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WATERTOWN ARSENAL LABORATORY

EXPERIMENTAL REPORT

NO. WAL. 710/801

ARMOR—AIRCRAFT

Metallurgical Properties of

Several Aluminum and Magnesium Alloys Ballistically Tested

at Normal and Subzero Temperatures

BY

P. V. Riffin
T/4, Ord. Dept.

DATE 25 February 1946

WATERTOWN ARSENAL
WATERTOWN, MASS.

Watertown Arsenal Laboratory
Report No. WAL 710/801
Problem No. B-3.5

ARMOR--AIRCRAFT

Metallurgical Properties of

Several Aluminum and Magnesium Alloys Ballistically Tested

at Normal and Subzero Temperatures

OBJECT

To determine the physical and metallurgical properties at both normal and subzero temperatures of two magnesium alloys (3SR and 52SR) and three aluminum alloys (75ST, 24ST and 14SW).

SUMMARY OF RESULTS

The magnesium alloys possess a very low hardness as compared to aluminum or steel although they do have a density and consequently a thickness advantage on an equivalent weight basis. The toughness as measured by notched bars was exceedingly low. If tensile strength is multiplied by a factor of 4.4 (the density advantage) then these physical properties are not remarkably different from that of hard homogeneous steel. In spite of this thickness advantage, the magnesium alloy plates are penetrated in a brittle manner in the ballistic tests and as a consequence are inferior to steel which is penetrated in a ductile manner up to very high hardnesses in an equivalent thickness range.

The aluminum alloys examined varied in both hardness and notched bar impact strength. The 75ST exhibited the highest hardness and lowest toughness; 24ST was intermediate in both, and 14SW exhibited the lowest hardness but highest toughness. The above results are comparable to the results of the ballistic test since 75ST exhibited the highest resistance to penetration and the poorest shock resistance whereas 14SW was just the reverse. The inferiority of both magnesium and aluminum alloys is probably attributable to punching and/or spalling which were generally encountered in these aluminum and magnesium alloy plates. It is considered that a basic investigation is worthwhile to evaluate and minimize this weakness in magnesium and aluminum alloys.

P. V. RIFFIN
T/4, Ord. Dept.

APPROVED:

R. C. LEECH 4/10
Capt., Ord. Dept.
Acting Director of Laboratory

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Form No. SPOBE 342L, 12 Mar. 1946

BINDING AREA

INTRODUCTION

In accordance with instructions[1] from the Office, Chief of Ordnance through the Ordnance Research Center, Aberdeen, a metallurgical examination has been conducted on ten (10) light alloy armor samples selected from a group of plates previously subjected to ballistic tests at the Ordnance Research Center, and an analysis of the results are inclosed in this report.

The group of plates submitted are listed in Table I which follows:

TABLE I

Plates Submitted

Wtn. No.*	APG. No.	Material	Thickness	Ballistic Testing Temperature
1	1	Dowmetal 52SR	1½"	Normal
2	5	" 52SR	1½"	Subzero
3	5	" 3SR	3/4"	Subzero
4	3	" 3SR	3/4"	Normal
5	5	Aluminum 75ST	1½"	Subzero
6	3	" 75ST	1½"	Normal
7	3	" 24ST	1½"	Normal
8	9	" 24ST	1½"	Subzero
9	2	" 14SW	1½"	Normal
10	5	" 14SW	1½"	Subzero

*To prevent confusion Wtn. numbers will be used in the description of all results in this report.

The ballistic tests were reported by the Ordnance Research Center in Armor Test Report No. AD-988[2] in which it was concluded that:

1. Letter file APG. 470.5/1194 - Wtn. 470.5/8653(r) received 27 Feb. 1945 and APG. 470.5/980 - Wtn. 470.5/115(r) dated 6 December 1944. See Appendix A.

2. Tabulation of ballistic test results are listed in Incl. 1 of correspondence in Appendix A.

1. "The aluminum alloy plates were, in general, slightly superior to homogeneous steel armor (according to Spec. ANOS-1) on an equivalent weight basis in resistance to penetration, but were decidedly inferior to steel on shock resistance and resistance to backspall."

2. "The magnesium alloy plates were considerably inferior to homogeneous steel armor on an equivalent weight basis in resistance to penetration, shock properties, and resistance to backspall."

EXPERIMENTAL PROCEDURE

The metallurgical tests conducted on the plates are as follows:

1. Chemical analysis.
2. Brinell hardness tests at temperatures ranging from 20°C. (68°F.) to -70°C. (-94°F.) were made by immersing the specimens in a mixture of dry ice and alcohol for ½ hour before taking readings. The impressions were made while the specimens were in the cooling bath.
3. Tensile tests.
4. V-notch Charpy impact tests at temperatures ranging from 20°C. (-68°F.) to -70°C. (-94°F.) using standard size V-notch bars .394" square as in Fed. Spec. QQ-M-151a.
5. Microscopic examination.

RESULTS AND DISCUSSION

1. Chemical analysis.

The compositions of the two magnesium alloys and the two aluminum alloys are listed in Table II which follows:

TABLE II

Chemical Analyses

Wtn. No.	Material*	Mn	Cu	Si	Zn	Cr	Fe	Mg	Al
2	52SR	.30	.03	---	.95	---	.07	base	3.02
3	3SR	1.46	.04	---	.06	---	---	base	---
6	75ST	.20	1.49	---	5.79	.24	.22	2.27	base
7	24ST	.62	4.68	.18	---	---	.29	1.61	base
9	14SW	.78	4.49	.90	---	---	.25	.31	base

*Designation: SR = Hot rolled; ST = Solution quenched and aged; and SW = Solution quenched.

The designations used for the alloys in the basic letter are those used by the Aluminum Company of America and the American Magnesium Company, a subsidiary of the Aluminum Company. Consequently it is assumed that the above companies manufactured the subject test plates. The analyses obtained correspond fairly well with those specified by the manufacturers.

2. Hardness tests.

The hardness of the series of plates was ascertained by both Rockwell and Brinell tests. Rockwell hardnesses at equal distances across the thickness direction of the plates are as follows:

Wtn. No.	Material	Hardness - Rockwell "E"			Ave. R"E"	Ave. BHN
1	Mg 52SR	56.0	54.0	54.5	55.0	54
2	Mg 52SR	55.5	55.5	55.5	55.5	54
3	Mg 3SR	43.5	42.5	43.5	43.0	48
4	Mg 3SR	40.0	39.5	39.5	39.5	48
		Hardness - Rockwell "B"			Ave. R"B"	Ave. BHN
5	Al 75ST	86.0	86.5	86.5	86.5	150
6	Al 75ST	87.0	87.5	86.5	87.0	150
7	Al 24ST	77.5	75.5	78.0	77.0	130
9	Al 14SW	74.5	70.0	75.0	73.0	120

In order to determine the effect of temperature on the hardness, Brinell tests were conducted on the several materials at temperatures ranging from 20°C. to -70°C. and the results are as follows:

Variation of Temperature upon Hardness (Brinell)

Wtn. No.	Material	20°C.	-10°C.	-40°C.	-70°C.
1	Mg 52SR	53.4, 55.1*	55.5, 55.1	56.8, 60.5	60.5, 60.5
3	Mg 3SR	47.5, 48.9	50.3, 50.3	53.4, 50.3	53.4, 53.4
6	Al 75ST	150, 150	150, 150	158, 158	158, 158
7	Al 24ST	129, 129	134, 138	134, 138	138, 138
9	Al 14SW	121, 121	125, 129	125, 125	129, 129

*All readings taken with reduced load (500 Kg).

It is evident that all the alloys under consideration increase in hardness a small amount at the reduced temperatures, and undoubtedly it is this change in hardness which caused the slight increase in ballistic efficiency observed in the ballistic results of the low temperature tests.

3. Physical tests.

Tensile tests were obtained in both the longitudinal and transverse directions of the plates using .505" diameter bars, and the results are given in the following table:

TABLE III

Physical Test Results

Wtn. No.	Material	Direction	T.S. psi.	Y.S. psi.(*)	Elong. %	Red. Area
1	52SR	Longitudinal	35,000	22,500	7.0	12.6
	"	Transverse	36,000	22,000	8.0	8.4
2	52SR	Longitudinal	36,600	22,500	14.0	21.9
	"	Transverse	36,100	21,250	10.0	12.6
3	3SR	Longitudinal	35,500	19,000	11.0	18.4
	"	Transverse	35,900	19,250	9.5	12.6
4	3SR	Longitudinal	34,600	18,500	12.5	19.8
	"	Transverse	33,300	16,700	7.5	5.7*
5	75ST	Longitudinal	85,200	52,500**	10.0	11.8
	"	Transverse	82,500	70,600	8.5	9.5
6	75ST	Longitudinal	85,750	74,400	9.5	11.8
	"	Transverse	82,500	70,000	7.5	11.0
7	24ST	Longitudinal	71,250	48,500	15.0	21.2
	"	Transverse	67,000	46,000	10.5	11.0
9	14SW	Longitudinal	64,500	40,700	17.0	20.5
	"	Transverse	64,200	41,000	14.5	17.7

*Broke outside gage length.

**Used dividers.

(*) 0.2% offset for Mg alloys, .1% offset for Al alloys.

The tensile properties are normal for the composition and heat treatment of the subject plates. The difference in ductility between the longitudinal and transverse direction reflects the effect of rolling which was not equal in the two directions. The two magnesium alloys were about equal in ductility although 52SR alloy was slightly greater in strength. It is also noted that the ductility of the aluminum alloys varied inversely as the strength and hardness. The ballistic efficiency of the armor varied directly as the hardness of the alloys.

4. V-notch Charpy impact tests.

The notched bar impact tests were obtained in both directions at room temperature with the notch perpendicular to the plate surface. The use of a notch across the thickness yields lower readings than those obtained when the notch is in the plane of the plate surface. However, the results are more uniform and do not markedly reflect changes in soundness or laminations which greatly affect the results with the notch in the plane of the plate surface. Tests in the longitudinal direction were made at temperatures ranging from 20°C. to -70°C. Transverse tests were made at 20°C. in order to obtain the effect of directionality upon the toughness of the materials. The average of duplicate tests taken midway between the surface and center is graphically illustrated in Figures 1 and 2.

The impact energy of the aluminum and magnesium alloys studied is considerably less than that obtained in good quality steel properly heat treated to high hardness. The impact values of both the aluminum and magnesium alloys are unaffected by reducing the testing temperature to -70°C. (-94°F.) because, at least in part, they are already brittle at room temperature. The magnesium alloys exhibit a very low impact value of from 1 to 3 ft.lbs. reflecting the inferior toughness of this material in the ballistic tests. The impact values of the aluminum alloys correlated very well with the brittleness and spalling condition observed in the ballistic tests. The 75ST alloy absorbed 2 to 3 ft.lbs. in the Charpy test and exhibited the poorest shock resistance; the 24ST alloy was intermediate in ballistic shock resistance and absorbed 5-6 ft.lbs., and the 14SW which exhibited the best shock resistance of these materials absorbed 10-11 ft.lbs. in the Charpy test. The 14SW and 24ST aluminum alloys, which possessed the highest impact values of these alloys, exhibited marked directional properties. The other alloys exhibited very little ductility in either direction and consequently differences in the soundness of these materials are not revealed.

5. Microscopic examination.

The alloys were all in the heat treated condition and their structures are revealed in Figures 3 and 4. The 52SR magnesium alloy contained some intermetallic compound out of the solid solution which was probably $Mg_4 Al_3$. The grain boundaries of this material were not revealed by the etching reagents available (diethylene glycol, citric acid, and oxalic acid). The 3SR magnesium alloy consisted of a solid solution of magnesium with a pink intermetallic compound scattered throughout the matrix and in the grain boundaries. The grain size diameter was found to be .010-.020 mm. (equivalent to an ASTM grain size of 8-9 as defined for steel.

The structure of the aluminum alloys was typical of the heat treated materials observed in the literature[1,2,3]. The intermetallic compound $Cu Al_2$ as well as intermetallic compounds not dissolved at the solution temperature (probably 900°-925°F.) were observed in those alloys.

6. General Considerations.

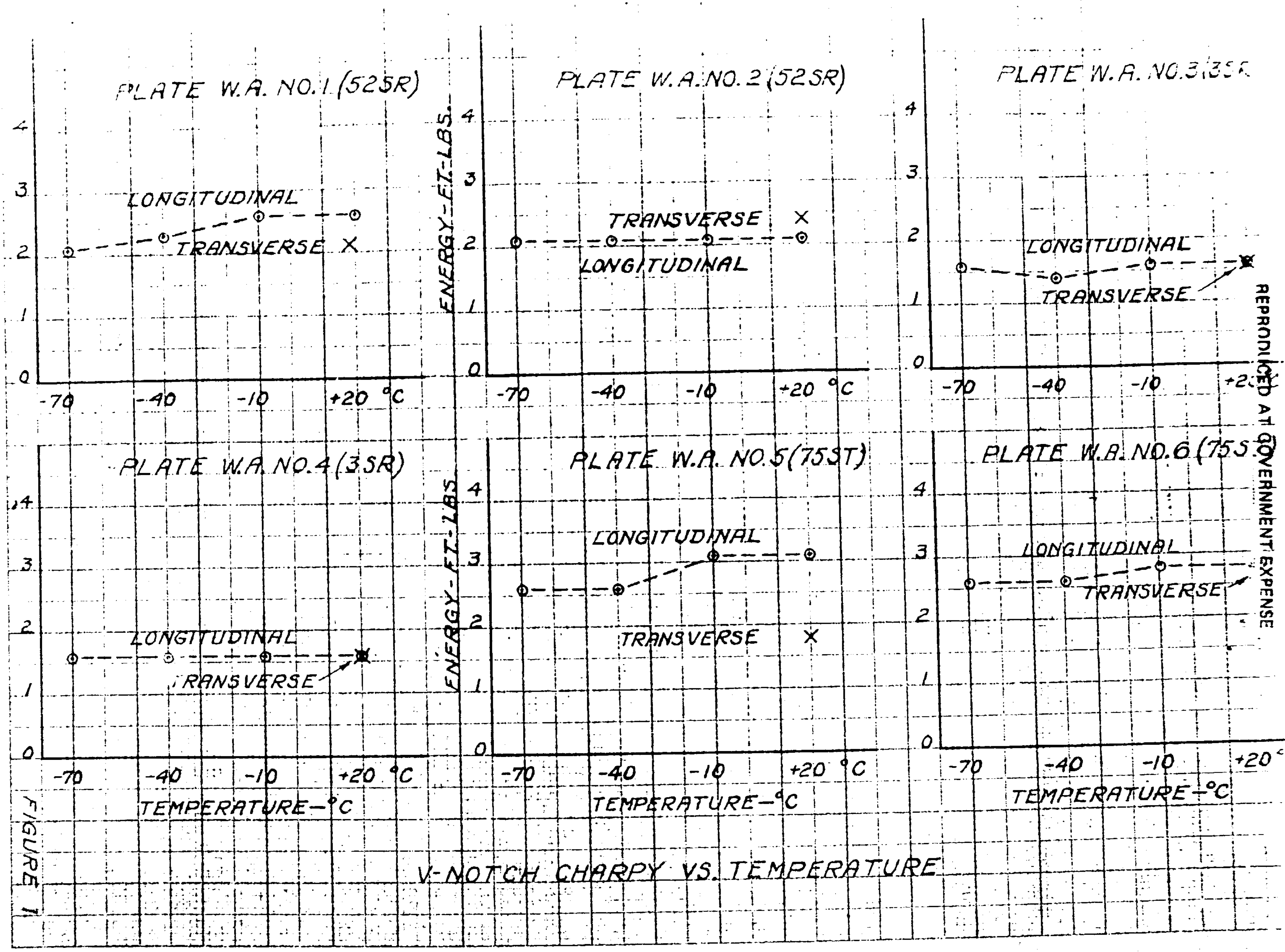
This is the first group of aluminum and magnesium alloy armor subjected to a metallurgical examination at this arsenal, and so conclusions regarding the effect of metallurgical characteristics upon ballistic properties must be considered tentative at best. Several extensive ballistic programs have been conducted in the past on magnesium and aluminum alloys, and it has been found that the penetration resistance increases with hardness and under certain testing conditions the protection is superior to that of steel on an equivalent weight basis. However under most conditions, the light alloys either punch or spall during penetration and the material then exhibits poor resistance to penetration as well as inferior shock properties. In this study the inferior toughness of these alloys was found to be associated with inferior toughness in the notch bar impact tests. Since the alloys investigated were not designed primarily for armor, they are probably not the best light alloys for the purpose.

The choice of these alloys was controlled, for the most part, by their ability to be heat treated to relatively high hardnesses. Associated with the increase in hardness in the group of aluminum alloys, there was noted a decrease in toughness in both ballistic and notch bar tests. It is considered advisable to investigate the processing and heat treatment of aluminum and magnesium alloys to determine the cause of inferior toughness. The present study indicates that the large quantity and regular pattern of the intermetallic compounds in the microstructure are partly responsible for the brittleness and spalling in the ballistic tests.

1. F. Keller and R. A. Bossert - "Revealing the Microstructure of 24S Alloy," T.P. No. 8, Aluminum Company of America, 1942.

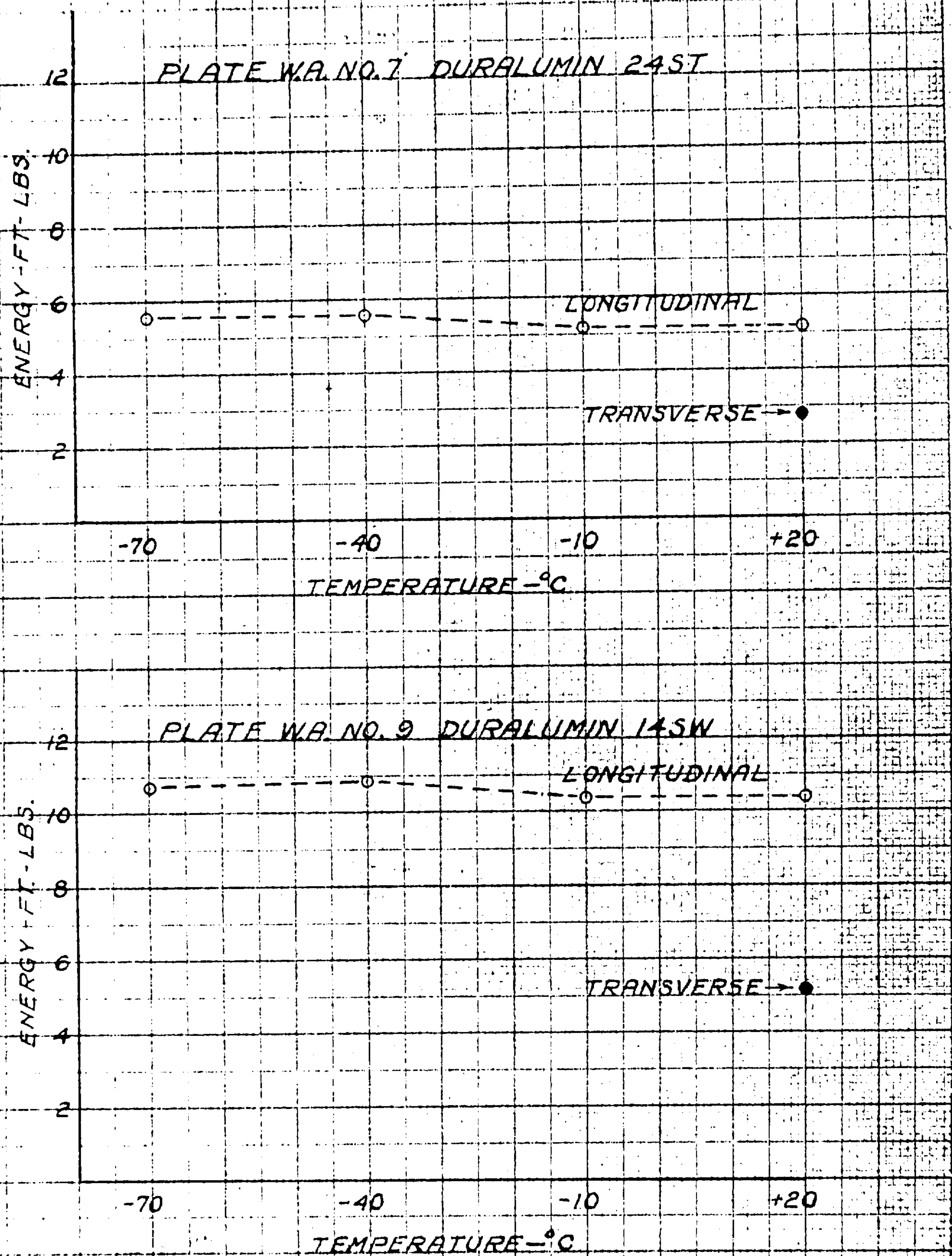
2. L. F. Mondolfo - "Metallography of Aluminum Alloys." John Wiley and Sons, Inc., 1943.

3. F. Keller - "Metallography of Alcoa 75S Alloy." Iron Age, p. 64, October 4, 1945.



V-NOTCH CHARPY VS. TEMPERATURE

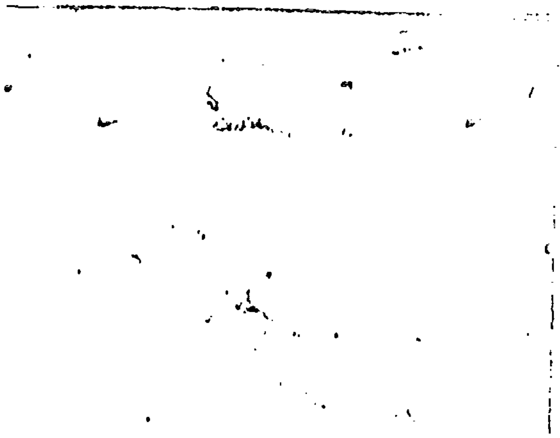
FIGURE 1



V-NOTCH CHARPY VS. TEMPERATURE

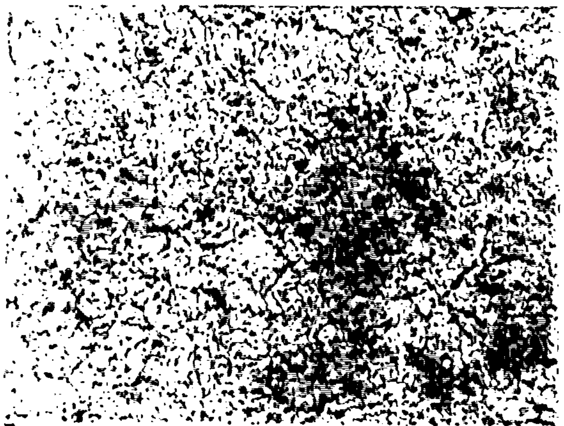
FIGURE - 2

Microstructure of Magnesium and Aluminum Alloys



A X500 Diethylene Glycol

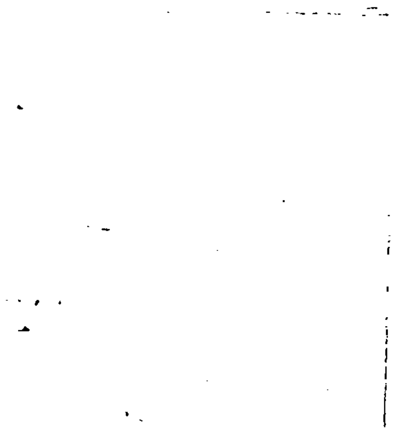
Plate 2 - 52SR magnesium alloy containing Al, Zn and Mn.



B X500 Diethylene Glycol

C X500 Citric Acid

Plate 3 - 3SR magnesium alloy containing Mn.



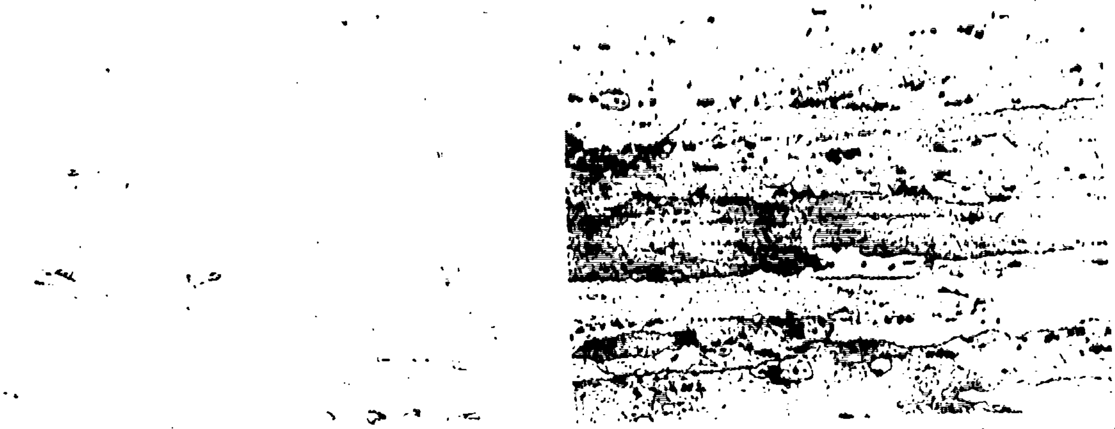
D X200 ½% HF

E X200 Keller's Reagent

Plate 5 - 75ST aluminum alloy containing Zn, Mg, and Cu.

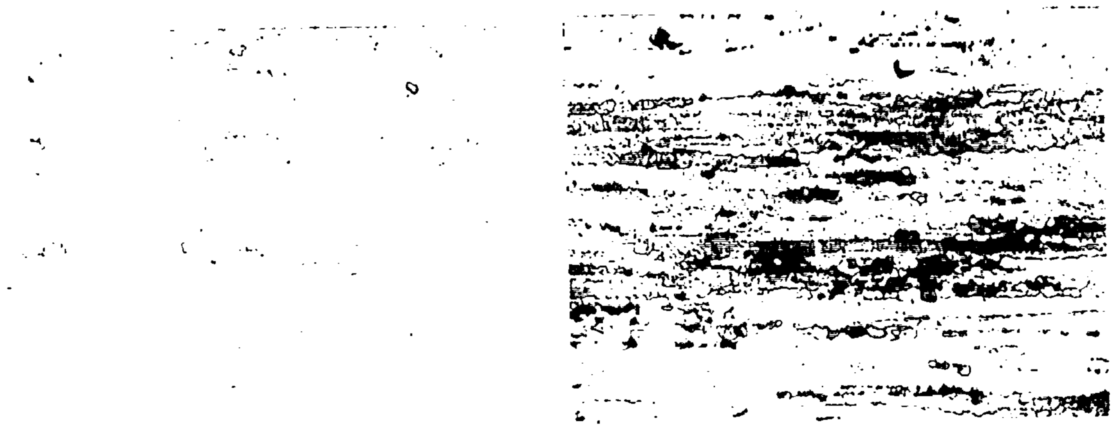
FIGURE 3

Microstructure of Aluminum Alloy Plates



A X200 ½% HF B X200 Keller's Reagent

Plate 7 - 24ST aluminum alloy containing Cu, Mg, and Mn.



C X200 ½% HF D X200 Keller's Reagent

Plate 9 - 14SW aluminum alloy containing Cu, Mn, Si, and Mg.

FIGURE 4.

COPY

ARMY SERVICE FORCES
ORDNANCE DEPARTMENT
ABERDEEN PROVING GROUND
MARYLAND

6 December 1944

APG 470.5/980
Attn: SPOTZ-F

Subject: Samples of Aluminum and Magnesium Alloy Aircraft Armor Plates for Metallurgical Analysis

To: Commanding Officer
Watertown Arsenal
Watertown 72, Massachusetts

Attention: Laboratory - Major N. A. Matthews

1. In accordance with a directive received from the Office, Chief of Ordnance, Washington (OO 470.5/15760, APG 470.5/603, dated 18 September 1944, Subject: "Shipment of Aircraft Armor Samples to Watertown Arsenal"), this station is forwarding four samples of Magnesium alloy plates and two samples of Aluminum alloy plates for metallurgical examination.

2. Summaries of the ballistic test results on the Aluminum and Magnesium alloy plates tested under this program, are attached herewith. Included in these summaries are the data on plates represented by the subject samples. The samples may be identified as follows:

Type	Plate No.	Thickness	Temp. at Test	Sample Size
Aluminum 75 ST	1	1-1/2"	Normal	12" x 36"
" "	5	"	Subzero	"
Magnesium 52SR	3	"	Normal	"
" "	5	"	Subzero	"
" 3SR	3	3/4"	Normal	"
" "	5	"	Subzero	"

3. It will be appreciated if a copy of the metallurgical test results is furnished this station as soon as available.

For the Commanding General:

(s/t) G. G. EDDY
Col., Ord. Dept.
Director

2 Incls.
Incl. 1 - Summary of Results on Aluminum Alloy Plates
2 - " " " " Magnesium Alloy Plates

Project No.: 4594 (26 Ar8-014)

COPY

RESULTS [illegible] PLATES FIRED AT NORMAL (55° to 65°F)

PLATE NO.	TYPE	BHN	AVG. TH.	TEMP.	CAL. .30 AP M2 at 0° OBL. NAVY BL	CAL. .50AP M2 at 0° OBL. NAVY BL	MACHINE GUN BURST CAL. .30 APM2 MAX. E.D.	MACHINE GUN BURST CAL. .50 AP M2 MAX. E.D.	20 [illegible] at CRIT[illegible]
							3/4"	PLATES	
1	XB 75 ST		.78	Normal	1941[2]		9/16"x9/16" W/BS	1-11/16"x 1-13/16"W/BS	
2	"		.79	"	1887		3/8"x7/16" W/BS	1-3/4"x 1-3/4"W/BS	
3	"		.77	"	1909		3/8"x½"W/BS	1-3/4"x1-3/4" W/BS	
7	"		.79	"					
4	"		.78	Subzero	1996		5/16"x7/8" W/BS	1-5/8"x1-7/8" W/BS	
5	"		.78	"	1907[3]		½"x5/8"W/BS	1-3/4"x1-5/8" W/BS	
6	"		.79	"	1974[3]		9/16"x5/8" W/BS	[illegible]"x2-1/8"W/BS	
							1"	PLATES	
1	"		1.01	Normal	2240	1651		2-1/8"x2-3/4" W/BS	
2	"		1.00	"	2290	1719		[illegible]x2-11/16" W/BS	
3	"		1.01	"	2316	1616			
7	"		1.01	"				2-3/16"x2-3/8" W/BS	
4	"		1.02	Subzero	2359	1660		2-1/4"x3-1/4" W/BS	
5	"		1.02	"	2363	1631		2-3/8"x2-7/8" W/BS	
6	"		1.02	"	2284	1694		2-7/8"x3"W/BS	
								1½" PLATES	
1	"		1.50	Normal		2112		15/16"x1-1/8" W/BS	
2	"		1.51	"		2121		7/8"x1-3/16" W/BS	
3	"		1.49	"		2135		1-1/8"x1-3/8" W/BS	
7	"		1.50	"					
8	"		1.49	"					
4	"		1.50	Subzero		2148		5/16"x1-1/8" W/BS	
5	"		1.52	"		2166		1-1/8"x1-3/8" W/BS	
6	"		1.52	"		2193		1"x1-1/8"W/BS	

NOTES:
1. All Plates 24" x 36" in size.
2. All Plates corrected to nominal thickness.
3. Difference between high partial and low compl[illegible]
4. Number in parentheses represents plate on whi[illegible]

GUN T AP M2 .D.	20 mm. AM BALL at 20°Obl. CRITICAL VEL.	20 MM. HE at 20° OBL. PROT. BL	57 mm. PP T21 at 0° OBL. CRIT. VEL.	REMARKS
x W/BS	1252			
BS		1814		
1-3/4"	1310	1830		
	1210	1777		20mm. HE at 1853f/s caused a 14"circular crack.
1-7/8"	1251 (8)[4]	See Remarks		1 rd. at 1932f/s caused plate to break in two.
1-5/8"	1233	1670(11)		Considerable cracking of these plates, with 20 mm. Ball and HE projectiles.
3"W/BS	1344 (9)	1678 (10)		
-3/4"		2329		
/16"	1709			
	1723	2337		
x2-3/8"	1663	2283		
3-1/4"	1705 (8)	2232 (8)		
2-7/8"	1758 (9)	2248 (9)		
x3"W/BS	1708 (11)	2218 (10)		17"x2" front spall on plate 10 with 20mm. HE.
S				
1-1/8"			above 974 f/s	
3/16"			See remarks	Plate broke into four pieces at 1142f/s.
1-3/8"			1035 [3]	(All plates broke after two or three rounds.
				(
			1061 f/s	(
			1041 f/s	(
-1/8"		1028		Plate broke at 1011f/s with 37mm. PP T21.
1-3/8"		1060		
8"W/BS		1066 [3]		Plate cracked excessively with 37mm. PP T21.

ness.
low complete penetrations greater than 50 f/s.
te on which ballistic value was obtained.

RESULTS OF EIGHTEEN 3/4", 1", AND 1-1/2" 24 ST Type ALUMINUM ALLOY PLATES T

Plate No.	Avg. Th.	Temp. At Test	Cal..30APM2 at 0° Obl. Navy BL	Cal..50APM2 at 0° Obl. Navy BL	PTP 5 Rds. MGB Cal..30APM2 at 0° Obl. Max. Exit Dia.	PTP 5 Rds. MGB Cal..50APM2 at 0° Obl. Max. Exit Dia.	2 Ba Cri
						3/4" Plat	
1	.76	Normal	1857 f/s		1/2x1/2 W/BS	1-1/4x1-1/2 W/BS	
2	.76	Normal	1815		1/2x9/16W/BS	1-7/16x1-3/4W/BS	
3	.76	Normal	1849		1/2x9/16W/BS	1-1/4x1-1/2 W/BS	
		Average	1840			Average	
7	.77	Subzero	1862		3/8x9/16	1-3/4x1-7/8 W/BS	
8	.77	Subzero	1896		1/2x9/16	1-5/8x1-7/8 W/BS	
9	.78	Subzero	1886		3/8x5/8	1-3/4x1-7/8 W/BS	
		Average	1881			Average	
						1" Pla	
1	1.04	Normal	2129	1652 f/s		2-9/16x2-3/4W/BS	
2	1.00	Normal	2128	1645		2 x 2-1/8 W/BS	
3	1.03	Normal	2114	1658		2-1/16x2-5/16W/BS	
		Average	2124	Average 1652		Average	
7	1.02		2219	1714		2-3/4x2-15/16W/BS	
8	1.04		2168	1674		2-5/8x3-1/16 W/BS	
9	1.01		2217	1711		2-1/2x2-9/16 W/BS	
		Average	2201	Average 1700		Average	
						1½" Pla	
1	1.48			2035		7/8x1 W/BS	
2	1.48			2038		7/8x1-1/8 W/BS	
3	1.49			1998		13/16x1 W/BS	
				Average 2024			
7	1.52			2069		1x1-1/8	
8	1.51			2043		1-1/8x1-3/8	
9	1.48			2076		7/8x1	
				Average 2063			

NOTE: All values corrected to nominal plate thickness.

24 ST Type ALUMINUM ALLOY PLATES TESTED AT NORMAL (35° TO 45°) AND SUBZERO (-70° TO -40°F.) TEMPERATURES

PTP Rds. MGB al..30APM2 t 0° Obl. . Exit Dia.	PTP 5 Rds. MGB Cal..50APM2 at 0° Obl. Max. Exit Dia.	20 mm. Am. Ball at 20° Obl. Critical Vel.	20 mm. HE at 20° Obl. Protection BL.	37 mm. PP T21 at 0° Obliquity Critical Vel.	Report N Sheet 3 Remar
	3/4" Plates				
x1/2 W/BS	1-1/4x1-1/2 W/BS	951 f/s	1966 f/s		Backspall on PTP impacts
x9/16W/BS	1-7/16x[illegible]W/BS	918	1917		
x9/16W/BS	1-1/4x1-1/2 W/BS	976	1892		
	Average	948	Average 1925		
x9/16	1-3/4x1-7/8 W/BS	1208	1942		Backspall on PTP impacts
x9/16	1-5/8x1-7/8 W/BS	1198	1855		
x5/8	1-3/4x1-7/8 W/BS	1109	1831		
	Average	1172	Average 1876		
	1" Plates				
	2-9/16x2-3/4W/BS	1511	2318		Backspall on PTP impacts.
	2 x 2-1/8 W/BS	1557	2342		
	2-1/16x2-5/16W/BS	1443	2213		
	Average	1504	Average 2291		
	2-3/4x2-15/16W/BS	1551	2488		Backspall on PTP impacts.
	2-5/8x3-1/16 W/BS	1552	2388		
	2-1/2x2-9/16 W/BS	1659	2475		
	Average	1587	Average 2450		
	1½" Plates				
	7/8x1 W/BS			891	
	7/8x1-1/8 W/BS			886	
	13/16x1 W/BS			901	
				Average 893	
	1x1-1/8			936	
	1-1/8x1-3/8			920	
	7/8x1			898	
				Average 918	

nal plate thickness.

([illegible] TO 45°) AND SUBZERO (-70° TO -40°F.) TEMPERATURES.

[illegible] mm. HE at [illegible]° Obl. [illegible]tection BL.	37 mm. PP T21 at 0° Obliquity Critical Vel.	Remarks
1966 f/s		Backspall on PTP impacts with Cal..50 proj.
1917		
1892		
1925		
1942		Backspall on PTP impacts with Cal..50 proj.
1855		
1831		
1876		
[illegible]318		Backspall on PTP impacts.
2362		
[illegible]13		
[illegible]1		
2488		Backspall on PTP impacts.
2388		
2475		
2450		
	891	
	886	
	901	
	Average 893	
	936	
	920	
	898	
	Average 918	

(3)

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ARMY SERVICE FORCES
ORDNANCE DEPARTMENT
ABERDEEN PROVING GROUND
MARYLAND

(undated)

APG 470.5/1194
SPOTZ-F

SUBJECT: Samples of 24 ST and 14 SW Aluminum Alloy Aircraft Armor Plate for Metallurgical Analysis

TO: Commanding Officer
Watertown Arsenal
Watertown 72, Massachusetts

ATTENTION: Laboratory - Major N. A. Matthews

1. In accordance with directive received from the Office, Chief of Ordnance, Washington (OO 470.5/15760, APG 470.5/603, dated 18 Sept. 44, Subject: "Shipment of Aircraft Armor Samples to Watertown Arsenal") four (4) samples are being forwarded to your station for metallurgical examination. The samples represent 1½" thick 24 ST and 14 SW types aluminum alloy plates which have been ballistically tested both at normal and subzero temperatures.

2. The ballistic results on the 1-1/2" thick plates represented by these plates are included in the two summary sheets attached herewith. The samples may be identified as follows:

Type	Plate No.	Thickness	Sample Size	Temperature of Test
24 ST	3	1-1/2"	12" x 36"	Normal
"	9	"	"	Subzero
14 SW	2	"	"	Normal
"	4	"	"	Subzero

3. It will be appreciated if a copy of the metallurgical test results is furnished this station as soon as available.

FOR THE COMMANDING GENERAL:

G. G. EDDY
Col, Ord. Dept.
Director

2 Incls. - Summary of Ballistic Results

4594 (26 Ar8-014)

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RESULTS OF EIGHTEEN 3/4", 1", and 1-1/2" 14SW ALUMINUM ALLOY PLATES

PLATE NO.	AVG. TH.	TEMP.	CAL. .30 AP M2 AT 0° OBL. NAVY B.L.	CAL. .50 AP M2 AT 0° OBL. NAVY B.L.	NO BURST CAL. .30 AP M2 AT 0° OBL. MAX. EXIT DIA.	NO B CAL. .5 2 MAX. E
						3/
1	.74	Normal	1751 [1]		1/4"x1/4".	1"x1" d/
2	.72	Normal	1809		1/4"x1/4".	1"x1-1/1
3	.73	Normal	1779		1/4"x1/4"	1-1/32"x
		Average	1780			
4	.74	Subzero	1836		1/2"x1/2" BS	1"x1-1/8
5	.74	Subzero	1794		5/16"x9/32"	15/16"x1
6	.74	Subzero	1855		1/4"x1/4"	15/16"x1
		Average	1828			
1	1.00	Normal	2096	1623		1-11/16"
2	1.01	Normal	2065	1612		1-7/8"x3
3	1.00	Normal	2120	1641		2-1/16"x
		Average	2094	1625		
4	1.01	Subzero	2153	1643		1-15/16"
5	1.01	Subzero	2138	1634 [2]		2-1/4"x2
6	1.01	Subzero	2146	1644		2"x2-3/
		Average	2146	1640		
1	1.49	Normal		1945		7/16"x1/
2	1.49	Normal		1954		7/16"x1/
3	1.48	Normal		1981		7/16"x7/
			Average	1960		
4	1.47	Subzero		2026		7/16"x1
5	1.48	Subzero		2052		7/16"x9/
6	1.48	Subzero		2020		7/16"x9/
			Average	2033		

NOTES:
1. All values corrected to nominal thicknes
2. Value approximate - difference between b

ALUMINUM ALLOY PLATES TESTED AT NORMAL (45° TO 55°F.) & SUB-ZERO (-70° to -40°F.) TEMPERATUR

MG BURST CAL. .30 AP M2 AT 0° OBL. MAX. EXIT DIA.	MG BURST CAL. .50 AP M2 2450 MAX. EXIT DIA.	20 mm. AM BALL AT 20° OBL. CRITICAL VEL.	20 mm. HE AT 20° OBL. PROTECTION BL.	37 mm. PP T21 AT 0° OBL. CRITICAL VEL.	
	3/4" PLATES				
/4"x1/4".	1"x1" W/BS.	856	1872		Backsp Cal. .
/4"x1/4".	1"x1-1/16" W/BS.	942	1929		
/4"x1/4"	1-1/3 "x1-1/16".	888	1879		
	Average	895	1893		
/ "x1/2" BS	1"x1- /8" BS	1010	1987		Backsp Cal. .
7/16"x9/32"	15/16"x1-1/8"	977	2007		
/4"x1/4"	15/16"x1-1/8"	1026	1965		
	Average	1004	1986		
	1" PLATES				
	1-11/16"x1-3/4"W/BS	1440	2372		Backsp
	1-7/8"x2" W/BS	1468	2321		
	2-1/16"x1-3/4" W/BS	1463	2390		
	Average	1457	2361		
	1-15/16"x2" BS	1551	2523		Backsp
	2-1/4"x2-7/16" BS	1573	2551		
	"x2-3/ " BS	1561	2500		
	Average	1562	2525		
	1½" PLATES				
	7/16"x1/2"			792	
	7/16"x1/2"			below 790	
	7/16"x7/16"			841	
	7/16"x11/16" W/BS			913 [2]	
	7/16"x9/16"			910 [2]	
	7/16"x9/16"			933 [2]	

ted to nominal thickness.
- difference between high partial and low complete penetrations greater than 50 f/s.

2

& SUB-ZERO (-70° to -40°F.) TEMPERATURES

20 mm. HE AT 0° OBL. PROTECTION BL.	37 mm. PP T21 AT 0° OBL. CRITICAL VEL.	REMARKS
1872		Backspall on PTP impacts with Cal. .50 projectiles.
1929		
1879		
1893		
1987		Backspall on PTP impacts with Cal. .50 projectiles.
2007		
1965		
1936		
2372		Backspall on PTP impacts.
2301		
2390		
2361		
2523		Backspall on PTP impacts.
2551		
2500		
2505		
	792	
	below 790	
	841	
	913 [2]	
	910 [2]	
	933 [2]	

netrations greater than 50 f/s.

COMPARISON OF 3/4", 1", AND 1½" MAGNESIUM ALLOY PLA

		BHN	AVG. TH.	TEMP.	Cal..30 AP M2 at 0° Obliquity Navy B.L.	Cal..50 AP M2 at 0° Obliquity Navy B.L.	Machine Gun Burst. Cal..30 AP M2 Max. E.D.	Ma Bu M
								3/4"
1	3SR		.73	Normal	1263 [1]		3/4"x3/4" W/BS	7/
2	"		.73	"	1258		3/4"x3/4" W/BS	7/
3	"		.78	"	1259		5/8"x3/4" W/BS	1"
4	3SR		.70	Subzero	1310 [2]		7/8"x7/8" W/BS	15
5	"		.70	"	1292		15/16"x1" W/BS	1-
6	"		.73	"	1272		7/8"x15/16"W/BS	1"
								3/4"
1	52SR		.75	Normal	1291		7/8"x15/16"W/BS	1"
2	"		.73	"	1286		13/16"x7/8"W/BS	1-
3	"		.76	"	1295		3/4"x3/4"W/BS	1-
4	52SR		.74	Subzero	1300		3/4"x15/16"W/BS	1-
5	"		.75	"	1312		7/8"x13/16"W/BS	1-
6	"		.70	"	1341		15/16"x15/16"W/BS	
								1"
1	52SR		.99	Normal	1465	1094		1
2	"		.98	"	1523	1090		1
3	"		.96	"	1489	1098		1
4	52SR		.99	Subzero	1509	1093		1
5	"		.97	"	1515	1076		1
6	"		.98	"	1462 [2]	1080		1
								1½"
1	52SR		1.46	Normal		1361		1
2	"		1.46	"		1334		[illegible]
3	"		1.48	"		1341		[illegible]
4	52SR		1.46	Subzero		1368		[illegible]
5	"		1.44	"		1387 [2]		[illegible]
6	"		1.46	"		1411		[illegible]

NOTES: 1. All ballistic values
2. Difference between hi

(-70° to -40°F.) TEMPERATURES

37 mm. PP T21 at 0° Obliquity CRITICAL VEL.	Report No.: AR-15091 Sheet 2A of 28 REMARKS
	Backspall obtained on all PTP impacts.
	20 mm Am. Ball not adequate test for 1" plate.
CP at 812	37 mm PP T21 not adequate test for 1½" plate.
CP at 864	
—	

Greater than 50 f/s.

AGNESIUM ALLOY PLATES AT NORMAL (60° to 70°) AND SUBZERO (-70° to -40°F.) TEMPERATURES

Machine Gun Burst. Cal..30 AP M2 Max. E.D.	Machine Gun Burst. Cal..50 AP M2 Max. E.D.	20 mm Am. Ball at 20° Obliquity CRITICAL VEL.	20 mm HE at 20° Obliquity PROTECTION B.L.	37 mm. PP T21 at 0° Obliquity CRITICAL VEL.	
	3/4" PLATES OF [illegible]R TYPE				
3/4"x3/4" W/BS	7/8"x1-1/8"W/BS		—		Backspall obtained
3/4"x3/4" W/BS	7/8"x1-1/8"W/BS		930		
5/8"x3/4" W/BS	1"x1-3/32" W/BS		944		
7/8"x7/8" W/BS	15/16"x1-1/16"W/BS		1006		
15/16"x1" W/BS	1-1/8"x1-1/4" W/BS		939		
7/8"x15/16"W/BS	1"x1-1/8" W/BS		971		
	3/4" PLATES OF 5[illegible]SR TYPE				
7/8"x15/16"W/BS	1"x1-1/16"W/BS		1050		
13/16"x7/8"W/BS	1-1/16"x1-1/8"W/BS		1038		
3/4"x3/4"W/BS	1-1/8"x1-3/16"W/BS		1052		
3/4"x15/16"W/BS	1-1/8"x1-3/16"W/BS		1068		
7/8"x13/16"W/BS	1-1/16"x1-1/8"W/BS		1131		
15/16"x15/16"W/BS	1-1/8"x1-1/8"W/BS		1125		
	1" PLATES OF 52SR TYPE				
	1-1/8"x1-3/8"W/BS	CP at 681	—		20 mm Am. Ball not
	1-1/4"x1-5/16"W/BS	CP at 660	1316		
	1-1/4"x1-7/16"W/BS		1278		
	1-1/4"x1-1/4"W/BS	CP at 669	1391		
	1-3/8"x1-1/2"W/BS	CP at 662	1306		
	1-3/16"x1-1/4"W/BS		1309		
	1½" PLATES OF 52SR TYPE				
	1-9/16"x1-9/16"W/BS		1823	CP at 812	37 mm PP T21 not ad
	1-5/8"x1-13/16"W/BS		1794	CP at 864	
	1-3/8"x1-5/8"W/BS		1808	—	
	1-9/16"x1-3/4"W/BS		1858		
	1-5/8"x1-5/8"W/BS		1870		
	1-13/16"x1-13/16"W/BS		1894		

allistic values corrected to nominal plate thickness.
erence between high partial and low complete penetrations greater than 50 f/s.