ภาควิชาวิศวกรรมเหมืองแร่และวัสดุ
คณะวิศวกรรมศาสตร์
มหาวิทยาลัยสงขลานครินทร์

การสอบปลายภาค ประจำภาคการศึกษาที่ 1 ปีการศึกษา 2552

วันที่ 5 ตุลาคม 2552 เวลา 09.00-12.00 น.

วิชา 237-407 Failure Mechanics and Analysis ห้อง หัวหุ่นยนต์

<u>คำชี้แจงสำหรับนักศึกษา</u>

1. ข้อสอบมีจำนวน 9 ข้อย่อย (3 หน้า รวมใบปะหน้านี้)
2. เอกสารประกอบข้อสอบ มีดังนี้
   - 2.1 Case study: Failure analysis of X-Msn oil fan blade on helicopter (5 หน้า)
   - 2.2 Mechanical properties of magnesium alloys (3 หน้า)
   - 2.3 ASTM Standard B 93/B 93M – 04 (4 หน้า)
3. ตอบคำถามลงในสมุดคำตอบ เขียนหมายเลขข้อให้ชัดเจน
4. สามารถนำเอกสาร และอุปกรณ์ช่วยสอบทุกชนิด เข้าห้องสอบได้
5. คะแนนสอบครั้งนี้คิดเป็น 30 % ของคะแนนรวมทั้งหมด

<u>คำชี้แจงสำหรับกรรมการจัดทำข้อสอบ และผู้คุมสอบ</u>

1. ให้แจกสมุดคำตอบคนละ 2 เล่ม

อ . ณรงค์ฤทธ์ โทธรัตน์

ผู้ออกข้อสอบ

แบบทดสอบการวิเคราะห์การชำรุดอย่างเป็นระบบ ปีการศึกษา 2552

I. ข้อกำหนดในการสอบ

1. สามารถนำเอกสารทุกชนิด และอุปกรณ์ช่วยสอบได้ทุกชนิด เข้าห้องสอบได้
2. จากรายงานผลการวิเคราะห์การชำรุด 1 ฉบับ

Case Study : Failure analysis of X-Msn oil cooler fan blade on helicopter

ให้นักศึกษา ใช้ความรู้ ด้าน Fracture Mechanics, Systematic Failure Analysis, Heat Treatment, Metallurgy , Materials Engineering และความรู้อื่น ๆ ด้านวิศวกรรม ศาสตร์ อธิบายผลการวิเคราะห์ เพื่อใช้ในการตอบ ข้อสอบ

3. เวลา 3 ชั่วโมง ข้อสอบ มีทั้งหมด 4 กลุ่มเป้าหมาย (**Materials Analysis, Process Analysis, Failure Analysis, Management & Prevention)**

II. วัตถุประสงค์ในการสอบ

เพื่อให้นักศึกษาสามารถวิเคราะห์ปัญหาเป็นระบบ นำทฤษฎี มาเชื่อมโยงกับการปฏิบัติ และประยุกต์ใช้ในการอธิบายปรากฏการณ์ที่เกิดขึ้นกับชิ้นงานจริงและมองในเชิงการบริหารจัดการได้

คำสำคัญ

HAF = High Amplitude Fatigue

NDI = Eddy Current Test

Shrinkage Cavity

Magnesium Alloy

ASTM AZ91C-T6 is categorized as *Magnesium Alloy*. It is composed of (in weight percentage) 8.70% Aluminum (Al), 0.13% Manganese (Mn), 0.70% Zinc (Zn), and the base metal Magnesium (Mg). It is usually used in sand casting and permanent mold casting. Another common designation of ASTM AZ91C-T6 magnesium alloy is UNS S13800. The use of magnesium alloys for pump castings in rocket motors, helicopter transmission gear housing, Oil cooler fan blade.

ผู้ออกข้อสอบ : ณรงค์ฤทธิ์ โทธรัตน์

ให้นักศึกษาตอบคำถามดังต่อไปนี้

1. จุดเด่นในการเลือกใช้วัสดุกลุ่มดังกล่าวทำ Oil cooler fan blade helicopter (5 คะแนน)

2. Mode การชำรุด ของใบพัดดังกล่าว คือ Mode ใด ลักษณะอะไรที่เป็นตัวบ่งชี้ว่าเป็นการชำรุด Mode นี้ (10 คะแนน)

3. มีองค์ประกอบใดบ้าง ที่ทำให้เกิดการชำรุด Mode ดังกล่าว อธิบายรายละเอียดของแต่ละองค์ประกอบและอิทธิพลของแต่ละองค์ประกอบที่มีต่อการชำรุด (20 คะแนน)

4. อธิบายกลไก การแตก ณ.จุดดังกล่าวในเชิง Fracture Mechanics (15 คะแนน)

5. สาเหตุหลักที่ทำให้เกิดการชำรุดดังคืออะไร มาจากกระบวนการใด เกิดขึ้นได้อย่างไร (10 คะแนน)

6. จงอธิบายผลของความแตกต่างถึงระหว่างใบที่เกิดการแตกร้าวและใบที่ไม่มีการแตกร้าว ในเชิงการวิเคราะห์การชำรุด (5 คะแนน)

7. หากมี ใบพัดดังกล่าว จากโรงงานผู้ผลิตเดียวกัน ใช้งานอยู่ในเครื่องบินจำนวน 40 ตัว และของใหม่ที่สำรองไว้ที่บริษัทผู้ซ่อมบำรุงรักษาเครื่องบิน ยังไม่ได้ใช้งาน 20 ตัว ท่านจะมีแนวทางการจัดการบริหารอย่างไร ที่จะไม่ให้เกิดการชำรุดรุนแรงในขณะที่เครื่องบินทำงาน (15 คะแนน)

8. หากท่านเป็นวิศวกรที่ควบคุมการผลิต ใบพัดดังกล่าว และ ยังมีใบพัดที่ผลิตเสร็จแล้วรอส่งมอบอีก 30 ตัว ท่านจะสร้างมั่นใจอย่างไรให้ลูกค้าที่จะรับส่งมอบเพื่อไปใช้งาน ว่าใบพัดมีคุณภาพสูงพอที่จะไม่เกิดปัญหาดังกล่าว จะมีแนวทางการจัดการบริหารอย่างไร (15 คะแนน)

9. หากท่านเป็นวิศวกรที่ควบคุมการผลิต จงเสนอแนวทางที่จะปรับปรุงคุณภาพของการผลิต Fan ดังกล่าว (15 คะแนน)

ผู้ออกข้อสอบ : ณรงค์ฤทธ์ โทธรัตน์

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Failure analysis of X-Msn oil cooler fan blade on helicopter

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ABSTRACT

An analysis on cracks found on AZ91C-T6 X-MSN oil cooler fan blades of a HH-47 helicopter was performed. Cracks on oil cooler fan blades, which are conditional parts, are variously distributed between 199 and 1023 operating hours. All cracks initiated from the blade root mid span as a form of multi-origin, and then developed by HAF (high amplitude fatigue). Cracks were initiated from gas porosity formed in the casting process, a shrinkage cavity and a pit instigated between base metal and coating layer. The blade with 1238 operating hours had a crack 42 mm out of the total length of 45 mm. This crack began from the convex side and penetrated through the concave side causing blade fracture. Therefore, improvement of blade manufacturing process is required and blades in operation are recommended to be eddying current inspected after paint coating removal every 250 h and to be replaced every 1000 operation hours to prevent fracture.

1. Introduction

The X-MSN oil cooler fan of the HH-47 helicopter is mounted on the rear of the transmission to cool lubricant. The oil cooler fan blade consists of 11 impellers with a maximum rotating speed of 10,517 rpm. The blade material, AZ91C-T6 Mg alloy, satisfies the standard alloy specifications when ICP (JOVIN Yvon Ultima 2) was performed to analyze the chemical composition. Cracks were observed on 15 blades as shown in Table 1, with distributed from 200 to 1238 operating hours. The blade with 1238 operation hours had a 42 mm crack developed over the total length of 45 mm, causing blade fracture. Oil cooler fan blade is a conditional item with eddy current inspection every 100 h.

SEM (scanning electron microscopy, HITACHI S-4700) and optical microscopy were used for fracture surface analysis and microstructure analysis, respectively.

2. Results

2.1. Crack pattern

Fig. 1 shows the results of macro analysis of cracks in 3 blades (#5,7,11). All 3 blades are observed from the convex side. The concave side crack on blade #11 was determined to initiate from the convex side then penetrated through the mid span. Other blades with cracks show the same pattern. Therefore, cracks on oil cooler fan seems to be initiated from convex side mid root where it sees the highest air pressure.

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Table 1
The cracks of oil cooler fan blade.

Fan No	Number of crack (size : mm)		Operating time (hours)	Other
	FWD	AFT		
1	–	3EA(18.8,16,9.5)	400	
2	2EA (4.5, 7.2)	1EA(4.3)	259	
3	–	1EA(5.4)	200	
4	1개(3.3)	1EA(3.1)	604	
5	1개(5.1)	1EA(7.2)	363	
6		2EA(30.5, 32.6)	1023	
7		1EA(40.1)	1234	
8		1EA(42.2)	1238	Fracture

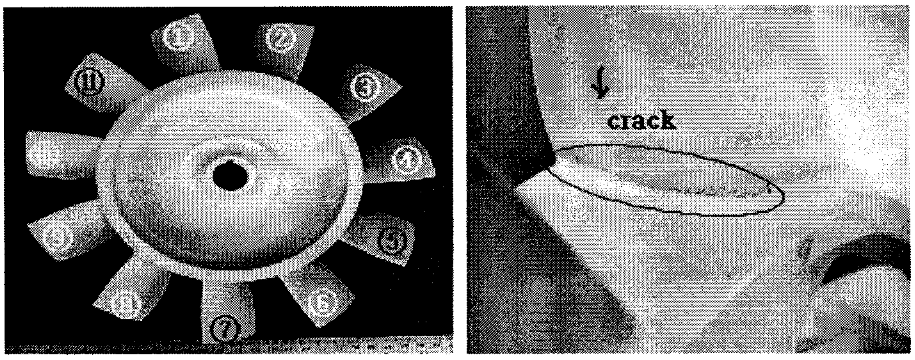


Fig. 1. The cracks of oil cooler fan blades (#5,7,11 blade).

2.2. Fracture surface analysis

After fractured and cracked blades were forced open macro and microscope observations were performed and fatigue cracks were identified. Fig. 2a shows the fatigue crack initiating from convex side then penetrating through the concave side.

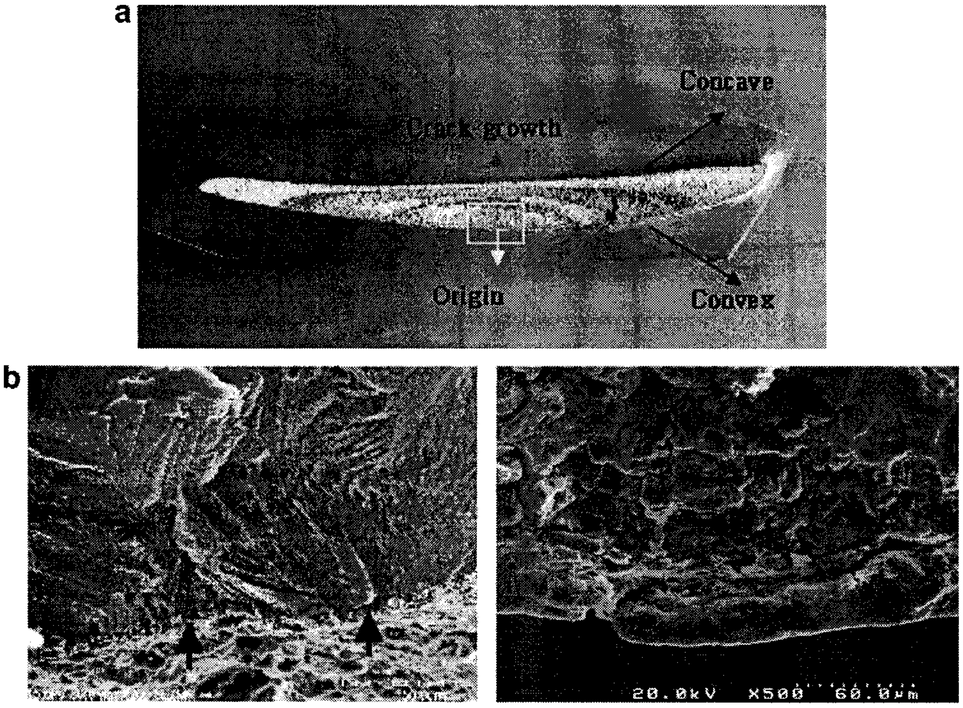


Fig. 2. (a) Photograph of fracture fan blade and (b) SEM of corroded multi-origins of fatigue crack.

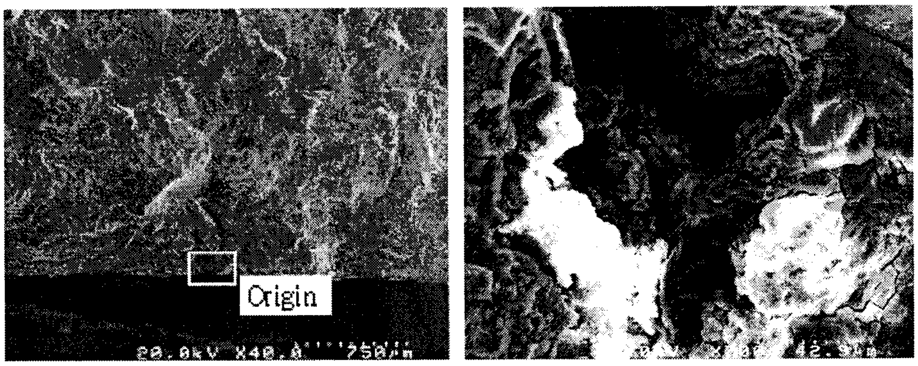
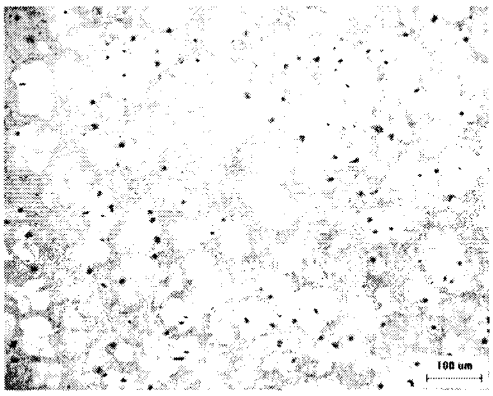


Fig. 3. Porosity of origin in the #5 crack fan blade.

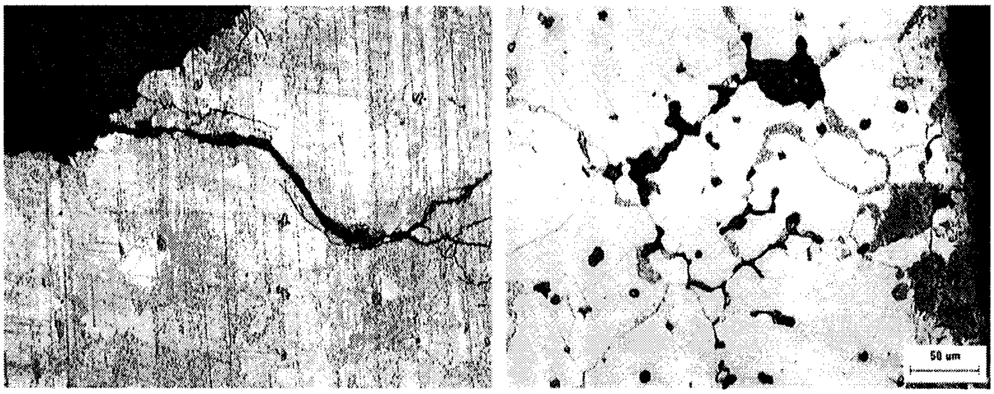
Fig. 2b shows cracks of multiple origins beginning from paint-coating-damaged area. As a result of EDX analysis, the crack initiation point seems to be pits caused by corrosion.

The result of SEM observation on the #5 fan blade cracks in Fig. 1 shows some fan blades had fatigue cracks initiating from porosity of 0.5 mm size and oxidizing as shown in Fig. 3. Pores are judged to be gas porosity which appeared during blade casting and shrinkage cavity. Cracks developed toward concave side up to 3.2 mm, which is 50% of the total thickness. The result of SEM observation on #11 fan blade cracks in Fig. 1 shows 2.2 mm crack growth from convex side to concave side and 0.6 mm growth from concave side to convex side.

While Fig. 4a, observation of the fan blade microstructure with cracks caused by paint coating damage, shows sound cast microstructure, Fig. 4b analyzing the fan blade microstructure with porosity, shows that cracks were initiated from surface porosity and is advancing with many casting defects near surface.



(a) Pit type origin fan blade



(b) Porosity type origin fan blade.

Fig. 4. Optical microstructures of different origins.

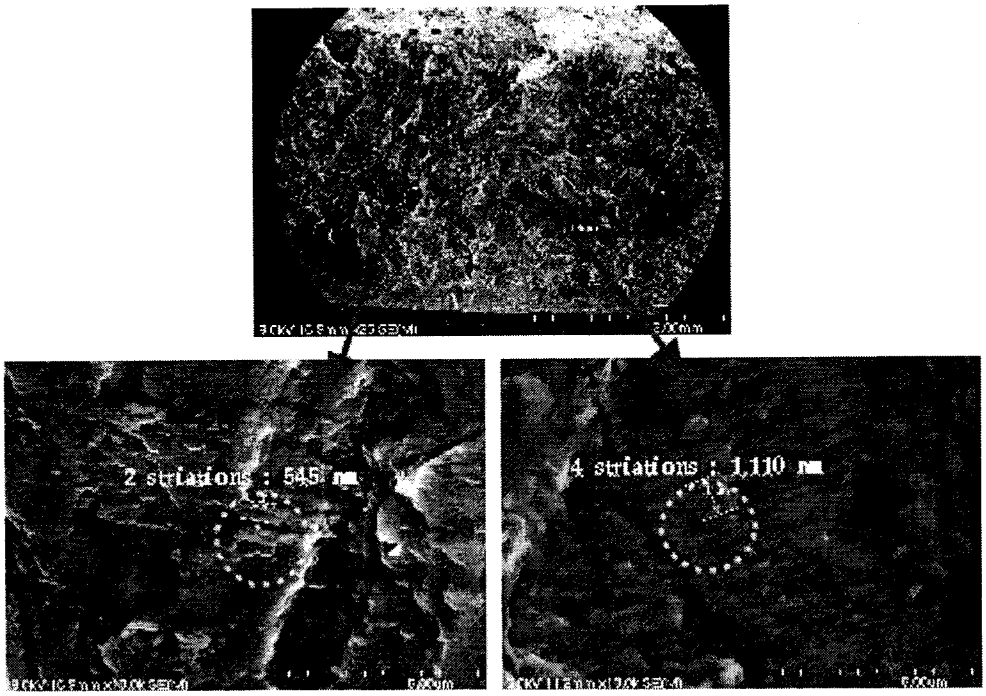


Fig. 5. Measurement striation space by SEM.

Striation spacing analysis by SEM on fatigue crack surface shows the features of HAF (high amplitude fatigue) that the space between crack beginning point and end point appears uniformly with approximately 272 nm and 277 nm as shown in Fig. 5 [1,2]. The striation spacing on #11 blades had approximately 264 nm and 270 nm. HAF seems to be caused by flexure vibration on oil cooler fan blade.

3. Discussion

As cast Mg alloy is vulnerable to oxidation, gas porosity and shrinkage cavity tend to appear during the casting process. If surface damage occurs during operation, it is easily oxidized. Although AZ91C-T6 X-MSN oil cooler fan blades are painted to prevent oxidation, pits occurred in the boundary layer due to paint coating damage from operation. While connected to quill shaft and impeller shaft during operation, X-MSN oil cooler fan rotates at a maximum of 10,517 rpm generating intense vibration. The vibration causes stress to be concentrated on pits and surface casting defects, instigating cracks. During operation, X-MSN oil cooler fan received constant amplitude of vibration, causing fatigue cracks to develop by HAF. The fatigue cracks advanced up to 42 mm in the 45 mm long-blade with 1238 operating hours ending in fracture.

As a result of correlation analysis between fan blade crack growth and fracture, many cracks on oil cooler fans were found after 200 operating hours. Accordingly, a measure to perform NDI (Eddy Current Test) every 250 operating hours after paint removal is established to prevent X-MSN oil cooler fan blade fracture [3]. Since fan blade crack doesnot advance to fracture until it reaches 90% of total blade length, part replacement after 1000 operating hours is recommended with safety factors considered.

4. Conclusions

As cracks and fractures on AZ91C-T6 X-MSN oil cooler fan blades initiated in the blade root mid span as a form of multi-origin. Cracks begun from pits on paint-damaged areas, porosities and shrinkage cavities formed in the casting process and propagated by vibration and then developing from high amplitude fatigue. The fatigue cracks advanced up to 42 mm in a 45 mm long-blade with 1238 operating hours and ended in blade fracture. Therefore the following are recommended as fracture preventive measures.

A. Eddy current inspection with paint removal after every 250 operating hours in order to prevent X-MSN oil cooler fan blade fracture. Crack was initiated after 200 operating hours.
B. Part replacement after 1000 operating hours to prevent crack advancement to fracture.
C. Reformation of casting and painting process for oil cooler fan blade quality improvement.

References

[1] ASM Handbook. 2002. Vol. 11. p. 627, p. 644.
[2] GEAE ROKAF Training Book. 2007. p. 109–118.
[3] T.O BH 55-1520-240-23 Para' 6–140.5.

Table 3 Nominal compositions and typical room-temperature mechanical properties of magnesium alloys

Alloy	Composition, %						Tensile strength		Yield strength						Elongation in 50 mm (2 in.), %	Shear strength		Hardness, HRB[c]
									Tensile		Compressive		Bearing					
	Al	Mn[a]	Th	Zn	Zr	Other[b]	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi		MPa	ksi	
Sand and permanent mold castings																		
AM100A-T61	10.0	0.1	...	...	...	...	275	40	150	22	150	22	...	...	1	...	...	69
AZ63A-T6	6.0	0.15	...	3.0	...	...	275	40	130	19	130	19	360	52	5	145	21	73
AZ81A-T4	7.6	0.13	...	0.7	...	...	275	40	83	12	83	12	305	44	15	125	18	55
AZ91C- and E-T6[d]	8.7	0.13	...	0.7	...	...	275	40	145	21	145	21	360	52	6	145	21	66
AZ92A-T6	9.0	0.10	...	2.0	...	...	275	40	150	22	150	22	450	65	3	150	22	84
EQ21A-T6	...	...	...	...	0.7	1.5 Ag, 2.1 Di	235	34	195	28	195	28	...	...	2	...	...	65-85
EZ33A-T5	...	...	...	2.7	0.6	3.3 RE	160	23	110	16	110	16	275	40	2	145	21	50
HK31A-T6	...	...	3.3	...	0.7	...	220	32	105	15	105	15	275	40	8	145	21	55
HZ32A-T5	...	...	3.3	2.1	0.7	...	185	27	90	13	90	13	255	37	4	140	20	57
K1A-F	...	...	...	...	0.7	...	180	26	55	8	...	...	125	18	1	55	8	...

Sheet and plate																		
AZ31B-H24	3.0	. . .	. . .	1.0	. . .	. . .	290	42	220	32	180	26	325	47	15	160	23	73
HK31A-H24	. . .	. . .	3.0	. . .	0.6	. . .	255	37	200	29	160	23	285	41	9	140	20	68
HM21A-T8	. . .	0.6	2.0	. . .	. . .	. . .	235	34	170	25	130	19	270	39	11	125	18	. . .
PE[j]	3.3	. . .	. . .	0.7	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

(a) Minimum.

(b) RE, rare earth; Di, didymium (a mixture of rare-earth elements made up chiefly of neodymium and praseodymium).

(c) 500 kg load, 10 mm ball.

(d) Properties of C and E are identical, but AZ91E castings have maximum contaminant levels of 0.005% Fe, 0.0010% Ni, and 0.015% Cu.

(e) Properties of A and B are identical, but AM60B castings have maximum contaminant levels of 0.005% Fe, 0.002% Ni, and 0.010% Cu.

(f) Properties of A and XB are identical, but AS41XB castings have maximum contaminant levels of 0.0035% Fe, 0.002% Ni, and 0.020% Cu.

(g) Properties of A, B, and D are identical, except that 0.30% max residual Cu is allowable in AZ91B, and AZ91D castings have maximum contaminant levels of 0.005% Fe, 0.002% Ni, and 0.030% Cu.

(h) For battery applications.

(i) Properties of B and C are identical, but AZ31C has 0.15% min Mn, 0.1% max Cu, and 0.03% max Ni.

ZE63A	T6	Excellent castability, pressure tight, weldable, highly developed properties in thin-wall castings
ZH62A	T5	Stronger than, but as castable as, ZE41A. Weldable, pressure tight
ZK51A	T5	Good strength at room temperature
ZK61A	T6	Excellent strength at room temperature. Only fair castability but capable of developing excellent properties in castings

Source: Ref 1

Magnesium-Aluminum Casting Alloys. The magnesium sand and permanent mold casting alloys that contain aluminum as the primary alloying ingredient (AM100A, AZ63A, AZ81A, AZ91C, AZ91E, and AZ92A) exhibit good castability, good ductility, and moderately high yield strength at temperatures up to approximately 120 °C (~250 °F). Of these alloys, AZ91E has become prominent; it has almost completely replaced AZ91C because it has superior corrosion performance. In AZ91E, the iron, nickel, and copper contaminants are controlled to very low levels. As a result, it exhibits excellent saltwater corrosion resistance.

In any of the magnesium-aluminum-zinc alloys, an increase in aluminum content raises yield strength but reduces ductility for comparable heat treatment. Final selection of the specific composition may be based on tests of the finished castings.

The K1A alloy is used primarily where high damping capacity is required. It has low tensile and yield strength.

Magnesium alloys that contain high levels of zinc (ZK51A, ZK61A, ZK63A, and ZH62A) develop the highest yield strengths of the casting alloys and can be cast into complicated shapes. However, these grades are more costly than the alloys of the AZ series. Therefore, these alloys are used where exceptionally good yield strengths are required. They are intended primarily for use at room temperature.

Because ZK61A has a higher zinc content, it has significantly greater strength than ZK51A (Table 3). Both alloys maintain high ductility after an artificial aging treatment (T5). The strength of ZK61A can be further increased (3 to 4%) by solution treatment plus artificial aging (T6), without impairing ductility. Both of these alloys have fatigue strengths equal to those of the magnesium-aluminum-zinc alloys, but they are more susceptible to microporosity and hot cracking, and are less weldable. Addition of either thorium or rare-earth metals overcomes these deficiencies. The strength properties of ZE63A are equivalent to those of ZK61A, and those of ZH62A are equivalent to or better than those of ZK51A (Table 3).

Alloy ZE63A is a high-strength grade with excellent tensile strength and yield strength; these superior properties are obtained by heat treating in a hydrogen atmosphere. Because hydriding proceeds from the surface, heat-treating time, wall thickness, and penetrability are limiting factors. This alloy has excellent casting characteristics.

The ZE41A alloy was developed to meet the growing need for an alloy with medium strength, good weldability, and improved castability in comparison with AZ91C and AZ92A. It has good fatigue and creep properties and maximum freedom from microshrinkage. Unlike the AZ alloys, there is a very close relationship between separately cast test bar properties and those obtained from the casting itself, even where relatively thick cast sections are involved. Alloy ZE41A is used at temperatures up to 160 °C (320 °F) in such applications as aircraft engines, helicopter and airframe components, and wheels and gear boxes.

Alloy ZC63 is a member of a new family of magnesium alloys containing neither aluminum nor zirconium. The alloy exhibits good castability, and it is pressure tight and weldable. No grain refining or hardeners are required to obtain its properties, but a heat treatment must be used to achieve the full properties. The alloy has attractive room-temperature and moderately elevated temperature properties. The corrosion resistance of the alloy is similar to that of AZ91C, but it is less than that of AZ91E.

Designation: B 93/B 93M – 04

INTERNATIONAL

Standard Specification for Magnesium Alloys in Ingot Form for Sand Castings, Permanent Mold Castings, and Die Castings[1]

This standard is issued under the fixed designation B 93/B 93M; 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 specification covers magnesium alloys in ingot form for remelting for the manufacture of sand castings, permanent mold castings, investment castings, and die castings.

NOTE 1—Supplementary information pertaining to the alloys covered by this specification when used in the form of castings is given in Specifications B 80, B 94, B 199 and B 403.

1.2 The values stated in either inch-pound units or SI units are to be regarded separately as standard. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other.

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 The following documents of the issue in effect on date of order acceptance form a part of this specification to the extent referenced herein:

2.2 *ASTM Standards:* [2]

B 80 Specification for Magnesium-Alloy Sand Castings
B 94 Specification for Magnesium-Alloy Sand Castings
B 199 Specification for Magnesium-Alloy Sand Castings
B 275 Practice for Codification of Certain Nonferrous Metals and Alloys, Cast and Wrought
B 403 Specification for Magnesium-Alloy Sand Castings
B 881 Specification for Magnesium-Alloy Sand Castings
E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E 35 Test Methods for Chemical Analysis of Magnesium and Magnesium Alloys
E 88 Practice for Sampling Nonferrous Metals and Alloys in Cast Form for Determination of Chemical Composition
E 527 Practice for Numbering Metals and Alloys (UNS)

3. Ordering Information

3.1 Orders for ingot to this specification shall include the following information:

3.1.1 Quantity in pounds (kilograms)

3.1.2 Alloy (Section 4 and Table 1 or Table 2), and

3.1.3 Form: as agreed upon between the purchaser and seller. Some forms in commercial use are:

Form	Approximate Size Length by Width by Height, in. (mm)	Approximate Weight, lb (kg)
Five-segment	23 by 2¾ by 1¾ (583 by 70 by 44)	5 (2.3)
Four-segment	28 by 4½ by 4 (711 by 114 by 102)	20 (9.1)
Self-Palletizing	26½ by 6⅝ by 2⅝ (672 by 168 by 67)	25 (11.3)

3.1.4 Inspection required at the manufacturer's works (see 8.1).

3.1.5 For inch-pound orders specify B93; for metric orders specify B93M. Do not mix units.

4. Chemical Composition

4.1 The ingots shall conform to the chemical composition limits prescribed in Table 1 for sand cast alloys and permanent mold-cast alloys and in Table 2 for die-cast alloys. Conformance shall be determined by the manufacturer by analyzing samples taken at the time the ingots are poured or samples taken from the ingots. If the manufacturer has determined the chemical composition of the material during manufacture, he shall not be required to sample and analyze the ingots.

4.2 The alloys shall conform to the chemical composition requirements prescribed in Table 1 and Table 2 (Note 2 and Note 3).

NOTE 2—Analysis shall regularly be made only for the elements specifically mentioned in the tables. If, however, the presence of other elements is suspected or indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements is not in excess of the limits specified in the last column of the table.

[1] This specification 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.

Current edition approved Oct 1, 2004. Published October 2004. Originally approved in 1934. Last previous edition approved in 2003 as B 93/B 93M – 03.

[2] 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.**

TABLE 1 Chemical Requirements for Alloy Ingot for Remelt to Sand, Permanent, Mold and Investment Castings—Composition %

Alloy[A] ASTM	UNS	Magnesium	Aluminum	Manganese	Zinc	Yttrium	Rare Earths	Zirconium	Silicon, max	Copper, max	Nickel, max	Silver	Iron, max	Others each max[B]	Total Others, max[B]
AM100A	M10101	remainder	9.4–10.6	0.13–0.35	0.2 max	...	...	...	0.20	0.08	0.010	...	...	...	0.30
AZ63A	M11631	remainder	5.5–6.5	0.15–0.35	2.7–3.3	...	...	...	0.20	0.20	0.010	...	...	...	0.30
AZ81A	M11811	remainder	7.2–8.0	0.15–0.35	0.5–0.9	...	...	...	0.20	0.08	0.010	...	...	...	0.30
AZ91C	M11915	remainder	8.3–9.2	0.15–0.35	0.45–0.9	...	...	...	0.20	0.08	0.010	...	...	...	0.30
AZ91E	M11918	remainder	8.3–9.2	0.17–0.50	0.45–0.9	...	...	...	0.20	0.015	0.0010	...	0.005	0.01	0.30
AZ92A	M11921	remainder	8.5–9.5	0.13–0.35	1.7–2.3	...	...	...	0.20	0.20	0.010	...	...	...	0.30
EQ21A	M18330	remainder	...	...	...	...	1.5–3.0[C]	0.3–1.0	0.01	0.05–0.10	0.01	1.3–1.7	...	...	0.30
EZ33A	M12331	remainder	...	...	2.0–3.0	...	2.6–3.9	0.3–1.0	0.01	0.03	0.010	...	...	...	0.30
K1A	M18011	remainder	...	...	...	...	...	0.3–1.0	0.01	0.03	0.010	...	...	...	0.30
QE22A	M18221	remainder	...	0.15 max	0.2 max	...	1.9[C]–2.4[C]	0.3–1.0	0.01	0.03	0.010	2.0–3.0	...	...	0.30
WE43A[DE]	M18431	remainder	...	0.15 max	0.20 max	3.7–4.3	2.4-4.4[E]	0.3–1.0	0.01	0.03	0.005	...	....	...	0.30
WE43B[DE]	M18433	remainder	...	0.03 max	...[F]	3.7–4.3	2.4–4.4[E]	0.3–1.0	...	0.01	0.004	...[F]	...	0.01	...
WE54A[DE]	M18410	remainder	...	0.15 max	0.20 max	4.75–5.5	1.5–4.0[E]	0.3–1.0	0.01	0.03	0.005	...	...	...	0.30
ZC63A	M16331	remainder	...	0.25–0.75	5.5–6.5	...	...	...	0.20	2.4–3.00	0.001	...	...	...	0.30
ZE41A	M16411	remainder	...	0.15 max	3.7–4.8	...	1.0–1.75	0.3–1.0	0.01	0.03	0.010	...	...	...	0.30
ZE63A	M16631	remainder	...	...	5.5–6.0	...	2.0–3.0	0.3–1.0	0.01	0.03	0.010	...	...	...	0.30
ZK51A	M16511	remainder	...	...	3.8–5.3	...	...	0.3–1.0	0.01	0.03	0.010	...	...	...	0.30
ZK61A	M16611	remainder	...	...	5.7–6.3	...	...	0.3–1.0	0.01	0.03	0.010	...	...	...	0.30

[A] These alloy designations were established in accordance with Practice B 275. UNS designations were established in accordance with Practice E 527.
[B] Includes listed elements for which no specific limit is shown.
[C] Rare earth elements are in the form of didymium, not less than 70 % Nd balance substantially Pr.
[D] Lithium content for WE43A/WE43B shall be 0.18 % max, and WE54A shall be 0.20 % max.
[E] Rare earths are 2.0 to 2.5 % and 1.5 to 2.0 % neodymium for WE43A and WE54A, respectively, the remainder being principally heavy rare earths.
[F] Zinc + Silver shall be 0.15 % max.

TABLE 2 Chemical Requirements for Alloys Used for Die Castings[A]

Alloy		Composition, %												
Designation[B]	UNS	Aluminum	Manganese	Rare Earth	Strontium	Zinc	Copper, max	Iron, max	Silicon	Nickel, max	Beryllium	Other Metallic impurities, max each[C]	Other Impurities, max	Magnesium
AS41A	M10411	3.7–4.8	0.22–0.48	...	...	0.10 max	0.04	...	0.60–1.4	0.01	...	...	0.30	remainder
AS41B	M10413	3.7–4.8	0.35–0.6	...	...	0.10 max	0.015	0.0035	0.60–1.4	0.001	0.0005-0.0015	0.01	...	remainder
AM50A	M10501	4.5–5.3	0.28–0.50	...	...	0.20 max	0.008	0.004	0.08 max	0.001	0.0005-0.0015	0.01	...	remainder
AM60A	M10601	5.6–6.4	0.15–0.50	...	...	0.20 max	0.25	...	0.20 max	0.01	...	...	0.30	remainder
AM60B	M10603	5.6–6.4	0.26–0.50	...	...	0.20 max	0.008	0.004	0.08 max	0.001	0.0005-0.0015	0.01	...	remainder
AZ91A	M11911	8.5–9.5	0.15–0.40	...	...	0.45–0.9	0.08	...	0.20 max	0.01	...	...	0.30	remainder
AZ91B	M11913	8.5–9.5	0.15–0.40	...	...	0.45–0.9	0.25	...	0.20 max	0.01	...	...	0.30	remainder
AZ91D	M11917	8.5–9.5	0.17–0.40	...	...	0.45–0.9	0.025	0.004	0.08 max	0.001	0.0005-0.0015	0.01	...	remainder
AJ52A[D]	M17521	4.6–5.5	0.26–0.5	...	1.8–2.3	0.20 max	0.008	0.004	0.08 max	0.001	0.0005-0.0015	0.01	...	remainder
AJ62A[D]	M17621	5.6–6.6	0.26–0.5	...	2.1–2.8	0.20 max	0.008	0.004	0.08	0.001	0.0005-0.0015	0.01	...	remainder
AS21A	M10211	1.9–2.5	0.2–0.6	...	...	0.20 max	0.008	0.004	0.7–1.2	0.001	0.0005-0.0015	0.01	...	remainder
AS21B[D]	M10213	1.9–2.5	0.05–0.15	0.06–0.25	...	0.25 max	0.008	0.0035	0.7–1.2	0.001	0.0005-0.0015	0.01	...	remainder

[A] The following applies to all specified limits in this table; for purposes of acceptance and rejection, an observed value or a calculated value obtained from analysis should be rounded off to the nearest unit in the last right-hand place of figures used in expressing the specified limit in accordance with the rounding-off procedure prescribed in Practice E 29.
[B] ASTM alloy designations were established in accordance with Practice B 275. UNS Numbers were established in accordance with Practice E 527.
[C] Includes listed elements for which no specific limit is shown.
[D] Alloys AJ52A, AJ62A, and AS21B are patented compositions for elevated temperature applications. Interested parties are invited to submit information regarding the identification of alternatives to these compositions to ASTM International. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this specification. Users of this specification are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

NOTE 3—The following applies to all specified limits in the tables: For purposes of acceptance and rejection, an observed value or a calculated value obtained from analysis shall be rounded off in accordance with the rounding off method of Practice E 29 to the nearest unit in the last right-hand place of figures used in expressing the specified limit.

TABLE 1 Chemical Requirements for Alloy Ingot for Remelt to Sand, Permanent, Mold and Investment Castings—Composition %

Alloy[A] ASTM	UNS	Magnesium	Aluminum	Manganese	Zinc	Yttrium	Rare Earths	Zirconium	Silicon, max	Copper, max	Nickel, max	Silver	Iron, max	Others each max[B]	Total Others, max[B]
AM100A	M10101	remainder	9.4–10.6	0.13–0.35	0.2 max	...	...	...	0.20	0.08	0.010	...	...	...	0.30
AZ63A	M11631	remainder	5.5–6.5	0.15–0.35	2.7–3.3	...	...	...	0.20	0.20	0.010	...	...	...	0.30
AZ81A	M11811	remainder	7.2–8.0	0.15–0.35	0.5–0.9	...	...	...	0.20	0.08	0.010	...	...	...	0.30
AZ91C	M11915	remainder	8.3–9.2	0.15–0.35	0.45–0.9	...	...	...	0.20	0.08	0.010	...	...	...	0.30
AZ91E	M11918	remainder	8.3–9.2	0.17–0.50	0.45–0.9	...	...	...	0.20	0.015	0.0010	...	0.005	0.01	0.30
AZ92A	M11921	remainder	8.5–9.5	0.13–0.35	1.7–2.3	...	...	...	0.20	0.20	0.010	...	...	...	0.30
EQ21A	M18330	remainder	...	...	...	...	1.5–3.0[C]	0.3–1.0	0.01	0.05–0.10	0.01	1.3–1.7	...	...	0.30
EZ33A	M12331	remainder	...	...	2.0–3.0	...	2.6–3.9	0.3–1.0	0.01	0.03	0.010	...	...	...	0.30
K1A	M18011	remainder	...	...	...	...	...	0.3–1.0	0.01	0.03	0.010	...	...	...	0.30
QE22A	M18221	remainder	...	0.15 max	0.2 max	...	1.9[C]–2.4[C]	0.3–1.0	0.01	0.03	0.010	2.0–3.0	...	...	0.30
WE43A[DE]	M18431	remainder	...	0.15 max	0.20 max	3.7–4.3	2.4–4.4[E]	0.3–1.0	0.01	0.03	0.005	...	....	...	0.30
WE43B[DE]	M18433	remainder	...	0.03 max	...[F]	3.7–4.3	2.4–4.4[E]	0.3–1.0	...	0.01	0.004	...[F]	...	0.01	...
WE54A[DE]	M18410	remainder	...	0.15 max	0.20 max	4.75–5.5	1.5–4.0[E]	0.3–1.0	0.01	0.03	0.005	...	...	...	0.30
ZC63A	M16331	remainder	...	0.25–0.75	5.5–6.5	...	...	...	0.20	2.4–3.00	0.001	...	...	...	0.30
ZE41A	M16411	remainder	...	0.15 max	3.7–4.8	...	1.0–1.75	0.3–1.0	0.01	0.03	0.010	...	...	...	0.30
ZE63A	M16631	remainder	...	...	5.5–6.0	...	2.0–3.0	0.3–1.0	0.01	0.03	0.010	...	...	...	0.30
ZK51A	M16511	remainder	...	...	3.8–5.3	...	...	0.3–1.0	0.01	0.03	0.010	...	...	...	0.30
ZK61A	M16611	remainder	...	...	5.7–6.3	...	...	0.3–1.0	0.01	0.03	0.010	...	...	...	0.30

[A] These alloy designations were established in accordance with Practice B 275. UNS designations were established in accordance with Practice E 527.
[B] Includes listed elements for which no specific limit is shown.
[C] Rare earth elements are in the form of didymium, not less than 70 % Nd balance substantially Pr.
[D] Lithium content for WE43A/WE43B shall be 0.18 % max, and WE54A shall be 0.20 % max.
[E] Rare earths are 2.0 to 2.5 % and 1.5 to 2.0 % neodymium for WE43A and WE54A, respectively, the remainder being principally heavy rare earths.
[F] Zinc + Silver shall be 0.15 % max.

TABLE 2 Chemical Requirements for Alloys Used for Die Castings[A]

Alloy		Composition, %												
Designation[B]	UNS	Aluminum	Manganese	Rare Earth	Strontium	Zinc	Copper, max	Iron, max	Silicon	Nickel, max	Beryllium	Other Metallic impurities, max each[C]	Other Impurities, max	Magnesium
AS41A	M10411	3.7–4.8	0.22–0.48	...	...	0.10 max	0.04	...	0.60–1.4	0.01	...	...	0.30	remainder
AS41B	M10413	3.7–4.8	0.35–0.6	...	...	0.10 max	0.015	0.0035	0.60–1.4	0.001	0.0005-0.0015	0.01	...	remainder
AM50A	M10501	4.5–5.3	0.28–0.50	...	...	0.20 max	0.008	0.004	0.08 max	0.001	0.0005-0.0015	0.01	...	remainder
AM60A	M10601	5.6–6.4	0.15–0.50	...	...	0.20 max	0.25	...	0.20 max	0.01	...	...	0.30	remainder
AM60B	M10603	5.6–6.4	0.26–0.50	...	...	0.20 max	0.008	0.004	0.08 max	0.001	0.0005-0.0015	0.01	...	remainder
AZ91A	M11911	8.5–9.5	0.15–0.40	...	...	0.45–0.9	0.08	...	0.20 max	0.01	...	...	0.30	remainder
AZ91B	M11913	8.5–9.5	0.15–0.40	...	...	0.45–0.9	0.25	...	0.20 max	0.01	...	...	0.30	remainder
AZ91D	M11917	8.5–9.5	0.17–0.40	...	...	0.45–0.9	0.025	0.004	0.08 max	0.001	0.0005-0.0015	0.01	...	remainder
AJ52A[D]	M17521	4.6–5.5	0.26–0.5	...	1.8–2.3	0.20 max	0.008	0.004	0.08 max	0.001	0.0005-0.0015	0.01	...	remainder
AJ62A[D]	M17621	5.6–6.6	0.26–0.5	...	2.1–2.8	0.20 max	0.008	0.004	0.08	0.001	0.0005-0.0015	0.01	...	remainder
AS21A	M10211	1.9–2.5	0.2–0.6	...	...	0.20 max	0.008	0.004	0.7–1.2	0.001	0.0005-0.0015	0.01	...	remainder
AS21B[D]	M10213	1.9–2.5	0.05–0.15	0.06–0.25	...	0.25 max	0.008	0.0035	0.7–1.2	0.001	0.0005-0.0015	0.01	...	remainder

[A] The following applies to all specified limits in this table; for purposes of acceptance and rejection, an observed value or a calculated value obtained from analysis should be rounded off to the nearest unit in the last right-hand place of figures used in expressing the specified limit in accordance with the rounding-off procedure prescribed in Practice E 29.
[B] ASTM alloy designations were established in accordance with Practice B 275. UNS Numbers were established in accordance with Practice E 527.
[C] Includes listed elements for which no specific limit is shown.
[D] Alloys AJ52A, AJ62A, and AS21B are patented compositions for elevated temperature applications. Interested parties are invited to submit information regarding the identification of alternatives to these compositions to ASTM International. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this specification. Users of this specification are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

NOTE 3—The following applies to all specified limits in the tables: For purposes of acceptance and rejection, an observed value or a calculated value obtained from analysis shall be rounded off in accordance with the rounding off method of Practice E 29 to the nearest unit in the last right-hand place of figures used in expressing the specified limit.

5. Workmanship, Finish and Appearance

5.1 The ingots shall be uniform in quality and shall be commercially free of slag or other foreign material.

6. Sampling for Chemical Analysis

6.1 Sufficient samples shall be taken by the manufacturer to ensure conformance to the chemical composition requirement of the alloy.

6.1.1 Samples may be taken from the molten metal when the ingot is poured or from the ingots. Samples shall be representative of the material.

6.2 In case of dispute, the sampling for chemical analysis shall be according to the requirements of Practice E 88.

6.2.1 If the shipment is in less than carload lots and also in the case of magnesium-zirconium alloys, one ingot section shall be taken for sampling for each 2200 lb (1000 kg) or fraction thereof.

7. Methods of Chemical Analysis

7.1 Any suitable method of chemical analysis may be used. In case of dispute, the analysis shall be made by methods given in Test Methods E 35 or any other standard methods of analysis approved by ASTM unless some other method is agreed upon between the purchaser and vendor.

8. Inspection

8.1 If the purchaser desires that inspection be made at the manufacturer's works where the material is made, it shall be so stated in the contract or purchase order.

8.1.1 If the purchaser elects to have the inspection made at the manufacturer's works, the manufacturer shall afford the inspector representing the purchaser all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification.

8.1.2 All tests and inspection shall be so conducted as not to interfere unnecessarily with the operation of the works.

9. Rejection

9.1 Material that does not conform to the requirements of this specification may be rejected and, if rejected, the seller's responsibility shall be limited to replacing the rejected material. The full weight of the rejected material shall be returned to the manufacturer.

10. Product Marking

10.1 Identification shall be by stamping with the alloy designation in Table 1 and Table 2.

11. Packaging and Package Marking

11.1 Ingots shall be packaged in such a manner as to prevent damage in ordinary handling and transportation. The type of packing and gross weight of individual containers or bundles shall be left to the discretion of the supplier unless otherwise agreed upon. Packaging methods shall be so selected as to permit maximum utility of equipment in unloading and subsequent handling. Each container or bundle shall contain only one size and alloy when packaged for shipment unless otherwise agreed upon.

11.2 Each package shall be marked with the purchase order number, quantity, specification number, alloy, gross or net weights, and the name of the manufacturer.

11.2.1 Each package shall be color-coded on two opposite corners, visible from four sides, with the colors listed in Table 3 when stated as a purchase order requirement.

TABLE 3 Color Code

Alloy	Color Code
AJ52A	Black and White
AJ62A	Black and Yellow
AM50A	Black
AM60A	Green and White
AM60B	White
AS21A	Blue and Green
AS21B	Blue and White
AS41A	Red
AS41B	Red and White
AZ91B	Blue and Yellow
AZ91C	Brown
AZ91D	Yellow
AZ91E	Brown and Yellow

11.3 Packages shall be such as to ensure acceptance by common or other carriers for safe transportation at the lowest rate to the point of delivery.

11.4 For those alloys listed, the various national regulations concerning the transportation of these alloys will be complied with in regard to hazardous materials.

12. Keywords

12.1 composition; die casting; high pressure die cast alloy; magnesium; permanent mold casting; sand casting

SUMMARY OF CHANGES

Committee B07 has identified the location of selected changes to this standard since the last issue (B 93/B 93M – 03) that may impact its use. (Approved October 2004.)

(1) Added the chemical requirements for Alloys AS21A, AS21B, AJ52A, and AJ62A to Table 2.
(2) Reduced the maximum berylliu, content of the alloys from 0.003 to 0.0015 % where specified in Table 2.
(3) Added color codes for the new alloys in Table 3.