Army Research Laboratory

Initial Evaluation of Advanced Powder Metallurgy Magnesium Alloys for Armor Development

by Tyrone Jones and Katsuyoshi Kondoh

ARL-TR-4828 May 2009

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ARL-TR-4828 **May 2009**

Initial Evaluation of Advanced Powder Metallurgy Magnesium Alloys for Armor Development

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*: May 2009

2. REPORT TYPE: Final

3. DATES COVERED (From - To): January 2008–January 2009

4. TITLE AND SUBTITLE: Initial Evaluation of Advanced Powder Metallurgy Magnesium Alloys for Armor Development

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S): Tyrone Jones and Katsuyoshi Kondoh*

5d. PROJECT NUMBER: 1L162618AH80

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRD-ARL-WM-TA
Aberdeen Proving Ground, MD 21005-5066

8. PERFORMING ORGANIZATION REPORT NUMBER: ARL-TR-4828

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
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14. ABSTRACT
The U.S. Army Research Laboratory (ARL) is interested in assessing the performance of different magnesium alloys. ARL and the Joining and Welding Research Institute (JWRI) conducted an effort to develop and evaluate advanced powder metallurgy magnesium alloys AZ31B and AMX602 (Mg-6Al-0.5Mn-2Ca/mass%) sheets. JWRI performed the mechanical and metallurgical analysis, while ARL performed the ballistic analysis. The thin-gauge magnesium alloy sheets were ballistically evaluated against the 0.22-cal. fragment-simulating projectile. The magnesium alloy powders' mechanical properties and ballistic performance were compared to the conventionally processed AZ31B-H24.

15. SUBJECT TERMS
armor, powder metallurgy, magnesium alloys, AZ31B, AMX602, ballistic performance, ballistic limit

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Tyrone Jones
Unclassified	Unclassified	Unclassified	UU	46	19b. TELEPHONE NUMBER (*Include area code*) 410-278-6223

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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Acknowledgments

Great appreciation is extended to U.S. Army Research Laboratory Engineer Peter Dehmer for the ballistic testing performed in the Building 4600 gas gun experimental facility.

1. Introduction

An initial ballistic evaluation of conventionally rolled AZ31B-H24 plate has been performed and serves as a baseline (*1*). Powder metallurgy (P/M) processing can control the microstructure by refining grains and intermetallics and producing nonequilibrium alloy compositions of metals (*2*). In particular, rapid solidification processing by atomization is often used to prepare raw powders with ultrafine microstructures. In this study, a water atomization process was applied to produce coarse magnesium alloy powders with fine grains and intermetallic compounds (*3*). Samples were consolidated by using the conventional P/M process such as cold compaction, spark plasma sintering, and hot extrusion. The alloy microstructures and mechanical properties, along with the ballistic performance of P/M wrought magnesium alloys, were evaluated. The effects of alloy elements and microstructures on the mechanical properties and ballistic performance are discussed in detail in this report.

2. Powder Metallurgy

Two kinds of magnesium alloy powder produced by water atomization process were prepared in this study—AZ31B (Mg-3Al-1Zn-0.3Mn/mass%) and AMX602 (Mg-6Al-0.5Mn-2Ca/mass%) (*4*) coarse powders. The powder size of each formulation was 1–4 mm, as shown in figure 1, reducing the potential of the magnesium catching fire. Samples were compacted by applying 300 MPa at room temperature. The relative density of the green compact 94-mm-diameter samples of AZ31B and AMX602 was 92% and 90%, respectively. Each powder was then supplied to the spark plasma sintering (SPS) process (*5*) to accelerate the metallurgical bonding between powders. In the SPS process, the raw powder filled a carbon die with a diameter of 95 mm. The temperature was controlled at 473 K in a vacuum less than 4 Pa, and a consolidation pressure of 10 MPa was applied during sintering in 1.8 ks.

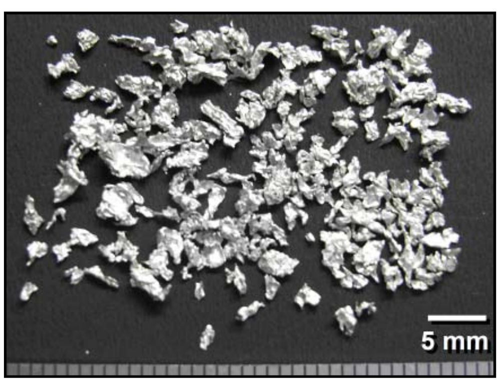

Figure 1. AZ31B and AMX602 powder size.

The relative density of the SPS compact of AZ31B and AMX602 was 72% and 70%, respectively. Each compact was heated at 573, 598, and 623 K and immediately processed by hot extrusion. The extrusion ratio and speed was 40 and 50 mm/s, respectively. The final plate specimen, 40 mm wide and 5 mm thick, was obtained by hot extrusion.

Mechanical Properties

Figure 2 indicates optical microstructures of AMX602 raw materials: atomized fine (a), coarse powders (b), machined chips (c), and cast ingot (d). Fine powder (a) reveals small dendrite structures formed by rapid solidification. Due to the smaller solidification ration during atomization, coarse powder shows larger grains than those of fine powder (a). Compared to machined chips (c) and cast material (d), the powders have almost the same grain size of 60–150 µm, and some intermetallic compounds were observed at their grain boundaries.

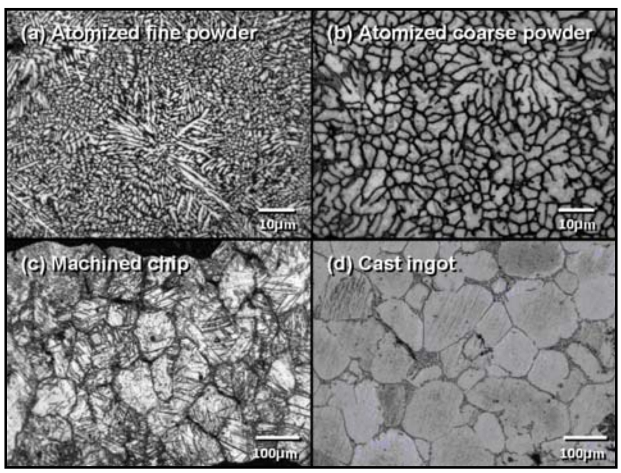

Figure 2. Optical microstructures of AMX602 (a–d).

In particular, machined chips, shown in figure 2c, have a lot of twinning induced by machining. Figure 3 shows x-ray diffraction patterns of AMX602 wrought alloys extruded at 573 and 673 K when using atomized powder compacts (a) and cast ingot (b). Their microstructures, observed by SEM, are shown in figure 4, where (a) and (b) indicate the powder compacts and cast ingot, respectively. When employing atomized powders, the fine grains caused by dynamic recrystallization are observed. The lower extrusion temperature of 573 K is effective in forming the finer microstructures with a mean grain size of ~0.45 µm, which is measured by applying the image-scanning software to the scanning electron microscopy (SEM) photo. Very fine white particles are Al_2Ca compounds precipitated during heating prior to hot extrusion.

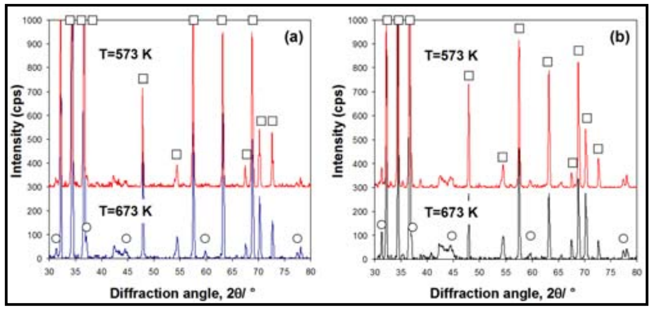

Figure 3. X-ray diffractions of AMX602: (a) atomized powder compacts and (b) cast ingot.

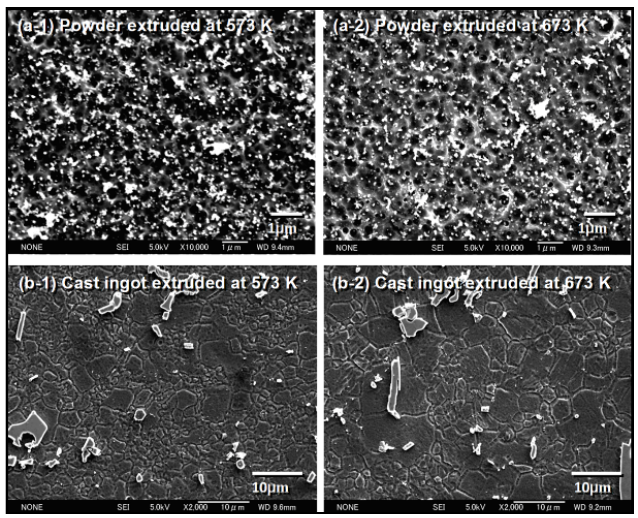

Figure 4. SEM of AMX602 (a-1, a-2, b-1, and b-2).

In the case of cast ingots, figure 4b-1, the mean grain size of extruded materials at 573 and 673 K is 1.96 and 3.29 µm, respectively. The higher temperature caused grain coarsening. Both wrought alloys using AMX602 cast ingots contained coarse intermetallics as well. As shown in figure 5, SEM-energy dispersive spectroscopy (EDS) analysis results on the specimen indicate the intermetallic dispersoids were mainly Al_2Ca compounds and exist at grain boundaries. The other results showed Al-Mn compounds with spherical shapes.

Both intermetallics are typical of the conventional AMX602 cast ingot. Micro Vicker's hardness of each material was as follows: powder extruded at 573 K, 113 Hv; powder extruded at 673 K, 94.3 Hv; cast ingot extruded at 573 K, 77.0 Hv; and cast ingot extruded at 673 K, 69.9 Hv. The hardness of wrought alloys using atomized powder compacts was higher than that using the cast ingot and showed a remarkable dependence on the grain size.

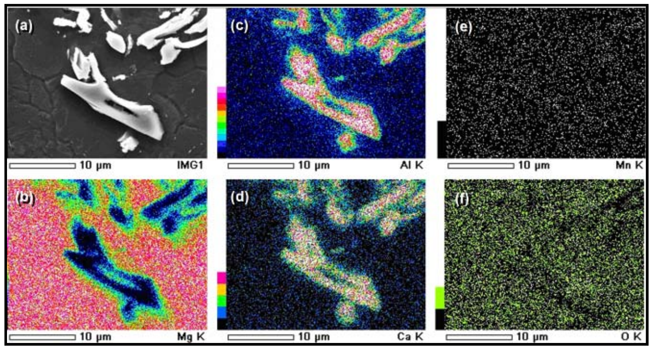

Figure 5. SEM-EDS of AMX602 of cast ingot extruded at 573 K (a–f).

The mechanical properties of wrought AMX602 alloys are shown in figure 6. Figure 6a shows tensile stress-strain curves in extruding the atomized powder compact and cast ingot material at 623 K. The extruded AMX602 alloy using the atomized powder compact indicates an increase of tensile strength (TS) and yield strength (YS) compared to the ingot extruded alloy, about 35% and 70%, respectively. In particular, a phenomenon suspected in yielding is detected when using the powder compact. In the fractured surface of each tensile test specimen, the powder compact extruded alloy, figure 6b, shows no fracture at primary particle boundaries and fine dimple patterns. This means the particle bonding is strong and cracks propagate inside particles, not grain boundaries. When testing the cast ingot, figure 6c, dimple patterns were observed, but some cracks occurred inside the coarse brittle intermetallics.

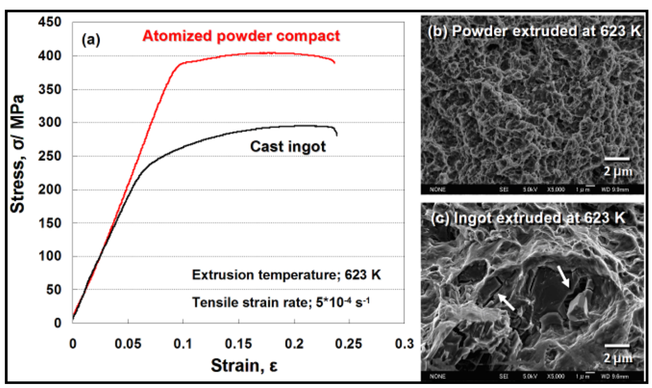

Figure 6. AMX602 stress-strain curve and SEM (a–c).

Figure 7 indicates a dependence of the tensile properties of wrought AMX602 alloys on the extrusion temperature. Both materials reveal the decrease of TS and YS, with increase in the extrusion temperature due to microstructure coarsening. However, the elongation increases with increasing temperature, 14.2% for the atomized powder and 17.7% for the cast ingot at 623 K. Note that the TS of 447 MPa and YS of 425 MPa is obtained in the extruded material by using the rapidly solidified AMX602 powder, which was superior to the conventional aluminum alloy 2014-T4 heat treatment.

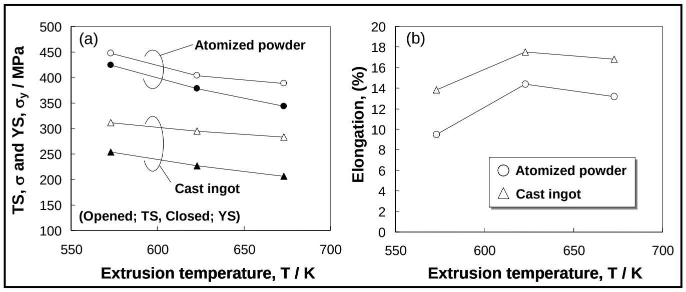

Figure 7. Tensile properties vs. temperature.

3. Terminal Ballistic Evaluation

3.1 Test Setup

Ten magnesium plate samples were produced for ballistic evaluation. The nominal dimensions of the samples were 308 × 38 × 5 mm. The test designation and the manufacturing of each sample are shown in table 1. The conventionally rolled plates were designated X-6 and X-7. The thin plates were held vertically in a test fixture by one clamp on each 308-mm edge.

Table 1. Manufacturing process.

Designation	Material
1-1	AZ31B SWAP cold compaction extrusion 300 °C
2-1	AZ31B SWAP SPS 200 °C extrusion 300 °C
4-1	AZ231B cold compaction extrusion 325 °C
5-1	AMX 602 SWAP cold compaction extrusion 325 °C
7-1	AMX 602 SWAP SPS 200 °C extrusion 325 °C
8-1	AZ31B SWAP cold compaction extrusion 350 °C
9-1	AZ31B SWAP SPS 200 °C extrusion 350 °C
10-1	AMX 602 SWAP SPS 200 °C extrusion 350 °C
X-6	AZ31B-H24 wrought plate
X-7	AZ31B-O wrought plate

Notes: SWAP = spinning water atomization process, and SPS = spark plasma sintering.

Ballistic testing of all magnesium plate samples was performed by the U.S. Army Research Laboratory (ARL) at Aberdeen Proving Ground, MD, in accordance with MIL-STD-662F (*6*). Ballistic results were characterized using the standard V_{50} test methodology, also documented in MIL-STD-662F. Due to the limitation of sample sizes, the V_{50} ballistic limit of samples 1-1, 2-1, and 4-1 was calculated using the average between the high partial penetration and low complete penetration. Pictures of the test setup are shown in appendix A.

3.2 Projectile

Because of the thin gauge of the samples, the 0.22-cal. fragment-simulating projectile (FSP) was selected to evaluate the magnesium alloy plates. The FSP used is produced in accordance with MIL-DTL-46593B (MR) (*7*) and is depicted in figure 8. This projectile design is utilized in acceptance tables for current military specifications.

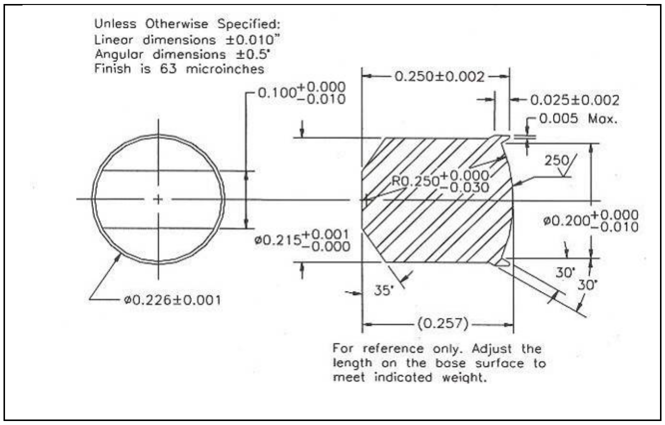

Figure 8. The 0.22-cal. FSP dimensions (*7*).

3.3 Ballistic Comparison

V_{50} ballistic limit for each magnesium plate is shown in table 2. Each sample was weighed, and the areal density and ballistic limits were calculated. The V_{50} ballistic limit firing records are shown in appendix B.

Table 2. Areal weights and ballistic limits.

Designation	Material	Thickness (mm)	Length (mm)	Width (mm)	Weight (g)	Areal Density (kg/m^2) (lb/sf)	V_{50} (m/s) (fps)
1-1	AZ31B SWAP cold compaction extrusion 300 °C	4.877	8.938	39.7	77.0	8.54 (1.75)	277 (909)
2-1	AZ31B SWAP SPS 200 °C extrusion 300 °C	4.851	9.000	39.7	78.0	8.59 (1.76)	269 (883)
4-1	AZ231b cold compaction extrusion 325 °C	4.902	8.875	39.7	77.1	8.59 (1.76)	277 (892)
5-1	AMX 602 SWAP cold compaction extrusion 325 °C	4.877	8.938	39.7	77.7	8.64 (1.77)	270 (886)
7-1	AMX 602 SWAP SPS 200 °C extrusion 325 °C	4.851	8.938	39.7	77.1	8.54 (1.75)	268 (879)
8-1	AZ31B SWAP cold compaction extrusion 350 °C	4.877	8.938	39.7	77.1	8.54 (1.75)	277 (909)
9-1	AZ31B SWAP SPS 200 °C extrusion 350 °C	4.877	8.938	39.7	77.1	8.64 (1.75)	277 (909)
10-1	AMX 602 SWAP SPS 200 °C extrusion 350 °C	4.851	8.875	39.7	77.1	8.59 (1.76)	275 (902)
X-6	AZ31B-H24 wrought plate	4.623	8.875	63.5	117.5	8.20 (1.68)	277 (909)
X-7	AZ31B-O wrought plate	4.750	8.875	63.5	98.2	8.59 (1.76)	273 (896)

Notes: SWAP = spinning water atomization process, and SPS = spark plasma sintering.

The data did not show a statistically significant difference in ballistic performance as a result of processing. The standard deviation of the each V_{50} was within the acceptable required testing limits. Based on this data, it is recommended that any future samples have a minimum thickness of 12.7 mm.

3.4 Material Response

Initial analysis of the material responses is shown in table 3 and figures 9–18. The projectile made an initial indentation, resulting in plastic shearing and the formation of a plug. The back of the samples showed different material failures. Magnesium alloy AMX602 proved to be a brittle material under all manufacturing processes. Some of the entry holes exhibited adiabatic shearing. Large spall failure (scabbing) occurred on the back of the magnesium alloy AMX602 samples after the fragment impact. Spalling is the detachment of a layer of material in the area surrounding the location of impact, occurring on either the front or rear surfaces of a sample. This indicates the ductility of magnesium alloy AMX602 needs to be improved. The manufactured powder magnesium alloy AZ31B petalled during impact, allowing some of the energy of the projectile to be dissipated through plastic deformation. Petalling is the peeling of material into segments after impact. Conventionally rolled magnesium alloy AZ31B showed little spall compared to powder-processed magnesium alloys.

Table 3. Material failure analysis.

Designation	Material	Material Response	
		Front	Back
1-1	AZ31B SWAP cold compaction extrusion 300 °C	Initial indentation, plastic shearing then plug formation	Petalling then spall failure
2-1	AZ31B SWAP SPS 200 °C extrusion 300 °C	Initial indentation, plastic shearing then plug formation	Petalling then spall failure
4-1	AZ231B cold compaction extrusion 325 °C	Initial indentation, plastic shearing then plug formation	Petalling then spall failure
5-1	AMX 602 SWAP cold compaction extrusion 325 °C	Initial indentation, plastic shearing then plug formation, some shear cracking at hole perimeter	Large spall failure
7-1	AMX 602 SWAP SPS 200 °C extrusion 325 °C	Initial indentation, plastic shearing then plug formation, some shear cracking at hole perimeter	Large spall failure
8-1	AZ31B SWAP cold compaction extrusion 350 °C	Initial indentation, plastic shearing then plug formation	Petalling then spall failure
9-1	AZ31B SWAP SPS 200 °C extrusion 350 °C	Initial indentation, plastic shearing then plug formation	Petalling then spall failure
10-1	AMX 602 SWAP SPS 200 °C extrusion 350 °C	Initial indentation, plastic shearing then plug formation, some shear cracking at hole perimeter	Large spall failure
X-6	AZ31B-H24 wrought plate	Initial indentation, plastic shearing then plug formation	Small spall failure
X-7	AZ31B-O wrought plate	Initial indentation, plastic shearing then plug formation	Small spall failure

Notes: SWAP = spinning water atomization process, and SPS = spark plasma sintering.

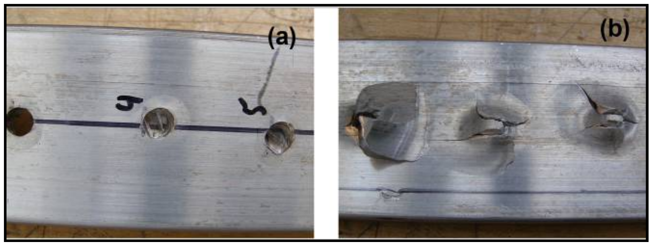

Figure 9. Designation 1-1: front (a) and back (b).

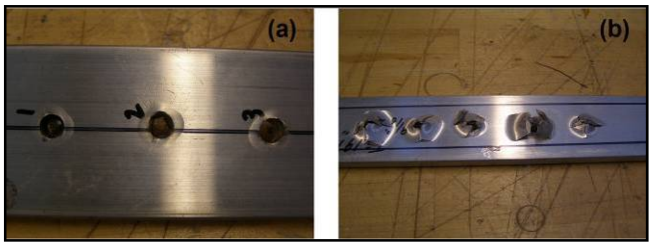

Figure 10. Designation 2-1: front (a) and back (b).

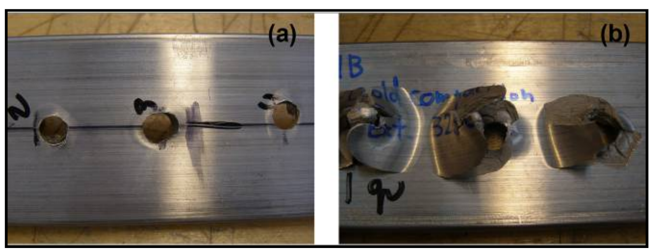

Figure 11. Designation 4-1: front (a) and back (b).

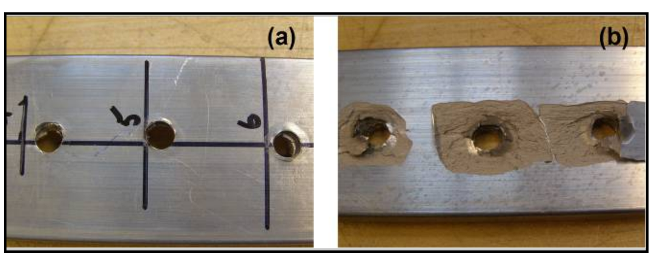

Figure 12. Designation 5-1: front (a) and back (b).

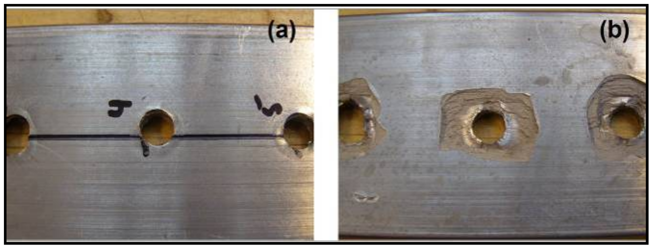

Figure 13. Designation 7-1: front (a) and back (b).

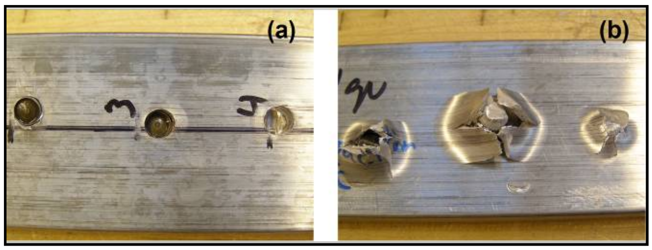

Figure 14. Designation 8-1: front (a) and back (b).

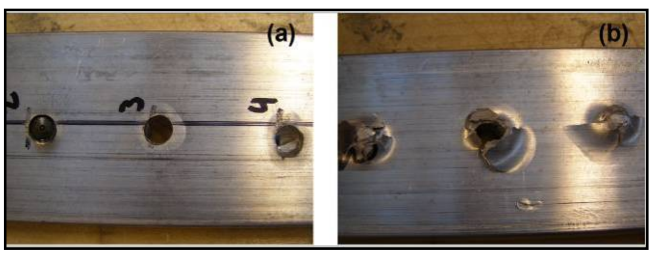

Figure 15. Designation 9-1: front (a) and back (b).

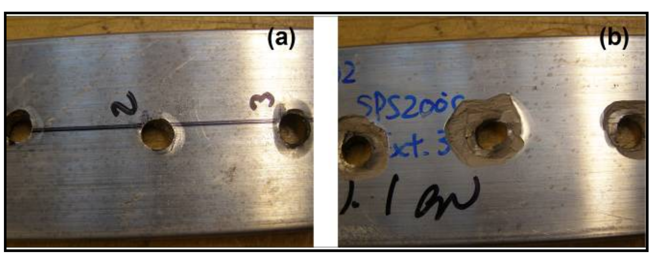

Figure 16. Designation 10-1: front (a) and back (b).

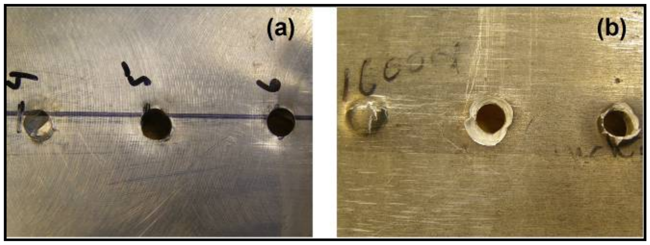

Figure 17. Designation X-6: front (a) and back (b).

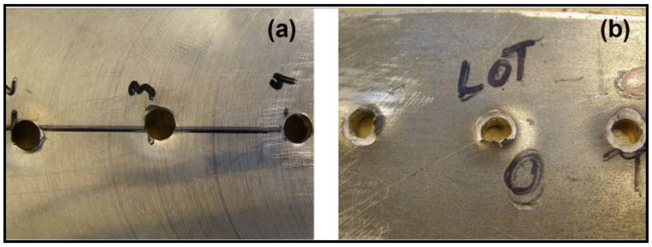

Figure 18. Designation X-7: front (a) and back (b).

4. Conclusions and Future Research

Ballistic performance appeared constant regardless of processing route. The magnesium plate may not be thick enough to properly show the effect of material processing differences. Therefore, it is recommended that future evaluations be conducted with magnesium plate with a minimum thickness of 12.7 mm.

These results indicated not only high TS and YS, but high elongation produced by good metallurgical bonding between primary powders. A large quantity of alloying elements in the matrix is not suitable to maintaining high elongation. The grain and intermetallics refinement was effective in improving the balance of strength and ductility of the magnesium alloys, although the thermal history in consolidating rapid, solidified magnesium alloy powder should be optimized. The effect of surface oxide (MgO) films of raw powder on the metallurgical bonding will also investigated by microstructural analysis. Furthermore, the materials strengthening by fine dispersoids, which have a good wettability with magnesium, e.g., titanium particles, will be considered in the future work.

5. References

1. Jones, T. L.; DeLorme, R. D.; Burkins, M. S.; Gooch, W. A. A Comparison of the Ballistic Performance between Rolled Plate in AZ31B-H24 Magnesium and 5083-H131 Aluminum. *Proceedings of the 24th International Symposium on Ballistics*, New Orleans, LA, 22–26 September 2008.

2. Yoshihito, K.; Hideo, M.; Akihisa, I. *Scripta Materialia* **2000**, *43* (12), 1119–1124.

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4. Kitahara, Y.; Shimazaki, H. *Mater. Sci. Forum* **2005,** *482*, 359–362.

5. Grosdidier, T.; Ji, G.; Launois, S. *Scripta Materialia* **2007**, *57* (6), 525–528.

6. MIL-STD-662F. V_{50} *Ballistic Test for Armor* **1997**.

7. MIL-DTL-46593B (MR). *Projectile, Calibers .22, .30, .50, and 20mm Fragment-Simulating* **2006**.

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Appendix A. Experimental Facility Range Setup

Figure A-1. The gas gun. The distance between the gun muzzle and the target was 1.4 m.

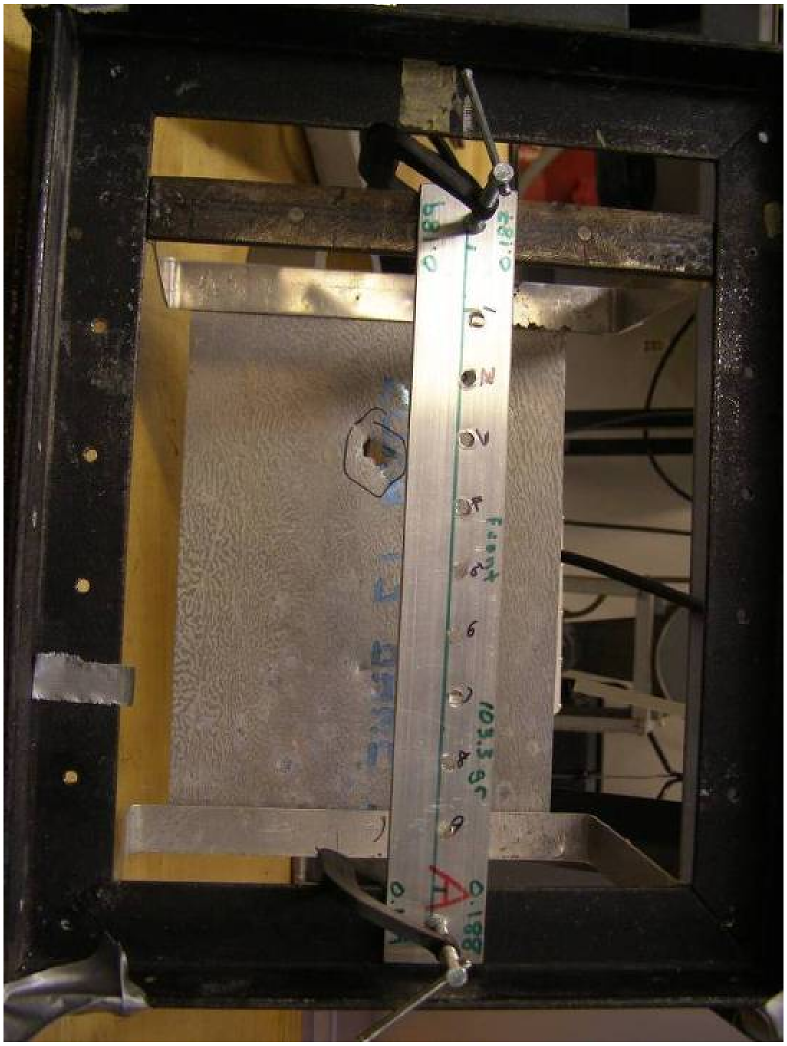

Figure A-2. A sample in the test rig with a 228- × 152.4- × 0.508-mm 2024Al witness plate placed 152 mm behind and parallel to sample. The distance between the clamps was 254 mm.

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Appendix B. V_{50} Ballistic Limit Firing Data

B.1 Material Sample 1-1

Date: 20 August 2008
Engineer: Tyrone Jones
Test facility: Bldg. 4600 - Dehmer
Target: Magnesium alloy AZ31B spinning water atomization process (SWAP) cold compaction extrusion 300 °C
Sample no.: 1-1
Sample size: 9 × 1.5 in
Sample thickness: 0.192 in
Sample weight: 77 gr
Area density: 1.75 psf
Obliquity: 0°
Projectile: 0.22-cal. fragment-simulating projectile (FSP)
Setup: Mg alloy sample – 6 in air – 0.020 in 2024Al

Table B-1. Material sample 1-1.

Shot No.	Striking Velocity (m/s)	Result (PP/CP)	Used for V_{50}	Comments
1	314	CP	No	—
2	292	CP	No	—
3	281	CP	Yes	—
4	264	PP	No	—
5	267	PP	No	—
6	273	PP	Yes	Dent on witness
V_{50} calculation: 277 m/s				
High partial (HP): 273 m/s				
Low complete (LC): 281 m/s				

Notes: • CP = complete perforation; penetrator or target material exits rear surface of the target.
• HP = highest partial perforation; V_{50} ballistic limit is typically above this velocity.
• LC = lowest complete perforation; V_{50} ballistic limit is typically below this velocity.
• PP = partial penetration; ;the penetrator is defeated by target.
• Result = result of shot; CP or PP.
• Striking velocity = velocity of the projectile just prior to impacting the target.

B.2 Material Sample 2-1

Date: 21 August 2008
Engineer: Tyrone Jones
Test facility: Bldg. 4600 - Dehmer
Target: Magnesium alloy AZ31B SWAP 200 °C extrusion 300 °C
Sample no.: 2-1
Sample size: 9 × 1.5 in
Sample thickness: 0.191 in
Sample weight: 78 gr
Area density: 1.76 psf
Obliquity: 0°
Projectile: 0.22-cal. FSP
Setup: Mg alloy sample – 6 in air – 0.020 in 2024Al

Table B-2. Material sample 2-1.

Shot No.	**Striking Velocity (m/s)**	**Result (PP/CP)**	**Used for V_{50}**	**Comments**
1	257	PP	No	—
2	278	CP	No	—
3	274	CP	No	Pinhole in witness
4	269	CP	Yes	Pinhole in witness
5	269	PP	Yes	—
V_{50} calculation: 269 m/s				
High partial (HP): 269 m/s				
Low complete (LC): 269 m/s				

B.3 Material Sample 4-1

Date: 22 August 2008
Engineer: Tyrone Jones
Test Facility: Bldg. 4600 - Dehmer
Target: Magnesium alloy AZ31B cold compaction extrusion 325 °C
Sample no.: 4-1
Sample size: 8.75 × 1.5 in
Sample thickness: 0.193 in
Sample weight: 77.1 gr
Area density: 1.76 psf
Obliquity: 0°
Projectile: 0.22-cal. FSP
Setup: Mg alloy sample – 6 in air – 0.020 in 2024Al

Table B-3. Material sample 4-1.

Shot No.	**Striking Velocity (m/s)**	**Result (PP/CP)**	**Used for V_{50}**	**Comments**
1	251	PP	No	—
2	269	CP	Yes	Dent on witness
3	268	CP	No	—
4	274	CP	Yes	—
V_{50} calculation: 272 m/s				
High partial (HP): 269 m/s				
Low complete (LC): 274 m/s				

B.4 Material Sample 5-1

Date: 28 August 2008
Engineer: Tyrone Jones
Test Facility: Bldg. 4600 - Dehmer
Target: Magnesium alloy AMX602 SWAP cold compaction extrusion 325 °C
Sample no.: 5-1
Sample size: 8.94 × 56 in
Sample thickness: 0.192 in
Sample weight: 77.7 gr
Area density: 1.77 psf
Obliquity: 0°
Projectile: 0.22-cal. FSP
Setup: Mg alloy sample – 6 in air – 0.020 in 2024Al

Table B-4. Material sample 5-1.

Shot No.	**Striking Velocity (m/s)**	**Result (PP/CP)**	**Used for V_{50}**	**Comments**
1	264	PP	No	Plug ejected
2	Void	—	No	—
3	272	CP	Yes	—
4	266	PP	Yes	Plug ejected
5	271	PP	Yes	Plug ejected
6	272	CP	Yes	—
V_{50} calculation: 270 m/s				
High partial (HP): 271 m/s				
Low complete (LC): 266 m/s				

B.5 Material Sample 7-1

Date: 29 August 2008
Engineer: Tyrone Jones
Test facility: Bldg. 4600 - Dehmer
Target: Magnesium alloy AMX602 SWAP 200 °C extrusion 325 °C
Sample no.: 7-1
Sample size: 8.94 × 1.5 in
Sample thickness: 0.191 in
Sample weight: 77.1 gr
Area density: 1.75 psf
Obliquity: 0°
Projectile: 0.22-cal. FSP
Setup: Mg alloy sample – 6 in air – 0.020 in 2024Al

Table B-5. Material sample 7-1.

Shot No.	**Striking Velocity (m/s)**	**Result (PP/CP)**	**Used for V_{50}**	**Comments**
1	271	PP	Yes	Plug ejected
2	270	CP	Yes	—
3	269	CP	Yes	—
4	269	CP	Yes	—
5	266	PP	Yes	Plug ejected
6	263	PP	Yes	Plug ejected
V_{50} calculation: 268 m/s				
High partial (HP): 271 m/s				
Low complete (LC): 269 m/s				

B.6 Material Sample 8-1

Date: 2 September 2008
Engineer: Tyrone Jones
Test facility: Bldg. 4600 - Dehmer
Target: Magnesium alloy AZZ31B cold compaction extrusion 350 °C
Sample no.: 8-1
Sample size: 8.94 × 1.56 in
Sample thickness: 0.192 in
Sample weight: 77.1 gr
Area density: 1.75 psf
Obliquity: 0°
Projectile: 0.22-cal. FSP
Setup: Mg alloy sample – 6 in air – 0.020 in 2024Al

Table B-6. Material sample 8-1.

Shot No.	**Striking Velocity (m/s)**	**Result (PP/CP)**	**Used for V_{50}**	**Comments**
1	270	PP	No	—
2	271	PP	No	—
3	271	PP	No	—
4	271	PP	Yes	—
5	280	PP	Yes	Dent on witness
6	277	CP	Yes	—
7	278	CP	Yes	—
V_{50} calculation: 268 m/s				
High partial (HP): 271 m/s				
Low complete (LC): 269 m/s				

B.7 Material Sample 9-1

Date: 8 September 2008
Engineer: Tyrone Jones
Test facility: Bldg. 4600 - Dehmer
Target: Magnesium alloy AZ31B SWAP SPS 200 °C extrusion 350 °C
Sample no.: 9-1
Sample size: 8.94 × 1.56 in
Sample thickness: 0.192 in
Sample weight: 77.1 gr
Area density: 1.75 psf
Obliquity: 0°
Projectile: 0.22-cal. FSP
Setup: Mg alloy sample – 6 in air – 0.020 in 2024Al

Table B-7. Material sample 9-1.

Shot No.	**Striking Velocity (m/s)**	**Result (PP/CP)**	**Used for V_{50}**	**Comments**
1	247	PP	No	—
2	265	PP	No	—
3	272	PP	Yes	Dent on witness
4	273	PP	Yes	—
5	283	CP	Yes	Pinhole in witness
6	280	CP	Yes	—
V_{50} calculation: 277 m/s				
High partial (HP): 273 m/s				
Low complete (LC): 280 m/s				

B.8. Material Sample 10-1

Date: 9 September 2008
Engineer: Tyrone Jones
Test facility: Bldg. 4600 - Dehmer
Target: Magnesium alloy AZ31B SWAP SPS 200 °C extrusion 350 °C
Sample no.: 10-1
Sample size: 8.88 × 1.56 in
Sample thickness: 0.191 in
Sample weight: 77.1 gr
Area density: 1.76 psf
Obliquity: 0°
Projectile: 0.22-cal. FSP
Setup: Mg alloy sample – 6 in air – 0.020 in 2024Al

Table B-8. Material sample 10-1.

Shot No.	Striking Velocity (m/s)	Result (PP/CP)	Used for V_{50}	Comments
1	280	CP	Yes	—
2	270	PP	Yes	Dent on witness
3	274	PP	Yes	Dent on witness
4	275	CP	Yes	—
V_{50} calculation: 275 m/s				
High partial (HP): 274 m/s				
Low complete (LC): 275 m/s				

B.9 Material Sample X-6

Date: 10 September 2008
Engineer: Tyrone Jones
Test facility: Bldg. 4600 - Dehmer
Target: Conventionally rolled magnesium alloy AZ31B H24
Sample no.: X-6
Sample size: 8.875 × 2.5 in
Sample thickness: 0.182 in
Sample weight: 117.5 gr
Area density: 1.68 psf
Obliquity: 0°
Projectile: 0.22-cal. FSP
Setup: Mg alloy sample – 6 in air – 0.020 in 2024Al

Table B-9. Material sample X-6.

Shot No.	**Striking Velocity (m/s)**	**Result (PP/CP)**	**Used for V_{50}**	**Comments**
1	269	PP	No	—
2	279	CP	Yes	Pinhole in witness
3	271	PP	No	Plug ejected
4	274	PP	Yes	—
5	276	PP	Yes	Plug ejected
6	279	CP	Yes	—
V_{50} calculation: 277 m/s				
High partial (HP): 276 m/s				
Low complete (LC): 279 m/s				

Table B.10 Material Sample X-7

Date: 10 September 2008
Engineer: Tyrone Jones
Test facility: Bldg. 4600 - Dehmer
Target: Conventionally rolled magnesium alloy AZ31B O
Sample no.: X-7
Sample size: 8.9 × 2 in
Sample thickness: 0.187 in
Sample weight: 98.2 gr
Area density: 1.76 psf
Obliquity: 0°
Projectile: 0.22-cal. FSP
Setup: Mg alloy sample – 6 in air – 0.020 in 2024 Al

Table B-10. Material sample X-7.

Shot No.	Striking Velocity (m/s)	Result (PP/CP)	Used for V_{50}	Comments
1	250	PP	No	—
2	269	PP	Yes	Plug ejected
3	272	CP	Yes	—
4	279	CP	Yes	—
5	273	PP	Yes	Plug ejected
V_{50} calculation: 273 m/s				
High partial (HP): 273 m/s				
Low complete (LC): 272 m/s				

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