disqualify the heat-treating equipment and associated process until the reason for the failure is determined and appropriate corrective action completed.

5.3.2 *Status of Alloys*—Alloys heat treated in the furnace since the time of the previous satisfactory tests and found unsatisfactory shall be rejected or reheat treated (beginning with the solution heat treatment where applicable) in an acceptable furnace, depending on the character of the failed tests. Alloys in which eutectic melting, and high temperature oxidation is found shall be rejected and no reheat treatment permitted. Alloys that fail for reasons other than those enumerated above may be reheat treated.

5.3.3 *Test Reports*—Test reports shall be identified as to the equipment used and heat-treat lots of material associated with the tests and shall be retained and readily retrievable for an appropriate period.

6. Procedure and Operations

6.1 *Sand and Mold Castings*:

6.1.1 *Heat Treatment*—Heat treat castings at temperatures not exceeding the maximum temperatures specified in Table 1. Suggested heat treating temperature ranges are shown in Table 1.

6.1.1.1 The furnace should be loaded in such a manner as to permit adequate circulation of the furnace atmosphere. Give attention to providing necessary suport to castings susceptible to warpage.

6.1.2 Hold the charge at temperature for a sufficient time to secure adequate solution heat treatment. Suggested holding periods at temperatures for castings up to 2 in. (50.8 mm) in thickness are given in Table 1. Longer holding periods will be required for castings with heavier sections.

6.1.2.1 Since magnesium castings are subject to excessive surface oxidation at temperatures of 750°F (399°C) and over, a protective atmosphere containing sufficient sulfur dioxide, carbon dioxide, or other satisfactory oxidation inhibitor should be used when solution heat treating at 750°F (399°C) and over.

6.1.2.2 Perform heat treating operations on the whole of a casting, never on a part only, and apply in a manner that will produce satisfactory uniformity.

6.1.3 *Cooling*—Cool castings in air from the solution heat treating temperature rapidly enough to ensure that the specified mechanical properties are obtained.

6.1.3.1 *Quenching*—When EQ21A and QE22A castings are quenched in water or other media, transfer them from furnace to quench tank with the minimum delay. It is recommended that the water, if used, be maintained at 150 to 180°F (66 to 82°C).

6.1.4 *Aging*—Perform aging, or precipitation heat treatment, when specified, at the temperature and times required to develop the specified properties. Aging conditions which have been used satisfactorily are shown in Table 1.

6.1.5 *Reheat Treatment*—Reheat treatment and resubmission of material rejected for improper heat treatment is permitted. Full information concerning the cause of all previous rejections of the lot shall accompany any resubmitted material.

6.2 *Wrought Products*:

6.2.1 Sheet and plate are supplied by the mill in O temper or in various H tempers. Sheet and plate may then be annealed for stress-relieving purposes in accordance with the recommended schedules in Table 2.

6.2.2 Extrusions are heat treated according to the recommended schedules in Table 3.

6.2.3 Forgings are heat treated according to the recommended schedules in Table 4.

TABLE 1 Recommended Heat Treatment Schedules for Magnesium Alloy Castings (for castings of up to 2 in. (50.8 mm) in section)[A]

Alloy		Final Temper	A—Mg-Al-Zn Group[B]						
			Aging Treatment[C]		Solution Heat Treatment[D]			Aging after Solution	
ASTM	UNS		Temperature± 10°F (±6°C)[E]	Time, h	Temperature± 10°F (±6°C)[E]	Time, h	Maximum Temperature, °F(°C)	Temperature,± 10°F (±6°C)	Time, h
AM100A	M10100	T5	450 (232)	5					
		T4			795 (424)	16 to 24	810 (432)		
					a. 775 (413)	6			
					b. 665 (352)	6			
					c. 775 (413)	10			
		T6						450 (232)	5
		T61						425 (218)	25
AZ63A	M11630	T5	500 (260) or	4					
			450 (232)	5					
		T4			725 (385)	10 to 14	735 (391)		
		T6						425 (218)	5
								450 (232)	5
AZ81A	M11810	T4			775 (413)	16 to 24	785 (418)		
					a. 775 (413)	6	[F]		
					b. 665 (352)	2			
					c. 775 (413)	10			
AZ91C	M11914	T5	335 (169) or	16					
			420 (215)	4					
		T4			775 (413)	16 to 24	785 (418)		
					a. 775 (413)	6	[F]		
					b. 665 (352)	2			
					c. 775 (413)	10			
		T6						335 (168)	16
								420 (216)	5–6
AZ91E	M11919	T6	...	...	775 (413)	16 to 24	785 (418)	335 (168)	16
								420 (216)	5–6
					a. 775 (413)	6	[F]		
					b. 665 (352)	2			
					c. 775 (413)	10			
AZ92A	M11920	T5	500 (260)	4					
		T4			765 (407)	16 to 24	775 (413)		
		T6						425 (218)	5
					d. 765 (407)	6	[F]		
					e. 665 (352)	2			
					f. 765 (407)	10			
ZC63A	M16331	T6	...	...	825 (440)[G]	8	840 (449)	370 (188)	16–24

Alloy		Final Temper	B—Mg-Zr Group						
			Aging Treatment[C]		Solution Heat Treatment[D]			Aging after T4	
ASTM	UNS		Temperature± 10°F (±6°C)[E]	Time, h	Temperature± 10°F (±6°C)[E]	Time, h	Maximum Temperature, °F(°C)	Temperature,± 10°F (±6°C)[E]	Time, h
EQ21A	M12210	T6	...	...	970 (521)[G]	4 to 8	980 (527)	400 (204)	8–16
EZ33A	M12330	T5	420 (216) or	5					
			650 (343)[H]	2					
QE22A	M18220	T6			980 (527)[G]	4 to 8	1000 (538)	400 (204)	8–16
WE43A	M18430	T6			975 (525)	4 to 8	990 (530)	480 (250)	16
WE43B	M18432	T6			975 (525)	4 to 8	990 (530)	480 (250)	16
WE54A	M18410	T6			975 (525)	4 to 8	990 (530)	480 (250)	16
ZE41A	M16410	T5	625 (329)[I] plus	2					
			350 (177)[I]	16					
ZE63A	M16630	T6[J]			900 (482)	10 to 72	915 (491)	285 (141)	48
ZK51A	M16510	T5	350 (177) or	12					
			424 (218)	8					
ZK61A[B]	M16610	T5	300 (149)	48					
		T6			930 (499) or	2	940 (505)	265 (129)	48
					900 (482)	10			

[A] Heavy sections may require a longer time than indicated in this table.
[B] The alloys shown in this table section (Mg-Al-Zn Group and ZK61A) are loaded into the furnace at 500°F (260°C) and brought to holding over a 2-h period at a uniform rate of temperature rise. This does not apply to ZC63A which has zinc and copper.
[C] Castings to T5 temper are aged from "as-cast" condition.
[D] After solution heat treatment, and before aging, castings are cooled to room temperature by fast fan cooling, except where indicated differently.
[E] Except where quoted differently.
[F] An alternative heat treatment, if required to minimize grain growth, consists of a sequential treatment as indicated for alloys AM100A, AZ81A, AZ91C, AZ91E, and AZ92A.
[G] Quench from solution heat treatment temperature either in water heated to 150°F (66°C) or in other suitable quench media.
[H] This alternative aging treatment for EZ33A alloy can be used where maximum resistance to creep at elevated temperature is not of prime importance.
[I] The 2 h at 625°F (329°C) is adequate to obtain satisfactory properties. The 16 h at 350°F (177°C) is optional to give a very slight improvement in mechanical properties.
[J] The alloy ZE63A has to be solution heat treated in a special hydrogen atmosphere since its mechanical properties are developed as a result of hydriding some of the alloy ingredients. Hydriding time is dependent upon the section thickness. As a guide, ¼-in. (6.4-mm) sections will require approximately 10 h treatment and ¾-in. (19.0-mm) sections 72 h treatment. Following solution heat treatment, ZE63A alloy should be quenched in oil, water spray, or air blast.

TABLE 2 Recommended Stress-Relieving Treatments for Wrought Magnesium Alloys

Alloy		Sheet				Extrusions and Forgings	
		Annealed		Hard Rolled			
ASTM	UNS	Temperature,° F (°C)	Time, min	Temperature,° F (°C)	Time, min	Temperature,° F (°C)	Time, min
A3A	M10030	500 (260)	15			500 (260)	15
AZ10A-F	M11100				60	500 (260)	15
AZ31B	M11311	650 (343)	120	300 (149)	60		
AZ31B-F	M11311					500 (260)	15
AZ61A	M11610	650 (343)	120	400 (204)	60		
AZ61A-F	M11610					500 (260)	15
AZ80A-F	M11800					500 (260)	15
AZ80A-T5	M11800					400 (204)	60
M1A	M15100	500 (260)	15	400 (204)	60	500 (260)	15
ZE10A	M11600	400 (204)	60				
ZK21A	M16210					500 (260)	15
ZK60A-F	M16600	450 (232)	180			500 (260)	16
ZK60A-T5	M16600					300 (149)	60

TABLE 3 Recommended Heat Treating Schedules for Magnesium Alloy Extrusions

Alloy		Aging			Solution Treatment		Aging after T4	
ASTM	UNS	Final Temper	Temperature °F(°C)	Time, h	Temperature, °F(°C)	Time, h	Temperature, °F(°C)	Time, h
AZ80A	M11800	T5	350 (177)	16				
ZK60A	M16600	T5	300 (149)	24				
		T4			930 (499)	2		
		T6			930 (499)	2	300 (149)	24

TABLE 4 Recommended Heat Treating Schedules for Magnesium Alloy Forgings

Alloy		Aging			Solution Treatment		Aging after T4	
ASTM	UNS	Final Temper	Temperature °F(°C)	Time, h	Temperature, °F(°C)	Time, h	Temperature, °F(°C)	Time, h
AZ80A	M11800	T4			750 (399)	2 to 4		
		T6			750 (399)	2 to 4	350 (177)	16 to 24

APPENDIX

(Nonmandatory Information)

X1. Notes

X1.1 The explanations and recommended practices included in this section are not mandatory, but are intended for information.

X1.2 A potential fire hazard exists in the heat treatment of magnesium alloys. If, through oversight or failure of the temperature control equipment, the temperature of the furnace appreciably exceeds the maximum solution heat treating temperature of the alloy, the castings may ignite and burn. A suitable sulfur dioxide or carbon dioxide atmosphere prevents the starting of a fire until the temperature limits have been exceeded by a considerable amount. Once a magnesium fire has started, the sulfur dioxide or carbon dioxide supplies oxygen to the burning materials. Each furnace used should be equipped with a safety cutout which will turn off the power to the heating elements and blowers in the event of any malfunctioning or failure of the temperature or atmosphere control equipment. These safety cutouts should be set at a temperature of not more than 10°F (6°C) above the maximum temperature permitted for the alloy being heat treated. Air flow switches should also be installed to guard against the stoppage of circulation of air.

X1.3 The temperatures for solution treatment shown in Table 1 are the maximum temperatures to which the alloys may be heated without danger of high-temperature deterioration of fusion of the eutectic. Magnesium alloy castings may be heat treated at lower temperatures, but in such cases a longer time at temperature than that shown in Table 1 would be necessary in order to develop satisfactory mechanical properties.

X1.4 AZ63A, AZ81A, AZ92A and AZ91C castings will be ruined if brought to the heat treating temperature too rapidly. Certain eutectic constituents present melt at a temperature lower than that used for the heat treatment, consequently time should be allowed for the constituents to dissolve before their melting point is reached.

X1.5 When protective atmospheres referred to in X1.2 are used, the concentration in the furnace atmosphere should be checked at periodic intervals.

X1.6 The T5 treatments recommended in Table 1 for "as cast" materials are used to improve mechanical properties, to provide stress relief and to stabilize the alloys in order to prevent dimensional changes later, especially during machining. Both yield strength and hardness are increased somewhat by this treatment at the expense of a slight amount of ductility. This treatment is often recommended for those applications where "as cast" mechanical properties suffice but dimensional stability is essential.

SUMMARY OF CHANGES

Committee B07 has identified the location of selected changes to this standard since the last issue (B 661 – 99) that may impact the use of this standard. (Approved Apr. 10, 2003.)

(*1*) UNS numbers were corrected in Table 1.
(*2*) Alloys WE43A and WE54A were removed from the text of paragraphs 4.5.2 and 6.1.3.1.