MIL-M-6857C
29 March 1974
SUPERSEDING
MIL-M-6857B
11 September 1963

# MILITARY SPECIFICATION

# MAGNESIUM ALLOY CASTINGS, HEAT TREATMENT OF

This specification is approved for use by all Departments and Agencies of the Department of Defense.

## 1. SCOPE

1.1 This specification covers the requirements for the heat treatment of magnesium alloy castings. The alloys to which this specification applies are listed in Table I.

## 2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on the date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

SPECIFICATIONS

Federal

| | |
|---|---|
| QQ-M-55 | Magnesium Alloy, Permanent and Semipermanent Mold Castings |
| QQ-M-56 | Magnesium Alloys, Sand Castings |

Military

| | |
|---|---|
| MIL-M-46062 | Magnesium Alloy Castings, High Strength |

FSC MISC

TABLE I

MAGNESIUM BASE CASTING ALLOYS COVERED BY THIS SPECIFICATION

| Alloy | Form | Federal Specification No. | Military Specification No. |
|---|---|---|---|
| AM100A | Permanent Mold | QQ-M-55 | MIL-M-46062 |
| AZ63A | Permanent Mold | QQ-M-55 | - |
| AZ63A | Sand Casting | QQ-M-56 | - |
| AZ81A | Permanent Mold | QQ-M-55 | - |
| AZ81A | Sand Casting | QQ-M-56 | - |
| AZ91C | Permanent Mold | QQ-M-55 | MIL-M-46062 |
| AZ91C | Sand Casting | QQ-M-56 | MIL-M-46062 |
| AZ92A | Permanent Mold | QQ-M-55 | MIL-M-46062 |
| AZ92A | Sand Casting | QQ-M-56 | MIL-M-46062 |
| EZ33A | Permanent Mold | QQ-M-55 | - |
| EZ33A | Sand Casting | QQ-M-56 | - |
| HK31A | Permanent Mold | QQ-M-55 | MIL-M-46062 |
| HK31A | Sand Casting | QQ-M-56 | MIL-M-46062 |
| HZ32A | Permanent Mold | QQ-M-55 | - |
| HZ32A | Sand Casting | QQ-M-56 | - |
| QE22A | Permanent Mold | QQ-M-55 | MIL-M-46062 |
| QE22A | Sand Casting | QQ-M-56 | MIL-M-46062 |
| ZH62A | Permanent Mold | QQ-M-55 | MIL-M-46062 |
| ZH62A | Sand Casting | QQ-M-56 | MIL-M-46062 |
| ZK51A | Sand Casting | QQ-M-56 | MIL-M-46062 |
| ZK61A | Sand Casting | QQ-M-56 | MIL-M-46062 |
| ZE41A | Sand Casting | (AMS 4439) | - |

STANDARDS

Federal

Fed. Test Method Std. No. 151 — Metals; Test Methods

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. The following document forms a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

Society of Automotive Engineers Aerospace Material Specifications

AMS 4439 Magnesium Alloy Castings, Sand ZE41A-T5

(Copies of SAE publications may be obtained from the Society of Automotive Engineers, Inc., 485 Lexington Avenue, New York 10017.)

## 3. REQUIREMENTS

3.1 Furnaces. Furnaces used for the solution heat treatment and aging of magnesium alloys shall be of the closed chamber type with forced air or protective atmosphere circulation. These furnaces shall be designed to preclude direct radiation from the heating elements or impingement of the flame on the work.

3.1.1 Temperature uniformity. The design and construction of the furnaces shall be such that the temperature in the working zone, for any charge, is capable of being maintained with ±10° F of the desired heat treating temperature after the charge has been brought up to temperature. At no time shall the temperature in any part of the working zone exceed the maximum permissible temperature for the alloy being heat treated. Each furnace used shall be equipped with 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 close as practicable above the maximum solution heat treating temperature for the alloy being heat treated. This will be above the variation expected but shall not be more than 10° F 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.

3.2 Heat control equipment.

3.2.1 Pyrometric equipment. A sufficient number of suitable automatic temperature control devices, properly arranged, shall be provided on all heat-treating equipment to assure adequate control of temperature in all working zones. The devices shall be so located as to avoid exposure to excessive dust, vibration, and temperature outside the range of 32° to 140° F.

3.2.1.1 Temperature-measuring and recording equipment. Automatic controlling and recording instruments shall be used. Instruments should be of the potentiometer type. Temperature-sensing elements should be located in, or as close as possible to, the working zone. The exact location of the temperature-sensing elements will be dependent upon the furnace design. However, they shall be in such a location as to give accurate measurement of the working or soaking, or both, zone temperature.

3.2.1.2 Accuracy. Temperatures shall be adjusted to within ±5° F of true

temperat.. e by applying corrections established by calibrating equipment as specified in 5.2.3. If corrections greater than ±5° F are indicated, the source of error shall be determined and adjustments to the measuring equipment shall be made so that the readings represent a true temperature within ±5° F.

3.3 Quenching. Rapid cooling from the solution heat treated condition is required to obtain optimum properties in the castings. The arrangements should be such that the cooling on the various parts of a furnace charge or casting is as uniform as possible.

3.3.1 Air quenching by means of fan cooling can be used if the quench rate is sufficiently rapid to obtain the desired properties.

3.3.2 Water quenching requires the use of a sufficient volume of water in the quench tank to insure that proper quenching rates are attained. Means shall be provided for circulation of the water to give violent agitation during the quench cycle in order to reduce the incidence of steam pockets. Means for heating or cooling to provide the desired water temperature are required.

3.3.2.1 Quenching equipment shall be located in such a manner and handling facilities shall be so arranged and equipped to permit rapid transfer of the load from the furnace to the quenching medium.

3.4 Miscellaneous equipment. Suitable jigs, fixtures, trays, hangers, racks, ventilators, etc., shall be provided as necessary for the proper handling of the work and for the maintenance of the equipment.

3.5 Approval. The equipment, methods, and processes shall be subject to the approval of the procuring activity.

## 4. PROCEDURE AND OPERATIONS

4.1 Heat Treatment. Magnesium alloy castings shall be solution heat treated within the temperature ranges specified in Table II. When unusual circumstances make strict compliance with Table II impractical, request for deviation approval with substantiating test data should be addressed to the procuring activity.

4.1.1 The furnace should be loaded in such a manner as to permit adequate circulation of the furnace atmosphere. Attention shall be given to providing necessary support to minimize warpage.

4.2 The charge shall be held at temperature for a sufficient time to secure adequate solution heat treatment. Suggested soaking times at temperature for castings up to 1 inch thickness are given in Table II. A longer soaking time may be required for castings with heavier sections.

TABLE II

SOLUTION HEAT TREATMENT OF MAGNESIUM ALLOY CASTINGS

| Alloy | Temperature Range °F | Time at Temperature 1/ -Hours | Max. Permissible Temperature 4/ °F |
|---|---|---|---|
| AM100A | 790 - 810 | 16 - 24 | 810 |
| AZ63A (Type 1) | 720 - 735 | 10 - 14 | 735 |
| AZ63A (Type 2) 2/ | 720 - 745 | 10 - 14 | 745 |
| AZ81A | 770 - 785 | 16 - 24 | 785 |
| AZ91C | 770 - 785 | 16 - 24 | 785 |
| AZ92A (Type 1) | 760 - 775 | 16 - 24 | 775 |
| AZ92A (Type 2) 2/ | 770 - 785 | 14 - 22 | 785 |
| HK31A | 1040 - 1060 | 2 | 1060 |
| QE22A | 975 - 995 3/ | 4 - 8 | 1000 |
| ZK61A | 920 - 935 | 2 | 935 |

1/ Heavy section castings, one inch thick or over, may require longer times than indicated.

2/ Contains calcium.

3/ Must be quenched in water held at 140-195° F.

4/ See Paragraph 4.2.1 for heating rate from 640° F to solution treating temperature.

4.2.1 In solution heat treating AZ63A (type 1 and type 2), AZ81A, AZ91C, AZ92A (type 1), AM100A and ZK61A, the castings shall be heated sufficiently slow to prevent eutectic melting. Two hours should be consumed in heating at a uniform rate from 640° F to the heat treating temperature.

4.2.2 AZ92A (type 2), HK31A and QE22A may be charged into the furnace which is at the heat treating temperature.

4.2.3 Since magnesium castings are subject to excessive surface oxidation at temperatures of 750° F and over, a protective atmosphere containing sufficient sulphur dioxide, carbon dioxide, or other satisfactory oxidation inhibitor shall be used when solution heat treating at 750° F and over. (See 6.2.)

4.3.4 Heat treating operations shall be performed on the whole of a casting, never on a part only, and shall be applied in a manner that will produce the utmost uniformity.

4.3 Cooling. Castings shall be cooled rapidly from the solution heat treating temperature to insure that the specified mechanical properties are obtained.

4.3.1 Castings cooled from the solution heat treatment by quenching in water or other liquid media shall be transferred from the furnace to the tank as rapidly as possible. The quenching media must be agitated and held at the specified temperature during the quench cycle. (See Note 3, Table II)

4.4 Aging. Precipitation heat treatment or artificial aging, when specified, shall be performed at the temperature and times required to develop the specified properties. Aging conditions which have been used satisfactorily are shown in Table III. No protective atmosphere is required.

4.5 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.

## 5. QUALITY ASSURANCE PROVISIONS

5.1 General. All heat treating and cooling equipment, temperature control devices, and all details of the heat treating procedure shall be subject to inspection by representatives of the procuring activity.

5.1.1 Acceptance or approval of the equipment shall in no case be construed as a guaranty of the acceptance of the heat treated product.

5.1.2 The supplier shall maintain on file, test reports in duplicate, showing results of the temperature survey required by this specification and make them available to representatives of the procuring activity.

5.2 Equipment.

5.2.1 Furnace temperature survey. A temperature survey shall be made for each furnace to be used on the contract or order. This survey may be waived at the discretion of the procuring activity provided that the results from previous tests with the same furnace and same type of load show that the uniformity is within the specified limits.

5.2.1.1 A new temperature survey shall be made after changes are made in the furnace construction.

TABLE III

| Alloy and Temper | Time and Temperature to Produce Temper Given in First Column |
|---|---|
| AM100A-T5 1/ | 5 hr. at 450 F |
| AM100A-T6 2/ | 5 hr. at 450 F or 24 hr. at 400 F |
| AZ63A-T5 1/ | 4 hr. at 500 F or 5 hr. at 450 F |
| AZ63A-T6 2/ | 5 hr. at 425 F or 5 hr. at 450 F |
| AZ91C-T5 1/ | 4 hr. at 425 F or 16 hr. at 335 F |
| AZ91C-T6 2/ | 4 hr. at 425 F or 16 hr. at 335 F |
| AZ92A-T5 1/ | 5 hr. at 450 F |
| AZ92A-T6 2/ (type 1) | 5 hr. at 425 F |
| AZ92A-T6 2/ (type 2) | 5 hr. at 450 F or 16 hr. at 400 F or 20 hr. at 350 F |
| EZ33A-T5 1/ | 5 hr. at 425 F or 2 hr. at 650 F +5 hr. at 425 F |
| HK31A-T6 2/ | 16 hr. at 400 F 3/ |
| HZ32A-T5 1/ | 16 hr. at 600 F |
| QE22A-T6 2/ | 8 hr. at 400 F |
| ZE41A-T5 1/ | 24 hr. at 480 F or 1 - 6 hr. at 620 - 680 F + air cool or 2 hr. at 625 F + air cool + 10 - 16 hr. at 340 F |
| ZH62A-T5 1/ | 2 hr. at 625 F + 16 hr. at 350 F |
| ZK51A-T5 1/ | 8 hr. at 425 F or 12 hr. at 350 F |
| ZK61A-T5 1/ | 48 hr. at 300 F |
| ZK61A-T6 2/ | 48 hr. at 265 F |

1/ The T5 temper is obtained by artificial aging from the as-cast (F) temper.

2/ The T6 temper is obtained by artificial aging from the solution heat treated (T4) temper.

3/ HK31A-T4 should be brought to aging temperature as rapidly as possible to minimize grain growth.

5.2.2 Temperature uniformity. The temperature uniformity shall be determined while the furnace contains a typical charge.

5.2.2.1 The initial temperature survey shall be made at the maximum and minimum temperature of solution heat treatments and precipitation heat treatments for which each furnace is to be used. There shall be at least one test location for each 25 cubic feet of air furnace volume up to a maximum of 40 test locations, with a minimum of nine test locations, one in each corner and one in the center. After the initial survey, each furnace shall be surveyed monthly, except as provided in 5.2.1 and 5.2.2.2. The monthly survey shall be at one operating temperature for solution heat treatment and one for precipitation heat treatment. There shall be at least one test location for each 40 cubic feet of load volume, with a minimum of nine test locations, one in each corner and one in the center. The surveys shall be performed 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, the temperature-sensing elements shall be similarly charged. If the furnace is normally charged cold, the temperature-sensing elements shall be charged cold. After insertion of the temperature-sensing elements, readings should be taken frequently enough to determine when the temperature of the test region of the furnace approaches the bottom of the temperature range being surveyed. From the time until thermal equilibrium is reached, the temperature of all test locations shall be determined at 2-minute intervals in order to detect any overshooting. After thermal equilibrium is reached, readings should be taken at 5-minute intervals for sufficient time to determine the recurrent temperature pattern, but not less than 30 minutes. 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 shall not exceed 20° F and shall not vary outside the range being surveyed. For furnaces of 10 cubic feet 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.

5.2.2.2 Monthly surveys may not be necessary when the furnace is equipped with a permanent multipoint recording system with at least two actual metal sensing thermo-couples in each load, and proven uniformity surveys show a history of satisfactory performance for a period of at least 6 months.

5.2.2.3 Furnace control temperature measuring instruments shall not be used to read the temperature of the test temperature sensing elements.

5.2.3 Accuracy of furnace pyrometer systems. The accuracy of temperature-measuring systems shall be checked under operating conditions weekly. Checks 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 3 months, rather than every week. The test temperature-sensing element, potentiometer, and cold junction compensation combination shall have been calibrated against Bureau of Standards' primary or secondary certified temperature-sensing elements within the previous 3 months, to an accuracy of ±2° F.

5.3 Test methods.

5.3.1 The routine operation of the equipment and heat treating procedure shall be judged by the mechanical properties obtained on the test bars heat treated with every furnace charge in accordance with Fed. Test Method Std. No. 151.

5.3.2 The tensile test results of the separately cast test bars or of test bars sectioned from the heat treated castings shall be used to judge the adequacy of the heat treatment to produce acceptable properties.

5.3.3 Microscopic examination. The tensile test may be supplemented by a microscopic examination of the test bars or selected castings at the discretion of the procuring activity. A single representative sample for each of the specified tests shall be taken. If the furnace selected for routine inspection contains a load which is homogeneous as to alloy, form, and size of part, two specimens shall be selected to represent the least massive and the most massive portions of the charge. In the event of nonhomogeneity as to type of alloy, and when the recommended heat treatments for the respective alloys differ, additional samples shall be prepared.

5.3.3.1 Eutectic melting and high temperature oxidation. Specimens from the heat treated samples shall be sectioned, mounted and prepared for microscopic examination. The unetched surface shall be examined at a suitable diameter magnification with a metallurgical microscope. The presence of eutectic melting or high temperature oxidation shall be considered evidence of improper heat treatment. Porosity should not be confused with eutectic melting.

5.3.4 Improper heat treatment.

5.3.4.1 Improper equipment. In case any of the tests indicate that the heat treatment was improper (5.3.3.1) and was caused by poor performance of the furnace (and not improper settings or insufficient time in the furnace), the furnace shall not be used for further heat treating until it is demonstrated that all equipment and operating requirements of this specification are being met.

5.3.4.2 Status of materials. Materials heat treated in the furnace since the time of the previous tests and found unsatisfactory shall be rejected or reheat treated (beginning with the solution heat treatment) 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.

## 6. NOTES

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

6.2 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 sulphur dioxide or carbon dioxide atmosphere prevents the starting of a fire until the temperature limits have been exceeded by a considerable amount. Many heat treaters use an atmosphere of 0.5-1.0 percent sulphur dioxide or 3.0-3.5 percent carbon dioxide for protection at temperatures as low as 600° F. Once a magnesium fire has started, the sulphur dioxide or carbon dioxide supply to the furnace should be shut off, since the burning magnesium unites with the oxygen of these 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 control equipment. These safety cutouts should be set at a temperature of not more than 10° F 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.

6.2.1 When protective atmospheres referred to in section 6.2 are used, the concentration in the furnace atmosphere should be checked at periodic intervals.

6.3 An effective method of extinguishing magnesium fire in a gas tight furnace is to introduce boron trifluoride gas ($BF_3$) through a small opening into the closed furnace. Details of this method may be found in NFPA Bulletin No. 48, "Storage, Handling and Processing of Magnesium", which is issued by the National Fire Protection Association.

6.4 The temperatures for solution treatment shown in Table II are the maximum temperatures to which the alloys may be heated without danger of high temperature deterioration or 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 II would be necessary in order to develop satisfactory mechanical properties.

6.5 AZ63A (type 1 and type 2), AZ81A, AZ91C, (type 1), AM100A and ZK61A castings will be irreversibly damaged if not brought slowly to the solution heat treating temperature. Certain eutectic constitutents in these alloys, melt at a temperature lower than that required for the solution heat treatment, consequently, time shall be allowed for the constituents to dissolve before their melting point is reached.

6.5.1 The presence of calcium in AZ92A (type 2) alloy greatly diminishes the danger of partial fusion and permits a more rapid rate of heating. The presence of calcium in AZ63A (type 2) does not eliminate the danger of partial fusion (eutectic melting) but it does allow a higher final temperature for solution heat treatment.

6.6 The aging treatments recommended in Table III 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, and dimensional stability is essential.

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