



An Analysis of Magnesium Alloy AZ31B-H24 for Ballistic Applications

by Tyrone L. Jones, Matthew S. Burkins, and William A. Gooch

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Weapons and Materials Research Directorate, ARL

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14. ABSTRACT The U.S. Army Research Laboratory is developing a ballistic specification for the use of magnesium alloy AZ31B-H24 as armor on Army platforms. Data were generated for a range of thicknesses of this magnesium alloy, 0.25 to 4 inches, with the use of five different projectiles. The magnesium performance is parametrically quantified on an equivalent areal density to meet the aluminum alloy 5083-H131, which means a mature, well defined, low-density metal. The results show that the performance of magnesium depends on the diameter of the threat. This research sets a baseline ballistic performance for magnesium alloy AZ31B-H24 for quality control purposes and for use in the development and evaluation of improved alloys.					
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1. Introduction

The U.S. Army Research Laboratory (ARL) has continued to expand the magnesium database for the purpose of creating a military specification for magnesium alloy AZ31B-H24. The favorable mechanical properties of this commercially available alloy have been documented in earlier work (1). The purpose of this document is to parametrically compare the ballistic effectiveness, on a weight basis, of the moderate strength, excellent damper AZ31B-H24 to the moderate strength, excellent ductility aluminum alloy 5083-H131. Data for 5083-H131 were obtained from military specification MIL-DTL-46027J(MR) (2).

2. Projectiles

2.1 Armor-Piercing (AP) Projectiles

The two projectiles of interest are the U.S. .30-cal M2 AP and the U.S. .50-cal M2 AP, as documented in MIL-DTL-46027J(MR). The U.S. .30-cal projectile contains a hardened steel core that has a hardness of Rockwell C60-65 (3). The core has a lead filler encased in a full metal jacket, as shown in figure 1; the lead filler is in front and back of this core. The U.S. .50-cal M2 AP, also shown in figure 1, is similar to the .30-cal M2 AP with size and weight differences and lead filler only in front of this core. The projectile contains a hardened steel core that has a hardness of Rockwell C60-65. The projectile dimensions and masses are listed in table 1.



Figure 1. M2 AP projectiles.

Table 1. M2 AP projectile dimensions and masses.

	.30-cal M2 AP (4)	.50-cal M2 AP
Length (mm)	35.6	57.9
Diameter (mm)	7.84	12.9
Projectile (g)	10.6	40.1
Core (g)	5.2	25.9
Nose (g)	1.3	3.6
Jacket (g)	4.2	16.3

2.2 Fragment-Simulating Projectiles (FSPs)

FSPs manufactured to meet the specifications of MIL-DTL-46593B (MR) (5) are used for the ballistic evaluation of 5083-H131 to meet the MIL-DTL-46027J(MR) specification. These projectiles are steel, right circular cylinders with a chiseled nose at the front end. The other end features an obturator flange. The .22-cal, .50-cal, and 20-mm FSPs were used to evaluate AZ31B-H24. Figure 2 details the shape and dimensions of each FSP.

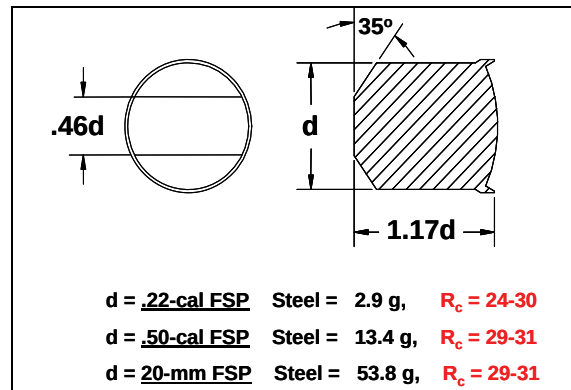


Figure 2. Normalized FSPs (3).

3. Magnesium Armor Solutions

The general mechanical properties of AZ31B-H24 magnesium, 5083-H131 aluminum, and rolled homogeneous armor (RHA) steel are provided for comparison in table 2. The tensile and Brinell hardness¹ properties for different tempers of AZ31B are provided in tables 3 and 4. A softer temper, AZ31B-O and a high strength experimental alloy, E675 were evaluated to assess the effect of strength on ballistic performance against some projectiles. The V_{50} ² protection ballistic limit

¹Brinell hardness is the load used to force a hardened sphere into a metal surface divided by the area of the indentation created in the surface.

² V_{50} is the velocity at which there is an equal probability of a partial or a complete perforation for the given armor and threat.

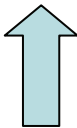
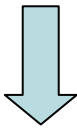
velocity of the metal plates was statistically determined following the standards of MIL-STD-662F (6). The magnesium data will be used to generate a military armor specification for AZ31B-H24.

Figures 3 through 7 provide the ballistic V_{50} limit velocity data for the plates as a function of areal density (weight per unit area; thickness times density) for the various projectiles.

Table 2. General mechanical properties (3).

Property	AZ31B	RHA	AL5083
Density (g/cm ³)	1.77	7.86	2.66
Ultimate Tensile Strength (MPa)	270	1170	350
Young's Modulus (GPa)	44	205	70
Specific Strength (MPa•cm ³ /g)	153	150	130
Specific Modulus (GPa•cm ³ /g)	24.9	26.1	26.3

Table 3. AZ31B tensile properties (3).

Relative Strength	Magnesium Alloy-Temper	Ultimate Tensile Strength		Tensile Yield Strength		ETF	Relative Ductility
		ksi	MPa	ksi	MPa	percent	
	AZ31B-H24	39	269	27	186	9	
	ZK10-F	37	255	27	186	10	
	AZ31B-O	36	248	21	145	12	
	AZ31B-O "Super Annealed"	35	241	19	131	14	

ETF = elongation to failure; ksi = kilopounds per square inch; MPa = megapascals

"Super annealed" AZ31B-O was created by precipitation hardening at 700 °F for 2 hours. We then cooled it to room temperature by decreasing the oven set point by 50 °F per hour.

Table 4. Brinell hardness properties.

Magnesium Alloy-Temper	Hardness ^a (HBN)
AZ31B-H24	61.0
AZ31B-F	59.0
AZ31B-O	54.0
AZ31B-O super annealed	33.6

^aTested on 500-kg Brinell scale

The limit velocities shown are acceptance velocities from MIL-DTL-46027J and actual test V_{50} for AZ31B. The AP ballistic performance data show AZ31B to be very similar in mass efficiency against these projectiles. The increased thickness of the monolithic AZ31B did not improve the overall ballistic performance. The FSP ballistic performance data show that at thinner gauge monolithic plate, the AZ31B outperforms 5083AL. The thickness of the plate is more of a factor than the strength at the lower areal densities. There is a cross-over, which depends on the threat diameter, where the strength surpasses the thickness and becomes the dominant factor in the overall ballistic performance. It is also clear that strength is more of a factor against the flat-headed high-energy FSPs than AP projectiles. In addition, the excellent ductility of 5083AL relocates some of the kinetic energy of the FSP into plastic deformation. Experimental observation

revealed that more ductility in AZ31B could improve the back face spalling and thus the ballistic performance of the plate. Hardness was not a factor for AZ31B against the AP core and FSP cylinder since the projectiles remained fully intact after impact. Hardness was not a factor for 5083AL against the AP core that remained fully intact. However, hardness was a small factor for 5083AL against the FSP cylinder since the projectile slightly mushroomed after impact.

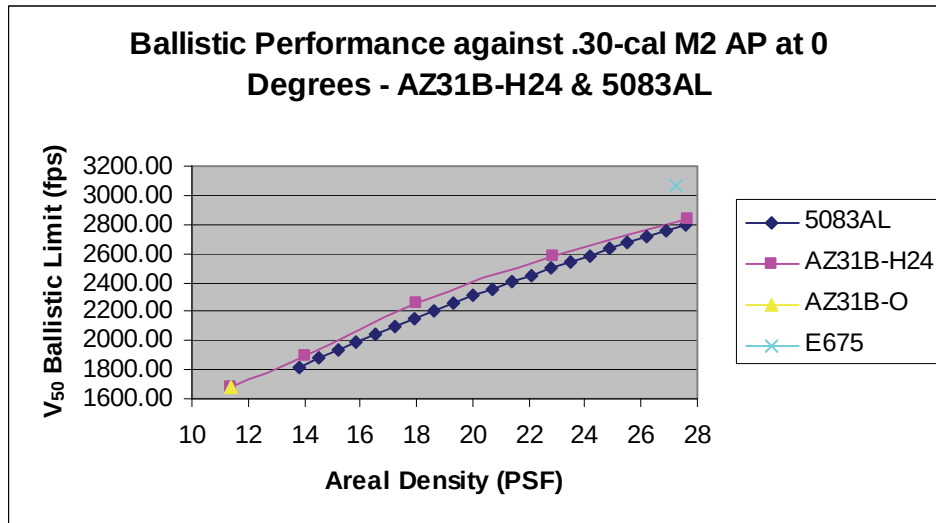


Figure 3. Estimated V_{50} ballistic limit of the .30-caliber M2 AP.

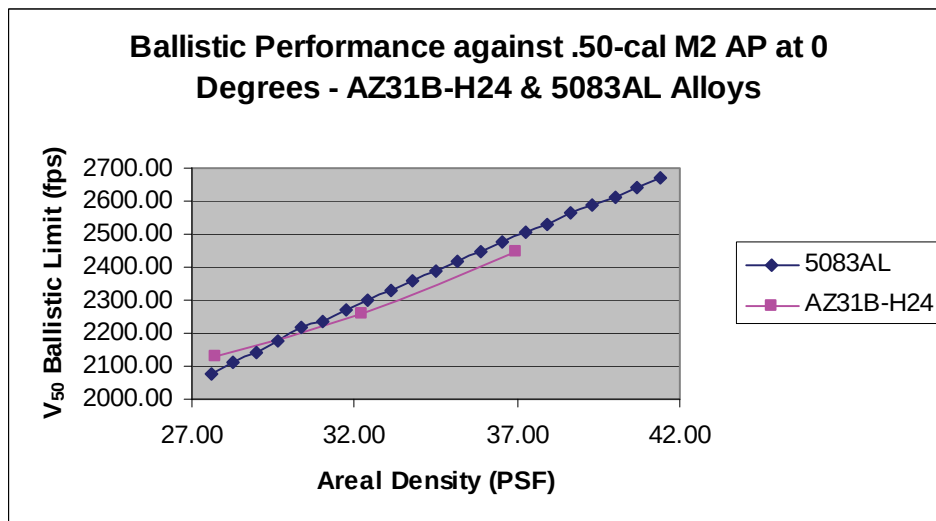


Figure 4. Estimated V_{50} ballistic limit of the .50-caliber M2 AP.

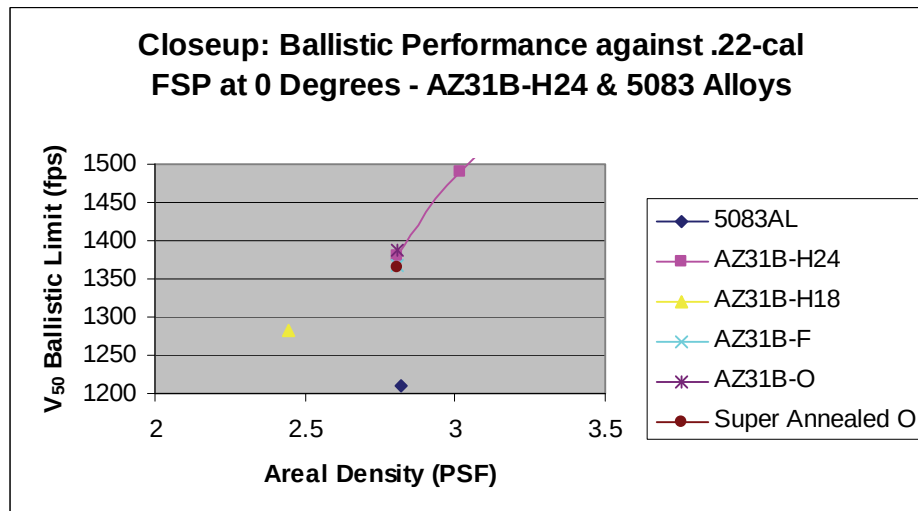
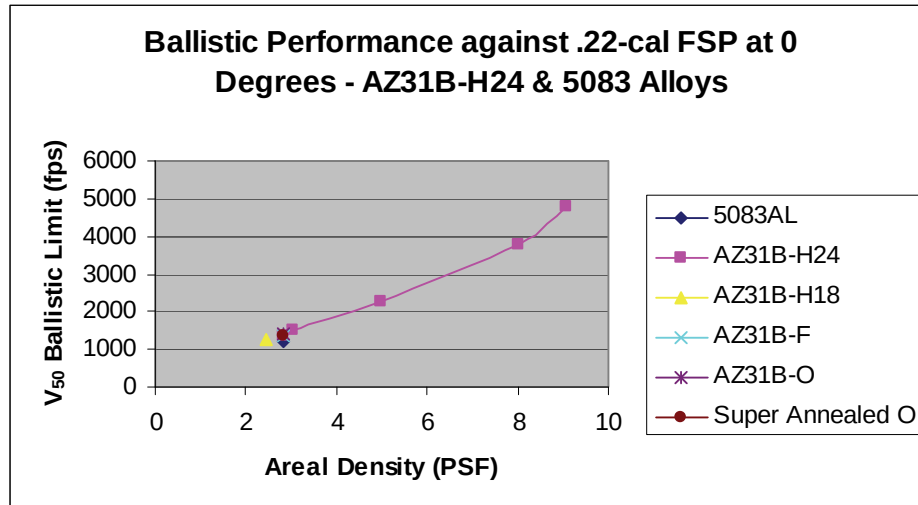


Figure 5. Estimated V₅₀ ballistic limit of the .22-caliber FSP.

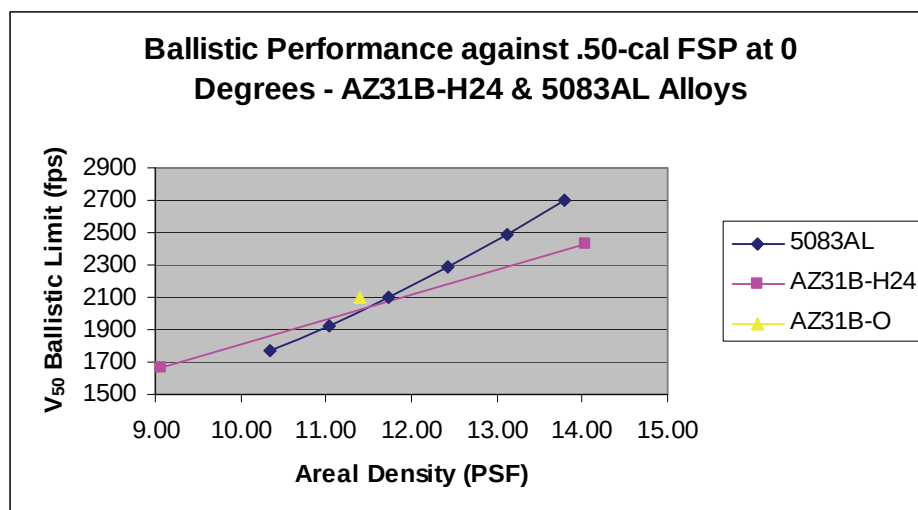


Figure 6. Estimated V₅₀ ballistic limit of the .50-caliber FSP.

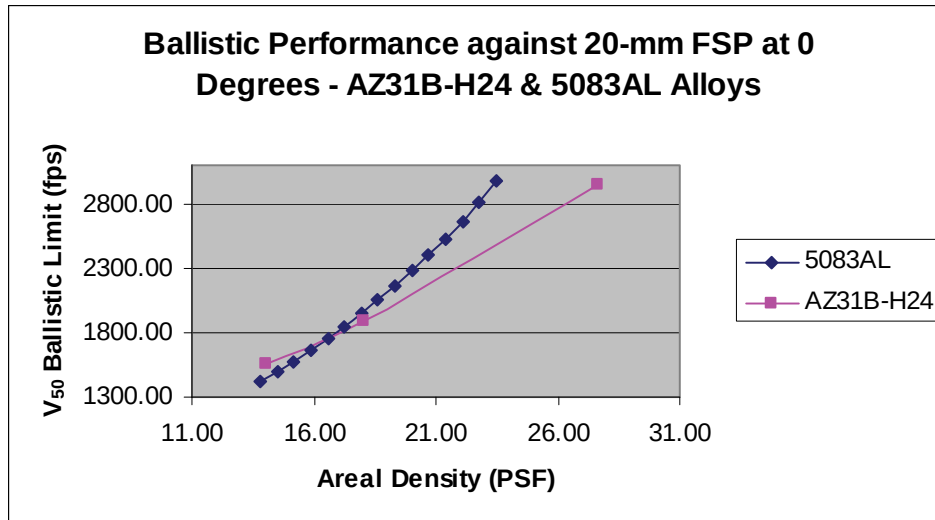


Figure 7. Estimated V_{50} ballistic limit of the 20-mm FSP.

4. Conclusions

AZ31B-H24 is competitive to 5083-H131 aluminum armor on an equivalent weight basis. This magnesium has a better ballistic performance than 5083-H131 against the AP projectiles while 5083-H131 offers better fragment protection. The spall strength of AZ31B might be improved with alloying. The cost of AZ31B-H24 is currently \$7 to \$8 per pound versus for \$2.50 to \$3 per pound for 5083-H131. ARL is currently working on the generation of a military armor specification that will allow armor system manufacturers to qualify their magnesium material for use in combat vehicles.

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GERMANY

NO. OF
COPIES ORGANIZATION

- 1 OSAKA UNIVERSITY
JOINING & WELDING RSCH INST
ATTN DR KATSUYOSHI KONDOH
11-1 MIHOGAOAKA IBARAKI
OSAKA 567-0047 JAPAN
- 2 DEFENCE PROCUREMENT AGCY
G LAUBE W ODERMATT
BALLISTICS WPNS & COMBAT
VEHICLE TEST CTR
CH 3602 THUN
SWITZERLAND
- 1 TDW
M HELD
POSTFACH 1340
D 86523 SCHROBENHAUSEN
GERMANY
- 4 DEFENSE RSCH AGENCY
W CARSON T HAWKINS B JAMES
B SHRUBSALL
PORTON DOWN
SALISBURY WTTTS SP 04 OJQ
UNITED KINGDOM
- 1 DEFENCE RSCH ESTAB
VALCARTIER ARMAMENTS DIV
R DELAGRAVE
2459 PIE XI BLVD N
PO BOX 8800
CORCELETTE QUEBEC GOA IRO
CANADA
- 2 DEUTSCH FRANZOSISCHES
FORSCHUNGSINSTITUT ST LOUIS
H ERNST H LERR
CEDEX 5 RUE DU
GENERAL CASSAGNOU
F 68301 SAINT LOUIS
FRANCE
- 1 DIEHL GMBH AND CO
M SCHILDKNECHT
FISCHBACHSTRASSE 16
D 90552 ROTBENBACH AD
PEGNITZ
GERMANY
- 1 DYNAMEC RSCH AB
A PERSSON
PARADESGRND7
SODERTALJE S151 36
SWEDEN

NO. OF
COPIES ORGANIZATION

- 2 ETBS DSTI
P BARNIER M SALLES
ROUTE DE GUERAY
BOITE POSTALE 712
18015 BOURGES CEDEX
FRANCE
- 1 FEDERAL MINISTRY OF DEFENCE
DIR OF EQPT & TECH LAND
RUV 2
D HAUG
POSTFACH 1328
53003 BONN
GERMANY
- 4 FRANHOFER INSTITUT FUR
KURZZEITDYNAMIK
ERNST MACH INSTITUT
V HOHLER E STRASSBURGER
R TRAM K THOMA
ECKERSTRASSE4
D 79 104 FREIBURG
GERMANY
- 1 MINISTRY OF DEFENCE
DGA/SPART
C CANNAVO
10 PLACE GEORGES CLEMENCEAU
BP 19
F 92211 SAINT CLOUD CEDEX
FRANCE
- 1 HIGH ENERGY DENSITY RSCH CTR
V FORTOV G KANEL
IZHORSKAY STR 13/19
MOSCOW 127412
RUSSIAN REPUBLIC
- 1 INGENIEURBURO DEISENROTH
F DEISENROTH
AUF DE HARDT 33 35
D 5204 LOHMAR 1
GERMANY
- 1 INST OF CHEMICAL PHYSICS
S RAZORENOV
142432 CHERNOGOLOVKA
MOSCOW REGION
RUSSIAN REPUBLIC

NO. OF
COPIES ORGANIZATION

- 7 INST FOR PROBLEMS IN MATLS SCI
S FIRSTOV B GALANOV O GRIGORIEV
V KARTUZOV V KOVTUN Y MILMAN
V TREFILOV
3 KRHYZHANOVSKY STR
252142 KIEV 142
UKRAINE
- 1 INST FOR PROBLEMS
OFSTRENGTH
G STEPANOV
TIMIRY AZEVSKAYA STR 2
252014 KIEV
UKRAINE
- 3 INST OF MECH ENGR PROBLEMS
V BULATOV D INDEITSEV
Y MESCHERYAKOV
BOLSHOY 61 VO
ST PETERSBURG 199178
RUSSIAN REPUBLIC
- 2 IOFFE PHYSICO TECH INST
E DROBYSHEVSKI A KOZHUSHKO
ST PETERSBURG 194021
RUSSIAN REPUBLIC
- 1 R OGORKIEWICZ
18 TEMPLE SHEEN
LONDON SW 14 7RP
UNITED KINGDOM
- 2 NATL DEFENCE HDQRTRS
PMO MRCV MAJ PACEY
PMO LAV A HODAK
OTTOWA ONTARIO KIA OK2
CANADA
- 1 OTO BRED A
M GUALCO
VIA VALDIOCCHI 15
119136 LA SPEZIA
ITALY
- 5 RAPHAEL BALLISTICS CTR
M MAYSELESS Y PARTOM
G ROSENBERG Z ROSENBERG
Y YESHURUN
BOX 2250
HAIFA 31021
ISRAEL

NO. OF
COPIES ORGANIZATION

- 1 ROYAL MILITARY ACADEMY
E CELENS
RENAISSANCE AVE 30
B 1040 BRUSSELS
BELGIUM
- 1 ROYAL NETHERLANDS ARMY
JHOENEVELD
V D BURCHLAAN 31
PO BOX 90822
2509 LS THE HAGUE
NETHERLANDS
- 1 DEFENCE MATERIEL ADMIN
WEAPONS DIRECTORATE
A BERG
S 11588 STOCKHOLM
SWEDEN
- 2 CENTRE DE RECHERCHES
ET D'ETUDES D'ARCUEIL
D BOUVART C COTTENNOT
16 BIS AVENUE PRIEUR DE
LA COTE D'OR
F 94114 ARCUEIL CEDEX
FRANCE