②

MTL TR 88-41

AD [ ]

STRUCTURES AND PROPERTIES OF MAGNESIUM BASE COMPOSITES

AD-A203 461

ERNEST S. C. CHIN
MATERIALS PRODUCIBILITY BRANCH

December 1988

DTIC
ELECTE
1 3 JAN 1989
S   D
E

US ARMY
LABORATORY COMMAND
MATERIALS TECHNOLOGY LABORATORY

U.S. ARMY MATERIALS TECHNOLOGY LABORATORY
Watertown, Massachusetts 02172-0001

89   1 12 029

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

Mention of any trade names or manufacturers in this report shall not be construed as advertising nor as an official indorsement or approval of such products or companies by the United States Government.

ADA203461

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER MTL TR 88-41	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) STRUCTURES AND PROPERTIES OF MAGNESIUM BASE COMPOSITES		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ernest S. C. Chin		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Materials Technology Laboratory Watertown, Massachusetts 02172-0001 ATTN: SLCMT-MEM		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS D/A Project 1L162105AH84
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Laboratory Command 2800 Powder Mill Road Adelphi, Maryland 20783-1145		12. REPORT DATE December 1988
		13. NUMBER OF PAGES 9
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES
Published in Magnesium Developments, 1988, p. 46-52. A selection of papers from a program presented at the World Materials Congress, McCormick Place, Chicago, Illinois, held September 26, 1988.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Composites,	Boron carbide,	Graphite,
Metal matrix,	Silicon carbide,	Fibers,
Magnesium,	Alumina,	Particulates. (grs)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

(SEE REVERSE SIDE)

Block No. 20

ABSTRACT

Chronic needs for higher performance in present and future military and commercial systems mandate improvements in material properties. High stiffness, high strength, and low density are among the material properties necessary to achieve future system performance goals. Such requirements can no longer be met using conventional metal alloys. Magnesium matrix composites are among the candidates to fulfill the aforementioned requirements. Ceramic fiber, particulate, and whisker reinforced magnesium composites have demonstrated significant improvements in specific stiffness and specific strength over the monolithic matrix alloys. Magnesium matrix composites can also compete with high strength aluminum alloys and other metal matrix composites for high performance and weight critical applications. However, magnesium composites are still relatively expensive and are still in the developmental stage. Six magnesium composites were studied: cast 55v/o continuous Al_2O_3 fiber/ZE41A Mg; cast 40v/o continuous graphite fiber/ZE41A Mg; cast 40v/o continuous graphite fiber/AZ91C Mg; PM extruded 20v/o B_4C particulate/AZ61A Mg; PM extruded 20v/o SiC particulate/ZK60A Mg; and PM extruded 20v/o α-SiC whisker/ZK60A Mg, cast 55v/o continuous Al_2O_3 fiber/ZE41A Mg. Both tensile and fracture toughness results on each of the composite systems will be presented. The nature of the reinforcement-matrix interfacial bond was revealed through detailed transmission electron microscopy. The effects of the interface as related to the tensile and toughness properties will be discussed.

Accession For

NTIS GRA&I	☒	
DTIC TAB	☐	
Unannounced	☐	
Justification		

By

Distribution/

Availability Codes

Dist	Avail and/or Special
A-1	20

→ Keywords →

STRUCTURES AND PROPERTIES OF MAGNESIUM BASE COMPOSITES

Ernest S. C. Chin

U.S. Army Materials Technology Laboratory
Materials Producibility Branch
Materials Exploitation Division
Watertown, MA 02172-0001

INTRODUCTION

Magnesium is recognized as an engineering alloy for a wide range of weight sensitive applications. Higher strength and better corrosion resistance magnesium alloys are constantly being developed. The incorporation of hard phases as reinforcements to a magnesium matrix can result in enchanced specific strength and specific modulus as compared to the monolithic materials. Consequently, magnesium composites can compete with other monolithic engineering alloys such as aluminum and steel in weight critical applications.

Metal matrix composites have been the subject of intense research and development within the past ten years. However, to a relatively conservative engineering community, any novel material must first prove itself to be reliable, reproducible, and economical before being accepted. This requires the availability of a comprehensive material property data base compiled through detailed characterization of state-of-the-art materials.

Understanding the interdependent factors that correlate mechanical properties with microstructures and processing is one of the keys to material optimization. This is especially true for metal matrix composites. Each component in the composite microstructure plays signifigant role in its performance. The effects of reinforcement distribution, size, and interfacial reaction zone on composite strength and toughness are some of the many issues being investigatied.

There are currently two types of magnesium composites: continuous fiber reinforceed and particulate/whisker reinforced magnesium. In continuous fiber reinforced composites, the matrix serves as a binder for the load bearing filaments. Properties of continuous fiber reinforced composites rely on the filament properties and the capability if the fiber/matrix interface to transfer load. Theoretical properties of continuous fiber reinforced composites can be calculated by the rule-of-mixtures[1]. In particulate and whisker reinforced composites, the primary strengthening mechanism is retardation of dislocation movements by the fine dispersion of reinforcement. Numerous theoretical models relating dispersion mean-free-path, interparticle spacing, and other factors with mechanical properties have been proposed[2].

Six composites were studied for this paper:

1. 55 volume percent(v/o) undirectional continuous alumina fiber/ ZE41A magnesium(α-Al$_2$O$_3$/ZE41A);
2. 40 v/o unindirectional continuous P-55 graphite fiber/ZE41A magnesium (Gr/ZE41A);
3. 40´v/o unindirectional P-55 graphite fiber/AZ91C magnesium (Gr/AZ91C);
4. 20 v/o boron carbide particulate /AZ61A magnesium(B$_4$C/AZ61A);
5. 20 v/o silicon carbide particulate /ZK60A magnesium(SiC$_p$/ZK60A);
6. 20 v/o silicon carbide whisker/ZK60A magnesium(SiC$_w$/ZK60A).

The α-Al$_2$O$_3$/ZE41A was processed by method of molten liquid metal infiltration [3]. All the Gr/Mg composites in this study were consolidated by investment casting [4]. The graphite fibers were pretreated with an oxide coating [5] through oxidation of an organometallic solution on the filament surfaces[5] prior to casting to enhance wetting and interfacial bonding.

Partculate and whisker reinforced magnesium composites were processed through powder metallurgy(PM) techniques. The particulates or whiskers were blended with the matrix powder, canned, degassed, hot pressed, and extruded[6]. The blending of metal powders and reinforcements was a key process where segregations of the hard phases in the composite microstructure must be avoided. The B$_4$C/ZK60A studied was a 3" diameter extrusion subjected to a 4:1 cross section reduction. Both the SiC$_p$/ZK60A and SiC$_w$/ZK60A were 2" diameter 13:1 extrusions. Further heat treatments were performed to strengthen the matrix alloy. The SiC$_p$/ZK60A, and SiC$_w$/ZK60A studied were in the T6, solution heat treated and artivicially aged, condition. The B$_4$C/AZ61 was studied in the as extruded (F) condition.

MATERIAL CHARACTERIZATION TECHNIQUES

In this study, tensile properties, toughness behavior, fracture characteristics, and microstructures were determined for each individual composite. The relationship between microstructure and properties were explored through observations. Longitudinal and transverse tensile properties were determined with tapered "dog bone" specimens sectioned from 1/2" thick α-Al$_2$O$_3$/ZE41A, 1/4" thick

Gr/ZE41A, and 1/4" thick Gr/AZ91C plates. Round button head and threaded specimens were tested in the radial and extrusion direction for $B_4C/AZ61A$, $SiC_p/ZK60A$, and $SiC_w/ZK60A$. Charpy V-notch specimens were sectioned from 1/2" thick $\alpha-Al_2O_3/ZE41A$, Gr/ZE41A, and Gr/AZ91C plates. Similarly, Charpy V-notch specimens were also sectioned from the 3"diameter $B_4C/ZK60A$, 2" diameter $SiC_p/ZK60A$, and 2" diameter $SiC_w/ZK60A$ extruded rods. Relative toughness of each composite was established through comparison of K_{IO} values obtained from slow bend testing of the Charpy specimens according to ASTM E399 test method without precracking. Fracture morphologies of each of the composites were determined through detailed scanning electron microscope(SEM) observations. Microstructural and interfacial characterizations were performed with metallography and transmission electron microscope(TEM) techniques.

RESULTS

MICROSTRUCTURES

Reinforcement Size and Distribution

The $\alpha-Al_2O_3/ZE41A$ fibers are 20 μm diameter polycrystalline filaments[7], whereas the graphite P-55's are 10 um diameter pitch base carbon fibers[8]. Metallography and SEM study of the polished microstructure showed relatively uniform fiber distribution in both the $\alpha-Al_2O_3/ZE41A$, Gr/AZ91C, and Gr/ZE41A composites(see Figure 1). Matrix rich zones separating laminate layers were observed in 1/4" thick plates and were prevalent in 1/2" Gr/Mg plates.

The whisker and particulate reinforcements varied in size and geometry throughout each of the dispersion strengthened composites. The B_4C particulates are polygonal in nature with a mean diameter of 10 μm(see Figure 2). The SiC particulates were fine spherical powders less than 5 μm in diameter(see Figure 3). The SiC whiskers were single crystals and had a mean diameter of 0.6 μm and an aspect ratio of 10:1 (see Figure 4). All the whiskers were aligned in the extrusion direction. The B_4C, SiC_w, and SiC_p reinforced Mg composites showed pockets of matrix rich zone in the transverse direction(see Figure 3). Larger unreinforced matrix rich zones were found in $SiC_p/ZK60A$ than in $SiC_w/ZK60A$. Sporadic clusters of reinforcement were found in all of the composites.
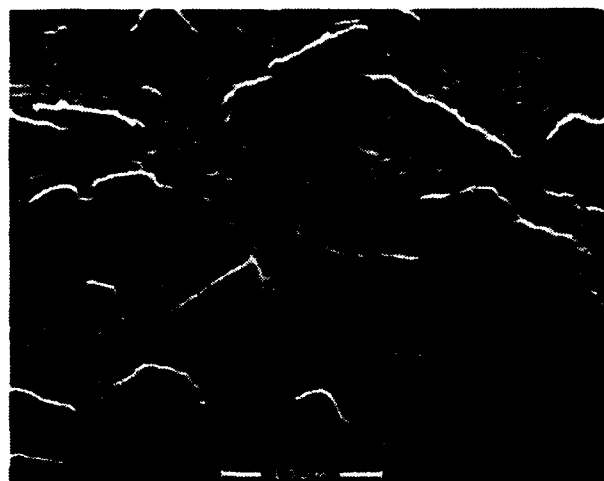

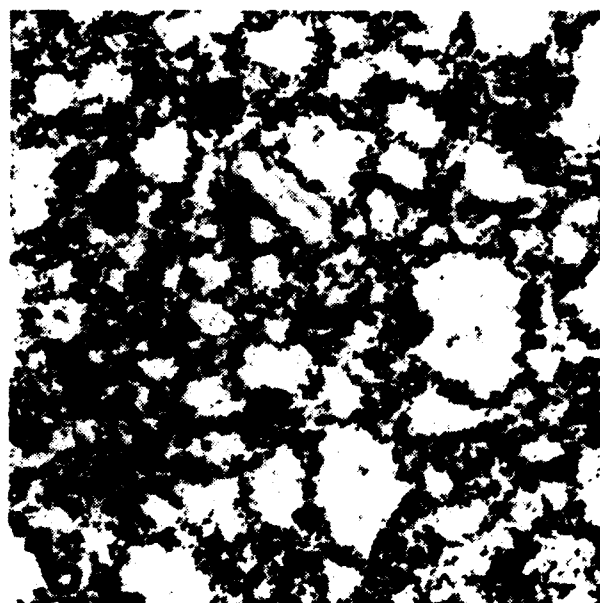Figure 2. SEM Micrograph of a Typical Polished Transverse Cross Section in $B_4C/AZ61A$.

Figure 1. Optical Micrograph of a Typical Transverse Cross Section in $\alpha-Al_2O_3/ZE41A$(Left) and Gr/AZ91C(Right).(1000X)

Figure 3. Optical Micrograph of a Typical Transverse Cross Section of $SiC_p/ZK60A$.(1000X)

47

Interface

Previous studies on α-Al$_2$O$_3$/ZE41A identified a
fine grained spinel(MgAl$_2$O$_4$) phase seperating the
fiber surface and the magnesium matrix [9] (see
Figure 5). In Gr/ZE41A composite, TEM had revealed
large silicon and rare earth rich oxide particles at
the interface (see Figure 6), whereas in Gr/AZ91C, a
thin layer of amorphous silicon oxide and a layer of
magnesium oxide defined the interfaces (see Figure
7). The silicon oxide layer remaining between the
fiber surface and the reacted magnesium oxide layer
was part of the original coating deposited by
oxidation of an organometallic solution. The
B$_4$C/AZ61A particulate/matrix interface showed a fine
thin reaction film(see Figure 8). In both the SiC$_p$
and SiC$_w$ reinforced ZK60A, no observable interfacial
reaction zone was detected (see figure 8 & 9).

Figure 6. TEM Micrograph of Transverse Cross
Section of Gr/ZE41A Interface.(330,000X)

Figure 4. Optical Micrograph of SiC$_w$/ZK60A
Longitudinal Cross Section.(1000X)

Figure 7. TEM Micrograph of Transverse Cross
Section of Gr/AZ91C Interface.(100,000X)
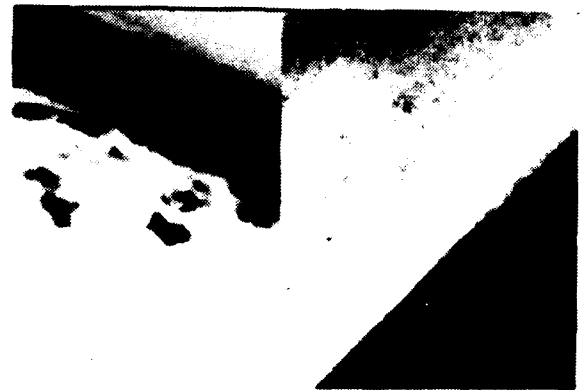
Figure 8. TEM Micrograph of Transverse Cross
Section of B$_4$C/AZ61A(Left) and
SiC$_p$/ZK60A(Right) Interface.(330,000X)

Figure 5. TEM Micrograph of Transverse Cross
Section of α-Al$_2$O$_3$/ZE41A
Interface.(38,000X)

Figure 9. TEM Micrograph of Transverse Cross
Section of SiC$_w$/ZK60A Interface.
(100,000X/Left,330,000X/Right)

Matrix

Except for Gr/AZ91C where only dislocations
were observed, substantial amount of matrix
precipitation was found in all of the composites.
The primary precipitation was large spherical MgZn
and rod like MgZn' (see Figure 10). The MgZn
precipitates were typically found at twin and grain
boundaries whereas the MgZn' resided within each
grain in a preferred orentation. The major
difference between each composite were the size and
distribution of these precipitates. The as-cast
α-Al$_2$O$_3$/ZE41A had greater quanity and finer MgZn' in
the matrix than the Gr/ZE41A. The B$_4$C/AZ61A matrix
was densely populated with matrix and grain boundary
Mg-Al-Zn precipitates.

Figure 10. TEM Micrograph of MgZn' and MgZn
Precipitation in SiC$_p$/ZK60A.(59,000X)

MECHANICAL PROPERTIES

A summary of the tensile and toughness
properties of each of the composites is found in
Table I, II, and III. The tensile moduli of the
continuously reinforced composites are superior to
those of the dispersion reinforced composites. As
expected in continuous reinforced composites, there
is a significant drop in tensile and toughness
properties from the longitudinal direction to the
transverse direction. A marked decrease in
properties from the 1/4" plate to the 1/2" plate in

the Gr/AZ91C is also noted. Although
α-Al$_2$O$_3$/ZE41A has a higher density than Gr/AZ91C,
it has[3] etter overall tensile and toughness
properties in the longitudinal and transverse
directions. In dispersion hardened composites, both
SiCw/ZK60A and SiC$_p$/ZK60A composites demonstrated
better strength and modulus than the B$_4$C/AZ61A. The
highest strength of all the dispersion composites
tested is SiC$_w$/ZK60A in the longitudinal direction.
The longitudinal tensile modulus in SiC$_w$/ZK60A are
identical, but both are higher than the B$_4$C/AZ61A.
In the transverse direction, better strength and
modulus was attained with SiC$_p$/ZK60A than with
SiC$_w$/ZK60A. The best toughness value attained with
all the tested composites is demonstrated with
B$_4$C/AZ61A.

Table I. Longitudinal Tensile Properties

Material	0.2%Yield	UTS(ksi)	Modulus(Msi)
55v/o			
α-Al$_2$O$_3$/ ZE41A (1/2"Plates)	–	77.2 sd=2.5 (3%)	31.3 sd=0.3 (<1%)
40v/o			
Gr/AZ91C (1/4" Plates)	–	85.0 sd=8.0 (9%)	26.7 sd=4.0 (15%)
(1/2" Plates)	–	62.0	17.8
40v/o			
Gr/ZE41A (1/4"Plates)	–	40.5 sd=6.0 (15%)	29.6 sd=2.0 (7%)
20v/o			
B$_4$C/AZ61A-F (3" Dia.Extr.)	38.5 sd=0.7 (2%)	47.9 sd=1.2 (3%)	8.5 sd=0.4 (5%)
20v/o			
SiCp/ZK60A-T6 (2" Dia.Extr.)	57.9 sd=0.5 (<1%)	67.0 sd=0.9 (1%)	10.0 sd=0.5 (5%)
20v/o			
SiC$_w$/ZK60A-T6 (2" Dia.Extr.)	64.9 sd=3.0 (5%)	83.7 sd=3.0 (4%)	10.1 sd=1.0 (10%)

*sd=Standard Deviation

Table II. Transverse Tensile Properties

Material	0.2%Yield	UTS(ksi)	Modulus(Msi)
55v/o			
α-Al2O3/ ZE41A (1/2"Plate)	–	33.4 sd=0.3 (<1%)	15.1 sd=0.4 (3%)
40v/o			
Gr/ AZ91C (1/4"Plates)	–	6.5 sd=1.5 (23%)	4.1 sd=0.3 (7%)
(1/2"Plates)	–	1.1	3.5
40v/o			
Gr/ ZE41A (1/4"Plates)	–	2.7 sd=0.7 (26%)	3.6 sd=1.0 (28%)
20v/o			
SiC$_w$/ZK60A (2"Extr.)	39.3 sd=2.5 (5%)	49.6 sd=1.1 (3%)	8.5 sd=0.4 (5%)
20v/o			
SiC$_p$/ZK60A (2"Extr.)	50.3 sd=0.8 (2%)	58.9 sd=7.6 (13%)	9.2 sd=0.6 (6%)

*sd=Standard Deviation

Table III. Fracture Toughness Properties

Material/Orientation	K_{IQ}	
55v/o α-Al$_2$O$_3$/ZE41A		
L-T	13.4	sd=0.3(2%)
T-L	10.3	sd=1.6(16%)
40v/o Gr/AZ91C		
L-T	2.3	sd=0.1(6%)
T-L	0.08	
40v/o Gr/ZE41A		
L-T	1.21	sd=0.1(10%)
T-L	0.22	sd=0.05(23%)
20v/o B$_4$C/AZ61A		
L-R	17.4	sd=0.6(3%)
20v/o SiC$_w$/ZK60A		
L-R	16.5	sd=0.5(4%)
R-L	12.1	sd=0.9(8%)
20v/o SiC$_p$/ZK60A		
L-R	14.7	sd=0.6(3%)
R-L	12.3	sd=0.5(4%)

*sd= Standard Deviation

FRACTOGRAPHY

Fracture morphologies from the tested tensile and toughness specimens were similar. The fracture morphology of α-Al$_2$O$_3$ was typical of a well bonded fiber reinforced composite in the longitudinal direction (see Figure 11) and fiber splitting was apparent in the transverse direction. In the Gr/AZ91C, fracture occured along the fiber surface and the silicon oxide coating interface (see Figure 12). Longitudinal fracture surfaces resembled those indentified in α-Al$_2$O$_3$/ZE41A. Fiber splitting was also characteristic of the transverse fracture morphlogy in Gr/AZ91C (see Figure 13). Rare earcth oxide and matrix debonding was the failure mechanism observed in Gr/ZE41A (see Figure 14). The longitudinal fracture surface was planar and characteristic of a brittle failure. In B$_4$C/AZ61A, fracture typically initiated at a surface or internal flaw. Fracture initiation defects were often agglomerates of reinforcements or oxides. The general fracture morphology was composed of ductile fracture through the matrix connecting particles which failed in cleavage (see Figure 15). In SiC$_p$/ZK60A, micro-void coalescence and decohesion of particulates were the primary failure mechanisms (see Figure 16). A similar failure mode was observed in SiC$_w$/ZK60A with whisker pull-outs as an added fracture mechanism (see Figure 17).

Figure 12. SEM Micrograph of Gr/AZ91C Longitudinal Fracture Surface.

Figure 13. SEM Micrograph of Gr/AZ91C Transverse Fracture Surface.
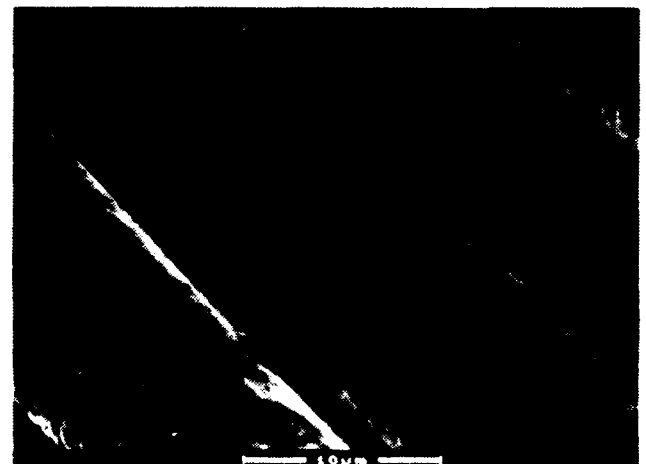
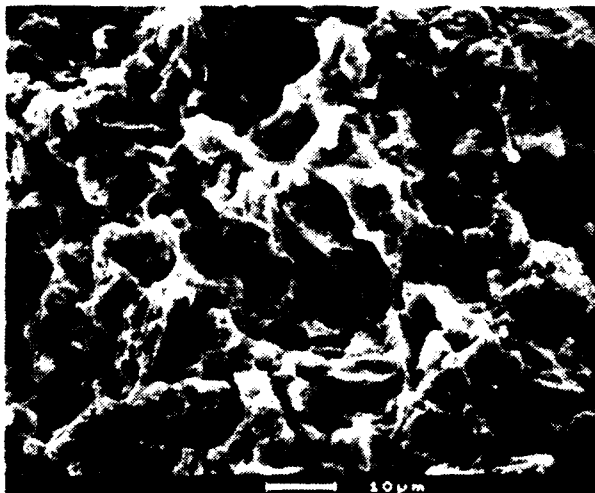Figure 14. SEM Micrograph of Gr/ZE41A Transverse Fracture Surface.

Figure 11. SEM Micrograph of α-Al2O3/ZE41A Longitudinal Fracture Surface.

50

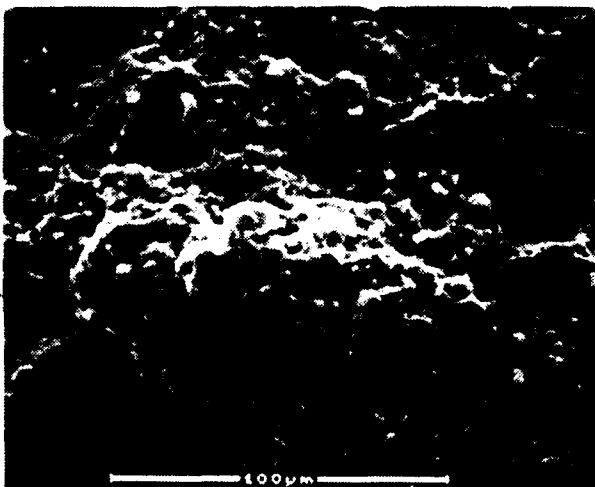Figure 15. SEM Micrograph of B_4C/AZ61A Fracture Surface.

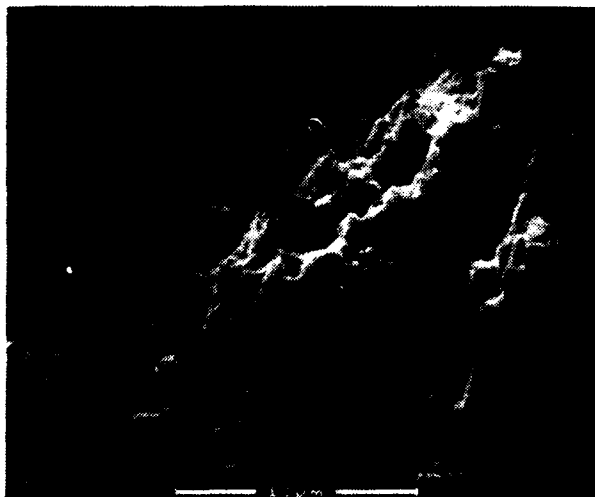Figure 16. SEM Micrograph of SiC_p/ZK60A Fracture Surface.

Figure 17. SEM Micrograph of SiC_w/ZK60A Fracture Surface.

DISCUSSION

Previous studies on the microstructure and properties of α-Al_2O_3/ZE41A[9] and Gr/AZ91C[10] recognized that both materials exhibit near theoetical longitudinal properties. The fracture morphologies of both α-Al_2O_3/ZE41A and Gr/AZ91C were consistent with that of a well bonded composite. The key common factor between the two composites appeared to be the interfacial reaction zone. An ultra-fine grain reaction product, $MgAl_2O_4$ in the case of α-Al_2O_3/ZE41A and MgO in the case of Gr/AZ91C, was present to provide good interfacial shear strength. The spinel phase $MgAl_2O_4$ was the reaction product from the α-Al_2O_3 and molten magnesium. The MgO resulted from reaction of the amorphous SiO coating material and molten magnesium. The mean grain diameter within the reaction zone was less than 500Å. Similarly, in B_4C/AZ61A where a thin film of fine grain reaction product was present, fracture occured through particle cleavage rather than interfacial debonding. This may have accounted for the best toughness result of all the composites tested in this study.

Transverse strength and toughness in Gr/AZ91C were extremely low compared to the α-Al_2O_3/ZE41A and the theoretical ROM prediction. The weakest link in the Gr/AZ91C was the unreacted amorphous silicon oxide coating which failed under tension in transverse loading. In Gr/ZE41A, the large grain rare earth oxide interface($>0.1\mu m$) formed a thick brittle reaction layer which accounted for the poor longitudinal tensile and toughness properties. The oxide was a reaction product from the amorphous SiO coating and the rare earths(La and Ce) in molten ZE41A Mg. A large brittle interface is known to have detrimental effects on fiber/matrix load transfer in metal matrix composites[11]. However, in the transverse direction under constant stress, the Gr/ZE41A tensile strength and modulus were comparable to Gr/AZ91C.

The SiC_w/ZK60A with all its whiskers aligned in the extrusion and loading direction allowed load transfer to the reinforcement as in continuously fiber reinforced composite. Better strength and toughness were achieved with SiC_w/ZK60A than SiC_p/ZK60A in the longitudinal direction and the reversed were true in the transverse direction. TEM showed no interfacial reaction in both SiC_w/ZK60A nor SiC_p/ZK60A. A clean and coherent interface provided the interfacial bonding. Fracture paths in these composites did follow the interface. Whisker pullouts were evident. Enchancement of the interfacial bond in SiC_w/ZK60A and SiC_p/ZK60A could further improve upon its current properties.

In B_4C/AZ61A, fracture always initiated from surface flaws or oxide inclusions. Fracture origin was not obvious in SiC_w/ZK60A or SiC_p/ZK60A. Either the critical flaw size that initiates fracture increases with the reinforcement size or the average defect diameter in the SiC/Mg was smaller than that of B_4C/AZ61A. It is conceivable that subject of a more severe extrusion reduction can decrease average defect size as would be in the case of the two SiC/Mg.

All the Gr/AZ91C and Gr/ZE41A toughness data was obtained through Charpy bars sectioned form the 1/2" plates. Sample tensile specimens taken form 1/2" plates had significantly lower properties than specimens from the 1/4" plates. The fracture

morphologies showed variation of structures within each specimen with noticeable amounts of delamination. Thus the K_{1c} data presented here does not represent that of a sound casting as did with 1/4" plate material. Better toughness can be anticipated with improvements in casting thicker plates.

Finally, what is presented here is a limited selection of all the magnesium composites being pursued today. The cast continuously fiber reinforced composites had demonstrated superior modulus over all the dispersion strengthened composites and would be ideal for stiffness critical applications. A more severe interfacial reaction than the extruded dispersion strengthened materials was noted for the cast composites. Further studies are needed to tailor the interfacial reaction. Better and more consistent strength and toughness were achieved with the particulate and whisker reinforced composites than with the continous fiber reinforced composites. The aforementioned trend relating properties and microstructure noted in this study certainly is consistant with that reported from continuous and discontinuous aluminum composites. The effects of reinforcement size, geometry, and dispersements on tensile, modulus, and toughness are similar. However, the effects of heat treatment response to mechanical work on magnesium composites should also be investigated.

CONCLUSIONS

1. Better strength and toughness were achieved with α-Al_2O_3/ZE41A than Gr/AZ91C Mg and Gr/ZE41A.

2. The α-Al_2O_3/ZE41A demonstrated ROM properties with 1/2" plates whereas the properties in Gr/AZ91C decreased significantly from the 1/4" plate to the 1/2" plate.

3. Presence of a thin and fine grain interfacial reaction layer was characteristic of a well bonded composite as was demonstrated in α-Al_2O_3/ZE41A, Gr/AZ91C, and B_4C/AZ61A.

4. A clean, coherent interface in SiC_p/ZK60A and SiC_w/ZK60A provided sufficient bonding to exhibit good mechanical properties.

5. B_4C/AZ61A with the larger particle size reinforcement demonstrated lower strength and modulus but better toughness than SiC_w/ZK60A and SiC_p/ZK60A.

6. SiC_w/ZK60A had better strength and toughness than SiC_p/ZK60A in the longitudinal direction.

7. Better transverse strength and modulus were achieved with SiC_p/ZK60A than SiC_w/ZK60A.

ACKNOWLEDGMENT

REFERENCES

1. C.T.Lynch and J.P.Kershaw, Metal Matrix Composites, CRC Press(1972),34.

2. G.S.Ansell,"The Mechanism of Dispersion Strengthening: A Review," Second Bolton Landing Conference, TMS Conference, vol.17, ed. by G.S.Cosper, and F.V.Lenel, Gorden and Breach Science Publisher, N.Y.(1968),61.

3. A.K.Dhingra, and W.H.Krueger,"New Engineering Material-Magnesium Castings Reinforced With DuPont Continuous Alumina Fiber FP," E.I.DuPont DeNemours and Company, Experimental Station, Wilmington, Delaware, Presented at the 36th World Conference on Magnesium, Oslo, Norway, June 25-26,1979.

4. D.M.Goddard,"Investment Cast Graphite Fiber-Reinforced Magnesium Composites",AFS Transactions, 86-123(1986), 667-670.

5. H.A.Katzman,"Fiber Coating for the Fabrication of Graphite-Reinforced Magnesium Composites,"J.Materials Science,22(1987),144-148.

6. M.Kumar, K.Vedula, and A.M.Ritter, eds., Powder Metallurgy Composites, The Metallurgical Society(1987).

7. J.Nunes,"Tensile Property Evaluation of Polycrystalline Alumina Filaments and Their Properties,"AMMRC TR 82-61, December 1982.

8. Union Carbide Technical Bulletin No. 465-248.

9. J.Nunes, E.Chin, J.Slepetz, and N.Tsangarakis,"Tensile and Fatigue Behavior of Alumina Fiber Reinforced Magnesium Composite,"The Proceedings of the 5th ICCM, eds., W.C.Harrigan,Jr.,J.Strife, and A.K.Dhingra,Metallurgical Society, Warrendale, PA(1985), 723-745.

10. E.Chin, and J.Nunes, "Alloying Effects in Graphite/Magnesium Composites,"Presented at the 117th TMS/SME Annual Meeting, Pheonix, AZ(1988).

11. L.J.Broutman et al.,eds., Composite Materials, vol.1, Academic Press(1984).

12. G.Mima, and Y.Tanaka,"Mechanism of Precipitation Hardening of Magnesium-Zinc Alloys,"Trans. JIM, 12(1971), 323-328.

DISTRIBUTION LIST

No. of Copies	To
1	Office of the Under Secretary of Defense for Research and Engineering, The Pentagon, Washington, DC 20301
	Commander, U.S. Army Laboratory Command, 2800 Powder Mill Road, Adelphi, MD 20783-1145
1	ATTN: AMSLC-IM-TL
	Commander, Defense Technical Information Center, Cameron Station, Building 5, 5010 Duke Street, Alexandria, VA 22304-6145
2	ATTN: DTIC-FDAC
1	Metals and Ceramics Information Center, Battelle Columbus Laboratories, 505 King Avenue, Columbus, OH 43201
	Commander, Army Research Office, P.O. Box 12211, Research Triangle Park, NC 27709-2211
1	ATTN: Information Processing Office
	Commander, U.S. Army Materiel Command, 5001 Eisenhower Avenue, Alexandria, VA 22333
1	ATTN: AMCLD
	Commander, U.S. Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD 21005
1	ATTN: AMXSY-MP, H. Cohen
	Commander, U.S. Army Electronics Research and Development Command, Fort Monmouth, NJ 07703
1	ATTN: AMDSD-L
1	AMDSD-E
	Commander, U.S. Army Missile Command, Redstone Scientific Information Center, Redstone Arsenal, AL 35898-5241
1	ATTN: AMSMI-RKP, J. Wright, Bldg. 7574
1	AMSMI-RD-CS-R/ILL Open Lit
1	AMSMI-RLM
	Commander, U.S. Army Armament, Munitions and Chemical Command, Dover, NJ 07801
2	ATTN: Technical Library
1	AMDAR-LCA, Mr. Harry E. Pebly, Jr., PLASTEC, Director
	Commander, U.S. Army Natick Research, Development, and Engineering Center, Natick, MA 01760
1	ATTN: Technical Library
	Commander, U.S. Army Satellite Communications Agency, Fort Monmouth, NJ 07703
1	ATTN: Technical Document Center
	Commander, U.S. Army Tank-Automotive Command, Warren, MI 43090
1	ATTN: AMSTA-ZSK
2	AMSTA-TSL, Technical Library
	Commander, White Sands Missile Range, NM 88002
1	ATTN: STEWS-WS-VT
	President, Airborne, Electronics and Special Warfare Board, Fort Bragg, NC 28307
1	ATTN: Library
	Director, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD 21005
1	ATTN: SLCBR-TSB-S (STINFO)
	Commander, Dugway Proving Ground, Dugway, UT 84022
1	ATTN: Technical Library, Technical Information Division
	Commander, Harry Diamond Laboratories, 2800 Powder Mill Road, Adelphi, MD 20783
1	ATTN: Technical Information Office
	Director, Benet Weapons Laboratory, LCWSL, USA AMCCOM, Watervliet, NY 12189
1	ATTN: AMSMC-LCB-TL
1	AMSMC-LCB-R
1	AMSMC-LCB-RM
1	AMSMC-LCB-RP
	Commander, U.S. Army Foreign Science and Technology Center, 220 7th Street, N.E., Charlottesville, VA 22901
1	ATTN: Military Tech

No. of Copies	To
	Commander, U.S. Army Aeromedical Research Unit, P.O. Box 577, Fort Rucker, AL 36360
1	ATTN: Technical Library
	Director, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, VA 23604-5577
1	ATTN: SAVDL-E-MOS (AVSCOM)
	U.S. Army Aviation Training Library, Fort Rucker, AL 36360
1	ATTN: Building 5906-5907
	Commander, U.S. Army Agency for Aviation Safety, Fort Rucker, AL 36362
1	ATTN: Technical Library
	Commander, USACDC Air Defense Agency, Fort Bliss, TX 79916
1	ATTN: Technical Library
	Commander, U.S. Army Engineer School, Fort Belvoir, VA 22060
1	ATTN: Library
	Commander, U.S. Army Engineer Waterways Experiment Station, P. O. Box 631, Vicksburg, MS 39180
1	ATTN: Research Center Library
	Commandant, U.S. Army Quartermaster School, Fort Lee, VA 23801
1	ATTN: Quartermaster School Library
	Naval Research Laboratory, Washington, DC 20375
1	ATTN: Code 5830
2	Dr. G. R. Yoder - Code 6384
	Chief of Naval Research, Arlington, VA 22217
1	ATTN: Code 471
1	Edward J. Morrissey, AFWAL/MLTE, Wright-Patterson Air Force, Base, OH 45433
	Commander, U.S. Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, OH 45433
1	ATTN: AFWAL/MLC
1	AFWAL/MLLP, M. Forney, Jr.
1	AFWAL/MLBC, Mr. Stanley Schulman
	National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, AL 35812
1	ATTN: R. J. Schwinghammer, EH01, Dir, M&P Lab
1	Mr. W. A. Wilson, EH41, Bldg. 4612
	U.S. Department of Commerce, National Bureau of Standards, Gaithersburg, MD 20899
1	ATTN: Stephen M. Hsu, Chief, Ceramics Division, Institute for Materials Science and Engineering
1	Committee on Marine Structures, Marine Board, National Research Council, 2101 Constitution Ave., N.W., Washington, DC 20418
1	Librarian, Materials Sciences Corporation, Guynedd Plaza 11, Bethlehem Pike, Spring House, PA 19477
1	The Charles Stark Draper Laboratory, 68 Albany Street, Cambridge, MA 02139
	Wyman-Gordon Company, Worcester, MA 01601
1	ATTN: Technical Library
	Lockheed-Georgia Company, 86 South Cobb Drive, Marietta, GA 30063
1	ATTN: Materials and Processes Engineering Dept. 71-11, Zone 54
	General Dynamics, Convair Aerospace Division, P.O. Box 748, Fort Worth, TX 76101
1	ATTN: Mfg. Engineering Technical Library
1	Mechanical Properties Data Center, Belfour Stulen Inc., 13917 W. Bay Shore Drive, Traverse City, MI 49684
1	Mr. R. J. Zentner, EAI Corporation, 626 Towne Center Drive, Suite 205, Joppatowne, MD 21085-4440
	Director, U.S. Army Materials Technology Laboratory, Watertown, MA 02172-0001
2	ATTN: SLCMT-TML
1	Author

AD

UNCLASSIFIED
UNLIMITED DISTRIBUTION

U.S. Army Materials Technology Laboratory,
Watertown, Massachusetts 02172-0001
STRUCTURES AND PROPERTIES OF MAGNESIUM
BASE COMPOSITES -
Ernest S. C. Chin

Technical Report MTL TR 88-41, December 1988, 9 pp -
illus-tbls, D/A Project 1L162105AH84

Key Words

Composites
Metal Matrix
Magnesium

Chronic needs for higher performance in present and future military and commercial systems mandate improvements in material properties. High stiffness, high strength, and low density are among the material properties necessary to achieve future system performance goals. Such requirements can no longer be met using conventional metal alloys. Magnesium matrix composites are among the candidates to fulfill the afore-mentioned requirements. Ceramic fiber, particulate, and whisker reinforced magnesium composites have demonstrated significant improvements in specific stiffness and specific strength over the monolithic matrix alloys. Magnesium matrix composites can also compete with high strength aluminum alloys and other metal matrix composites for high performance and weight critical applications. However, magnesium composites are still relatively expensive and are still in the developmental stage. Six magne-sium composites were studied: cast 55v/o continuous Al2O3 fiber/ZE41A Mg; cast 40v/o continuous graphite fiber/ZE41A Mg; cast 40v/o continuous graphite fiber/AZ91C Mg; PM extruded 20v/o B4C particulate/AZ61A Mg; PM extruded 20v/o SiC particulate/ZK60A Mg; and PM extruded 20v/o a-SiC whisker/ZK60A Mg, cast 55v/o continuous Al2O3 fiber/ZE41A Mg. Both tensile and fracture toughness results on each of the composite systems will be presented. The nature of the reinforcement-matrix interfacial bond was revealed through detailed transmission electron microscopy. The effects of the interface as related to the tensile and toughness properties will be discussed.