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REPORT NO. 14-46

THE EFFECT OF PLATE TENSILE STRENGTH ON THE BALLISTIC LIMITS OF 3"0 STS AND 4"0 CLASS B ARMOR AGAINST 3" M62 CAPPED PROJECTILES AT 20°, 30°, AND 40° OBLIQUITY. (U)

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NPG REPORT NO. 14-46

THE EFFECT OF PLATE TENSILE STRENGTH ON THE BALLISTIC LIMITS OF 3"0 STS AND 4"0 CLASS B ARMOR AGAINST 3" M62 CAPPED PROJECTILES AT 20°, 30°, and 40° OBLIQUITIES.

Submitted by: R H Lyddane
R. H. LYDDANE
Senior Physicist
Head of Armor & Projectile Lab.

Prepared by: A. A. CONRAD
Ensign, USN

Reviewed by: W. O. Floyd
W. O. FLOYD
Capt., USN
Experimental Officer

Reviewed by: G K Williams
G. K. WILLIAMS
Comdr., USN
Armor Officer

Approved by: C. T. Joy
C. T. JOY
Rear Admiral, USN
Commanding Officer

Reviewed by: W H Benson
W. H. BENSON
Capt., USN
Ordnance Officer

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NPG Report No. 14-46

THE EFFECT OF PLATE TENSILE STRENGTH ON THE BALLISTIC LIMITS OF 3"0 STS AND 4"0 CLASS B ARMOR AGAINST 3" M62 CAPPED PROJECTILES AT 20°, 30°, and 40° OBLIQUITY.

1. This report represents a continuation of the work being carried out by the Armor and Projectile Laboratory at the Naval Proving Ground on the effect of plate tensile strength on ballistic limits. Previous results have been given in Reports 9-45 and 16-45.

2. The plates were heat treated and physical properties were obtained under the supervision of Lt. Cdr. D. L. Winchell, USNR. The ballistic testing and the interpretation of the results were carried out by the author under the supervision of Dr. R. H. Lyddane, head of the Armor and Projectile Laboratory.

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PREFACE

AUTHORIZATION

This study was authorized in Bureau of Ordnance letter NP9/A9 (Re3) dated 9 January 1943 as a part of Naval Proving Ground research project APL-3.

OBJECT

The investigation described in this report was conducted to determine the effect of plate tensile strength on the ballistic limits of 3"0 STS and 4"0 Class B armor against 3" M62 projectiles at 20°, 30°, and 40° obliquities.

SUMMARY

The subject tests were conducted at 20°, 30°, and 40° obliquities with 3" M62 capped projectiles at e/d values of 1.01 (3"0 STS), and 1.39 (4"0 Class B). The plates were heat treated over a range of tensile strength from 110,000 psi to 225,000 psi.

Owing to wide variations in type of projectile failure and to plate non-uniformity, no general statement can be made regarding the optimum hardness of the subject 3" armor under the test conditions described, and no consistent effects on ballistic limits of variations in obliquity or tensile strength were noted. However, the optimum hardness of the 4" armor appears to be in the neighborhood of 150,000 psi for the 20° and 30° obliquity tests.

The variations in ballistic limits are qualitatively analysed from the standpoint of the energy requirements for plate and projectile failures which, in turn, were observed to depend on the plate tensile strength.

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I. INTRODUCTION

References (1) and (2) are Naval Proving Ground reports on previous studies of the optimum tensile strength of homogeneous armor. With capped projectiles it was found that when the projectiles were undeformed the optimum tensile strength was in the neighborhood of the highest tensile strength at which a petals wiped plate failure occurred; with uncapped projectiles it was in the neighborhood of the highest tensile strength at which petals intact failure occurred. When the tensile strength was increased above the optimum for undeformed projectiles, low energy plate failures, such as spalls or punchings thrown, occurred. The increase in tensile strength, however, was often accompanied by considerable projectile damage resulting in a striking increase in ballistic limit.

The tests described herein were conducted over a 120,000 psi range of tensile strength with 3" M62 capped AP projectiles. The 20° and 30° tests were at e/d values of 1.01 and 1.39; the 40° test at 1.01.

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II. MATERIALS AND METHODS

Plates:

3'0 STS Carnegie-Illinois Plate No. 179770
4'0 Class B Carnegie-Illinois Plate No. TT233-1/16

Plates were heat treated in 3' x 3' sections. The detailed heat treatments and results of physical tests are given in Appendix A.

Projectiles:

3" M62 Chevrolet 14.7 lb. capped AP projectiles.
Lot CM-C-59

Methods of Measurement:

All ballistic limits in this report are expressed in terms of $F(e/d,\theta)$ values, where $F(e/d,\theta)$ is defined as follows:

$$F(e/d,\theta) = \frac{41.57\ M^{1/2}\ V_L\ \cos\theta}{e^{1/2} d}$$

M is the projectile mass in pounds. V_L is the limit velocity in feet per second (the minimum velocity for the projectile to pass completely through the plate). θ, the obliquity, is the angle between the normal to plate and the line of flight. e is the plate thickness in inches at the point of impact. d is the projectile diameter in inches. All quantities entering into the above defining expression are measured directly except the limit velocity. The depth of penetration of an incomplete penetration in a bracket of a complete and incomplete penetration was used to estimate the limit velocity.

III. RESULTS

The results given in detail in Appendix B are summarized in Tables I - III.

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Table I

3" M62 Projectiles at 20° Obliquity

Tensile Strength psi	F(e/d,θ)	% SK 78841	Plate Condition	Projectile Condition
		3"O C.I. No. 179770		
109,000	55,200 ± 600	115	Petals wiped.	Intact. Effective.
127,000	56,900 ± 800	119	Petals wiped and Intact.	Intact. Effective.
138,000	55,300 ± 500	115	Punching thrown and Petals wiped.	Nose cracked. Effective.
156,000	53,900 ± 500	113	Punching thrown.	Intact. Effective.
182,000	55,000 ± 500	115	Spall. Plate badly cracked.	Nose broken and Sheared. Effective.
197,000	Above 58,300	Above 122	Plate cracked. Punching thrown.	Shattered.
226,000	59,000 ± 1000	123	Punching thrown. Plate cracked.	Nose and body split and broken. Not Effective.
		4"O C.I. No. TT233 1/16		
116,000	59,000 ± 300	113	Petals wiped and Intact.	Body swollen and cracked. Effective.
129,000	Estimated 60,500	Est. 117	Petals wiped and Intact.	Body swollen and cracked. Effective.
152,000	65,900 ± 300	126	Punching thrown.	Split in two. Not Effective.
177,000	62,600 ± 300	121	Punching thrown.	Smashed and cracked. Not Effective.
222,000	61,600 ± 1000	118	Punching thrown. Plate badly cracked.	Shattered.

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Table II

3" M62 Projectiles at 30° Obliquity

Tensile Strength psi	F(e/d,θ)	% SK 78841	Plate Condition	Projectile Condition
		5"0 C.I. No. 179770		
109,000	53,700 ± 500	108	Petals wiped.	Intact. Effective
127,000	56,500 ± 1000	115	Petals wiped.	Slightly deformed. Effective.
138,000	56,900 ± 600	115	Petals wiped and broken.	Bent and cracked. Not Effective.
156,000	62,800 ± 500	127	Laminations. Deep spall.	Smashed and cracked. Not Effective.
182,000	63,000 ± 800	127	Punching thrown. Spall. Plate cracked.	Shattered.
197,000	61,000 ± 800	123	Punching thrown.	Shattered.
226,000	61,000 ± 1000	123	Punching thrown.	Shattered.
		4"0 C.I. No. TT233 1/16		
116,000	58,600 ± 200	107	Petals wiped and Intact.	Slightly deformed. Effective.
130,000	63,400 ± 500	115	Punching thrown.	Swollen and cracked. Effective.
161,000	63,700 ± 200	117.5	Punching thrown.	Shattered.
182,000	60,500 ± 100	111	Punching thrown.	Shattered.
223,000	61,300 ± 300	113	Punching thrown.	Shattered.

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Table III

3" M62 Projectiles at 40° Obliquity

Tensile Strength psi	F(e/d,θ)	% SK 78841	Plate Condition	Projectile Condition
		3"0 C.I. No. 179770		
109,000	Above 63,000	Above 122	No complete Penetration.	Shattered.
127,000	63,800 ± 500	123	Petals wiped and broken.	Shattered.
138,000	62,700 ± 500	121	Punching thrown.	Shattered.
156,000	62,700 ± 500	121	Punching thrown.	Shattered.
182,000	59,600 ± 800	115	Punching thrown. Spall started.	Shattered.
197,000	58,000 ± 1000	112	Plate cracked. Punching thrown.	Shattered.
226,000	56,500 ± 1000	109	Plate cracked. Punching thrown.	Split and broken. Not Effective.

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TABLE IV

Key to symbols in Figs. 1-3

○ --- No projectile damage

□ --- Slight projectile damage

△ --- Intermediate degree of projectile damage

▽ --- Considerable projectile damage

◇ --- Maximum projectile damage

Above symbols are shaded as shown below to indicate types of plate failures.

○ --- Petals intact, wiped, or broken

● --- Spall

◑ --- Punching thrown

Note: Symbol with arrow directly below it indicates that no completed penetration was made and the correct value of $F(e/d,\theta)$ lies above that particular point on the curve.

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NPG PHOTO NO. 3459 (APL) 24 SEPTEMBER 1946

F(b/d,θ) vs TENSILE STRENGTH

3" M62 CAPPED PROJECTILES

3"C, 450 HOMOGENEOUS PLATE

30° OBLIQUITY

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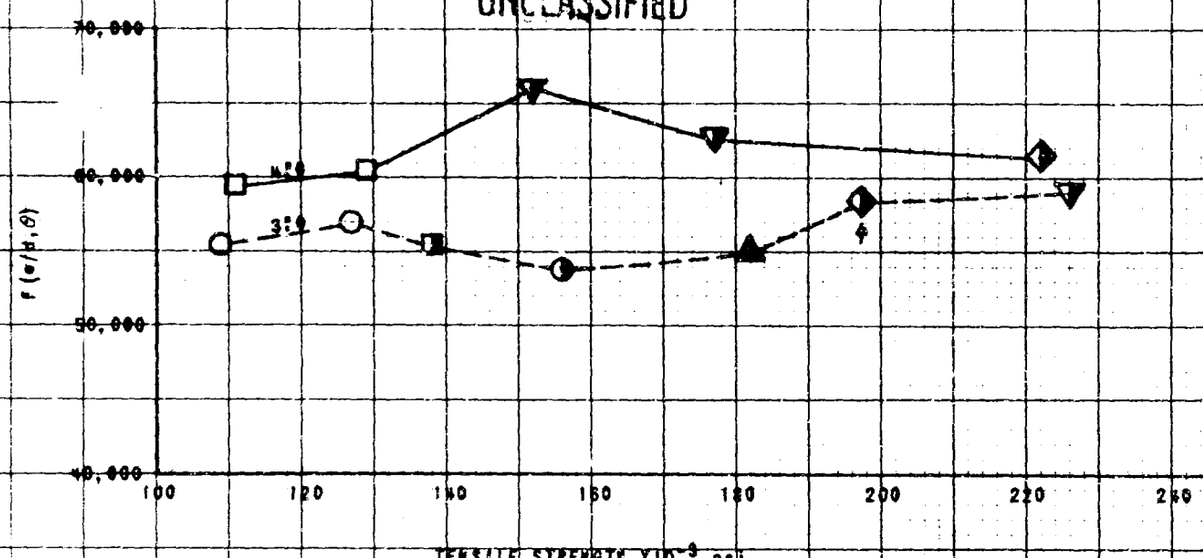
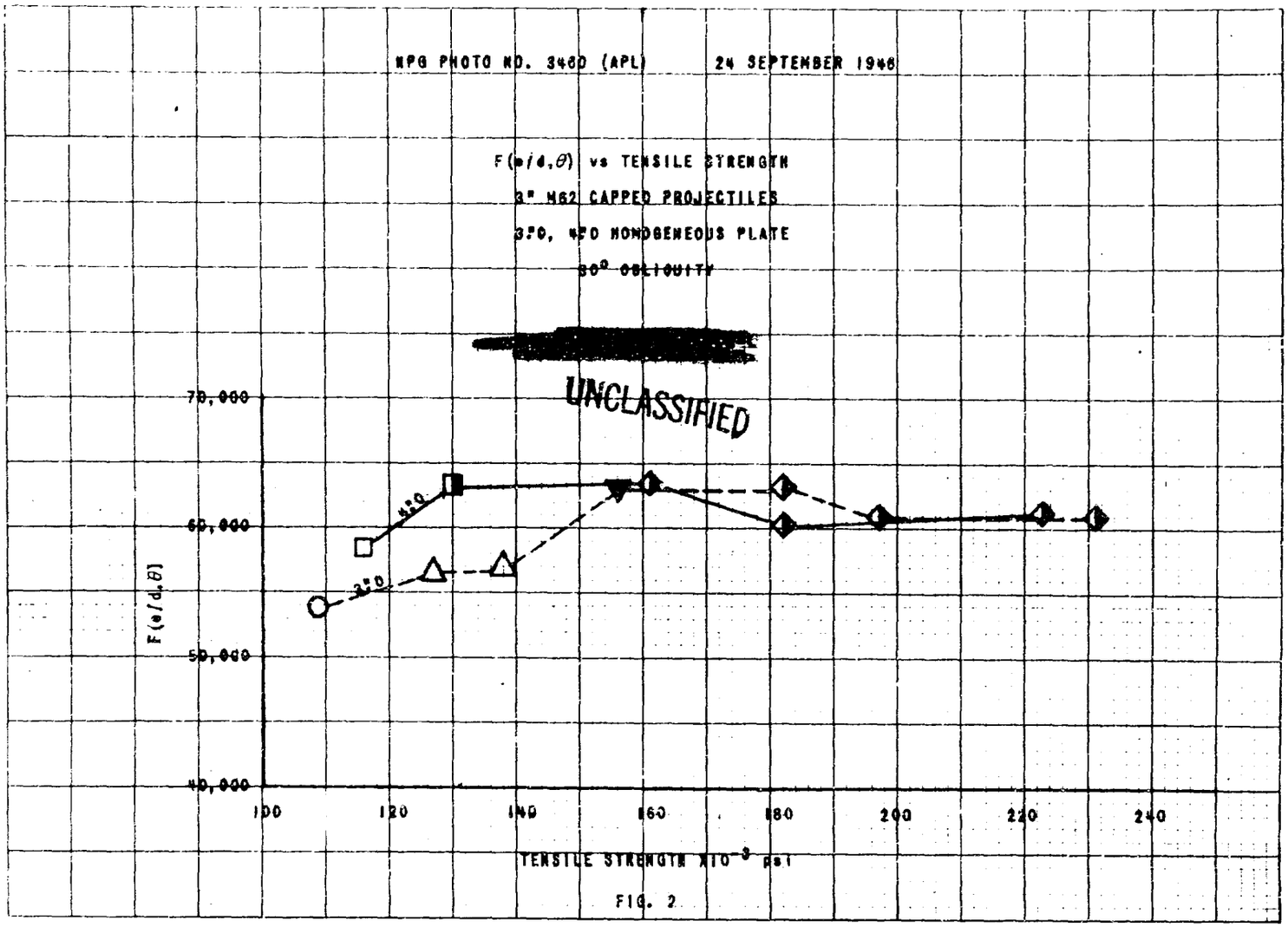


FIG. 1


NPG PHOTO NO. 3460 (APL) 24 SEPTEMBER 1946
F(w/d,θ) vs TENSILE STRENGTH
3" M62 CAPPED PROJECTILES
3.0, 4.0 HOMOGENEOUS PLATE
30° OBLIQUITY
[redacted]
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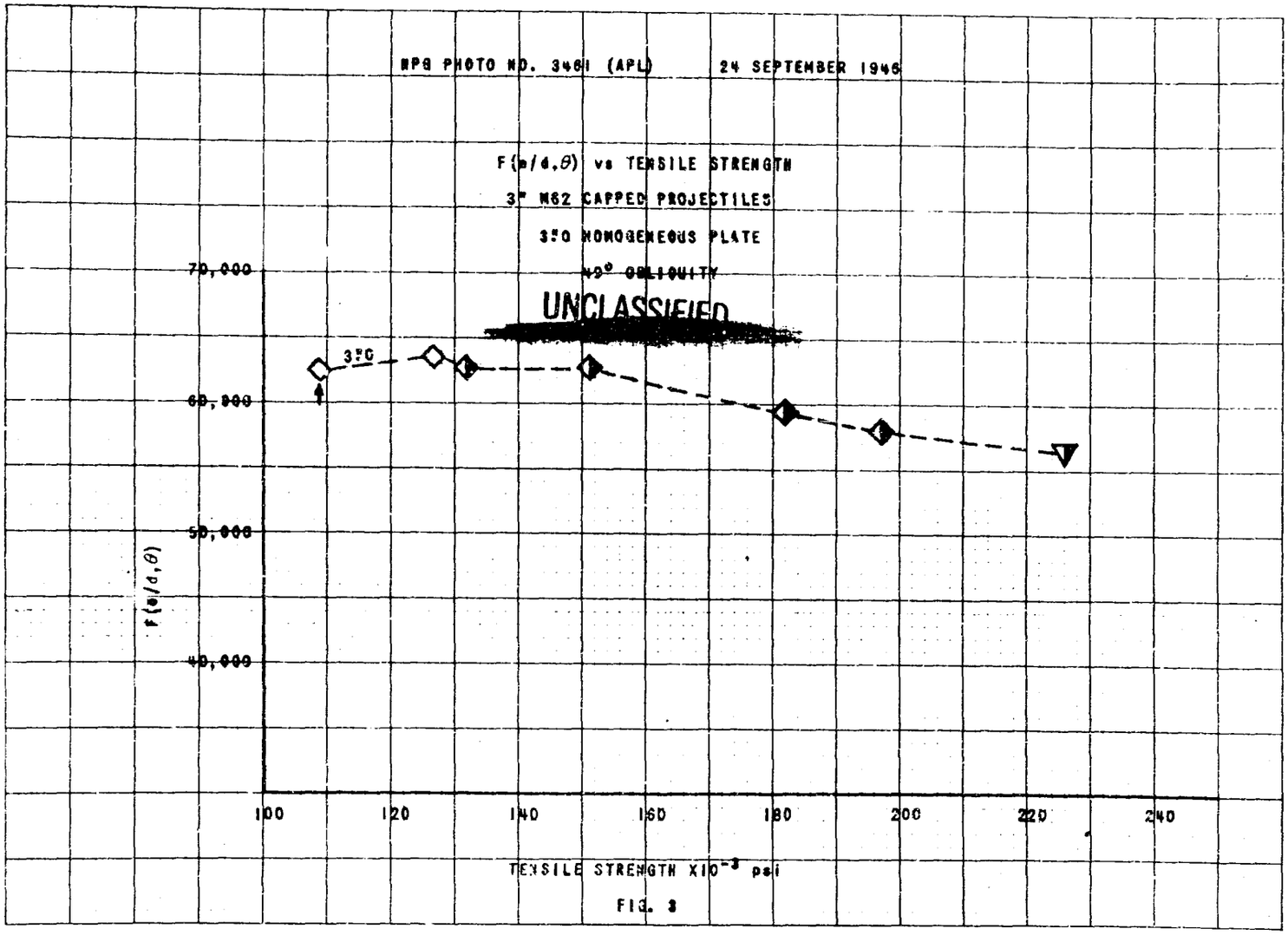
70,000
60,000
50,000
40,000
F(w/d,θ)
4.0
3.0
100
120
140
160
180
200
220
240
TENSILE STRENGTH X10^-3 psi

FIG. 2


NPG PHOTO NO. 3461 (APL) 24 SEPTEMBER 1946
F(e/d,θ) vs TENSILE STRENGTH
3" M62 CAPPED PROJECTILES
3"0 HOMOGENEOUS PLATE
45° OBLIQUITY
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3"0
70,000
60,000
50,000
40,000
F(e/d,θ)
100
120
140
160
180
200
220
240
TENSILE STRENGTH X10^-3 psi

FIG. 3

IV. DISCUSSION

Figs. 1-3, the key to which is given in Table IV, show that there is no general statement which can be made regarding the optimum hardness of the subject 3" armor plate and that except for the normal increase in $F(e/d,\theta)$ with e/d and obliquity no other consistent pattern of behavior was observed with changes in obliquity. These indeterminate results can only be attributed to the wide variation in type of projectile failure encountered in these tests. On the other hand, the 4" armor plate appears to have its optimum hardness in the neighborhood of 150,000 psi.

Certain qualitative evaluations of the effect of plate tensile strength on the types of plate and projectile failures can be made which agree in general with a similar analysis reported in reference (2). The types of plate and projectile failures may be classified in the order of increasing energy requirements (magnitude of effect on ballistic limit) as follows:

Plate Failures	Projectile Failures
Spall	Intact
Button thrown	Nose damaged
Punching thrown	Nose and body damaged
Petals broken, wiped or intact	Entire projectile deformed
	Shattered

This classification indicates that low limits will be obtained when the projectile falls into one of the first three above categories (projectile effective conditions) and the plate fails by punching or spalling. Figs. 1-3 support this hypothesis since it will be observed that the round, square or triangular shaded symbols (indicating the above mentioned failures) fall almost without exception on the low side of the curves. Conversely, those symbols indicating severe projectile damage and desirable plate failures (clear diamond or clear inverted triangle) are found at the high points of the curves in which they occur. These observations clearly specify the characteristics to be developed for optimum performance of homogeneous armor - extensive projectile deforming properties combined with the petals broken, wiped, or intact plate failures.

The occurrence of high limits with allegedly low energy punching type of plate failure, as noted in Figs. 1-3 does not contradict the above classification. There are two reasons for such high limits, the first of which is the fact that the punching thrown type of failure is usually accompanied by the most severe types of projectile damage. Secondly, the energy required for the punching thrown type of failure varies widely

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and in many cases cannot be distinguished from the petals wiped failure by merely examining the back of the plate. With the subject armor - projectile combination, no petal failure of any kind was observed on plates of 140,000 psi tensile strength or above and it is therefore obvious that the punching becomes the most desirable type of failure obtainable in plates of high tensile strength.

The type of plate failure, then, was associated with tensile strength, and in general, the energy requirements for failure decreased as tensile strength increased. Also the amount of projectile damage and the energy required for projectile failure increased directly with plate tensile strength.

V. CONCLUSIONS

1. No general conclusion can be made regarding the optimum hardness of the subject 3" homogeneous armor under the test conditions described herein. The subject 4" armor had its optimum in the neighborhood of 150,000 psi tensile strength.

2. Variations in ballistic limit are directly related to the types of plate and projectile failures.

3. At projectile velocities near the limit, the type of plate failure is largely a function of tensile strength.

4. At projectile velocities near the limit, projectile damage increases with tensile strength, e/d, and obliquity.

VI. REFERENCES

1. Effect of Plate Tensile Strength on the Ballistic Limits of 2"0 Homogeneous Armor of Four Different Compositions against 37mm Capped AP, 3" M62 Capped AP, and 3" M79 Monobloc SAP Projectiles. First Partial Report, U. S. Naval Proving Ground Report No. 9-45, dated 7 June 1945.

2. Effect of Plate Tensile Strength on the Ballistic Limits of 0"7, 1"2, 1"5, and 2"0 STS at 0° and 30° Obliquity against 37mm Capped and Uncapped M51B2 Projectiles. U. S. Naval Proving Ground Report No. 16-45, dated December 1945.

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VII. APPENDIX A

Heat Treatments and Physical Properties

Symbols:

hrs.	hours (at indicated temperature)
min.	minutes
WQ	water quench
AC	air cool
psi	pounds per square inch
BHN	Brinell Hardness Number. Hultgren Ball VPN 940, 3000 Kg. load.
Tensile	ultimate tensile strength
Yield	yield strength (0".002 offset)
% E	% elongation, 2" gauge length
% RA	% reduction of area, 0".505 dia.

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Sect. No.	APL No.	Heat Treatment: Hardening	Heat Treatment: Tempering WQ Cold	Physical Properties: BHN	Tensile psi	Yield psi	% E	% RA
		Carnegie - Illinois 3"0 Plate No. 179770						
A9	560	No treatment at NPG, Tested as received		226	109,000	91,000	26	68
A11	614	1550°F 2 hrs. WQ 3-3/4 min. AC	1200°F 2 hrs 1200°F 2 hrs	---	127,000	106,000	22	64
A12	561	1550°F 2 hrs. WQ 3-3/4-4 min. AC	1100°F 2 hrs 1100°F 2 hrs	285	138,000	125,000	20	63
A8	566	1550°F 2 hrs. WQ 3-3/4-4 min. AC	950°F 2 hrs 950°F 2 hrs 1000°F 2 hrs	321	156,000	143,000	18	57
A4	565	1550°F 2 hrs. WQ 3-3/4-4 min. AC	850°F 2 hrs 850°F 2 hrs 900°F 2 hrs	369	182,000	171,000	14	45
A3	563	1550°F 2 hrs. WQ 3-3/4-4 min. AC	750°F 2 hrs 750°F 2 hrs 800°F 2 hrs	403	197,000	188,000	12	43
A5	562	1550°F 2 hrs. WQ 3-3/4-4 min. AC	550°F 2 hrs 550°F 2 hrs	444	226,000	197,000	9	32
		Carnegie - Illinois 4"0 Plate No. TT233 1/16						
A1	648	No treatment at NPG, Tested as received.		244	116,000	95,000	24	68
A7	652	No treatment at NPG, Tested as received.		244	116,000	95,000	23	68
A8	658	1550°F 2 hrs. WQ 6-7 min. AC Transfer to 600°F 2 hrs heat to	1150°F 2 hrs 1150°F 2 hrs	273	129,000	118,000	21	65
A5	656	1550°F 2 hrs. WQ 6-7 min. AC Transfer to 600°F 2 hrs heat to	1150°F 2 hrs 1150°F 2 hrs	273	130,000	113,000	21	64
A6	657	1550°F 2 hrs. WQ 6-7 min. AC Transfer to 600°F 2 hrs heat to	1025°F 2 hrs 1025°F 2 hrs	322	152,000	141,000	18	59

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Sect. No.	APL No.	Heat Treatment: Hardening	Heat Treatment: Tempering WQ Cold	BHN	Physical Properties: Tensile psi	Yield psi	% E	% RA
		Carnegie - Illinois 4"0 Plate No. TT233 1/16						
A3	650	1550°F 2 hrs. WQ 6-7 min. AC Transfer to 600°F 2 hrs heat to	1025°F 2 hrs 1025°F 2 hrs	337	161,000	148,000	16	54
A9	659	1550°F 2 hrs. WQ 6-7 min. AC Transfer to 600°F 2 hrs heat to	925°F 2 hrs 925°F 2 hrs	375	177,000	168,000	14	52
A2	649	1550°F 2 hrs. WQ 6-7 min. AC Transfer to 600°F 2 hrs heat to	925°F 2 hrs 925°F 2 hrs	385	182,000	171,000	14	51
A10	660	1550°F 2 hrs. WQ 6-7 min. AC	600°F 2 hrs 600°F 2 hrs	448	222,000	200,000	11	45
A4	651	1550°F 2 hrs. WQ 6-7 min. AC	600°F 2 hrs 600°F 2 hrs	450	223,000	201,000	11	49

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APPENDIX B

Ballistic Data

Symbols:

e	Plate thickness at impact in inches.
d	Projectile diameter in inches.
θ	Obliquity.
M	Projectile mass in pounds.
V_s	Striking velocity in feet per second.
$V_{s\%}$	Striking velocity in % of empirical limit velocity given by BuOrd Sk. 78841.
Pene.	Depth of penetration in inches measured from the front surface of the plate normal to the plane of the plate.
Δd	Increase in diameter in inches of the forward bourrelet of the projectile as a result of the impact.
$F(e/d,\theta)$	F coefficient defined by the relation: $F = \frac{41.57\ M^{1/2}\ V_L \cos\theta}{e^{1/2} d}$ Where V_L is the estimated limit velocity (minimum velocity for complete penetration) in feet per second.

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Abbreviations:

Cp	Complete penetration. Major portion of projectile completely through the plate.
Inc	Incomplete penetration. Major portion of projectile rejected.
Sip	Projectile stuck in plate.
Intact	Projectile whole but may be deformed.
Eff.	Projectile would detonate if loaded and fuzed. Cavity and base plug not injured.
P.T.	Punching thrown.
P.S.	Punching started.
B.T.	Button thrown.
Lam.	Laminations.
P.W.	Petals wiped.
P.B.	Petals broken.
S.C.	Star crack.
P.I.	Petals intact.

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APL Impact No.	e in.	θ	M lbs.	Vs f.s.	Vs % Sk. 78841	Pene. in.	Δd in.	Plate Condition	Projectile Condition
					Carnegie - Illinois Plate No. 179770				
					Tensile Strength - - - 109,000 psi				
					M62 Chevrolet Projectiles at 20°				
4306	3".038	20°10'	14.70	1873	112	Inc. 5".5	0".011	S.C.	Nose cracked, Effective
4308	3".018	20°10'	14.70	1959	118	CP	0".011	P.W.	Intact, Effective
4307	3".025	20°10'	14.70	2048	123	CP	0".032	P.W.	Intact, Effective
					F = 55,200 ± 600 (115%)				
					M62 Projectiles at 30°				
4154	3".036	29°50'	14.70	1975	105	SIP 10".0	--	P.W.	Nose cracked, Effective
4155	3".030	30°00'	14.70	2005	107	Inc. 6".0	0".040	S.C.	Intact, Effective
4156	3".025	29°50'	14.70	2047	109	CP	0".007	P.W.	Intact, Effective
					F = 53,700 ± 500 (108%)				
					M62 Projectiles at 40°				
4304	3".023	40°00'	14.70	2478	112	Inc. 4".0	--	Bulge	Shattered
4305	3".030	40°10'	14.70	2701	122	Inc. 6".0	--	Bulge	Shattered
					F >122%				

APL Impact No.	e in.	θ	M lbs.	Vs f.s.	Vs % Sk. 78841	Pene. in.	Δd in.	Plate Condition	Projectile Condition
					Carnegie - Illinois Plate No. 179770 Tensile Strength - - - 127,000 psi M62 Chevrolet Projectiles at 20°				
4601	2".992	20°00'	14.70	1702	103	Inc. 3".0	0".004	Bulge	Base dented, Effective
4602	2".990	20°00'	14.70	1913	116	Inc. 3".8	0".002	Bulge, Star crack	Side dented, Effective
4603	2".988	20°00'	14.70	2012	122	CP	0".001	P.W. & P.I.	Side dented, Effective
					F = 56,900 ± 800 (119%)				
					M62 Chevrolet Projectiles at 30°				
4604	3".001	30°20'	14.70	2064	111	SIP 4".0	--	P.W.	Effective, Slightly Deformed
4606	2".991	30°20'	14.70	(est) 2115	114	Inc.	--	Dented	Broken up
					F = 56,500 ± 1000 (115%)				
					M62 Chevrolet Projectiles at 40°				
4607	2".989	40°00'	14.70	2238	102	Inc. 1".5	--	Dented	Shattered
4608	2".997	40°00'	14.70	2662	121	Inc. 2".3	--	Dented	Base broken & chewed off Not Effective
4609	3".000	40°00'	14.70	(est) 2745	125	CP	--	P.W. & P.B.	Shattered
					F = 63,800 ± 500 (123%)				

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APL Impact No.	e in.	θ	M lbs.	Vs f.s.	Vs % Sk. 78841	Pene. in.	Δd in.	Plate Condition	Projectile Condition
					Carnegie - Illinois Plate No. 179770 Tensile Strength - - - 138,000 psi M62 Chevrolet Projectiles at 20°				
4310	3.000"	20°00'	14.70	1824	110	Inc. 4.0"	0.014"	P.S. & Bulge	Intact, Effective
4311	2.999"	20°00'	14.70	1875	113	SIP 4.0"	0.016"	P.W. & P.T.	Nose cracked, Effective
4309	3.000"	20°10'	14.70	1943	117	CP	0.046"	P.T.	Nose cracked, Effective
					P = 55,300 ± 500 (115%)				
					M62 Projectiles at 30°				
4158	3.005"	30°10'	14.70	2094	112	Inc. 2.0"	--	Bulge	Shattered
4157	3.005"	30°10'	14.70	2181	117	CP	--	P.W. & P.B.	Plug out, bent body cracked, Not Effective
					P = 56,900 ± 600 (115%)				
					M62 Projectiles at 40°				
4313	3.008"	40°00'	14.70	2536	115	Inc. 3.5"	--	Bulge	Shattered
4314	3.004"	40°00'	14.70	2616	119	Inc. 4.0"	--	P.S. Bulge	Shattered
4312	3.012"	39°50'	14.70	2701	122	CP	--	P.T. (P.B. at bottom)	Nose broken off, Not Effective
					P = 62,700 ± 500 (121%)				

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APL Impact No.	e in.	θ	M lbs.	Vs f.s.	Vs % Sk. 78841	Pene. in.	Δd in.	Plate Condition	Projectile Condition
					Carnegie - Illinois Plate No. 179770 Tensile Strength - - - 156,000 psi M62 Chevrolet Projectiles at 20°				
4319	2".999	19°40'	14.70	1834	111	Inc. 2".0		Bulge	Bent. Large piece of nose broken out exposing cavity Not Effective
4320	3".003	19°50'	14.70	1897	114	CP		P.T. & small spall	Intact, Effective
4318	2".999	20°00'	14.70	2009	121	CP		P.T. & lam.	Intact, Effective
					F = 53,900 ± 500 (113%)				
					M62 Projectiles at 30°				
4175	3".004	30°10'	14.70	2230	120	Inc. 1".5	--	Bulge	Shattered
4176	3".003	29°50'	14.70	2324	125	Inc. (P)	--	Deep spall, Lam.	Shattered
4174	3".004	29°50'	14.70	2396	129	CP	--	Deep spall, Lam.	Smashed and cracked, nose broken off. Not Effective
					F = 62,800 ± 500 (127%)				
					M62 Projectiles at 40°				
4315	3".001	40°00'	14.70	2542	115	Inc. 2".5	--	P.S.	Shattered
4317	2".998	39°50'	14.70	2616 (est)	119	Inc.	--	P.T. & grain also chunk out	Shattered
4316	3".004	40°00'	14.70	2700	122	CP	--	P.T.	Shattered
					F = 62,700 ± 500 (121%)				

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APL Impact No.	e in.	θ	M lbs.	Vs f.s.	Vs % Sk. 78841	Pene. in.	Δd in.	Plate Condition	Projectile Condition
					Carnegie - Illinois Plate No. 179770				
					Tensile Strength - - - 182,000 psi				
					M62 Chevrolet Projectiles at 20°				
4322	3".000	20°10'	14.70	1863	113	Inc. 1".0	--		Not Effective Nose broken & sheared off
4321	3".002	20°00'	14.70	1896	114	SIP 8".0	--	Spall, Plate badly cracked	Effective. Nose broken & sheared.
					F = 55,000 ± 500 (115%)				
					M62 Projectiles at 30°				
4171	3".002	30°00'	14.70	23.5	124	Inc.	--	P.T.	Shattered
4173	3".004	29°50'	14.70	2413	129	CP	--	P.T. & spall	Shattered
4172	3".000	30°00'	14.70	2490	134	CP	--	P.T. & Plate cracked	Shattered
					F = 63,000 ± 800 (127%)				
					M62 Projectiles at 40°				
4325	2".997	40°10'	14.70	2393	109	Inc.	--	P.T.	Shattered
4324	2".999	39°50'	14.70	2527	115	CP (P)	--	P.T.	Shattered
4323	2".999	40°00'	14.70	2607	119	CP	--	P.T. spall started	Smashed and broken. Not Effective
					F = 59,600 ± 800 (115%)				

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APL Impact No.	e in.	θ	M lbs.	Vs f.s.	Vs % Sk. 78841	Pene. in.	Δd in.	Plate Condition	Projectile Condition
					Carnegie - Illinois Plate No. 179770				
					Tensile Strength - - - 197,000 psi				
					M62 Chevrolet Projectiles at 20°				
4328	2".994	20°10'	14.70	1953	118	Inc. (P)	--	Plate cracked P.T.	Split & cracked into large pieces.
4329	2".996	20°00'	14.70	2003	121	Inc. (P)	--	Plate cracked P.T.	Shattered & split pieces of nose thru
					F >58,300 (122%)				
					M62 Projectiles at 30°				
4162	2".992	29°50'	14.70	2207	119	Inc.	--	P.T.	Shattered
4164	2".989	29°50'	14.70	2325	125	CP (P)	--	P.T.	Shattered
4165	2".995	29°50'	14.70	2402	130	CP	--	P.T.	Shattered
					F = 61,000 ± 800 (123%)				
					M62 Projectiles at 40°				
4326	2".992	40°10'	14.70	2397	109	Inc.	--	Plate cracked	Shattered
4327	2".985	40°10'	14.70	2612	119	CP	--	Corner of plate broken off. P.T.	Shattered
					F = 58,000 ± 1000 (112%)				

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APL Impact No.	e in.	θ	M lbs.	Vs f.s.	Vs % Sk. 78841	Pene. in.	Δd in.	Plate Condition	Projectile Condition
					Carnegie - Illinois Plate No. 179770				
					Tensile Strength - - - 226,000 psi				
					M62 Projectiles at 20°				
4131	2".998	20°10'	14.70	1991	120	Inc. (P)	--	Plate cracked P.T.	Split & broken Not Effective
4130	3".003	20°10'	14.70	2173	131	CP	--	P.T.	Nose sheared off, stump cracked & chewed, split, Not Effective
					F = 59,000 ± 1000 (123%)				
					M62 Projectiles at 30°				
4159	3".001	30°10'	14.70	2002	107	Inc.	--	P.T.	Shattered
4160	3".004	29°50'	14.70	2175	117	Inc.	--	P.T.	Shattered
4161	3".007	29°50'	14.70	2410	129	CP	--	P.T.	Shattered
					F = 61,000 ± 1000 (123%)				
					M62 Projectiles at 40°				
4333	3".000	40°00'	14.70	2347	107	Inc. (?)	--	Plate cracked P.T.	Split & broken
4332	2".990	40°10'	14.70	2484	113	CP	--	Plate cracked P.T.	Split & broken
					F = 56,500 ± 1000 (109%)				

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APL Impact No.	e in.	Θ	M lbs.	Vs f.s.	Vs % Sk. 78841	Pene. in.	Δd in.	Plate Condition	Projectile Condition
Carnegie - Illinois Plate No. TT 233 1/16 A-7									
Tensile Strength - - - 116,000									
M62 Chevrolet Projectiles at 20°									
4761	3"815	20°00'	14.70	2194	108	Inc. 3"5	--	Bulge	Nose & body split
4762	3"816	20°20'	14.70	2283	112.5	Inc. 3"75	--	Bulge	Nose & body split
4763	3"810	20°20'	14.70	2320	114	CP	--	P.W. & P.I.	Swollen & cracked Effective
F = 59,000 ± 300 (113%)									
M62 Projectiles at 30°									
4741	3"840	29°40'	14.70	2495	108	CP	--	P.W. & P.I.	Slightly deformed Effective
4742	3"880	29°50'	14.70	2323	100	Inc. 2"4	--	Bulge	Broken up
4743	3"868	30°10'	14.70	2479	106	SIP 8"5	--	P.W. & P.I.	Slightly deformed Effective
F = 58,600 ± 200 (107%)									
Carnegie - Illinois Plate No. TT 233 1/16 A-8									
Tensile Strength - - - 129,000									
M62 Chevrolet Projectiles at 20°									
4784	3"781	20°20'	14.70	2352	117	CP	--	P.W. & P.I.	Cracked & swollen Effective
4789	3"739	20°30'	14.70	2297	115	Inc. 3"0	--	Bulge	Split open & bent
4790	3"731	20°30'	14.70	2330	117	Inc. 2"5	--	Bulge	Nose split & bent around body
Estimated F = 60,500 (117%)									

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APL Impact No.	⌀ in.	θ	M lbs.	Vs f.s.	Vs % Sk. 78841	Pene. in.	Δd in.	Plate Condition	Projectile Condition

<u>Carnegie - Illinois Plate No. TT 233 1/16 A-5</u>
Tensile Strength - - - 130,000
M62 Projectiles at 30°

4779	3".908	30°00'	14.70	Missed	Est. 114	Inc. 2".5	--	Bulge	Shattered
4780	3".948	30°00'	14.70	2771	117	CP	--	P.T.	Swollen & cracked
4781	3".962	30°00'	14.70	2694	114	Inc. 2".5	--	Bulge	Effective
									Shattered

F = 63,400 ± 500 (115%)

<u>Carnegie - Illinois Plate No. TT 233 1/16 A-6</u>
Tensile Strength - - - 152,000
M62 Chevrolet Projectiles at 20°

4772	3".956	20°30'	14.70	Missed	---	Inc.	--	Bulge	Shattered
4773	3".931	20°30'	14.70	2586	124	Inc.	--	P.T.	Shattered
4774	3".905	20°20'	14.70	2634	127	CP	--	P.T.	Split in two
									Not Effective

F = 65,900 ± 300 (126%)

<u>Carnegie - Illinois Plate No. TT 233 1/16 A-3</u>
Tensile Strength - - - 161,000
M62 Projectiles at 30°

4753	3".761	30°00'	14.70	2596	114	Inc.	--	Bulge	Shattered
4754	3".779	29°40'	14.70	2657	117	Inc.	--	P.T.	Shattered
4755	3".787	29°50'	14.70	2697	118	CP	--	P.T.	Shattered

F = 63,700 ± 200 (117.5%)

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APL Impact No.	e in.	G	M lbs.	Vs f.s.	Vs % Sk. 78841	Pene. in.	Δd in.	Plate Condition	Projectile Condition
Carnegie - Illinois Plate No. TT 233 1/16 A-9									
Tensile Strength - - - 177,000									
M62 Chevrolet Projectiles at 20°									
4801	3".745	19°40'	14.70	2454	123	Inc.	--	Plate cracked P.T.	Broke up
4802	3".759	19°40'	14.70	2400	120	SIP 8".0	--	Plate cracked P.T.	Shattered, Base stuck flush
4803	3".757	19°30'	14.70	2431	122	CP	--	P.T.	Smashed & cracked Not Effective
F = 62,600 ± 300 (121%)									
Carnegie - Illinois Plate No. TT 233 1/16 A-2									
Tensile Strength - - - 182,000									
M62 Projectiles at 30°									
4748	3".783	29°50'	14.70	2520	111	Inc.	--	P.T.	Shattered
4749	3".811	29°50'	14.70	2544	111	Inc.	--	Punching started	Shattered
4750	3".804	29°45'	14.70	2560	112	CP	--	P.T.	Shattered
F = 60,500 ± 100 (111%)									
Carnegie - Illinois Plate No. TT 233 1/16 A-10									
Tensile Strength - - - 222,000									
M62 Chevrolet Projectiles at 20°									
4804	3".823	20°00'	14.70	2221	109	Inc.	--	P.T.	Shattered
4805	3".821	20°00'	14.70	2315	114	Inc.	--	P.T.	Shattered
4806	3".831	20°20'	14.70	2450	120	CP	--	Plate cracked Spall P.T.	Shattered
F = 61,600 ± 1000 (118%)									

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APL Impact No.	e in.	θ	M lbs.	Vs f.s.	Vs % Sk. 79841	Pene. in.	Δd in.	Plate Condition	Projectile Condition
					Carnegie - Illinois Plate No. TT 233 1/16 A-4 Tensile Strength - - - 223,000 M62 Projectiles at 30°				
4756	3".801	29°50'	14.70	2379	104	Inc.	--	Bulge	Shattered
4757	3".797	29°40'	14.70	2560	112	SIP	--	P.T. Lam.	Shattered, Base SIP
4758	3".794	30°00'	14.70	2615	114	CP	--	P.T.	Shattered

F = 61,300 ± 300 (113%)