U. S. NAVAL PROVING GROUND

DAHLGREN, VIRGINIA

UNITED STATES NAVY BUREAU OF ORDNANCE

REPORT NO. 11-46

A STUDY OF NON-UNIFORMITY IN 3"0 and 4"0 HOMOGENEOUS ARMOR.

July 1946

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U. S. NAVAL PROVING GROUND

DAHLGREN, VIRGINIA

REPORT NO. 11-48

A STUDY OF NON-UNIFORMITY
IN 3"0 and 4"0 HOMOGENEOUS ARMOR

APPROVED:

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REAR ADMIRAL, U. S. NAVY

COMMANDING OFFICER.

P R E F A C E

AUTHORIZATION

This study was authorized in the Bureau of Ordnance letter NP9/A9 (Re3) dated 9 January 1943 as part of Naval Proving Ground Research Project APL-7.

OBJECT

The tests described in this report were conducted as part of a broad program to investigate causes of non-uniformity in homogeneous armor, effects of non-uniformity on ballistic properties, and the supersonic method of determining plate non-uniformity.

SUMMARY

Specially prepared plates of 3"0 and 4"0 gauge were obtained from Carnegie-Illinois for the subject investigation, which was conducted with 3" M79 SAP projectiles at 0° obliquity and 3" M61 and M62 capped AP prjectiles at 20° or 30° obliquity.

In the tests relating to the causes of non-uniformity in homogeneous armor the following observations were made:

1. Plate quality bore a direct relation to position in the ingot. Sections prepared from the bottom of an ingot were sound but internal defects became more evident as the distance from the bottom of the ingot increased. Furthermore, with similar types of plate failure, ballistic limits tended to be slightly higher in sections prepared from the bottom of the ingot.

2. Plates from different ingots of the same heat were of the same ballistic quality, provided they came from comparable positions within the ingots.

3. There was a slight indication of non-uniformity between different heats of steel of the same composition. Identical ballistic performance was obtained in the M79 tests but one heat showed a small superiority in the test with M61 projectiles.

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In the tests relating to the effects of non-uniformity in homogeneous armor the following observations were made:

1. Non-uniform plate quality was associated with non-uniform ballistic quality. Unsound plate areas, because of poor types of plate failures, had limits as much as 7% below the limits of sound areas.

2. Variations in the tensile strength did not appreciably affect ballistic performance. In the M79 tests the limits were the same for tensile strengths from 114,000 psi to 142,000 psi and in the M61 tests from 117,000 psi to 142,000 psi indicating that these tests were conducted with plates which were in the optimum tensile region.

3. Variations in the heat treatment of plates affected the ballistic performance. Two sections which were austempered had M79 limits 4% above the limits of armor given the standard heat treatments. However, a section which was given a standard treatment but with an eight minute quench from the hardening temperature, instead of the usual four minute quench, had the same ballistic properties as a plate given the standard treatment.

4. Thermal checks affected ballistic quality. 470 plates which contained thermal checks showed deep laminations or separations in the ballistic tests, though the limits were only about 2% below those of plates of average quality of the same tensile strength.

5. Forging, as compared with rolling, tended to improve ballistic performance. In the test with M79 projectiles a forged section and rolled sections of the same heat had equal ballistic properties; but in the test with M61 projectiles at 30° the forged plate had limits which were 3-8% higher.

In the tests relating to the supersonic method of detecting metallurgical non-uniformities better than 96% agreement was obtained between quality indicated by the supersonic reflectoscope and quality obtained in ballistic tests.

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I. INTRODUCTION

When a number of impacts are made, under constant test conditions, on a single plate or on plates of supposedly the same ballistic quality, it has often been observed that limits are obtained which vary by rather large amounts. The identification and control of factors causing these variations are of obvious importance in the development of armor.

The tests described herein are related to three aspects of the study of non-uniformity in homogeneous armor: 1. the causes of non-uniformities; 2. the effects of non-uniformities; and 3. the non-destructive detection of non-uniformities. In the first category the following three factors were studied: position in ingot, variations in plates and ingots of one heat, variations in heats of the same composition. In the second category known non-uniformities such as variations in tensile strength, variations in heat treatment or method of working, and internal defects were evaluated from the standpoint of the effect they had on ballistic quality. Lastly, the supersonic reflectoscope was used as a non-destructive method of detecting internal defects in armor.

Fig. 1

NPG PHOTO NO. 3271 (APL).
Projectiles used in study of armor non-uniformity. Left to Right: 3" M79, 3" M61, 3" M62.
15 April 1946

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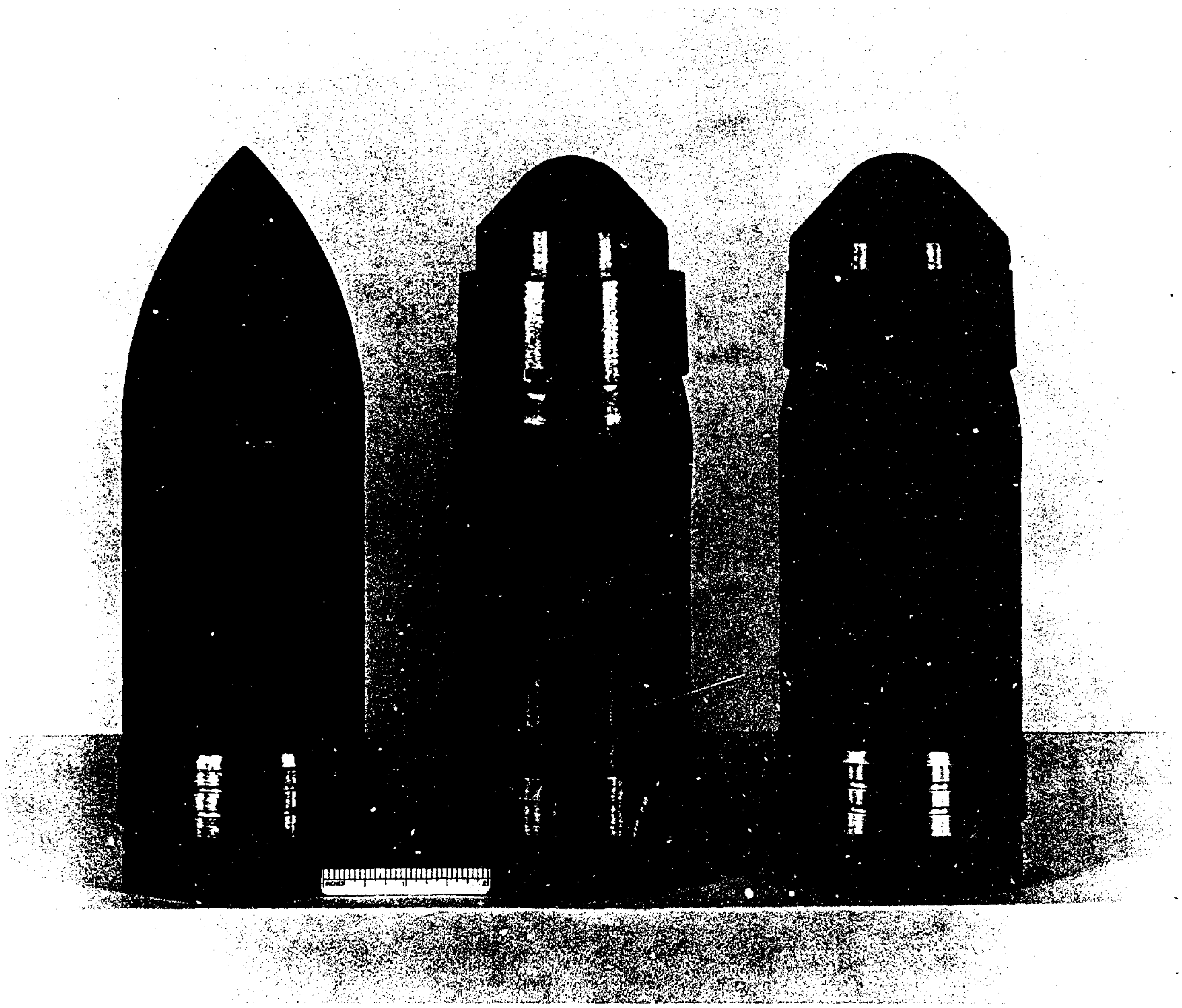

Fig. 2

NPG PHOTO NO. 3776 (APL).
Operator making test with Sperry Supersonic Reflectoscope.
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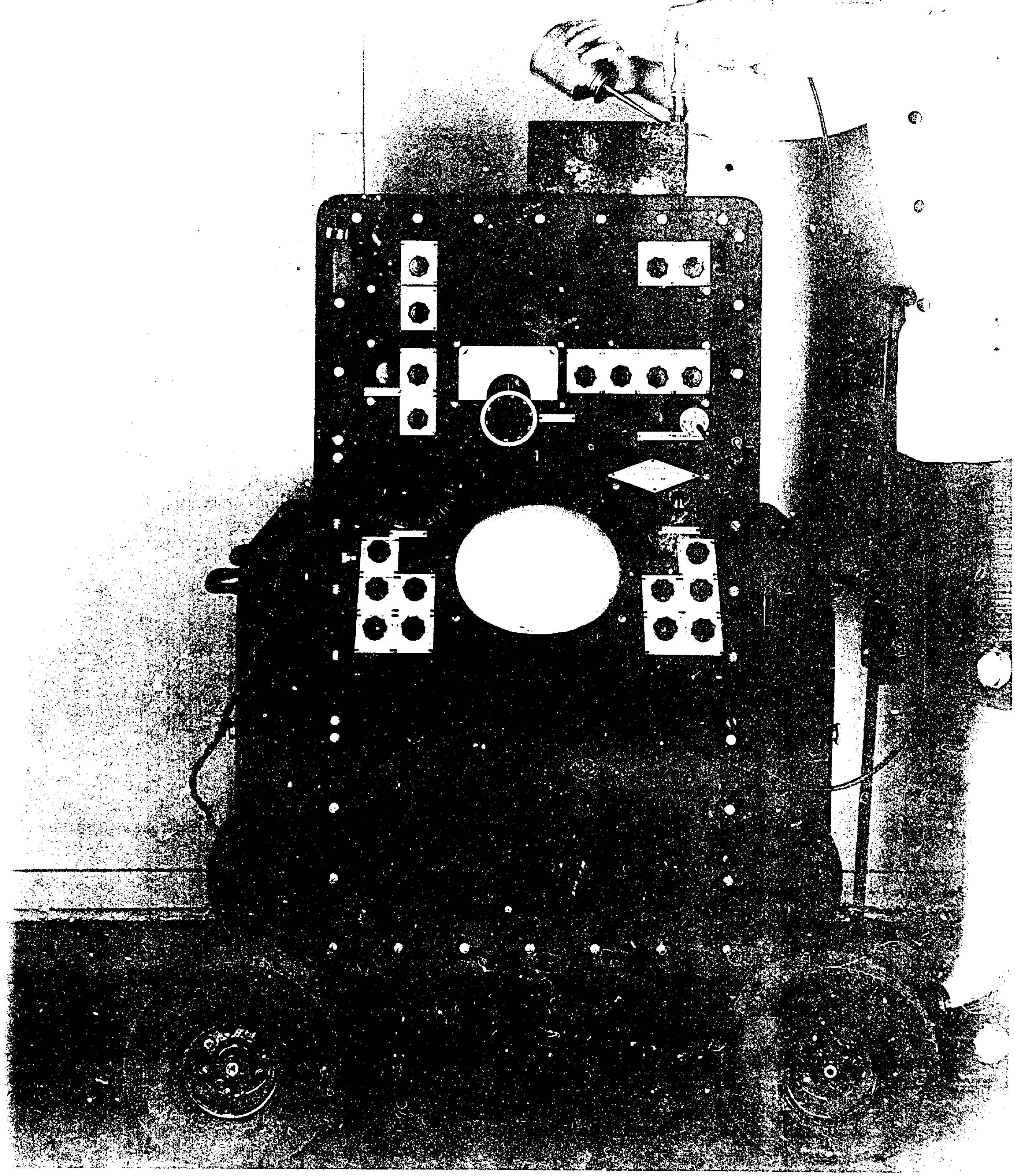

II. MATERIALS AND METHODS

A. Plates

3"O Carnegie-Illinois No. 89001 Heat No. 20247 Ingot No. 1
3"O Carnegie-Illinois No. 89002 Heat No. 20247 Top Ingot No. 2
3"O Carnegie-Illinois No. 89003 Heat No. 20247 Center Ingot No. 2
3"O Carnegie-Illinois No. 89004 Heat No. 20247 Bottom Ingot No. 2
3"O Carnegie-Illinois No. GG346(Forged) Heat No. 20247 Ingot No. 3
3"O Carnegie-Illinois No. 127804 Heat No. 15267
4"O Carnegie-Illinois No. 139957 Heat No. 14349
4"O Carnegie-Illinois No. 167162 Heat No. 21518

The melting and rolling practice and ladle analyses of these plates are given in Appendix A.

The heat treatments and physical properties of sections of these plates are given in Appendix B.

The plates were tested in 36" x 36" sections.

B. Projectiles

The projectiles used in the tests described herein are illustrated in Fig. 1.

3" Frankford Arsenal M79 15-pound monobloc uncapped SAP projectiles.
3" Bethlehem Steel Co. M61 14.2 pound capped AP projectiles.
3" Chevrolet M62 14.7 pound capped AP projectiles.

C. Supersonic Reflectoscope, SR04, manufactured by Sperry Products, Inc.

Fig. 2 is a view of the supersonic reflectoscope used in the subject investigations and shows the operator applying a film of oil to the surface of a steel block while surveying it with the searching unit containing the quartz crystal.

They Sperry supersonic reflectoscope is an instrument which employs a vibrating crystal to send and receive supersonic signals through a plate (or other solid medium) and visually indicates on a cathode ray oscilloscope the time elapsed between the transmission of the signals and return of their reflections. If the plate being tested is free from defects having reflecting surfaces, the reflections will come from the opposite side only. If the plate contains defects possessing reflecting surfaces, reflections will be received in a shorter time and will appear on the oscilloscope between the indication representing the signal entering the plate and that representing the signal being reflected from the back of the plate. The location on the oscilloscope trace of the reflection from the defect indicates the depth of the defect below the surface of the plate. There is also some evidence that the visual appearance of the reflection depends somewhat on the character of the flaw.

The crystal may be vibrated at frequencies of 1, 2.25, or 5 megacycles depending on the transmission or sensitivity characteristics desired. A frequency of 5 megacycles was used in the tests described in this report.

D. Methods of Measurements

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

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

$\underline{M}$ is the projectile mass in pounds. V_L is the limit velocity in feet per second and is the minimum velocity required for a projectile to pass completely through the plate. $\underline{\theta}$, the obliquity, is the angle in degrees between the normal to the plate and the line of flight. $\underline{e}$ is the plate thickness in inches at the point of impact. $\underline{d}$ is the projectile diameter, at the bourrelet, in inches. All of the quantities entering into the defining expression above are measured directly except the limit velocity. The limit velocity for any test condition is calculated from the striking and residual velocities, reference 1, or estimated from the depth of penetration.

In this report the limits, observed $F(e/d, \theta)$ values, are expressed as percentages of the standard Navy $F(e/d, \theta)$ values given by the 1931 empirical formula (BuOrd Sk. 78841):

$$F(e/d, \theta) = 6(e/d - 0.45)(\theta^2 + 2000) + 40{,}000$$

The detailed ballistic data are given in Appendix C.

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NPG PHOTO NO. 3076 APL

EFFECT OF LOCATION IN INGOT ON PLATE QUALITY

Plate 89001

Top of Ingot

 (1) (2)	A APL 180 Varied: No flaws to large flaws Petals wiped - deep laminations and button thrown	A-1 APL 165 Large and small flaws Petals wiped. Button thrown and laminations
	A-2 APL 175 Varied: No flaws to large flaws Petals wiped - split and laminations	A-3 APL 176 Varied: No flaws to large flaws Petals wiped - Button thrown and laminations
	A-4 APL 166 Varied: No flaws to large flaws Petals wiped. Petals wiped - broken and laminations	A-5 APL 90 Varied: No flaws to large flaws Petals wiped - button thrown and laminations
	A-6 APL 178 Varied: No flaws to large flaws Petals wiped - button thrown and laminations	A-7 APL 89 No flaws Petals intact - wiped
	A-8 APL 179 No flaws Petals wiped	A-9 APL 167 No flaws Petals wiped

Bottom of Ingot

(1) Supersonic flaw indications
(2) Types of plate failures

15 April 1946 Fig. 3

III. DISCUSSION

Position in Ingot

Sections of the plates rolled from Ingots Nos. 1 and 2 of Heat No. 20247 were tested so as to compare the ballistic properties at varying distances from the top of the ingot. Plate 89001 was rolled from Ingot No. 1 and plates 89002, 89003, and 89004 were rolled from the top, center, and bottom of Ingot No. 2. The areas of the plate sections which are compared in Table I were metallurgically uniform, having the same heat treatments and desirable types of plate failures.

TABLE I

Effect of Position in Ingot

APL No.	Tensile Strength psi	Location in Ingot	M79 Limits (% Sk. 78841)	and Plate Failures
		Ingot No. 1		
165	119,000	Top	104	Petals wiped
166	118,000	Center	104	Petals wiped
167	121,000	Bottom	105	Petals wiped
		Ingot No. 2		
168	118,000	Top	104	Petals wiped
169	116,000	Center	104	Petals intact and wiped
170	118,000	Bottom	105	Petals wiped
171	117,000	Bottom	106	Petals intact

Table I shows a small but consistent increase in limit in sections prepared from the bottom of the ingot.

The effect of position in the ingot is more striking when sections corresponding to various distances from the top of the ingot are compared on the basis of metallurgical non-uniformities which, of course, are ultimately reflected in ballistic performance. As shown in Fig. 3, the bottom sections of plate 89001 were sound, but sections nearer to the top of the ingot contained internal defects, as revealed by the supersonic reflectoscope and by the types of plate failures.

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Different Plates of One Heat

Table I also shows that for the same relative position in the ingot, heat treatment, and type of plate failure, the ballistic properties of different plates of one heat were practically identical.

Different Heats

Sections of 3" plates prepared from different heats of steel of the same composition and heat treated to the same tensile strengths had the ballistic properties listed in Table II.

TABLE II

Differences between Heats

Heat No.	APL No.	Tensile Strength psi	Limits (% Sk. 78841) and Plate Failures M79 at 0°		M61 at 30°	
20247	89	114,000	105	Petals wiped or intact	104	Petals wiped
15267	172	114,000	104	Petals wiped	105 *109	Petals wiped Petals broken Laminations
15267	173	114,000	104	Petals intact and wiped	-	-

* Projectile deformed

The ballistic performance of the two heats was the same in the test with M79 projectiles but Heat No. 15267 appeared to be slightly superior against M61 projectiles. Sections of this heat deformed some of the M61 projectiles resulting in a higher limit. A projectile which remained undeformed gave, by the method of residual velocities, about the same limit as that obtained with a section from Heat No. 20247.

Type of Plate Failure

It has been generally observed that the manner in which a plate fails is related to its ballistic performance. Whether a good or a poor plate failure occurs is primarily dependent on the metallurgical characteristics of the impact

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area. At tensile strengths below 140-150,000 psi, poor failures are caused by non-uniformities or internal defects in the steel. Steel of this quality is called "dirty". Plate failures such as petals intact, petals wiped, or, at the higher strengths, petals broken, are considered to be desirable. The appearance of laminations, splits, and separations in the back of the plate, or the button thrown type of plate failure are often associated with lowered plate limits.

Table III shows the variation in limits within a given 36" x 36" APL plate section between the areas having desirable and undesirable types of plate failures. The limit for the desired type of plate failure is given first, for each APL plate, followed by the limit and variation in limit obtained when the plate failure was of a poor type.

[redacted]

TABLE III

Relation of Type of Plate Failure to Ballistic Limit

APL No.	Tensile Strength psi	M79 at 0° Limit	Variation	Plate Failure	M61 at 30° Limit	Variation	Plate Failure
90	142,000	105	--	Petals wiped			
		107	+2	Petals broken Laminations			
166	118,000				113 min.	--	Petals wiped and broken
					110	-3	Lam. Petals wiped and intact
175	128,000	106	--	Estimated from SIP (1)	110	--	Petals wiped
		103	-3	Splits. Petals intact	103	-7	Lam. Splits Petals broken
176	137,000	105	--	Petals wiped			
		102	-3	Petals intact Splits			
		101	-4	Lam. Very large button thrown			
178	135,000	109	--	Petals wiped			
		105	-4	Lam. Very large button thrown			
180	126,000	105	--	Petals wiped	114	--	(2) Petals wiped
		102	-3	Button thrown	109	-5%	Separations. Petals wiped and broken

(1) Stuck in Plate.
(2) M62 projectiles.

Table III indicates that laminations, splits, separations, or button thrown failures are associated with decreases of 3-7% in limits.

Each of the plate sections listed in Table III was prepared from Ingot No. 1, Heat No. 20247, which has been discussed, and illustrates the effect of non-uniform metallurgical quality on ballistic performance.

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Tensile Strength

The effect of plate tensile strength on ballistic properties has been discussed at length in two previous reports, references 2 and 3. The range of tensile strength covered by the plates used in the subject investigation was not wide enough to reveal clearly any significant effects but the results are summarized in Table IV. The plate sections included in Table IV had standard heat treatments and good types of failure. All projectiles were undeformed.

TABLE IV

Effect of Tensile Strength on Ballistic Performance

APL No.	Tensile Strength psi	Limits (% Sk. 78841) and Plate Failures M79 at 0°	M61 at 30°
89	114,000	105 Petals intact	104 Petals wiped
172	114,000	104 Petals wiped	105 Petals wiped
173	114,000	104 Petals intact and wiped	
169	116,000	104 Petals intact and wiped	
171	117,000	106 Petals intact and wiped	109 Petals wiped
166	118,000	104 Petals wiped	
168	118,000	104 Petals wiped	109 Petals wiped
170	118,000	105 Petals wiped	
165	119,000	104 Petals wiped	*105 Button thrown
167	121,000	105 Petals wiped	108 Petals wiped
175	128,000	106 Estimated from SIP	110 Petals wiped
176	137,000	105 Petals wiped	
90	142,000	105 Petals wiped	109 Estimated from bulge

* Poor type of plate failure

Table IV shows that the M79 limits varied negligibly with tensile strength indicating that the plate sections were in the region of optimum tensile strength. The M61 limits rose 4-5% as tensile strength increased from 114,000 psi to 117,000 psi and remained essentially constant as tensile strength increased to 142,000 psi indicating that the optimum

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tensile region was from 117,000 psi to 142,000 psi.

Austempering

Two sections of plate 89001 were isothermally transformed to bainites at 570°F and drawn to 135,000 psi and 141,000 psi. The ballistic properties of these sections are compared with sections of the same tensile strength given standard heat treatments in Table V.

TABLE V

Comparison between Austempered and Standard Plates

Heat Treat.	APL No.	Tensile Strength psi	Limits (% Sk. 78841) and Plate Failures M79 at 0°	M61 at 30°
Aust.	178	135,000	109 Petals wiped	
Std.	176	137,000	105 Petals wiped	
Aust.	179	141,000	109 Petals wiped	108 Petals wiped
Std.	90	142,000	105 Petals wiped	109 Est. from bulge

As shown in Table V the austempered sections had M79 limits 4% above those of sections given standard heat treatments. The M61 tests were unsatisfactory but they seemed to indicated about the same performance for austempered and standard heat treated sections.

Long Quenching Time

One section of plate 89001 was given an eight minute water quench instead of the usual four minute quench from the hardening temperature. In effect this resulted in a section almost completely transformed to martensite whereas the section quenched for four minutes contained austenite in the center regions which was transformed upon subsequent drawing. The eight minute quench section was cracked around the edges. As shown in Table VI, this section gave the same ballistic results with M79 projectiles as a section given the usual four minute quench.

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TABLE VI

Effect of Long Quenching Time

Quench	APL	Tensile Strength psi	Limits (% Sk. 78841) M79 at 0°
8 min.	180	126,000	106 estimated from SIP
4 min.	175	128,000	105 estimated from SIP

Thermal Checks

Three sections of 4"0 Class B plates known to contain thermal checks were tested and the results compared with a Class B plate of average quality in Table VII.

TABLE VII

Effect of Thermal Checks

Condition	APL No.	Tensile Strength psi	Limits (% Sk. 78841) & Plate Failures			
			M79 at 0°		M62 at 30°	
Thermal Checks	181	113,000	97	Petals wiped and broken. Separation	106	Petals wiped and broken. Separation
Thermal Checks	182	113,000	98	Petals wiped and broken. Laminations	111	Petals wiped and broken. Separation.
Thermal Checks	183	115,000	95	Petals wiped Separation	108	Petals wiped and broken. Separation
Sound	(DD37)	108,000	97	Petals wiped	109	Petals wiped

As Table VII shows, the thermal checks caused laminations and separations to appear in the plate failures. However, the thermally checked plates had about the same limits as the plate of average quality but of somewhat lower tensile strength. A 5,000 to 7,000 psi increase in the tensile strength of the sound plate would probably raise the limits about 2% above those of the plates with thermal checks.

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Forged Plate

One section of Heat No. 20247, Ingot No. 3, was forged to finish dimensions, rather than rolled, and given a standard heat treatment to 115,000 psi. Its ballistic performance is compared with that of two rolled sections of the same heat in Table VIII.

TABLE VIII

Comparision of Forged and Rolled Plates

Condition	APL No.	Tensile Strength psi	Limits (% Sk. 78841) & Plate Failures M79 at 0°		M61 at 30°	
Rolled	89	114,000	105	Petals intact	104	Petals wiped
Forged	184	115,000	105	Petals wiped	112	Petals wiped
Rolled	171	117,000	106	Petals intact	109	Petals wiped

The forged and rolled plates had equal ballistic properties in the test with M79 projectiles. The forged plate showed rather marked superiority in the test with M61 projectiles having a limit 8% above that of a plate of slightly lower tensile strength and a limit 3% above that of a slightly higher tensile plate which has previously been shown to be on the lower edge of the region of optimum tensile strength.

Supersonic Reflectoscope

In the discussion of the types of plate failures it was noted that plate areas which showed laminations, separations, splits, or other undesirable failures had limits below those areas which failed in the more desirable manner with petals intact, wiped, or broken. Defects or planes of weakness within the plate, such as thermal checks, cracks, segregations, laminations, etc., are primary causes of undesirable plate failures. A non-destructive method for detecting the presence of such internal defects would obviously be a valuable tool in procuring and developing high quality armor. The preliminary tests described in this report indicate that the supersonic reflectoscope is the most satisfactory instrument available for the non-destructive testing of armor plate.

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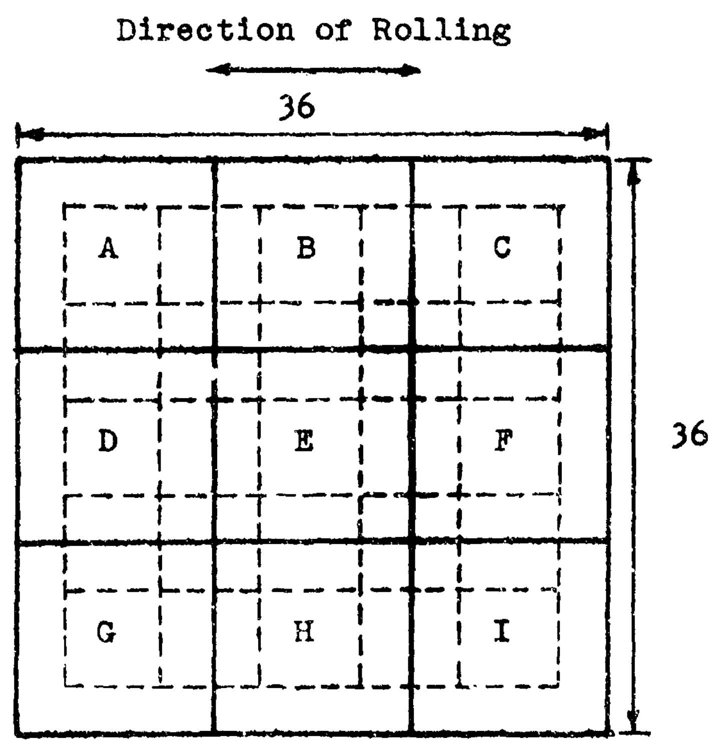
NPG PHOTO NO. 3075 APL   15 April 1946

DIAGRAM SHOWING LOCATION ON APL PLATES OF
TESTS MADE WITH SUPERSONIC REFLECTOSCOPE



Letters identify 12" x 12" regions of plate. The position of each impact listed in ballistic data, Appendix C, is described by one of these letters.

Tests were made with supersonic reflectoscope at least every six inches, starting 3" from edge of plate. Points of tests are indicated by intersection of dotted lines.

Fig. 4

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Fig. 5

NPG PHOTO NO. 3259 (APL).
Supersonic reading obtained at indicated point on macroetched section of APL 166, Region A. A - initial pulse. B - back reflection. C - second back reflection (not usually considered in evaluating readings). No flaws indicated.
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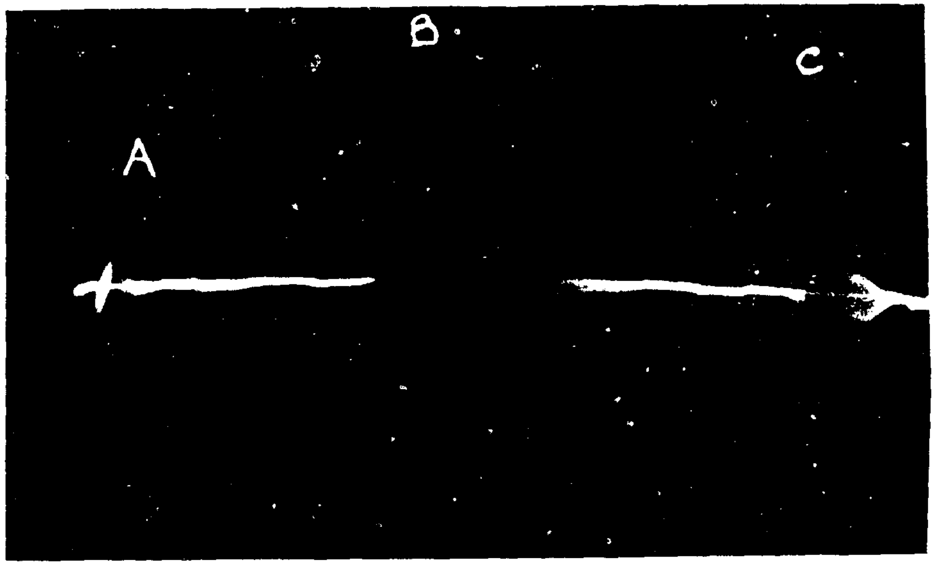

Fig. 6

NPG PHOTO NO. 3256 (APL).
Supersonic reading obtained at indicated point on macroetched section of APL 178, Region C. A - initial pulse. B - back reflection. C - large flaw indication.
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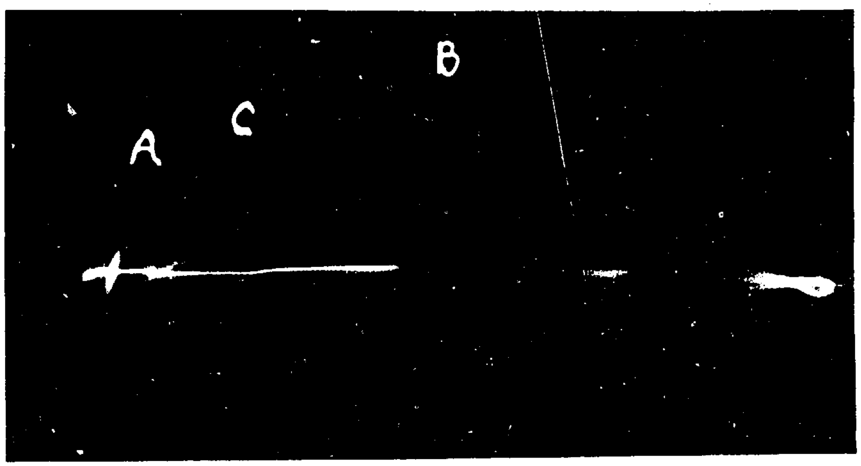

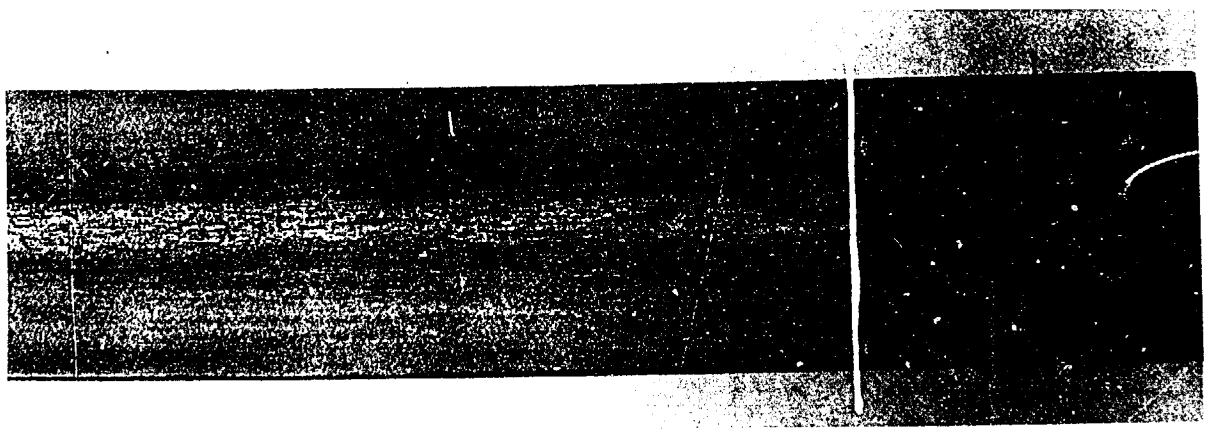

Fig. 7

NPG PHOTO NO. 3255 (APL).
Supersonic reading obtained at indicated point on macroetched section of APL 180, Region E. A - initial pulse. B - back reflection. C - large flaw indication. D - medium flaw indication. E - small flaw indication.
15 April 1946

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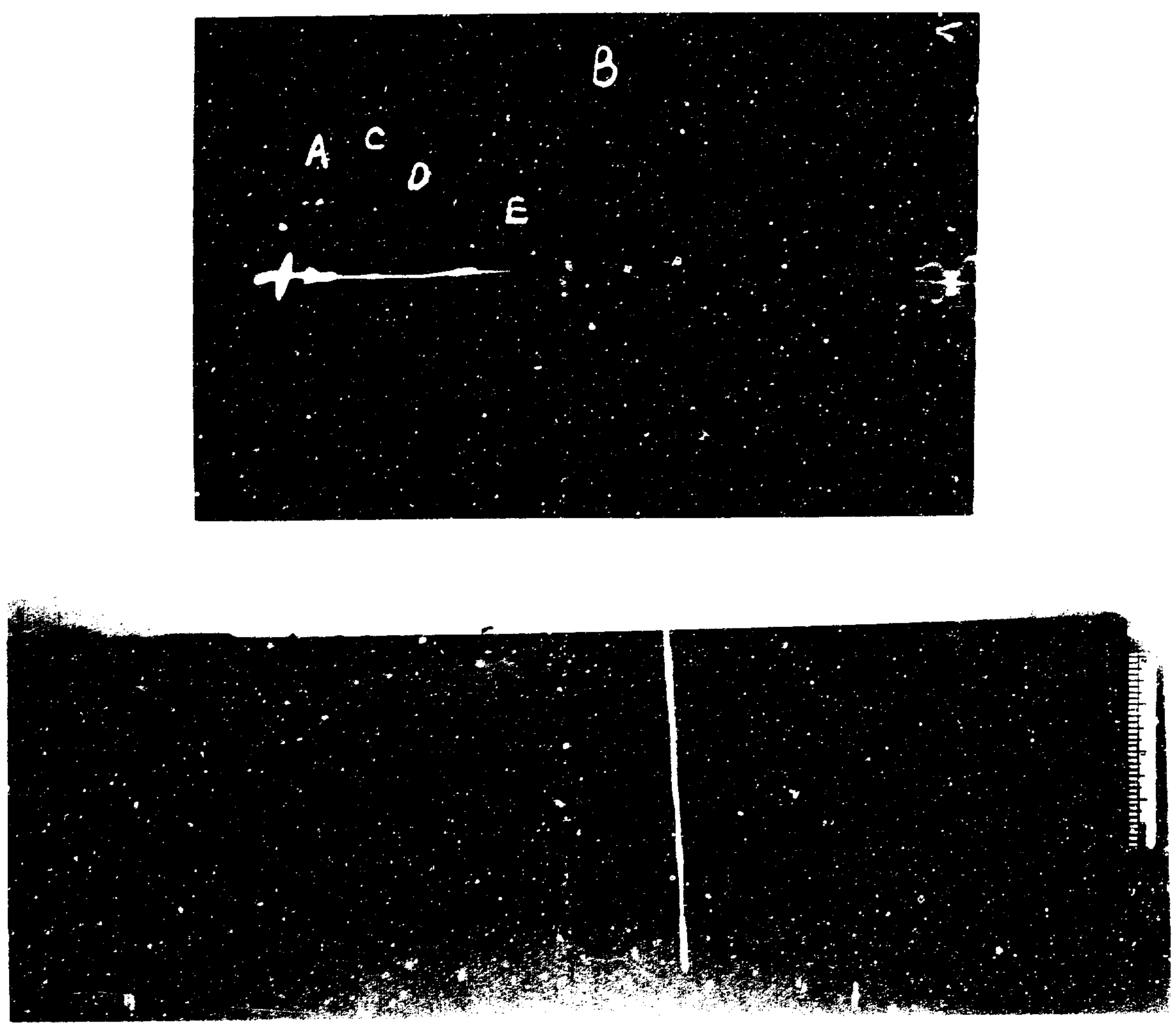

Fig. 8

NPG PHOTO NO. 3257 (APL).
Supersonic reading obtained at indicated point on macroetched section of APL 182, Region A. A - initial pulse. B - back reflection. C and D - large flaw indications. E - small flaw indication. Note that the unsoundness of this section has permitted only partial transmission of sound waves to the back wall resulting in a very small back reflection.
15 April 1946

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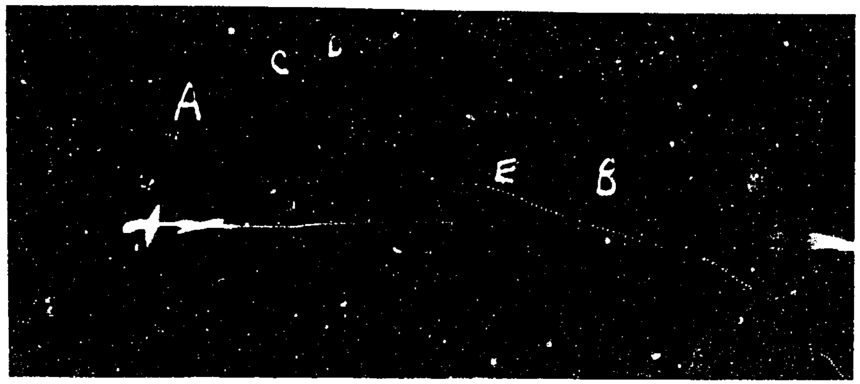

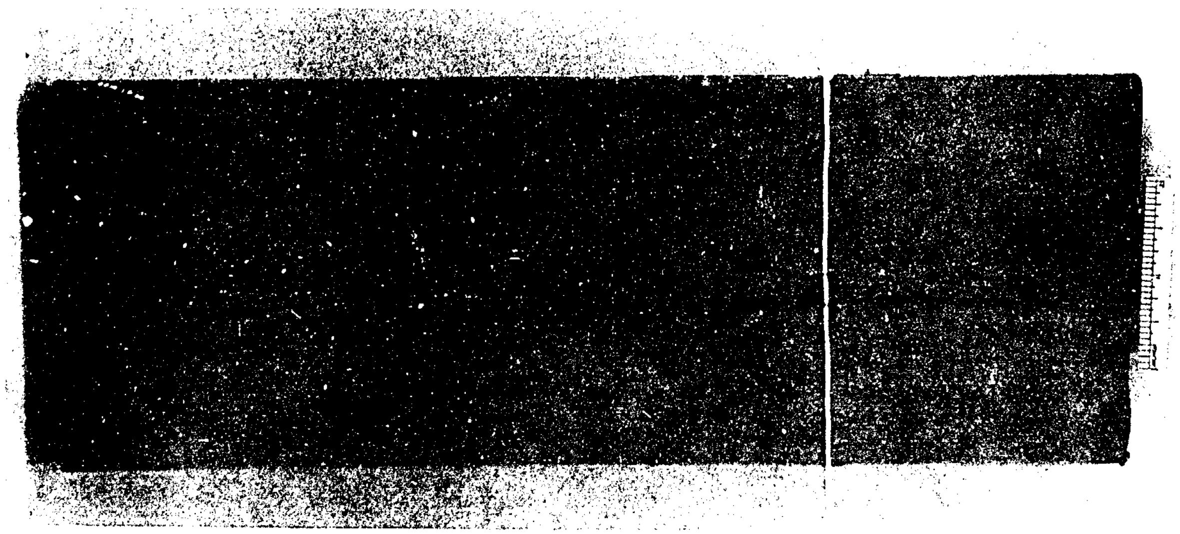

With only a few exceptions each of the impact areas listed in the detailed ballistic data, Appendix C, was surveyed for flaws with the 5 megacycle supersonic searching unit. Fig. 4 shows the location of tests on an APL plate. Fig. 3, previously referred to, lists the results of supersonic testing and the type of failures obtained on plate 89001. Figs. 5-8 are composite photographs of supersonic readings and the corresponding macroetch sections taken from some of the APL plates used in the subject investigation. The supersonic readings were taken about 0"25 below the macroetched surfaces at the cross section indicated in the photographs.

Table IX gives the statistics of the excellent correlation obtained between plate quality as indicated by the supersonic reflectoscope and plate quality as indicated by the types of plate failures occurring in ballistic testing.

TABLE IX

Correlation between Supersonic Quality and Ballistic Quality

Ballistic Quality	Quality Indicated by Supersonic Reflectoscope	Number of Impacts (1) M79	M61 or M62
Good	Good	28	21
Bad	Bad	9	23
Good	Bad	1	0
Bad	Good	0	2

(1) 25 additional impacts are shown in Appendix C but lack of through openings or projectiles stuck in plate prevented analyses of plate failures.

Table IX shows better than 96% agreement between actual plate quality obtained in ballistic tests and plate quality determined by the supersonic reflectoscope.

Inasmuch as the supersonic tests were conducted after the ballistic tests, except for impact numbers above 4500, there is some question as to whether the defects detected by the reflectoscope were present prior to ballistic testing. However, one hundred percent correlation was obtained on impacts above number 4500 between quality indicated by the reflectoscope and quality subsequently obtained in ballistic tests. If future results substantiate this agreement, it may be concluded that those variations in ballistic performance which are caused by internal defects or non-uniformities can be rather accurately predicted, before ballistic testing, by

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careful supersonic examination.

It is to be noted that there are problems of surface preparation and crystal deterioration which create certain practical difficulties in using the reflectoscope. More serious is the occasional breakdown of the instrument itself due, probably, to the rough handling to which it must necessarily be subjected in the testing of large plates. The instrument cannot be effectively used on plates less than 2"0 thick.

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IV. CONCLUSIONS

On the basis of the subject tests of 3"0 and 4"0 homogeneous armor the following general conclusions are made:

(1) Sections of armor plate prepared from different regions of the same ingot show metallurgical and ballistic non-uniformity.

(2) Plate areas containing internal defects resulting in poor types of plate failure have ballistic limits substantially below those of sound plate areas.

(3) Changes in heats, heat treatments, methods of working, or tensile strength of armor plate may cause variations in ballistic performance.

(4) The supersonic reflectoscope may be successfully employed as an instrument for the non-destructive testing of armor plate.

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V. REFERENCES

(1) Penetration of Homogeneous Plate of One Tensile Strength (110,000 psi) by 3" M79 AP Projectiles. Partial Report U. S. Naval Proving Ground Report No. 8-44 dated 18 April 1944.

(2) 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.

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

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APPENDIX A

MELTING AND ROLLING PRACTICE

The following information was copied from records submitted by Carnegie-Illinois on the subject heats.

Carnegie-Illinois Heat No. 20247

C. I. Plates Nos. 89001, 89002, 89003, 89004 and GG346.

Ladle Analysis

C	Mn	P	S	Si	Ni	Cr
.34	.26	.012	.025	.07	3.59	1.67

A. - Open hearth heat, regular armor grade. Nineteen heats preceded this heat since the last general repair. Tapped May 30, 1941.

B. - Open Hearth Record

Charge - 75,000# Nickel low Mn cold metal
2,500# Nickel
9,000# Lime

Melted - 1.35% carbon - 5 hrs. before tap

Additions In Furnace

3,500# Cinder	1456# Nickel 2:17 before tap
3,000# Lime	800# Nickel 1:42 before tap
	4450# FeCr 0:22 before tap

In Ladle	In Mold
50# Coal	13# Al total
50# FeMn	
235# Alsifer	

Time of heat - 15 hrs. 20 min.

Tap Test - carbon .22/.22, Mn .16/.17, FeO 8.21
Medium thin slag - dull top, dull bottom
no run off, bottom of hearth O.K.

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Tap - 8 min. tapping time, ladle held 4 min., 16 min. pouring, 3 hrs. before stripping. Ladle hot, 2-1/2" nozzle, nozzle O.K. Warm molds, Crucible clay and graphite on molds.

Temperatures

Bath Temperature	2915°F.	(rod boil)
Tapping Temperature	2964°F.	
Pouring Temperature	2834°F.	(start)
Pouring Temperature	2817°F.	(finish)

Product

3 - 29" x 60" - 80" body 37,000# cave top 3#Al/Ton.
1 - 29" x 60" - 74" body 34,000# cave top 3#Al/Ton.

C. - Rolling Mill Record

Ingots were taken hot to 32" mill and placed in the soaking pits. Total time in soaking pits 10 hrs. Heated to 2375°F. and the first ingot was rolled to 14" x 55" and the 2nd to 9" x 55". Slow cooled for 72 hrs. to 150°C. in sand insulated cooling bins and conditioned at 150°C. by scarfing. The slabs were kept on a preheater at 150°C. until transferred to the 140" mill reheating furnaces. Heated for 10 hrs. to 2375°F., cross rolled to 84" plate width and finished longitudinally to 3" gauge. Total reduction in cross sectional area was 7 to 1.

Plate 89001 Ingot #1.
Plate 89002 Top cut of Ingot #2.
Plate 89003 Middle cut of Ingot #2.
Plate 89004 Bottom cut of Ingot #2.

Plate 89001 was stress relieved by heating 3 hrs. to 675°C. holding 3-1/2 hrs. and air cooling. It was then flame cut into 10 small plates 36" x 36" x 3".

Carnegie-Illinois Heat No. 15267

C.I. Plates Nos. 127804A1 and A2

Ladle Analysis

C	Mn	P	S	Si	Ni	Cr
.35	.22	.011	.022	.06	3.81	1.75

A. - Open hearth heat, regular armor grade. Tapped September 17, 1940.

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B. - Open Hearth Record

Charge - 60,000# cold metal
7,500# lime

Melted - 0.90% carbon - 4 hrs. 16 min. before tap

Additions In furnace
500# Ore 1482# Nickel 2 hrs. 31 min. before tap
800# Lime 3600# FeCr 24 min. before tap
600# Staflux 150# FeMn 25 min. before tap

In Ladle	In Mold
125# coal 180# FeSi	12# Al total

Time of heat - 14 hrs. 15 min.

Tap test - carbon .18/.19, Mn .13/.14, FeO 8.49%
Heavy slag - dull top, dull bottom, no run off, bottom of hearth O.K.

Tap - 9 mins. tapping time, ladle held 11 mins., 14 mins. pouring. Ladle hot, 2-1/2 nozzle, nozzle O.K. Warm molds, Crucible clay and graphite on molds.

Temperatures

Bath Temperature	2970°F.	(rod boil)
Tapping Temperature	2998°F.	
Pouring Temperature	2864°F.	(start)
Pouring Temperature	2815°F.	(finish)

Product
1 - 34" x 60" 57,100# cave top 4#Al/ingot
1 - 29" x 60" 30,500# cave top 3#Al/ingot

C. - Rolling Mill Record

The 34" x 60" ingot was taken hot to the 32" mill and placed in the soaking pits. Total time in soaking pits 17 hrs. and 45 min. Heated to 2335°F. and rolled to 55" by 21" gauge. Slow cooled for 72 hrs. to 150°C. and conditioned. Annealed at Harvey Shop and shipped to Gary Works. Cross rolled to 108" and finished longitudinally to 3" gauge. Total reduction in cross sectional area was 7 to 1.

Carnegie-Illinois Heat No. 14349

C. I. Plates Nos. 139957A1 and A2.

Ladle Analysis

C	Mn	P	S	Si	Ni	Cr
.30	.25	.012	.022	.06	3.76	1.71

A. - Open hearth, regular armor grade. Tapped October 12, 1940.

B. - Open hearth record.

Charge - 49,000# Nickel low Mn cold metal
6,000# Lime

Melted - 1.32 carbon - 5 hrs. 1 min. before tap

Additions In furnace

1000# Lime 1795# Nickel 2 hrs. 31 min. before tap
1200# Ore 2900# FeCr 24 min before tap
200# Spar 30# FeMn 24 min before tap

In Ladle	In Mold
150# Coal 145# FeSi	8# Al total

Time of heat - 14 hrs. 20 min.

Tap Test - Carbon .14/.15, Mn .17/.17, FeO 9.79%
Medium heavy slag, dull top, dull bottom, no runoff. Bottom of hearth O.K.

Tap - 8 min. tapping time, ladle held 7 min., 12 min. pouring. Ladle hot, 2-1/2" nozzle, nozzle O.K., warm molds, Crucible clay and graphite on molds.

Temperatures

Bath Temperature	2958°F.	(Rod boil)
Tapping Temperature	2991°F.	
Pouring Temperature	2864°F.	(Start)
Pouring Temperature	2845°F.	(Finish)

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Product

3 - 29" x 60" ingots cave top
2-1/2# Al/ingot

C. - Rolling Mill Record

Ingots were taken hot to 32" mill and placed in soaking pits in 5 hrs. 10 min. Total time in soaking pits 9 hrs. 20 min. Heated to 2360°F., and rolled to 55" x 12-1/2" slow cooled for 72 hrs. to 150°C., and conditioned by scarfing. The slabs were transferred to the 144" mill, heated for 10 hrs. to 2375°F., cross rolled to 84" plate width and finished longitudinally to 4" gauge. Total reduction in cross-sectional area was 5 to 1.

Carnegie-Illinois Heat No. 21518

C. I. Plate No. 167162

Ladle Analysis

C	Mn	P	S	Si	Ni	Cr
.32	.26	.012	.020	.07	3.68	1.76

A. - Open hearth heat, double armor. Tapped November 29, 1940.

B. - Open Hearth Record

Charge - 61,000# Nickel low manganese cold metal
7,800# Lime

Melted - 1.140 - 5 hrs. 24 min. before tap

Additions In furnace
283# Nickel 2 hrs. 34 min. before tap
1,800# Cinder 675 Nickel 2 hrs. 4 min. before tap
1,000# Lime 400# Pig. 49 min. before tap
400# Staflux 3700# FeCr 26 min. before tap

In Ladle	In Mold
150# Coal 850# AMS Metal	No additions

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Time of heat - Charge to tap - 17 hrs. 55 min.

Tap Test - Carbon .16/.17, Manganese .17/.18, FeO 8.35% Medium slag, dull top, dull bottom, no run off, bottom of hearth O.K.

Tap - 8 mins. tapping time, ladel held 5 mins., 15 mins. pouring. Ladle hot, 2-1/2" nozzle, Nozzle O.K. Warm molds, Crucible clay and graphite on molds.

Temperature

Tapping Temperature	2964°F.	
Pouring Temperature	2834°F.	(Start)
Pouring Temperature	2817°F.	(Finish)

Product

Double Armor Ingot with Heat 22517
1 - 29" x 60" 37,000# cave top

C. - Rolling Mill Record

Ingot was taken hot to 32" mill and placed in the soaking pits. Total time in soaking pits 10 hrs. and 5 min. Heated to 2373°F. and rolled to 55" x 13". Slow cooled for 72 hrs. to 150°C. in sand insulated cooling bins and conditioned at 150°C. The slabs were transferred to the 140" mill, heated to 2375°F., cross rolled to 82" plate width and finished longitudinally to 4" gauge. Total reduction in cross-sectional area was approximately 5 to 1.

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APPENDIX B

HEAT TREATMENT AND PHYSICAL PROPERTIES

Sect. No.	APL No.	Heat Treatment: Time to Temp.	Temp.	Time at Temp.	Quench	Physical Properties: Tensile psi.	Yield psi.	% E	% RA
Heat No. 20247 - Ingot No. 1 - Plate No. 89001									
A7	89	7 hrs.	1535°F	2 hrs.	4 min. water quench				
		6 hrs.	1175°F	5 hrs.	water quench cold				
		11 hrs.	1540°F	3-1/2 hrs.	4 min. water quench				
		18 hrs.	1190°F	1 hr.	furnace cool to 1075°				
		7 hrs.	1075°F	1 hr.	water quench cold	114,000	95,000	24.0	67.6
A5	90	5 hrs.	1530°F	2 hrs.	furnace cool to 1445°F				
		2 hrs.	1445°F	5 hrs.	4 min. water quench				
		13-1/2 hrs.	1105°F	5 hrs.	water quench cold				
		11 hrs.	1540°F	6 hrs.	4 min. water quench				
		4 hrs.	1040°F	3-1/4 hrs.	water quench cold	142,000	124,000	19.0	59.3

Sect. No.	APL No.	Heat Treatment: Time to Temp.	Temp.	Time at Temp.	Quench	Physical Properties: Tensile psi.	Yield psi.	% E	% RA
				Heat No. 20247 - Ingot No. 1 - Plate 89001 (Cont'd)					
A1	165	3-1/2 hrs.	1540°F	2-1/2 hrs.	4 min. water quench				
		3-1/2 hrs.	1540°F	2-1/4 hrs.	4 min. water quench				
		3-1/2 hrs.	1135°F	4-1/2 hrs.	water quench cold				
		3 hrs.	1115°F	4 hrs.	water quench cold				
		3-1/4 hrs.	1140°F	4-1/2 hrs.	water quench cold	119,000	98,000	23.0	65.0
A4	166	Same treatment as APL 165				118,000	97,000	22.0	65.7
A9	167	Same treatment as APL 165				121,000	100,000	23.2	65.0
A2	175	10 hrs.	1540°F	5 hrs.	3 min. water quench transfer to salt bath				
		6 hrs.	570°F	8 hrs.	transfer to draw furnace				
		6 hrs.	1090°F	5 hrs.	water quench cold				
		8-1/2 hrs.	1540°F	4 hrs.	4 min. water quench				
		15 hrs.	1140°F	1-1/4 hrs.	water quench cold				
		12 hrs.	1140°F	45 mins.	water quench cold	128,000	107,000	22.8	64.1

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Heat Treatment						Physical Properties			
Sect. No.	APL No.	Time to Temp.	Temp.	Time at Temp.	Quench	Tensile psi.	Yield psi.	% E	% RA
		Heat No. 20247 - Ingot No. 1 - Plate 89001 (Cont'd)							
A3	176	17 hrs.	1535°F	2 hrs.	4 min. water quench				
		9 hrs.	1150°F	4 hrs.	water quench cold				
		10 hrs.	1540°F	4 hrs.	4 min. water quench				
		13 hrs.	1085°F	1 hr.	water quench cold	137,000	120,000	20.3	61.7
A6	178	10 hrs.	1535°F	3 hrs.	3-1/2 min. water quench				
		Salt bath	570°F	8 hrs.	transferred				
		5 hrs.	1090°F	3 hrs.	water quench cold	135,000	115,000	20.0	61.1
A8	179	10 hrs.	1540°F	3 hrs.	3-1/2 min. water quench				
		Salt bath	570°F	9 hrs.	transferred				
		9 hrs.	1060°F	3 hrs.	water quenched cold	141,000	122,000	19.5	57.3
A	180	5 hrs.	1535°F	2 hrs.	8 min. water quench				
		13 hrs.	1145°F	3 hrs.	water quench cold				
		(quench cracks around edge of plate)				126,000	105,000	22.2	64.7

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Sect. No.	APL No.	Heat Treatment: Time to Temp.	Heat Treatment: Temp.	Heat Treatment: Time at Temp.	Heat Treatment: Quench	Physical Properties: Tensile psi.	Physical Properties: Yield psi.	Physical Properties: % E	Physical Properties: % RA
Heat No. 20247 - Ingot No. 2 - Plate 89002 (Top of Ingot)									
A	168	3-1/2 hrs.	1535°F	2-1/2 hrs.	4 min. water quench				
		3-1/2 hrs.	1540°F	2-1/2 hrs.	4 min. water quench				
		3-1/2 hrs.	1135°F	5 hrs.	water quench cold				
		3 hrs.	1115°F	3-1/2 hrs.	water quench cold	118,000	97,000	23.5	64.5
Plate 89003 (Center of Ingot)									
A	169	Same treatment as APL 168				116,000	94,000	24.3	65.9
Plate 89004 (Bottom of Ingot)									
A	170	Same treatment as APL 168				118,000	97,000	24.3	65.8
A1	171	Same treatment as APL 168				117,000	98,000	25.0	66.7
Heat No. 20247 - Ingot No. 3 - Plate GG 346 (Forged)									
A	184	4 hrs.	1560°F	3-1/2 hrs.	4-1/2 min. water spray				
		4 hrs.	1549°F	2 hrs.	4-1/2 min. water spray				
		3-1/2 hrs.	1150°F	3-1/2 hrs.	water quench cold				
		3 hrs.	1120°F	3-1/2 hrs.	water quench cold	115,000	88,000	24.3	65.6

Heat Treatment						Physical Properties			
Sect. No.	APL No.	Time to Temp.	Temp.	Time at Temp.	Quench	Tensile psi.	Yield psi.	% E	% RA
				Heat No. 15267 - Plate 127804					
A1	172	3-1/2 hrs.	1550°F	2-1/2 hrs.	4 min. water quench				
		3-1/2 hrs.	1550°F	2-1/2 hrs.	4 min. water quench				
		3-1/2 hrs.	1160°F	3-1/2 hrs.	water quench cold				
		3 hrs.	1135°F	3-1/2 hrs.	water quench cold				
		3 hrs.	1170°F	8-3/4 hrs.	water quench cold	114,000	92,000	24.3	64.7
A2	173	Same treatment as APL 172				114,000	92,000	24.3	64.7
				Heat No. 14349 - Plate 139957 (Thermal Checked)					
A1	181	5 hrs.	1540°F	2-1/4 hrs.	5-1/2 min. water spray				
		5 hrs.	1540°F	5-1/2 hrs.	5-1/2 min. water spray				
		5 hrs.	1140°F	4-1/2 hrs.	water quench cold				
		5 hrs.	1115°F	4-3/4 hrs.	water quench cold	113,000	92,000	23.8	64.3
A2	182	Same treatment as APL 181				113,000	92,000	23.8	64.3

Heat Treatment						Physical Properties			
Sect. No.	APL No.	Time to Temp.	Temp.	Time at Temp.	Quench	Tensile psi.	Yield psi.	% E	% RA
				Heat No. 21518 - Plate 167162 (Thermal Checked)					
A	183	5 hrs.	1535°F	2 hrs.	5-1/2 min. water quench				
		5 hrs.	1540°F	2 hrs.	5-1/2 min. water quench				
		5-1/2 hrs.	1145°F	2-1/2 hrs.	water quench cold				
		5 hrs.	1110°F	4-1/4 hrs.	water quench cold	115,000	96,000	23.0	68.2

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APPENDIX C

Detailed Ballistic Data

Symbols

θ . . . . Obliquity. Angle between trajectory and normal to plate at impact.

e . . . . Plate thickness at impact in inches.

d . . . . Projectile diameter at the bourrelet, in inches.

$F(e/d, \theta)$ . . . . . Limit coefficient defined by the relation

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

% . . . . Limit or striking coefficient in % of empirical $F(e/d, \theta)$ value (BuOrd Sk. 78841)

V_S . . . . Striking velocity in feet per second.

V_R . . . . Residual velocity in feet per second.

V_L . . . . Limit velocity in feet per second calculated from following formula:

$$V_L^2 = V_S^2 - V_R^2$$

V_S % Sk. 78841. . . . Striking velocity in % of the V_L computed from Sk. 78841 for the subject impact.

V_L % Sk. 78841. . . . Calculated or estimated limit velocity in % of the V_L computed from Sk. 78841 for the subject impact.

Cp. . . . . Complete penetration. Major portion of projectile completely through plate.

Inc. . . . . Incomplete penetration. Major portion of projectile rejected.

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Sip.	Projectile stuck in plate.
Intact	Projectile whole but may be deformed.
Effective	Cavity and base plug not injured. Projectile would detonated if loaded and fuzed.

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APL No.	APL Impact No.	Location of Impact	e in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				3" M79 SAP Projectiles at 0° obliquity; Heat No. 20247 Ingot #1 Plate 89001; Tensile Strength 114,000 psi						
89	472	B	3.009	1532	102	104	SIP 4"4	Star crack	Broken in two	None
	473	A	3.020	1611	107	103	Cp. 417	Petals intact	Intact	None
	1053	G	3.020	1663	111	106	Cp. 480	Petals wiped	Intact	None
	471	C	2.993	1670	111	105	Cp. 550	Petals intact	Intact	None
				$F(e/d,\theta) = 49{,}100\pm500$ (105%)						
				Tensile Strength 142,000 psi						
90	478	B	3.010	1583	106	105	Cp. 145	Petals wiped	Intact	None
	477	A	3.020	1640	109	104	Cp. 483	Petals wiped	Intact	None
	1052	I	3.010	1676	112	107	Cp. 459	Lam. Petals Broken	Intact	Large - Very large
				$F(e/d,\theta) = 49{,}100\pm500$ (105%)						
				Tensile Strength 119,000 psi						
165	977	B	2.990	1529	102	103	SIP 8"4	Petals wiped	Intact	Large
	976	C	2.990	1582	106	104	Cp. 313	Petals wiped	Intact	Large
			$F(e/d,\theta) = 48{,}300\pm300$ (104%)							

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APL No.	APL Impact No.	Location of Impact	e in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Tensile Strength 118,000 psi						
166	997	B	2.997	1560	104	104	Cp. - 0	Petals wiped	Intact	None
	996	C	2.995	1587	106	104	Cp. 261	Petals wiped	Intact	None
				$F(e/d,\theta) = 48,500 \pm 300$ (104%)						
				Tensile Strength 121,000 psi						
167	999	E	2.982	1528	102	104	SIP 5"9	Petals Intact	Intact	None
	998	G	2.980	1562	105	106	SIP 9"0	Petals wiped	Intact	None
				$F(e/d,\theta) = 48,900 \pm 500$ (105%)						
				Tensile Strength 128,000 psi						
175	1016	C	2.996	1575	104	106	SIP 5"4	Star Crack	Intact	None
	1017	G	3.001	1582	106	103	Cp. 363	Splits Petals Intact	Intact	Large

Top $F(e/d, \theta) = 49,300 \pm 800$ (106%)
Bottom $F(e/d, \theta) = 47,900 \pm 800$ (103%)

[redacted]

APL No.	APL Impact No.	Location of Impact	e in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Tensile Strength 137,000 psi						
176	1020	H	3.000	1549	103	106	Inc. 4"5	Star crack	Intact	None
	1022	A	3.001	1552	104	102	Cp. 237	Petals Intact-Splits	Intact	Large
	1018	C	2.985	1585	106	101	Cp. 468	Lam. very large button thrown	Intact	No readings
	1021	I	2.993	1592	106	105	Cp. 276	Petals wiped	Intact	None
				Top F(e/d,θ) = 47,300±500 (101%)						
				Bottom F(e/d,θ) = 49,000±500 (105%)						
				Tensile Strength 135,000 psi						
178	1026	H	3.003	1575	105	108	Inc. 4"3	Star crack	Intact	None
	1025	B	3.013	1598	106	107	SIP 9"4	Petals wiped	Intact	None
	1024	C	3.014	1603	107	105	Cp. 239	Lam. very large button thrown	Intact	Large
	1023	G	3.005	1641	109	109	Cp. 200	Petals wiped	Intact	None

Top right corner F(e/d,θ) = 49,200±800 (105%)
Top center F(e/d,θ) = 50,200±500 (107%)
Bottom F(e/d,θ) = 51,000±500 (109%)

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APL No.	APL Impact No.	Location of Impact	e in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Tensile Strength 141,000 psi						
179	1027	C	3.000	1635	109	109	Cp. 57	Petals wiped	Intact	None
	1028	G	2.994	1651	110	109	Cp. 260	Petals wiped	Intact	None
				F(e/d,θ) = 50,800±500 (109%)						
				Tensile Strength 126,000 psi						
180	1030	A	2.981	1532	103	105	SIP 5"0	Petals wiped	Intact	None
	1031	D	2.986	1558	105	105	SIP 10"0	Petals wiped	Intact	Small-Large
	1029	I	2.995	1648	110	102	Cp. 629	Button thrown	Intact	Small-Large
			Top left corner F(e/d,θ) = 48,900±800 (105%)							
			Bottom right corner F(e/d,θ) = 47,500±800 (102%)							
			Heat No. 20247 Ingot #2 Plate 89002							
				Tensile Strength 118,000 psi						
168	1003	C	2.968	1534	103	105	SIP 7"6	Petals wiped	Intact	None
	1002	G	2.970	1552	104	104	Cp. 151	Petals wiped	Intact	None
				F(e/d,θ) = 48,500±300 (104%)						

APL No.	APL Impact No.	Location of Impact	e in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Heat No. 20247 Ingot #2 Plate 89003 Tensile Strength 116,000 psi						
169	1005	C	2.982	1575	106	104	Cp. 207	Petals intact & wiped	Intact	None
	1004	G	2.988	1592	107	105	Cp. 245	Petals intact & wiped	Intact	None
				F(e/d,θ) = 48,500±500 (104%)						
				Heat No. 20247 Ingot #2 Plate 89004 Tensile Strength 118,000 psi						
170	1007	C	2.971	1541	104	105	SIP 7"8	Petals wiped	Intact	None
	1006	G	2.948	1565	106	106	Cp. 100	Petals wiped	Intact	None
				F(e/d,θ) = 49,000 ± 300 (105%)						
				Tensile Strength 117,000 psi						
171	1000	C	2.950	1604	108	107	Cp. 264	Petals wiped & intact	Intact	None
	1001	G	2.977	1608	108	106	Cp. 338	Petals Intact	Intact	None
				F(e/d,θ) = 49,400±500 (106%)						

APL No.	APL Impact No.	Location of Impact	e in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Heat No. 20247 Ingot #3 Plate GG346 (Forged) Tensile Strength 115,000 psi						
184	1032	C	3.085	1582	103	105	SIP 4"3	Star crack	Intact	None
	1033	G	3.100	1663	108	105	Cp. 355	Petals wiped	Intact	None
				F(e/d,θ) = 49,500±500 (105%)						
				Heat No. 15267 Plate 127804 Tensile Strength 114,000 psi						
172	1013	B	3.018	1549	103	105	SIP 6"8	Petals intact & wiped	Intact	None
	1012	C	3.022	1597	105	104	Cp. 262	Petals wiped	Intact	None
				F(e/d,θ) = 48,600±500 (104%)						
				Tensile Strength 114,000 psi						
173	1015	C	3.010	1570	105	104	Cp. 220	Petals intact & wiped	Intact	None
	1014	G	3.007	1580	105	104	Cp. 129	Petals intact & wiped	Intact	None
				F(e/d,θ) = 49,100±500 (104%)						

APL No.	APL Impact No.	Location of Impact	e in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Heat No. 14349 Plate 139957 Tensile Strength 113,000 psi						
181	990	B	4.047	1798	95	97	SIP 8"1	Petals wiped	Intact	Large
	989	C	4.047	1870	99	97	Cp. 330	Petals wiped & broken-Separation	Intact	Large
				$F(e/d,\theta) = 49,300 \pm 500$ (97%)						
				Tensile Strength 113,000 psi						
182	991	C	4.040	1858	98	100	SIP 6"1	Star crack	Intact	Large
	992	B	4.040	1889	99	97	Cp. 458	Lam. Petals wiped & broken	Intact	Large
				$F(e/d,\theta) = 49,800 \pm 800$ (98%)						
				Heat No. 21518 Plate 167162 Tensile Strength 115,000 psi						
183	995	A	4.105	1824	95	97	SIP 7"8	Petals wiped	Intact	Large & Small
	994	B	4.110	1832	96	94	Cp. 348	Petals wiped. Separation	Intact	Large & Small
	993	C	4.120	1905	99	96	Cp. 427	Petals intact Separation	Intact	Large & Small
				$F(e/d,\theta) = 48,500 \pm 800$ (95%)						

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APL No.	APL Impact No.	Location of Impact	e in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Average Quality Class B - Carnegie Illinois Plate No. DD37 Tensile Strength 108,000 psi						
119	765	-	4.160	1915	98	97	Cp. 096	Petals intact & wiped	Intact	-
	769	-	4.160	1931	99	96	Cp. 436	Petals intact & wiped	Intact	-
249	1517	-	4.061	1959	102	99	Cp. 509	-	Intact	-
				F(e/d,θ) = 49,800 ± 500 (97%)						
				3" M61 capped AP Projectiles at 30° obliquity						
				Heat No. 20247 Ingot #1 Plate 89001 Tensile Strength 114,000 psi						
89	1341	A	3.005	1927	102	105	Inc. 3".5	Crack & Bulge	Base dented eff.	None
	1342	B	2.997	2030	108	103	Cp. 392	Petals wiped	Not recovered	None
				F(e/d,θ) = 51,600±500 (104%)						

APL No.	APL Impact No.	Location of Impact	e in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Tensile Strength 142,000 psi						
90	1348	C	3.020	2011	106	109	Inc. 2"5	Crack & Bulge	Not eff.	None
	1349	G	2.995	2102	112	114	SIP 5"3	Button Thrown Lam.	Intact Eff.	None-Med. Large
	1350	H	2.995	2131	113	108	Cp. 598	Button Thrown Lam.	Bent Eff.	Large
				Top right corner F(e/d,θ) = 54,100±1000 (109%)						
				Bottom Center F(e/d,θ) = 53,600±1000 (108%)						
				Bottom left corner F(e/d,θ) = 56,600±1000 (114%)						
				Tensile Strength 119,000 psi						
165	2050	I	2.982	1887	103	104	SIP 8"0	Petals Broken Splits	Intact Eff.	Large & Small
	2049	H	2.975	1928	105	105	Cp. 258	Petals wiped Button started	Base Scarred Eff.	Large
	2048	G	2.970	1949	107	105	Cp. 366	Petals wiped & broken Lam.	Intact Eff.	Large
	2047	D	2.967	1988	108	105	Cp. 548	Button Thrown Lam.	Intact Eff.	Large
	2046	A	2.980	2009	109	-	Cp.	Button Thrown Lam.	Intact Eff.	Large & Small
				F(e/d,θ) = 52,100±400 (105%)						

APL No.	APL Impact No.	Location of impact	a in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Tensile Strength 118,000 psi						
166	4546	G	2.996	1954	107	111	Inc.2"	Bulge	Bent Swollen Eff.	None
	4555	F	2.997	2065	111	110	Cp. 289	Lam. Petals wiped & intact	Side Deformed Eff.	None-Large
	4547	D	2.997	2073	112	113	Base SIP	Petals wiped & broken	Nose broken off Not eff.	None
	4551	I	2.997	2103	115	-	Cp	Deep lam. Petals wiped & broken	Nose chewed. Bent Eff.	Large
	4548	A	2.996	2160	118	119	SIP 6".0	Petals wiped & broken	Split Not eff.	None
	4550	H	2.998	2205	121	124	Inc.2".8	Bulge	Split in two not eff.	None
	4549	E	2.977	2376	129	132	Inc.2".5	Bulge	Broken up not eff.	None

Lower right corner $F(e/d,\theta) = 54{,}600 \pm 1000$ (110%)
Remainder of plate $F(e/d,\theta) > 120\%$

Note: APL 166 tested with 3" M62 capped AP projectiles at 30° obliquity

APL No.	APL Impact No.	Location of Impact	e in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Tensile Strength 121,000 psi						
167	2057	A	3.000	1888	102	105	Inc.3"5	Bulge & crack	Cracked & bent eff.	None
	2056	C	2.987	1968	106	106	Cp. 0	Petals wiped	Intact Eff.	None
	2058	D	2.986	1968	106	109	Inc.3"3	Bulge & crack	Not eff. Base smashed	None
	2059	B	2.990	2053	111	108	Cp. 511	Petals wiped	Intact Eff.	None
				F(e/d,θ) = 53,100±500 (108%)						
				Tensile Strength 128,000 psi						
175	1337	H	3.003	1957	103	106	Inc.3"4	Bulge & crack	Base dented eff.	Large
	1338	I	3.006	1997	106	103	Cp. 380	Lam. Split-Petals broken	Intact Eff.	Large & Small
	1336	B	2.994	2128	113	110	Cp. 492	Petals wiped	Intact Eff.	None

Top F(e/d,θ) = 54,600±800 (110%)
Bottom F(e/d,θ) = 51,600±800 (104%)

APL No.	APL Impact No.	Location of Impact	e in.	V_S (f.s.)	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Tensile Strength 137,000 psi						
175	1340	F	2.995	1962	103	-	Inc.	Button started	Not recovered	Large
	1339	B	2.990	1984	105	-	Cp.	Large Button thrown & started. Lam.	Intact Eff.	No reading
				$F(e/d,\theta) = 52000 \pm 200$ (105%)						
				Tensile Strength 135,000 psi						
178	1343	I	3.000	1984	105	108	Inc. 2"5	Bulge	Base Smashed Not Eff.	None
	1344	A	3.019	2045	108	110	Inc. 4"0	Button started	Base smashed Not Eff.	None
	1345	D	3.015	2072	109	108	Cp. 292	Lam. Button Thrown	Intact Eff.	None
				$F(e/d,\theta) = 54,100 \pm 500$ (109%)						
				Tensile Strength 141,000 psi						
179	1347	B	2.988	2089	111	108	Cp. 445	Petals wiped	Base off, not eff.	Weak reflection
	1346	H	2.988	2140	114	108	Cp. 624	Petals wiped	Intact Eff.	No reading
				$F(e/d,\theta) = 53,600 \pm 500$ (108%)						

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APL No.	APL Impact No.	Location of Impact	e in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Tensile Strength 126,000 psi						
180	4559	F	2.987	2072	111	-	Cp.	Large button thrown. Lam.	Side & base deformed eff.	Large
	4552	E	2.989	2079	112	-	Cp.	Petals wiped & broken. Lam.	Side deformed eff.	Large
	4553	G	2.986	2082	112	114	SIP 3"5	Petals wiped	Side deformed eff.	None
	4560	B	2.988	2096	113	109	Cp. 540	Separation Petals intact & broken	Intact Eff.	Large
	4554	C	2.985	2100	113	-	Cp.	Separation & button thrown	Slightly deformed eff.	Large

Area showing no flaws $F(e/d,\theta) = 56,500 \pm 1000$ (114%)
Area showing flaws $F(e/d,\theta) = 54,100 \pm 1000$ (109%)

Note: APL 180 tested with 3" M62 capped AP projectiles at 30° obliquity

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APL No.	APL Impact No.	Location of Impact	e in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Heat No. 20247 Ingot #2 Plate 89002 Tensile Strength 118,000 psi						
168	1974	D	2.966	1928	106	109	Inc.4"0	Bulge & crack	Bent Eff.	Weak reflection
	1975	H	2.970	1946	106	109	Inc.4"8	Bulge and crack	Base deformed eff.	Weak reflection
	1973	A	2.958	1954	108	108	Cp. 113	Petals wiped	Intact Eff.	None
	1972	B	2.963	1978	109	108	Cp. 230	Petals wiped	Intact Eff.	None
	1977	F	2.969	1981	109	109	Cp. 105	Petals wiped	Base broken off-not eff.	None
	1976	I	2.970	1986	109	111	SIP 4	Petal wiped	Intact Eff.	None
				F(e/d,θ) = 54,100±500 (109%)						
				Heat No. 20247 Ingot #2 Plate 89004 Tensile Strength 117,000 psi						
171	1982	H	2.980	1990	108	109	SIP 8"0	Petals wiped	Base plug out Not eff.	None
	1979	F	2.960	1996	110	111	SIP [illegible]	Petals wiped	Base plug out not eff.	None
	1980	E	2.980	2001	110	110	Cp. 0	Petals wiped	Intact Eff.	None
	1981	G	2.980	2021	110	110	Cp. 50	Petals wiped	Base torn not eff.	None

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APL No.	APL Impact No.	Location of Impact	e in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Heat No. 20247 Ingot #2 Plate 89004 Tensile Strength 117,000 psi						
171 Cont'd.	1978	C	2.960	2050	112	108	Cp. 518	Petals wiped	Not recovered	None
				$F(e/d,\theta) = 54,400 \pm 500$ (109%)						
				Heat No. 20247 GG346 (Forged) Tensile Strength 115,000 psi						
184	2051	B	3.080	1985	105	108	Inc. 4"0	Bulge and crack	Base dented eff.	None
	2052	A	3.075	2054	109	-	Inc.	Petals wiped	Base cracked not eff.	None
	2053	D	3.085	2071	110	111	SIP 8"0	Petals wiped	Intact Eff.	None
	2054	H	3.080	2118	112	113	SIP 8"0	Petals wiped	Base cracked not eff.	None
	2055	I	3.080	2183	114	-	Cp.	Petals wiped	Base dented eff.	None
				$F(e/d,\theta) = 56,100 \pm 800$ (112%)						

APL No.	APL Impact No.	Location of Impact	e in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Heat No. 15267 Plate 127804 Tensile Strength 114,000 psi						
172	2043	D	3.019	1947	105	108	Inc.3"0	Bulge	Base cracked not eff.	None
	2044	G	3.017	1980	107	110	Inc.3"5	Bulge	Base deformed eff.	None
	2042	A	3.020	1983	107	105	Cp. 360	Petals wiped	Intact eff.	None
	2045	H	3.018	2035	110	109	Cp. 162	Lam. Petals broken	Base cracked not eff.	None-Med.
				Projectiles intact Top $F(e/d,\theta)$ = 52,700±1000 (105%) Projectiles deformed Bottom $F(e/d,\theta)$ = 54,200±500 (109%)						
				3" M62 Capped AP Projectiles at 20° obliquity Heat No. 14349 Plate 139957 Tensile Strength 113,000 psi						
181	4562	F	4.053	2386	112	108	Cp. 586	Petals wiped & broken Separation	Intact Eff.	Large
	4561	E	4.052	2505	118	105	Cp.1101	Petals intact, wiped & broken Separation	Base & side deformed. Eff.	Large
				$F(e/d,\theta)$ = 56,500 ± 1000 (106%)						

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APL No.	APL Impact No.	Location of Impact	e in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Tensile Strength 113,000 psi						
182	4566	D	4.048	2336	110	-	Cp.	Petals intact and broken Separation	Base & side deformed. eff.	Large
	4563	A	4.050	2386	112	107	Cp.686	Petals wiped & broken Separation	Base deformed. Eff.	Large & Small
	4564	H	4.037	2387	113	115	SIP 4[illegible]5	Bulge	Eff.	Large
	4565	F	4.040	2411	114	111	Cp. 525	Petals wiped & intact Separation	Side & base deformed. Eff.	Large
				F(e/d,θ) = 58,900±2000 (111%)						
				Heat No. 21518 Plate 167162 Tensile Strength 115,000 psi						
183	4568	F	4.115	2377	110	107	Cp. 577	Petals intact & wiped Separation	Base & side dented. Eff.	Large & small
	4567	E	4.115	2376	111	109	Cp. 374	Petals wiped & broken. Separation	Side deformed. Eff.	Large & Small
				F(e/d,θ) = 57,600±1000 (108%)						

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APL No.	APL Impact No.	Location of Impact	e in.	V_S f.s.	V_S %Sk. 78841	V_L %Sk. 78841	Pene. in. or V_R (f.s.)	Plate Condition	Proj. Condition	Supersonic flaw indications
				Ave ge Plates--Carnegie Illinois No. DD-37 Tensile Strength 108,000 psi						
521	3664	-	4.187	2300	105	106	SIP 9"0	Petals wiped	Intact Eff.	-
	3665	-	4.194	2342	107	109	SIP 7"0	Petals wiped	Intact Eff.	-
	3666	-	4.200	2406	109	112	Inc.2"3	Bulge	Bent & broken, not eff.	
	3667	-	4.178	2454	112	-	Cp.	Petals wiped	Nose offset. Effective	-
520	3663	-	4.083	2485	116	-	Cp.	Petals wiped	Intact Effective	

$F(e/d,\theta) = 58,500 \pm 500 (109\%)$

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