

LABORATORY

UNCLASSIFIED

AD-A954 867



WATERTOWN ARSENAL LABORATORY

INVENTORY

EXPERIMENTAL REPORT

NO WAL 710/783

MAR 11 1958

CAST IRON

Correlation of Tensile Mechanical Properties of Cast Iron and
Cast Steel Under Impact and Tensile Resistance to Various Degrees
of Ballistic Strain

BY

W. S. SULLIVAN
Assoc. Ordnance Engineer

Watertown Arsenal
Physical Science Lab

UNCLASSIFIED

710/783

FOR OFFICIAL USE ONLY
INFORMATION CONTAINED IN THIS REPORT
IS NOT TO BE RELEASED WITHOUT PRIOR
APPROVAL OF COMMANDING OFFICER,
WATERTOWN ARSENAL, WATERTOWN 72, MASS.

DATE 20 Nov 1945

WATERTOWN ARSENAL
WATERTOWN, MASS.

UNCLASSIFIED

PHOTOGRAPH THIS SHEET

AD-A954 867

DTIC ACCESSION NUMBER

LEVEL

INVENTORY

WAL 710/783

DOCUMENT IDENTIFICATION

20 NOV 1945

This document has been approved for public release and sale; its distribution is unlimited.

DISTRIBUTION STATEMENT

ACCESSION FOR

NTIS GRA&I

DTIC TAB

UNANNOUNCED

JUSTIFICATION

per ltr

BY

DISTRIBUTION /

AVAILABILITY CODES

DIST

AVAIL AND/OR SPECIAL

A-1

DISTRIBUTION STAMP

UNANNOUNCED



DTIC ELECTE
AUG 06 1985
S E D

DATE ACCESSIONED

DATE RETURNED

85 8 2 087

DATE RECEIVED IN DTIC

REGISTERED OR CERTIFIED NO.

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-DDAC

UNCLASSIFIED

~~CONFIDENTIAL~~

Watertown Arsenal Laboratory
Report No. WAL 710/783
Problem B-4.78

20 November 1945

CAST ARMOR

Correlation Between Metallurgical Properties of Several 1" and 2"
Cast Armor Samples and Their Resistance to Various Degrees
of Ballistic Shock

OBJECT

To determine the metallurgical characteristics of 1" and 2" cast armor samples after subjection to various degrees of ballistic shock, and, by the application of analytical methods devised at this laboratory, to determine the optimum conditions of ballistic shock testing for discrimination between material of good and poor metallurgical properties.

CONCLUSIONS

The requirements for shock resistance of 1" and 2" cast armor plates submitted under Specification AXS-492-5 should reflect the following determinations:

- a. The projectiles used should be the 57 mm. proof projectile, T1, for 1" plates and the 105 mm. proof projectile, T8, for 2" plates;
- b. The incident velocity for both projectiles should be 1030 \pm 15 feet-per-second;
- c. The criterion of success should be the ability of the armor to resist cracking in any degree.

J. F. Sullivan

J. F. Sullivan
Assoc. Ordnance Engineer

M. Yoffa

M. Yoffa
Physical Science Aide

APPROVED:

N. A. Matthews
N. A. MATTHEWS
Lt. Col., Ord. Dept.
Director of Laboratory

~~CONFIDENTIAL~~

UNCLASSIFIED

UNCLASSIFIED

DISTRIBUTION

Report No. WAL 710/783 Total No. of Copies 15

Date Distributed 14 Dec 45 Extra Copies 2

Authors - 2
ARMOR FILE - 1
Laboratory Report File - 1

Office, Chief of Ordnance

TECHNICAL DIVISION

Ordnance Technical Library
SPOTB - Tech. Reports - 2
SPOTB - For British Army Staff
SPOTR
SPOTH
SPOTT
SPOTC
SPOTS
Others
SPOTX - Ar - 3

INDUSTRIAL DIVISION

SPOIR
SPOIM
SPOIS

DETROIT

~~SPOME - EE~~ - SPOMD-W - 2
SPOME - EM

Frankford Arsenal

Springfield Armory

Watervliet Arsenal

Rock Island Arsenal

Picatinny Arsenal

Ordnance Research Center - 2

Paint & Automotive Chemical Laboratory

Others

FOR OFFICIAL USE ONLY

*Passed by Report Review Board
10 Dec. 1945
H. H. [Signature]*

UNCLASSIFIED

INTRODUCTION

In response to a request of the Ordnance Research Center¹, a metallurgical examination of several 1" and 2" cast armor plates which had been subject to ballistic shock tests with 57 mm. and 105 mm. proof projectiles, respectively, in an attempt to develop an adequate ballistic shock test for incorporation into Specification AXS-492-5, was undertaken at this laboratory.

The criterion of success under these shock tests revolved around the ability of the plates to resist "excessive" cracking and/or Army complete penetration at a prescribed velocity^{2,3}.

Results of the metallurgical tests on those plates indicated a very poor correlation between their metallurgical properties and their success under the ballistic tests as judged under the above criterion, and it was the opinion of this laboratory⁴ that the prescribed shock tests were not satisfactory for incorporation into Specification AXS-492-5.

Meanwhile, before transmittal of that report to the Ordnance Research Center had been effected, additional tests of 1" and 2" cast armor samples had been completed^{5,6} and subsequently samples from those tests were forwarded to this laboratory with a request for metallurgical evaluation⁷.

During a visit to the Ordnance Research Center by a representative of this laboratory near the end of July 1945, it was contended that a better correlation might exist between the metallurgical properties of these plates and their ballistic integrity as judged by their ability to resist any cracking under impact of proof projectiles at a prescribed velocity.

As a preliminary investigation of this contention, samples which were extremely successful or extremely unsuccessful under such a test were examined metallurgically and a good correlation was indicated⁸.

The present report is an evaluation of the correlation between the metallurgical properties of the samples and their success under the various tests as judged by various criteria.

TEST PROCEDURE

The metallurgical examination included the following tests:

- a. Fibre fracture tests;⁹
- b. Cross sectional Brinell hardness survey;
- c. V-notch Charpy impact tests.

Sections, 6"x12"x2" and 4"x8"x1", were notched by flame cutting in from the middle of the two longer sides and were fractured under the impact of a steam forge hammer. A one-half inch thick section cut from the middle of one of the fractured halves of each sample was surface ground. Brinell hardness surveys were made on the cross sectional surfaces, after which

two V-notch Charpy impact specimens were machined from each section from positions halfway between the surface and the center in the case of the 1" thick plates and from near the center of the 2" thick plates. One impact specimen from each plate was tested at +70°F, and the other at -40°F.

The results of these tests are recited in Tables I and II, for 1" and 2" plates, respectively.

The results of the ballistic tests conducted at the Ordnance Research Center have been summarized in Tables III and IV, for 1" and 2" plates, respectively.

DATA AND DISCUSSION

The shock which may be transmitted to armor in service may originate from many sources.

The metallurgical properties which are desirable for general resistance to shock are well known and their presence may be determined by well established tests.

A specific shock test, to be valid, therefore, must produce results which correlate well with the results of metallurgical tests.

In this report certain unique methods have been developed to determine the correlation between metallurgical and ballistic characteristics of the subject plates.

Upon the completion of the metallurgical tests described above, their results, without reference to ballistic behavior, were submitted to an experienced armor metallurgist for evaluation. On the basis of their possession, or lack, of the desirable metallurgical characteristics—(a tempered martensitic structure, purely fibrous fracture, and high Charpy impact value)—the rating "Good", "Borderline +," "Borderline -," or "Poor" was given each sample as it appears in Tables I and II.

(Whether or not a specific Charpy impact value is considered adequate depends upon the hardness of the sample. A schematic representation of the expected relationship between the Charpy impact value of a given steel with a microstructure of tempered martensite and its hardness is given in Figure 2.)

By means of these unbiased metallurgical ratings, there thus became available the basis for determination of correlations between the metallurgical characteristics of these samples and their ability to satisfy the requirements of the various tests.

The firings at the Ordnance Research Center had been conducted at three different levels of severity for each projectile caliber (or armor thickness), as follows:

57 mm. Proof Projectile T1 against 1" plate at 900 f/s.
57 mm. Proof Projectile T1 against 1" plate at 1000 f/s.
57 mm. Proof Projectile T1 against 1" plate at 1100 f/s.

105 mm. Proof Projectile T8 against 2" plate at 1000 f/s.
105 mm. Proof Projectile T8 against 2" plate at 1100 f/s.
105 mm. Proof Projectile T8 against 2" plate at 1200 f/s.

The results of these tests appear in Tables III and IV, for 1" and 2" plates, respectively.

Success or failure of any plate under each of these tests can be judged from the standpoint of any of at least five criteria: its ability to resist—

- a. Army complete penetration¹⁰.
- b. Cracking in any degree.
- c. Excessive cracking.
- d. Both (a) and (b).
- e. Both (a) and (c).

The results of the ballistic tests, as set out in Tables III and IV, have been represented in Tables V and VI, respectively, as judged by the above criteria.

The use of a criterion of shock resistance incorporating the ability of a plate to withstand Army complete penetration at a given velocity has always been considered by this laboratory as unsound, in that successful resistance to complete penetration (Army) is brought about by the possession of metallurgical characteristics irrelevant to and even inconsistent with those characteristics which are requisite for superior shock resistance.

Accordingly, this laboratory could not conscientiously endorse the adoption of criteria (a), (d) or (e).

Neither can this laboratory whole-heartedly endorse criterion (c) because of the inherent arbitrariness of the term "excessive."

Criterion (b) can be endorsed, however, because the inability of armor plate to withstand the bending induced by ballistic shock is logically demonstrated by a tendency to crack under such a bending stress¹¹.

Since such a bending stress is best applied in a sustained rather than an instantaneous manner the use of a mushrooming projectile is to be desired. The proof projectiles used in the ballistic test by the Ordnance Research Center are considered quite satisfactory.

To illustrate that the stand of this laboratory with regard to the above criteria is well taken, and to provide preliminary data for the localization of the ideal conditions for shock testing, certain methods of evaluating the measure of correlation between the results of the metallurgical evaluations and the results of the several ballistic tests have been undertaken.

By reviewing Tables I and V, and Tables II and VI, respectively, the results of the ballistic tests made on the several samples at each of the three respective levels of severity and according to each of the five criteria recited above were compared with the results of the metallurgical evaluation. According to the measure of agreement between the metallurgical and ballistic results, a value, called its Correlation Index, was assigned to each sample, as follows:

Metallurgical Rating	Correlation Index	
	If OK Ballistically	If NG Ballistically
OK (Good)	3	0
B+ (Borderline +)	2	1
B- (Borderline -)	1	2
NG (Poor)	0	3

A tabulation of the results of such an examination is presented in Tables VII to XVI. Summaries of the average correlation indices for each combination of velocity and criterion appear in Tables XVII and XVIII, for 1" and 2" plates respectively.

From these summaries it is apparent that the best correlation (as imaged by the highest average correlation index) flows from the combination of the use of criterion b (ability to resist cracking in any degree) and a striking velocity of 1100 feet-per-second (among the velocities used), for either caliber of projectile fired against the appropriate thickness of plate.

There is, thus, good evidence that the stand of this laboratory has been well taken.

Mere correlation, however, is not considered conclusive in this examination for it can be well argued that were the striking velocities increased the correlation between the metallurgical results and the results of ballistic tests judged by other tests would improve.

In anticipation of such a contention, certain basic arguments have been advanced, above, against the use of other criteria, and the following exploration of the data will further corroborate the stand of this laboratory.

Tables VII to XVII were re-examined with special attention focused on samples having low correlation indices, i.e., values of 1 or 0.

If the ballistic result of a test showing poor correlation is OK, then the test may be assumed to be insufficiently severe; if, on the other hand, the ballistic result of such a test is NG, the test may be assumed to be too severe.

Examination of the percentage of poor correlation indices which have been "OK" ballistically under a given criterion and velocity will indicate whether or not that criterion and/or velocity is insufficiently severe, properly severe, or over-severe.

In a general way, percentages less than 50 would indicate over-severity, and values greater than 50 would indicate insufficient severity. Fifty percent would indicate the proper level of severity.

The results of such an examination appear in Table XIX and XX, for 1" and 2" plates, respectively, and have been graphically represented as functions of striking velocity and criterion in Figures 2 and 3.

These results indicate that the "excessive cracking" criterion (c) is insufficiently severe over the entire range of velocities investigated, that the "Army complete penetration" criterion (a) exhibits its irrelevance by its variable trend from under-severity to over-severity and back to proper severity, and that the "cracking in any degree" criterion (b) proceeds steadily and logically from under-severity to over-severity.

They also indicate that the combination of an irrelevant, or under-severe criterion, with, respectively, a relevant, or intermediately severe criterion, affords no more valid criterion than the latter.

Thus, coupling the irrelevant "Army complete penetration" criterion (a) with the relevant "cracking in any degree" criterion (b) affords no criterion more valid than the "cracking in any degree" criterion, nor does the combination of the under-severe "excessive cracking" criterion (c) with the intermediately severe (although irrelevant) "Army complete penetration" criterion (a) afford, in any way, a more valid criterion than the latter (a).

Further examination of these data provides a means of estimating that incident velocity for each proof projectile which will supply the optimum severity under the "cracking in any degree" criterion (b). (This will provide improved information over the introductory analysis which merely indicated the best of the tested velocities.)

By plotting the apparent trend of the severity of the "cracking in any degree" criterion (as applied both to 1" and 2" plates) from under-severity to over-severity as the incident velocity was increased, it is possible to demonstrate that the optimum velocity for incidence of both proof projectiles (57 MM T1 and 105 MM T8) lies between 1025 feet-per-second and 1050 feet-per-second, and in view of the probable extent of experimental error, the velocity may be considered identical for both. (See Figure 4.)

Since one of the 2" samples (C-65) was so completely "out of line" that it was earlier concluded that a mixup in identification had occurred¹², it was considered desirable to re-plot the trend line for 2" samples with that sample eliminated. (Its inclusion in earlier calculations in no way qualitatively affected the results.) The intersection of this trend line with the 50 percent (or optimum severity) line further localizes the optimum velocity. This has been interpreted as the average of the three intersects, or 1030 feet-per-second.

On the basis of the above analysis, therefore, it is the opinion of this laboratory that the requirements for shock resistance of 1" and 2" cast armor plates, submitted under Specification AXS-492-5 should reflect the following determinations:

- a. The projectiles used should be the 57 mm. proof projectile, T1, for 1" plates and the 105 mm. proof projectile, T8, for 2" plates;
- b. The incident velocity should be 1030 ± 15 feet-per-second;
- c. The criterion of success should be the ability of the armor to resist cracking in any degree.

REFERENCES

1. APG. 470.5/1476 - Wtn. 470.5/8755. 25 April 1945. See Appendix A.
2. Ordnance Research Center Report No. Ar-16241. 9 April 1945. See Appendix B.
3. Ordnance Research Center Report No. Ar-16242. 10 April 1945. See Appendix B.
4. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/760. "Metallurgical Examination of 1" and 2" Thick Cast Armor Used for the Development of 57 MM. and 105 MM. Proof Projectile Shock Tests." M. Yoffa and A. Hurlich. 28 June 1945. See Appendix B.
5. Ordnance Research Center Report No. Ar-16646. 6 July 1945. See Appendix B.
6. Ordnance Research Center Report No. Ar-16647. 6 July 1945. See Appendix B.
7. APG. 470.5/76 - Wtn. 470.5/243. 23 July 1945. See Appendix A.
8. Wtn. 470.5/256 - APG. 470.5/112. 1st Indorsement. 12 September 1945. See Appendix A.
9. Watertown Arsenal Laboratory Report No. WAL 710/532. "Development of a Fracture Test to Indicate the Degree of Hardening of Armor Steels Upon Quenching." A. Hurlich. 1 August 1943.
10. Ordnance Department Bulletin. Number 21-45. 11 October 1945.
11. Watertown Arsenal Laboratory Experimental Report No. WAL 710/685. "Armor Plate Ballistic Testing." H. H. Zornig, et al. 2 August 1944.
12. See Reference 8.

TABLE I

Summary of Metallurgical Tests Conducted at Watertown Arsenal Laboratory

on 1" Cast Armor Samples in Conjunction with Development of a

Shock Test for Incorporation into Specification AXS-492-5

Company	Plate or Heat No.	Size of Samples As-Received	Ave. BHN*	Fibre Fracture Rating	V-Notch Charpy Data		Metallurgical Evaluation
					Yt. Lbs. at +70°F.	Yt. Lbs. at -40°F.	
American Steel Foundries	C26	12"x12"x1"	331	Fc tr	22.9	13.0	Borderline -
" "	C22	12"x12"x1"	334	F	25.0	13.0	Borderline -
American Radiator	J43	4"x8"x1"	334	F (shrinkage)	26.5	28.0	Good
" "	J160	4"x8"x1"	359	Cbf 1/2	22.9	10.6	Poor
" "	B412	4"x8"x1"	341	Fc 1/4	7.9	4.1	Poor
Ordnance Steel Fdry.	E154	4"x8"x1"	334	Fc (tr shrinkage)	34.2	15.5	Borderline -
Pratt & Litchworth	E157	4"x8"x1"	324	F (shrinkage)	24.7	18.1	Borderline -
" "	E138	4"x8"x1"	311	Fc 1/8	26.5	17.4	Borderline -
" "	E162	4"x8"x1"	328	F (shrinkage)	45.8	15.8	Borderline -
" "	E167	4"x8"x1"	328	F	17.4	12.1	Poor
" "	E170	4"x8"x1"	313	F	43.6	22.5	Borderline +
" "	E183	4"x8"x1"	334	Fc 1/8	23.2	13.3	Poor
" "	E186	4"x8"x1"	334	F (shrinkage)	29.5	13.0	Poor
" "	E188	4"x8"x1"	315	Cbf 1/4	28.0	10.6	Poor
Sivyer Steel Company	20B599	12"x12"x1"	311	Fc 1/8	30.3	26.5	Good
Scullin Steel Co.	48	12"x12"x1"	305	Fc 1/3	17.4	21.1	Poor
" "	49	12"x12"x1"	311	Fc 1/4	16.8	19.4	Poor
Symington-Gould (D)	3719	4"x8"x1"	324	Fc 1/8	28.0	15.1	Borderline -
" "	4375	4"x8"x1"	331	Fc tr	16.4	13.6	Poor
" "	4380	4"x8"x1"	301	F (shrinkage)	20.3	16.8	Borderline -
" "	3747	4"x8"x1"	299	F (shrinkage)	28.8	18.4	Borderline -
Symington-Gould (R)	34576	4"x8"x1"	321	F	35.8	28.0	Good

TABLE I (Cont'd)

* Average of 3 cross-sectional BHM readings determined at Watertown Arsenal.

F₀F = fibrous, F_c = fibrous matrix with spots of crystallinity, Cbf = bright crystalline patch surrounded by fibrous border. Fractions represent portion of crystalline area.

F_c tr = trace of crystallinity. Tr shrinkage = trace of shrinkage.

TABLE II

Summary of Metallurgical Tests Conducted at Watertown Arsenal Laboratory
 on 2" Cast Armor Samples in Conjunction with Development of a
 Shock Test for Incorporation into Specification AIS-492-5

Company	Plate No.	Size of Sample As-Received	Fibre Fracture Rating**	V-Notch Charpy Data		Metallurgical Evaluation
				ft. lbs. at +70°F.	ft. lbs. at -40°F.	
American Steel Foundries	D277	12"x12"x2"	F	51.9	54.5	Good
	D256	12"x12"x2"	F	61.4	79.1	Good
	D257	12"x12"x2"	F	54.6	47.0	Good
	D266	12"x12"x2"	F	53.7	54.6	Good
	D261	12"x12"x2"	F	67.5	47.5	Good
Continental Foundry & Machine	663	12"x12"x2"	F	37.1	23.3	Good
	345	12"x12"x2"	Fc 1/3 -- D	29.1	17.1	Poor
	664	12"x12"x2"	Fc 1/4 -- D	38.2	25.1	Poor
	665	12"x12"x2"	Fc 1/2	33.4	21.0	Poor
	346	12"x12"x2"	F -- D	31.2	29.5	Borderline +
Continental Foundry & Machine (W)	1367(Sq.163)	6"x12"x2"	Fc 1/8	32.6	35.0	Borderline +
	2508(Sq.176)	6"x12"x2"	Ffc 1/4	56.8	37.4	Good
Continental Foundry & Machine (C)	5925	6"x12"x2"	Fc tr	50.1	42.4	Good
	5951	6"x12"x2"	Fc 1/4	40.7	26.5	Poor
Scullin Steel Company	S48	12"x12"x2"	Fc 1/2	37.4	22.0	Poor
	S50	12"x12"x2"	F	68.6	55.5	Borderline +
	680	12"x12"x2"	Cbf 1/2	41.5	30.3	Borderline +
	681	12"x12"x2"	Cbf 1/2	37.4	32.6	Borderline +
	682	12"x12"x2"	Cbf 1/2	28.0	32.6	Borderline +
Symington-Gould (D)	3705	6"x12"x2"	Fc tr (shrinkage)	41.1	42.0	Good
	3719	6"x12"x2"	Fc tr	29.5	37.4	Good
	3746	6"x12"x2"	Fc 1/4	24.7	23.0	Poor
	4397	6"x12"x2"	F (shrinkage)	38.6	46.6	Good
	4422	6"x12"x2"	Fc 1/10	23.6	23.6	Good
Union Steel	3734	6"x12"x2"	Fc 1/2	34.2	20.1	Poor
	4014	6"x12"x2"	Fc 1/4 (Slight Conchoidal)	47.5	22.2	Poor

TABLE II (CONT'D)

• Average of 3 cross-sectional BHM readings determined at Watertown Arsenal.

• f_{f} = fibrous, f_{c} = fibrous matrix with spots of crystallinity, Cb_{f} = bright crystalline patch surrounded by fibrous border, D = dendritic, $\text{f}_{\text{c tr}}$ = trace of crystallinity.
Fractions represent portion of crystalline area.

TABLE III

Summary of Ballistic Tests of 1" Cast Armor Plates Conducted at
 Ordnance Research Center for Development of Shock Test for
 Incorporation into Specification AXS-492-5

Company	Plate or Heat No.	57 MM Proof Projectile Velocity	
		900±15 ft./sec.	1100±15 ft./sec.
American Steel Foundries	C26	PP(A) 2-1/2" cracking.	CP(A) 2-1/2" cracking.
"	C22	PP(A) 1" cracking.	CP(A) 4" cracking.
American Radiator	J43	PP(A) No cracking.	PP(A) No cracking.
"	J160	PP(A) No cracking.	PP(A) 1 1/4" cracking.
Ordnance Steel Foundry	B412	Plate broke in 3 pieces.	CP(A) 3-1/2" cracking.
Pratt & Letchworth	E154	PP(A) 2-1/4" cracking.	
	E157	PP(A) 3-3/4" cracking.	
"	E138	PP(A) 2-3/4" cracking.	
"	E162	PP(A) 2" cracking.	
"	E167	PP(A) 2-5/8" cracking.	
"	E170	PP(A) 1-1/2" cracking.	
"	E183	CP(A) 4" cracking.	
"	E186	PP(A) 1-1/2" cracking.	PP(A) 1-1/4" cracking.
"	E188	PP(A) 2-1/4" cracking.	CP(A) 4-1/4" cracking.
Sivyer Steel Co.	208599	PP(A) Fine cracking.	PP(A) 2-1/2" cracking.
Scullin Steel Co.	48	PP(A) Fine cracking.	CP(A) 3-1/2" cracking.
"	49	PP(A) 2" cracking.	
Symington-Gould (D)	3719	PP(A) No cracking.	CP(A) 2-1/2" cracking.
"	4375	PP(A) No cracking.	PP(A) No cracking.
"	4380	PP(A) No cracking.	CP(A) 9 1/2" cracking.
"	3741	CP(A) 3" cracking.	
Symington-Gould (R)	34576	PP(A) 2-3/4" cracking.	CP(A) 3-1/4" cracking.

TABLE IV

Summary of Ballistic Tests of 2" Cast Armor Plates Conducted at Ordnance Research Center for Development of Shock Test for

Incorporation into Specification AMS-492-5

		105 MM Proof Projectile Velocity		
		1000-15 ft./sec.	1100-15 ft./sec.	1200-15 ft./sec.
Company	Plate No.			
American Steel Foundries	D277	PP(A) No cracking.	PP(A) No cracking.	PP(A) No cracking.
"	D256	PP(A) No cracking.	PP(A) No cracking.	PP(A) 5-1/2" cracking.
"	D257	PP(A) No cracking.	PP(A) No cracking.	PP(A) No cracking.
"	D266	PP(A) No cracking.	PP(A) No cracking.	PP(A) 4 1/4" cracking.
"	D261	PP(A) No cracking.	PP(A) No cracking.	PP(A) 2 3/4" cracking.
Continental Fdry & Machine	C63	PP(A) No cracking.	PP(A) No cracking.	PP(A) 5" cracking.
"	B48	CP(A) 7" cracking.	CP(A) 10" cracking.	PP(A) 3" cracking.
"	C64	PP(A) No cracking.	PP(A) No cracking.	PP(A) No cracking.
"	C65	PP(A) No cracking.	PP(A) No cracking.	PP(A) No cracking.
"	B46	PP(A) 3-1/2" cracking.	CP(A) 6-1/2" cracking.	PP(A) 5-1/4" cracking.
Continental Fdry & Machine (W)	1367(Sq.183)		PP(A) No cracking.	CP(A) 4-1/2" cracking.
"	2508(Sq.178)		PP(A) No cracking.	PP(A) 3/4" cracking.
Continental Fdry & Machine (C)	5928		PP(A) 1 1/4" cracking.	CP(A) 4-3/4" cracking.
"	5951		CP(A) 5-1/2" cracking.	PP No cracking.
Scullin Steel Co.	S48	PP(A) 2-1/2" cracking.	PP(A) No cracking.	
"	S50	PP(A) No cracking.	CP(A) 9-1/4" cracking.	
"	630	PP(A) No cracking.	CP(A) 6-1/2" cracking.	
"	681	PP(A) No cracking.	CP(A) 5-1/2" cracking.	
"	682	PP(A) No cracking.	PP(A) No cracking.	CP(A) 6-1/2" cracking.
Symington-Gould (D)	3705	PP(A) No cracking.	PP(A) No cracking.	PP(A) 3-1/2" cracking.
"	3719	PP(A) No cracking.	CP(A) 5-1/4" cracking.	PP(A) No cracking.
"	3746	PP(A) No cracking.	PP(A) No cracking.	PP(A) No cracking.
"	4397	PP(A) 3-1/4" cracking.	CP(A) 9-1/2" cracking.	
"	4422	PP(A) No cracking.	CP(A) 4-1/2" cracking.	
Union Steel	373A	CP(A) 8-3/4" cracking.	CP(A) 8-5/8" cracking.	
"	401A			

TABLE VII

Summary of Correlations between Metallurgical Test Results and Ballistic Test Results of 1" Cast Armor Plates as Judged by "Army Complete Penetration" Criterion

Company	Plate or Heat No.	Striking Velocity (F/S-15) of 57 MM Proof Projectile T1								
		900			1100					
		Ball. Res.	Met. Res.	Corr. Ind.	Ball. Res.	Met. Res.	Corr. Ind.			
ASF	026	-	-	-	OK	B-	1	NG	B-	2
"	022	-	-	-	OK	B-	1	NG	B-	2
Amrad	J43	-	-	-	OK	OK	3	OK	OK	3
"	J160	-	-	-	OK	NG	0	OK	NG	0
OSF	B412	-	-	-	NG	NG	3	-	-	-
P&L	E154	-	-	-	OK	B-	1	NG	B-	2
"	E157	-	-	-	OK	B-	1	-	-	-
"	E138	-	-	-	OK	B-	1	-	-	-
"	E162	-	-	-	OK	B-	1	-	-	-
"	E167	-	-	-	OK	B-	1	-	-	-
"	E170	-	-	-	OK	B+	2	-	-	-
"	E153	-	-	-	OK	NG	3	-	-	-
"	E186	-	-	-	OK	NG	0	-	-	-
"	E185	-	-	-	OK	NG	0	-	-	-
Sivyer	202599	-	-	-	OK	NG	0	-	-	-
Scullin	48	OK	NG	0	NG	NG	3	OK	NG	3
"	49	-	-	-	OK	NG	0	OK	NG	3
Sym-G (D)	3719	-	-	-	OK	B-	1	NG	B-	2
"	4375	-	-	-	OK	NG	0	OK	NG	0
"	4380	-	-	-	OK	B-	1	NG	B-	2
"	3741	OK	B-	1	NG	B-	2	-	-	-
Sym-G (R)	34576	-	-	-	OK	OK	3	NG	OK	0

TABLE VIII

Summary of Correlations between Metallurgical Test Results and Ballistic Test Results of 1" Cast Armor Plates as Judged by

"Cracking in Any Degree" Criterion

Company	Plate or Heat No.	Striking Velocity (F/S ^{1/2}) of 57 MM. Proof Projectile T1								
		900			1000			1100		
		Ball. Res.	Met. Res.	Corr. Ind.	Ball. Res.	Met. Res.	Corr. Ind.	Ball. Res.	Met. Res.	Corr. Ind.
ASF	026	-	-	-	NG	B-	2	NG	B-	2
"	022	-	-	-	NG	B-	2	NG	B-	2
Amrad	J43	-	-	-	OK	OK	3	OK	OK	3
"	J160	-	-	-	OK	NG	0	NG	NG	3
OSF	B412	-	-	-	NG	NG	3	-	-	2
PAL	E154	-	-	-	NG	B-	2	NG	B-	-
"	E157	-	-	-	NG	B-	2	-	-	-
"	E138	-	-	-	NG	B-	2	-	-	-
"	E162	-	-	-	NG	B-	2	-	-	-
"	E167	-	-	-	NG	B-	2	-	-	-
"	E170	-	-	-	NG	B+	3	-	-	-
"	E153	OK	NG	0	NG	NG	3	NG	NG	3
"	E106	-	-	-	NG	NG	3	NG	NG	3
"	E148	-	-	-	NG	OK	0	NG	OK	0
Sivyer	200599	-	-	-	NG	NG	3	NG	NG	3
Seullin	48	-	-	-	NG	NG	3	NG	NG	3
"	49	-	-	-	NG	NG	3	NG	NG	3
Sym-G (D)	3719	NG	NG	3	OK	B-	1	NG	B-	2
"	4375	-	-	-	OK	NG	0	OK	NG	0
"	4380	-	-	-	OK	B-	1	NG	B-	2
"	3741	NG	B-	2	NG	B-	2	-	-	0
Sym-G (A)	B4576	-	-	-	NG	OK	0	NG	OK	0

TABLE IX

Summary of Correlations between Metallurgical Test Results and Ballistic Test Results of 1" Cast Armor Plates as Judged by "Excessive ($> \frac{1}{2}$ ") Cracking" Criterion

Company	Plate or Heat No.	Striking Velocity (F/S-15) of 57 MM. Proof Projectile T1									
		900			1000			1100			
		Ball. Res.	Met. Corr. Ind.	Excessive Cracking	Ball. Res.	Met. Corr. Ind.	Excessive Cracking	Ball. Res.	Met. Corr. Ind.	Excessive Cracking	
ASF	C26	-	-	OK	B-	1	OK	B-	1	B-	1
"	C22	-	-	OK	B-	1	OK	B-	1	OK	1
Amred	J43	-	-	OK	OK	3	OK	OK	3	OK	3
"	J160	-	-	OK	NG	0	NG	NG	0	NG	0
OSF	B412	-	-	NG	NG	3	OK	B-	1	B-	1
P&L	E154	-	-	OK	B-	1	OK	B-	1	OK	1
"	E157	-	-	OK	B-	1	OK	B-	1	OK	1
"	E138	-	-	OK	B-	1	OK	B-	1	OK	1
"	E162	-	-	OK	B-	1	OK	B-	1	OK	1
"	E167	-	-	OK	NG	0	OK	NG	0	OK	0
"	E170	-	-	OK	B+	2	OK	B+	2	OK	2
"	E183	-	-	OK	NG	0	OK	NG	0	OK	0
"	E186	OK	NG	OK	NG	0	OK	NG	0	OK	0
"	E188	-	-	OK	NG	0	OK	NG	0	OK	0
Sivyer	20B599	-	-	OK	OK	3	OK	OK	3	OK	3
Scullin	48	-	-	OK	NG	0	OK	NG	0	OK	0
"	49	-	-	OK	NG	0	OK	NG	0	OK	0
Syn-G (D)	3719	-	-	OK	B-	1	OK	B-	1	OK	1
"	4375	-	-	OK	NG	0	OK	NG	0	OK	0
"	4380	-	-	OK	B-	1	OK	B-	1	OK	1
"	3741	OK	B-	OK	B-	1	OK	B-	1	OK	1
Syn-G (R)	34576	-	-	OK	OK	3	OK	OK	3	OK	3

Table X

Summary of Correlation between Metallurgical Test Results and Ballistic Test Results of 1" Cast Armor Plates as Judged by Army Complete Penetration or Cracking in Any Degree* Criterion

Company	Plate or Heat No.	Striking Velocity (F/S-15) of 57 MM. Proof Projectile T1													
		900						1000						1100	
		Ball. Res.	Met. Res.	Corr. Ind.	Ball. Res.	Met. Res.	Corr. Ind.	Ball. Res.	Met. Res.	Corr. Ind.	Ball. Res.	Met. Res.	Corr. Ind.		
ASF	026	-	-	-	NG	B-	2	NG	NG	2	B-	2	B-	2	
"	022	-	-	-	NG	B-	2	NG	NG	2	B-	2	B-	2	
Amrad	J43	-	-	-	OK	OK	3	OK	OK	3	OK	3	OK	3	
"	J160	-	-	-	OK	OK	0	NG	NG	0	NG	3	NG	3	
OSF	B412	-	-	-	NG	NG	3	NG	NG	2	B-	2	B-	2	
P&L	E154	-	-	-	NG	B-	2	NG	NG	2	B-	2	B-	2	
"	E157	-	-	-	NG	B-	2	NG	NG	2	B-	2	B-	2	
"	E138	-	-	-	NG	B-	2	NG	NG	2	B-	2	B-	2	
"	E162	-	-	-	NG	B-	2	NG	NG	2	B-	2	B-	2	
"	E167	-	-	-	NG	B-	3	NG	NG	3	B+	1	B-	1	
"	E170	-	-	-	NG	B-	3	NG	NG	3	B+	1	B-	1	
"	E183	-	-	-	NG	B-	3	NG	NG	3	B+	1	B-	1	
"	E186	OK	NG	0	NG	NG	3	NG	NG	3	NG	3	NG	3	
"	E188	-	-	-	NG	NG	3	NG	NG	3	NG	3	NG	3	
"	E188	-	-	-	NG	NG	3	NG	NG	3	NG	3	NG	3	
Sivyer	203599	-	-	-	NG	OK	0	NG	NG	0	OK	0	OK	0	
Scullin	45	-	-	-	NG	NG	3	NG	NG	3	NG	3	NG	3	
"	49	-	-	-	NG	NG	3	NG	NG	3	NG	3	NG	3	
Sym-G (D)	3719	-	-	-	OK	B-	1	OK	OK	1	B-	1	B-	1	
"	4375	-	-	-	OK	B-	0	OK	OK	0	B-	0	B-	0	
"	4380	-	-	-	OK	B-	1	OK	OK	1	B-	1	B-	1	
"	3741	-	-	-	OK	B-	2	OK	OK	2	B-	2	B-	2	
Sym-G (R)	34576	-	-	-	NG	OK	0	NG	NG	0	OK	0	OK	0	

TABLE XI

Summary of Correlation between Metallurgical Test Results and Ballistic Test Results of 1" Cast Armor Plates as Judged by "Army Complete Penetration or Excessive ($\frac{1}{4}$ "*) Criterion"

Company	Plate or Heat No.	Striking Velocity (FS-15) of 57 MM. Proof Projectile T1								
		900			1100					
		Ball. Res.	Met. Res.	Corr. Ind.	Ball. Res.	Met. Res.	Corr. Ind.			
ASF	C26	-	-	-	OK	B-	1	NG	B-	2
"	C22	-	-	-	OK	B-	1	NG	B-	2
Amrad	J43	-	-	-	OK	OK	3	OK	OK	3
"	J160	-	-	-	OK	NG	0	OK	NG	0
OSF	B412	-	-	-	NG	NG	3	-	-	-
P&L	E154	-	-	-	OK	B-	1	NG	B-	2
"	E157	-	-	-	OK	B-	1	-	-	-
"	E138	-	-	-	OK	B-	1	-	-	-
"	E162	-	-	-	OK	B-	1	-	-	-
"	E167	-	-	-	OK	NG	0	-	-	-
"	E170	-	-	-	OK	B+	2	-	-	-
"	E183	-	-	-	NG	NG	3	-	-	-
"	E186	OK	NG	0	OK	NG	0	OK	NG	0
"	E188	-	-	-	OK	NG	0	OK	OK	3
Sivyer	203599	-	-	-	OK	NG	3	OK	NG	3
Scullin	48	-	-	-	OK	NG	0	-	-	-
"	49	OK	NG	0	NG	NG	3	-	-	-
Sym-G (D)	3719	-	-	-	OK	B-	1	NG	B-	2
"	4375	-	-	-	OK	NG	0	OK	NG	0
"	4380	-	-	-	OK	B-	1	NG	B-	2
"	3741	OK	B-	1	NG	B-	2	-	-	-
Sym-G (R)	34576	-	-	-	OK	OK	3	NG	OK	0

TABLE XII

Summary of Correlations between Metallurgical Test Results and

Ballistic Test Results of 2" Cast Armor Plates as Judged by

"Army Complete Penetration" Criterion

Company	Plate No.	Striking Velocity (F/S ¹⁵) of 105 MM. Proof Projectile T8														
		1000					1100					1200				
		Ball. Res.	Met. Res.	Corr. Ind.	Ball. Res.	Met. Res.	Corr. Ind.	Ball. Res.	Met. Res.	Corr. Ind.	Ball. Res.	Met. Res.	Corr. Ind.			
ASF	D277	-	-	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3	
"	D256	-	-	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3	
"	D257	-	-	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3	
"	D266	-	-	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3	
"	D261	-	-	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3	
Continental	C63	-	-	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3	
"	B48	NG	NG	3	-	-	NG	NG	0	NG	NG	0	NG	NG	0	
"	C64	-	-	-	-	-	OK	OK	0	OK	OK	0	OK	OK	0	
"	C65	-	-	-	-	-	OK	OK	0	OK	OK	0	OK	OK	0	
"	B46	OK	B+	2	-	-	M?	B+	1	B+	B+	1	B+	B+	1	
Continental (W)	1367	-	-	-	-	-	OK	OK	2	OK	OK	2	OK	OK	2	
"	2508	-	-	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3	
Continental (C)	5926	-	-	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3	
"	5951	-	-	-	-	-	OK	OK	0	OK	OK	0	OK	OK	0	
Scullin	S48	OK	NG	0	-	-	NG	NG	3	NG	NG	3	NG	NG	3	
"	S50	-	-	-	-	-	OK	OK	2	OK	OK	2	OK	OK	2	
"	680	OK	B+	2	-	-	NG	B+	1	NG	B+	1	NG	B+	1	
"	681	OK	B+	2	-	-	NG	B+	1	NG	B+	1	NG	B+	1	
"	682	OK	B+	2	-	-	NG	B+	1	NG	B+	1	NG	B+	1	
Syn-G (D)	3705	-	-	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3	
"	3719	-	-	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3	
"	3746	OK	NG	0	-	-	NG	NG	3	NG	NG	3	NG	NG	3	
"	4397	-	-	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3	
"	4422	OK	NG	0	-	-	NG	NG	3	NG	NG	3	NG	NG	3	
Union	373A	OK	NG	0	-	-	OK	OK	3	OK	OK	3	OK	OK	3	
"	401A	NG	NG	3	-	-	NG	NG	3	NG	NG	3	NG	NG	3	

TABLE XIII

Summary of Correlations between Metallurgical Test Results and Ballistic Test Results of 2" Cast Armor Plates as Judged by

"Cracking in Any Degree" Criterion

Company	Plate No.	Striking Velocity (F/s ¹⁵) of 105 MM. Proof Projectile T6							
		1000		1100		1200			
		Ball. Res.	Met. Res.	Corr. Ind.	Ball. Res.	Met. Res.	Corr. Ind.		
ASF	D277	-	OK	-	OK	3	OK	OK	3
"	D256	-	OK	-	OK	3	NG	OK	0
"	D257	-	OK	-	OK	3	OK	OK	3
"	D266	-	OK	-	OK	3	NG	OK	0
"	D261	-	OK	-	OK	3	NG	OK	0
Continental	C63	-	OK	-	OK	3	NG	OK	0
"	348	NG	NG	3	NG	3	-	NG	-
"	C64	-	OK	-	OK	0	NG	NG	3
"	C65	-	(OK)	-	(NG)	(0)	(OK)	(NG)	(0)
"	346	NG	NG	1	B+	1	NG	B+	1
Continental (W)	1367	-	OK	-	OK	2	NG	OK	0
"	2508	-	OK	-	OK	3	NG	OK	0
Continental (C)	5928	-	OK	-	OK	3	NG	OK	3
"	5951	-	NG	3	NG	3	NG	NG	3
Scullin	848	NG	OK	-	OK	2	OK	B+	2
"	S50	-	OK	-	OK	1	NG	-	-
"	680	OK	NG	2	NG	1	-	-	-
"	681	OK	NG	2	NG	1	-	-	-
"	682	OK	NG	2	NG	1	-	-	-
Sym-Q (D)	3705	-	OK	-	OK	3	NG	OK	0
"	3719	-	OK	-	OK	3	NG	OK	0
"	3746	OK	NG	0	NG	3	OK	OK	3
"	4397	-	OK	-	OK	3	NG	OK	3
"	4422	NG	NG	3	NG	3	OK	OK	3
Union	373A	OK	NG	0	NG	3	-	-	-
"	4CLA	NG	NG	3	NG	3	-	-	-

TABLE XV

Summary of Correlations between Metallurgical Test Results and Ballistic Test Results of 2" Cast Armor Plates as Judged by "Army Complete Penetration or Cracking in Any Degree" Criterion

Company	Plate No.	Striking Velocity (F/S-15) of 105 MM. Proof Projectile T8					
		1000		1100		1200	
		Ball. Res.	Met. Res.	Ball. Res.	Met. Res.	Ball. Res.	Met. Res.
		Corr. Ind.	Corr. Ind.	Corr. Ind.	Corr. Ind.	Corr. Ind.	Corr. Ind.
ASF	D277	-	-	OK	OK	OK	OK
"	D256	-	-	OK	OK	NG	OK
"	D257	-	-	OK	OK	OK	OK
"	D266	-	-	OK	OK	NG	OK
"	D261	-	-	OK	OK	NG	OK
Continental	C63	-	-	OK	OK	NG	OK
"	B48	NG	NG	NG	NG	-	-
"	C64	-	-	OK	OK	NG	NG
"	C65	-	-	OK	OK	OK	OK
"	B46	NG	B+	NG	B+	-	-
Continental (W)	1367	-	-	OK	B+	NG	B+
"	2508	-	-	OK	OK	NG	OK
Continental (C)	5928	-	-	OK	OK	NG	OK
"	5951	-	-	NG	NG	NG	NG
Scullin	S48	NG	NG	NG	NG	-	-
"	S50	-	-	OK	B+	OK	B+
"	680	OK	B+	NG	B+	-	-
"	681	OK	B+	NG	B+	-	-
"	682	OK	B+	NG	B+	-	-
Sym-G (D)	3705	-	-	OK	OK	NG	OK
"	3719	-	-	OK	OK	NG	OK
"	3746	OK	NG	NG	NG	-	-
"	4397	-	-	NG	NG	-	-
"	4422	NG	NG	OK	OK	OK	OK
"	373A	OK	NG	NG	NG	-	-
Union	401A	NG	NG	NG	NG	-	-

TABLE XVI

Summary of Correlation between Metallurgical Test Results and Ballistic Test Results of 2" Cast Armor Plates as Judged by "Army Complete Penetration or Excessive (.83") Criterion"

Company	Plate No.	Striking Velocity (F/S-15) of 105 MM. Proof Projectile T8											
		1000				1100				1200			
		Ball. Res.	Met. Res.	Corr. Ind.	Ball. Res.	Met. Res.	Corr. Ind.	Ball. Res.	Met. Res.	Corr. Ind.			
ASF	1277	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3
"	1256	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3
"	1257	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3
"	1266	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3
"	1261	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3
Continental	063	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3
"	340	NG	NG	3	NG	NG	0	OK	OK	0	OK	OK	0
"	064	-	-	-	OK	OK	0	OK	OK	0	OK	OK	0
"	065	-	-	-	OK	OK	0	OK	OK	0	OK	OK	0
"	346	OK	B+	2	NG	B+	1	OK	B+	1	OK	B+	1
Continental (W)	1367	-	-	-	OK	OK	2	OK	OK	2	OK	OK	2
"	2508	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3
Continental (C)	5926	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3
"	5951	-	-	-	OK	OK	0	OK	OK	0	OK	OK	0
Scullin	848	OK	NG	0	NG	NG	3	OK	B+	2	OK	B+	2
"	850	-	-	-	OK	OK	1	OK	B+	1	OK	B+	1
"	680	OK	B+	2	NG	B+	1	OK	B+	1	OK	B+	1
"	651	OK	B+	2	NG	B+	1	OK	B+	1	OK	B+	1
"	682	OK	B+	2	NG	B+	1	OK	B+	1	OK	B+	1
Sym-G (D)	3705	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3
"	3719	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3
"	3746	OK	NG	0	NG	NG	3	OK	OK	3	OK	OK	3
"	4197	-	-	-	OK	OK	3	OK	OK	3	OK	OK	3
"	4422	OK	NG	0	NG	NG	3	OK	OK	3	OK	OK	3
"	3734	OK	NG	0	NG	NG	3	OK	OK	3	OK	OK	3
Union	601A	NG	NG	3	NG	NG	3	OK	OK	3	OK	OK	3

TABLE XVII

Summary of Average Correlation Indices of
1" Cast Armor Plates Fired at Various Striking Velocities
and Evaluated by Various Criteria

<u>Criterion*</u>	<u>Striking Velocity</u>	<u>Average Corr. Index</u>
a.	900	0.33
a.	1000	1.36
a.	1100	1.69
b.	900	1.67
b.	1000	1.86
b.	1100	1.92
c.	900	0.33
c.	1000	1.05
c.	1100	1.15
d.	900	1.67
d.	1000	1.86
d.	1100	1.92
e.	900	0.33
e.	1000	1.36
e.	1100	1.69

*See "Notes on Abbreviations."

TABLE XVIII

Summary of Average Correlation Indices of
2" Cast Armor Plates Fired at Various Striking Velocities
and Evaluated by Various Criteria

<u>Criterion*</u>	<u>Striking Velocity</u>	<u>Average Corr. Index</u>
a.	1000	1.40
a.	1100	2.27
a.	1200	2.13
b.	1000	1.90
b.	1100	2.38
b.	1200	1.13
c.	1000	1.10
c.	1100	2.04
c.	1200	2.31
d.	1000	1.90
d.	1100	2.38
d.	1200	1.13
e.	1000	1.40
e.	1100	2.27
e.	1200	2.13

*See "Notes on Abbreviations."

TABLE XIX

Summary of Percentage of Poor Correlation Indices Resulting
from "OK" Ballistic Tests Conducted on 1" Cast Armor Plates
at Various Velocities and Evaluated by Various Criteria

<u>Criterion*</u>	<u>Str. Vel.</u>	<u>No. Poor Corr. Ind.</u>	<u>No. "OK" Ballistically</u>	<u>P.C.</u>
a	900	3	3	100.0
a	1000	14	14	100.0
a	1100	4	3	75.0
b	900	1	1	100.0
b	1000	7	4	57.1
b	1100	3	1	33.3
c	900	3	3	100.0
c	1000	17	17	100.0
c	1100	9	9	100.0
d	900	1	1	100.0
d	1000	7	4	57.1
d	1100	3	1	33.3
e	900	3	3	100.0
e	1000	14	14	100.0
e	1100	4	3	75.0

*See "Notes on Abbreviations."

TABLE XX

Summary of Percentage of Poor Correlation Indices Resulting
from "OK" Ballistic Tests Conducted on 2" Cast Armor Plates
at Various Striking Velocities and Evaluated by Various Criteria

<u>Criterion*</u>	<u>Striking Velocity</u>	<u>No. Poor Corr. Ind.</u>	<u>No. "OK" Ballistically</u>	<u>P.C.</u>
a	1000	4	4	100.0
a	1100	7	3	42.9
a	1200	4	2	50.0
b	1000	3	2	66.7
b	1100	6	2	33.3
b	1200	10	1	10.0
c	1000	5	5	100.0
c	1100	7	6	85.7
c	1200	3	3	100.0
d	1000	3	2	66.7
d	1100	6	2	33.3
d	1200	10	1	10.0
e	1000	4	4	100.0
e	1100	7	3	42.9
e	1200	4	2	50.0

*See "Notes on Abbreviations."

Notes on Abbreviations Used in Tables

- Table III, IV CP(A) - Army Complete Penetration - obtained if it is possible to see light through a hole in the plate, or if any portion of the projectile in the plate is visible from the rear of the plate.
- Table III, IV PP(A) - Army Partial Penetration, the result of any impact that does not fulfill the requirements for CP(A).
- Table V, VI, XVII, XVIII, XIX, XX
- Criterion a - "Army complete penetration" criterion.
 - Criterion b - "Cracking in any degree" criterion.
 - Criterion c - "Excessive ($>4\frac{1}{2}$ " as regards 1" plates, $>8\frac{1}{2}$ " as regards 2" plates) cracking" criterion.
 - Criterion d - Combination of criteria a and b.
 - Criterion e - Combination of criteria a and c.
- Tables VII to XVI
- Ball. Res. - Ballistic results as indicated in Tables V and VI.
 - Met. Res. - Metallurgical ratings given in Tables I and II.
 - Corr. Ind. - Correlation index, as determined in text.

GRAPHICAL REPRESENTATION OF TABLE XIX

(LETTERS REFER TO CRITERIA OF EVALUATION)

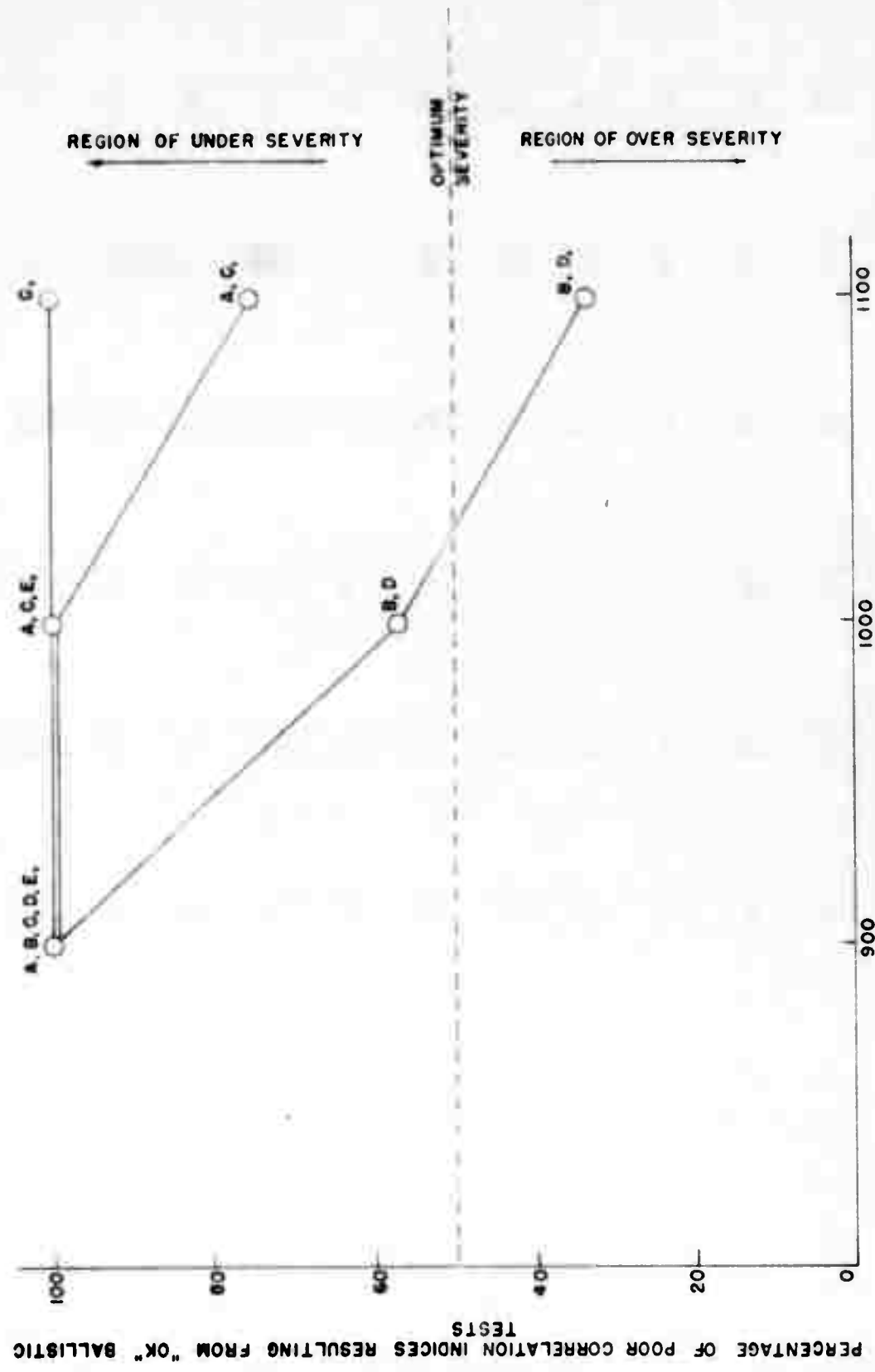


FIGURE 2

57 MM. PROOF PROJECTILE, T1, AGAINST 1" CAST ARMOR

PERCENTAGE OF POOR CORRELATION INDICES RESULTING FROM "OK" BALLISTIC TESTS

SCHEMATIC REPRESENTATION OF EXPECTED RELATIONSHIP BETWEEN
CHARPY IMPACT VALUE AND HARDNESS OF A GIVEN STEEL WITH
TEMPERED MARTENSITIC MICROSTRUCTURE

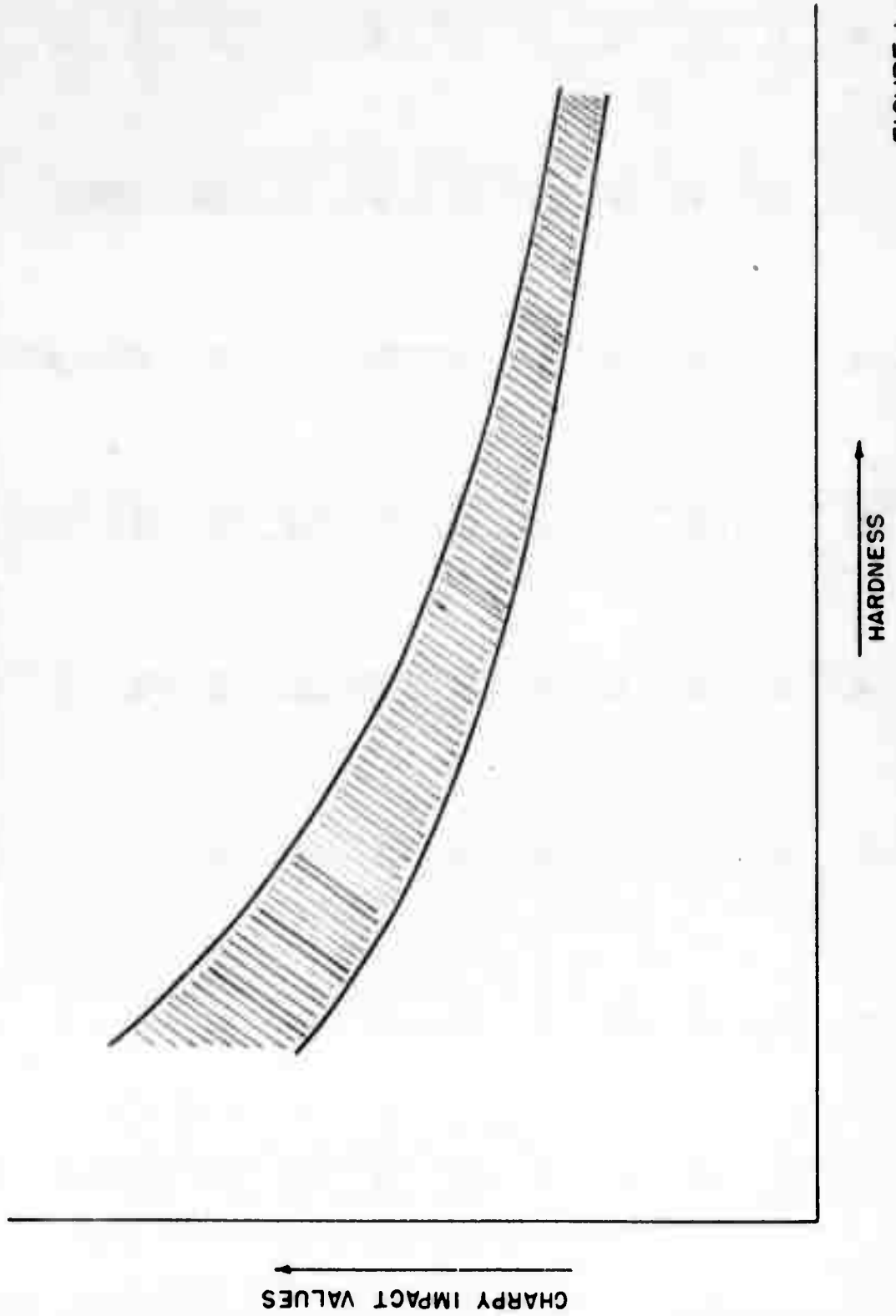


FIGURE 1

GRAPHICAL REPRESENTATION OF TABLE XX

(LETTERS REFER TO CRITERIA OF EVALUATION)

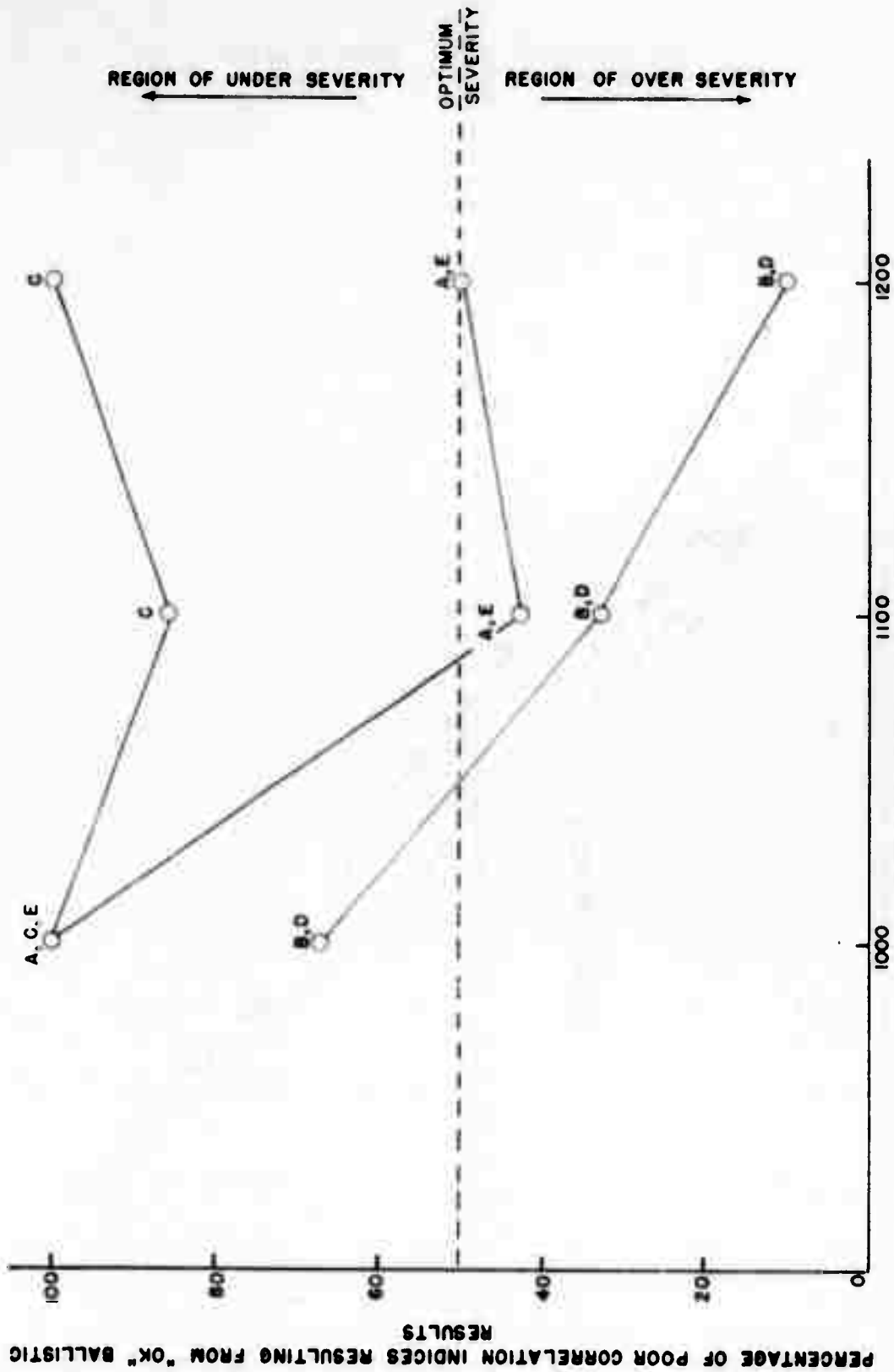


FIGURE 3

105 MM. PROOF PROJECTILE, T8, AGAINST 2" CAST ARMOR

APPENDIX A
Correspondence

COPY

ARMY SERVICE FORCES
ORDNANCE DEPARTMENT
ABERDEEN PROVING GROUND
MARYLAND

APG 470.5/1476
Attn:
SPOTZ-F

25 April 1945

SUBJECT: Development of Shock Test for 1" and 2" Cast Armor -
Metallurgical Samples

TO: Commanding Officer
Watertown Arsenal
Watertown, Mass.

Attn: Laboratory - Lt. Col. N. A. Matthews

1. Fifteen samples of 2" cast plates, each approximately 6"x12" in size, and seventeen samples of 1" cast plates, each approximately 4"x8" in size are being forwarded to your station for metallurgical analysis.
2. These samples represent acceptance plates which have been shock tested with 105 mm and 57 mm proof projectiles respectively in an attempt to establish required velocities for these tests for Specification AXS-492-5.
3. It is desired that the samples be subjected to fiber fracture tests, hardness surveys, Charpy impact tests, and any other metallurgical tests deemed advisable by your office in an attempt to correlate the shock test results with the metallurgical quality of the armor. The samples may be identified as follows:

<u>2" Plates</u>			
<u>Company</u>	<u>Plate No.</u>	<u>Heat No.</u>	<u>Sample No.</u>
Continental(W)	2	1367(Sq.183)	1
" "	2	2508(Sq.178)	2
" (C)	145	5928	3
" "	147	5951	4
Symington-Gould(D)	L328	3705	5
" "	L330	3719	6
" "	L333	4380	7
" "	L334	3741	8
" "	L335	3746	9
" "	L336	4397	10
" "	L340	4422	11
Union Steel	827	373A	12
" "	833	639B	13
" "	842	401A	14
" "	844	657B	15

Restricted

COPY

APG
SUBJECT: Metallurgical Samples
TO: Watertown Arsenal

1" Plates

<u>Company</u>	<u>Plate No.</u>	<u>Heat No.</u>	<u>Sample No.</u>
American Radiator	LB352	J43	1
" "	BL355	J160	2
Ordnance Stl. Fdry.	2	B142	3
Pratt & Litchworth	Z216	E154	4
" " "	Z218	E157	5
" " "	Z244	E138	6
" " "	Z250	E162	7
" " "	Z252	E167	8
" " "	Z254	E170	9
" " "	Z259	E183	10
" " "	Z261	E186	11
" " "	Z263	E188	12
Symington-Gould(D)	L330	3719	13
" " "	L332	4375	14
" " "	L333	4380	15
" " "	L334	3741	16
" " " (R)	GB329	B4576	17

4. It will be appreciated if the results are furnished in a letter report as soon as available.

FOR THE COMMANDING GENERAL:

(S/T) G. G. EDDY
Col., Ord. Dept.
Director
Ordnance Res. & Dev. Cn.

2220(113 Ar3-305)

2
RESTRICTED

Plate No.	Company
D27	ASF
D25	"
D25	"
D26	"
D26	"
C63	Continental
B48	"
C64	"
C65	"
B46	"
136	Continental (W)
250	"
592	Continental (C)
595	"
S48	Scullin
S50	"
680	"
681	"
682	"
370	Sym-G (D)
371	"
374	"
439	"
442	"
373	Union
401	"

COPY

APG 470.5/1476
Attn: SPOTZ-F
Wtn. 470.5/8735(r)

1st Ind.

Hurlich/ELR/mf

CO, ASF, Watertown Arsenal, Watertown 72, Mass., 5 May 1945

To: The Director, ASF, Ord. Res. & Dev. Ctr., Aberdeen Proving Ground, Md.
Attn: SPOTZ-F

1. Reference basic letter, it is requested that the results of the ballistic shock tests conducted upon the 1" and 2" cast armor plates be transmitted to this arsenal in order to correlate the results of the metallurgical examination to be made at this station with the ballistic characteristics of the armor.

For the Commanding Officer:

N. A. MATTHEWS
Lt. Col., Ord. Dept.
Assistant

APG 470.5/1476
Attention: SPOTZ-F
Wtn. 470.5/8735(r)

2nd Ind.

Oshry/nes
Ext. 5190

ASF, Ordnance Research and Development Center, Aberdeen Proving Ground, Md.

To: Commanding Officer, Watertown Arsenal, Watertown 72, Mass.

1. In accordance with request in first indorsement, summaries of ballistic results on plates represented by subject samples are being forwarded herewith.

2. Thirty additional plates, fifteen 1" and fifteen 2" are being awaited from Gary Proof Range for ballistic tests under this same program. Samples of these plates will also be sent to Watertown Arsenal for metallurgical examination upon completion of the ballistic tests.

FOR THE COMMANDING GENERAL:

(S) C. J. Yaeger
Maj. Ord. Dept.

(for) Stuart McLain
Lt. Col., Ord. Dept.
Acting Chief
Arms & Ammn, Div.

Incl. - Summary of Results (2 sheets)

COPY

SUMMARY OF RESULTS

Company	Plate No.	Heat No.	Avg. BHN	Required Vel. 900 f/s + 15 f/s	Required Vel. 1000 f/s + 15 f/s	Required Vel. 1100 f/s + 15 f/s
American Radiator	B352	J43	325	Passed	Passed	Passed
"	B355	J160	331	Passed	Passed	Passed
Ordnance Steel Fdry.	2	B412	321	Failed*	Failed*	Failed
Pratt & Letchworth	Z216	E154	316	Passed	Passed	Failed
"	Z218	E157	316	Passed	Passed	Failed
"	Z244	E138	311	Passed	Passed	Failed
"	Z250	E162	316	Passed	Passed	Failed
"	Z252	E167	316	Passed	Passed	Failed
"	Z254	E170	311	Passed	Passed	Failed
"	Z259	E183	311	Failed	Failed	Failed
"	Z261	E186	311	Passed	Passed	Passed
"	Z263	E188	316	Passed	Passed	Failed
Symington-Gould(D)	330	3719	252	Passed	Passed	Failed
"	332	4375	266	Passed	Passed	Failed
"	333	4380	216	Passed	Passed	Failed
"	334	3742	245	Passed	Failed	Failed
" (R)	339	44576	321	Passed	Passed	Failed

NOTES: *This plate broke in 3 pieces; all other plates failed because of Army complete penetrations (light visible through impact). No plate produced cracking greater than 4-1/2", except Ordnance Steel Foundry plate #2 that broke.

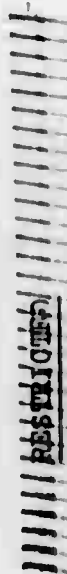
RESTRICTED

COPY

SUMMARY OF RESULTS

Company	Plate No.	Heat No.	Avg. BHN	Required Vel. 1000 f/s + 15 f/s	Required Vel. 1100 f/s + 15 f/s	Required Vel. 1200 f/s + 15 f/s
Continental Forgy. & Mach. (C)	145	5928	240	Passed	Passed	Passed
	147	5951	240	Failed	Failed	Failed
	2	1367	245	Passed	Passed	Passed
Symington-Gould (D)	2	2508	252	Passed	Passed	Failed
	L328	3705	259	Passed	Passed	Failed
	L330	3719	252	Passed	Passed	Passed
Union Steel	L333	4380	261	Passed	Passed	Failed
	L334	3741	245	Failed	Failed	Failed
	L335	3746	242	Passed	Failed*	Failed
	L336	4397	245	Passed	Passed	Failed
	L340	4422	267	Passed	Failed*	Failed
	827	373A	264	Passed	Failed	Failed
	833	639B	267	Passed	Failed	Failed
	842	401A	267	Failed*	Failed*	Failed*
	8444	657B	267	Passed	Failed*	Failed*

NOTE: *Cracking in excess of 8-1/2" obtained on these plates as well as Army complete penetrations. All other plates that failed were on basis of Army complete penetrations only.



Appendix A - Page 5

COPY

Wtn. 470.5/8735(r)
APG. 470.5/1476
Attn: SPOTZ-F

3rd Ind.

/avk

ASF, Watertown Arsenal, Watertown MA, Massachusetts, 19 July 1945.

To: The Director, ASF, Ordnance Research and Development Center, Aberdeen Proving Ground, Maryland. Attn: SPOTZ-F

1. Reference paragraph 4 of basic letter, results of metallurgical examination made on 1" and 2" cast armor samples are contained in Watertown Arsenal Laboratory Memorandum Report No. WAL 710/760(r) which was forwarded to your station, reference letter file Wtn 461/905 dated 9 July 1945.

For the Commanding Officer:

N. A. MATTHEWS
Lt. Col., Ord. Dept.
Assistant

1 Incl w/d
Summary of Results (2 sheets)

//////////RESTRICTED//////////

COPY

ARMY SERVICE FORCES
ORDNANCE DEPARTMENT
ABERDEEN PROVING GROUND
MARYLAND

APG 470.5/76
SPOTZ-F

23 July 1945

SUBJECT: Development of Shock Test for 1" and 2" Cast Armor -
Metallurgical Samples

TO: Commanding Officer
Watertown Arsenal
Watertown, Massachusetts

ATTENTION: Laboratory
Lt. Col. N. A. Matthews

1. Fifteen samples of 2" cast plates, each approximately 12"x12" in size, and five samples of 1" cast plates, each approximately 12"x12" in size are being forwarded to your station for metallurgical analysis.
2. These samples represent acceptance plates which have been shock tested with 105 mm and 57 mm proof projectiles respectively in an attempt to establish required velocities for these tests for Specification AXS-492-5.
3. It is desired that the samples be subjected to fiber fracture tests, hardness surveys, Charpy impact tests, and any other metallurgical tests deemed advisable by your office in an attempt to correlate the shock test results with the metallurgical quality of the armor. The samples may be identified as follows:

<u>Company</u>	<u>2" Plates</u> <u>Plate No.</u>	<u>Heat No.</u>	<u>Sample No.</u>
Continental Fdry. & Mach. (E. Chi.)	C8192-1 Sq C63	8192	C-63
"	B2327-2 Sq B48	2327	C-48
"	C8227-2 Sq C64	8227	C-64
"	C8260-2 Sq C65	8260	C-65
"	B2256-1 Sq B46	2256	C-46
ASF - Cast Armor Plant (Granite City)	G-7974-D-277	7526	ASF 277
"	G-7974-D-256	7447	ASF 256
"	G-7974-D-257	7454	ASF 257
"	G-7974-D-266	7481	ASF 268
"	G-7974-D-261	7468	ASF 261
Scullin Steel Co.	S-48	1-907	S-48
"	S-50	1-915	S-50
"	680	5-018	S-680
"	681	5-023	S-681
"	682	2-177	S-682

COPY

APG

Subject: Development of Shock Test

To: Watertown Arsenal

1" Plates

<u>Company</u>	<u>Plate No.</u>	<u>Heat No.</u>	<u>Sample No.</u>
ASF - Cast Armor	C26	3560	C26
Plant	C22	3540	C22
Sivyer Steel Co.	20B599	20B599	20B599
Scullin Steel Co.	48	3-333	S-48
"	49	5-020	S-49

4. It will be appreciated if the results of the metallurgical analysis are furnished in a letter report as soon as they are available.

FOR THE COMMANDING GENERAL:

G. G. EDDY
Col Ord Dept
Director
Ord. Res. & Dev. Ctr.

Project No. 2220 (113 Ar3-305)

COPY

WAR DEPARTMENT
ABERDEEN PROVING GROUND
MARYLAND

Rouse/ewr
6103

APG 470.5/112
SPOTZ-F

7 August 1945

SUBJECT: Test of 1" and 2" Thick Cast Armor

TO: Commanding Officer
Watertown Arsenal
Watertown 72, Massachusetts

ATTN: Laboratory, Lt. Col. N. A. Matthews

1. Reference your report WAL 710/760, "Metallurgical Examination of 1" and 2" Thick Cast Armor Used for the Development of 57 mm. and 105 mm. Proof Projectile Shock Test", page 1, under Abstracts, "Complete penetrations are not considered reliable indices of the shock resistance of armor. As presently conducted, the subject ballistic shock tests are not considered satisfactory for inclusion in Specification AXS-492-5." A further study covered by this report and the detailed results of the ballistic tests on plates covered by this report indicate that there may be a correlation between the tendency for complete penetration, and the difference in impact value at normal and subzero temperatures. This was pointed out to Mr. Sullivan from your station during his recent visit to Aberdeen Proving Ground and he was in agreement that a correlation of this type might exist.

2. On July 17, 1945, a letter request for metallurgical examination of a number of cast plates recently tested with proof projectiles was forwarded to your station. Mr. Sullivan was given detailed ballistic information on the plates represented by these samples. It is requested that the metallurgical tests on these plates be expedited and results forwarded to this station after which it is believed a sounder basis for judging the value of the complete penetration criterion in shock tests may be made.

FOR THE COMMANDING GENERAL:

Stuart McLain
Lt. Col., Ord. Dept.
Acting Chief, Arms &
Ammunition Division

COPY

Wtn. 470.5/256
APG. 470.5/112
Attn: SPOTZ-F

1st Ind.

Sullivan/ELR/avk

ASF, Watertown Arsenal, Watertown 72, Massachusetts, 12 September 1945.

To: The Director, ASF, Ord. Res. & Dev. Ctr., Aberdeen Proving Ground, Md.
Attn: SPOTZ-F, Major C. J. Yaeger

1. Reference basic correspondence, during the recent visit of Mr. Sullivan of this laboratory to your station it was agreed to concentrate preliminary metallurgical study on the seven (7) two-inch thick cast plates which, based upon their resistance to cracking upon impact of the 105 mm. PP T8 projectile, represented extremes of ballistic behavior. These plates were: D-277, D-257 (both produced by American Steel Foundries), S-50 (Scullin), and C-65 (Continental) which resisted cracking; B-48, B-46 (both Continental) and S-48 (Scullin) which cracked even under a reduced test. A summary of the metallurgical findings on samples ostensibly cut from these plates and the ballistic results appears in Table I, attached.

2. The first three plates and the last three plates in that list indicate a correlation between the ballistic results, as judged on a crack/no-crack criterion, and the metallurgical characteristics,—those which were satisfactory ballistically having fibrous fractures and high impact values even at reduced temperatures and those which were unsatisfactory ballistically failing to fracture purely fibrously and having low impact values even at room temperature.

3. Sample C-65, however, which apparently resisted cracking both at 1100 f/s and 1200 f/s striking velocities possesses metallurgical characteristics which would logically be associated with inferior ballistic behavior. Thus, were one to predict ballistic behavior purely from a consideration of the metallurgical characteristics of this sample, he would anticipate poor resistance to shock. The partially crystalline fracture and the low impact values obtained on this sample ordinarily are reflected in poor ballistic behavior. The plate, however, exhibited satisfactory resistance to shock.

4. In order to delve more deeply into the problem, data obtained in the previous study of 2" cast plates (reported in WAL 710/760) were re-examined from the viewpoint of a crack/no-crack criterion of ballistic acceptability. These data are recited in Table II. They indicate a good correlation between the results of metallurgical and ballistic tests.

5. We are thus faced with a preponderance of data indicating good correlation and a single datum which glaringly indicates no correlation. It must be borne in mind that we are dealing with plates whose ballistic behavior is sharply discriminated. The plates which have been judged o.k. withstood successive impacts at 1100 feet/second and at 1200 feet/second. The plates which have been judged NG cracked under impact at 1100 feet/second and cracked again under impact at 1000 feet/second. We, thus, are not operating in a twilight zone of nebulous differences.

2

RESTRICTED

COPY

Wtn. 470.5/256
APG. 470.5/112
Attn: SPOTZ-F

1st Ind.
(Cont'd)

12 Sept. 1945

6. This makes the lack of correlation, even in a lone case, more disturbing than it would ordinarily be. However, it is felt that, in view of the favorable correlation apparent in the cases of ten out of the eleven samples under consideration, and in view of the consistent metallurgical results obtained on even the eleventh sample, the lack of correlation may reflect a defect in sampling the plate (wherein the sample selected may not be representative of the true quality of the plate) or may, on the other hand be due to a mixup in identification. It would thus be desirable to examine an additional sample of plate O-65 at this laboratory, and it would be appreciated if such a sample would be forwarded.

7. In general, then, there is indicated a much better correlation between results of these tests based upon a no-cracking criterion and metallurgical test results than between results based upon ballistic limits and metallurgical results. When the further modification of the weight of the test projectile suggested during the visit of Mr. Sullivan has been made, it is felt that a much better correlation will appear.

8. The complete results of the metallurgical examination of the subject armor will be forwarded by memorandum report.

For the Commanding Officer:

N. A. MATTHEWS
Lt. Col., Ord. Dept.
Assistant

2 Incls
Tables I & II

³
RESTRICTED

COPY

TABLE I

2" Cast Homogeneous Plates

Reference - AR-16646

105 mm. PP T8

<u>Company</u>	<u>Plate No.</u>	<u>Ave. BHN</u> <u>Co. Wtn.</u>	<u>Fracture</u>	<u>Charpy</u> <u>+10°F. -10°F.</u>	<u>Ballistic</u> <u>(No Crack Criterion)</u>
ASF-CAP	D-277	251 262	F	51.9 54.5	OK
ASF-CAP	D-257	245 253	F	54.6 47.0	OK
Scullin	S-50	232 214	F	68.6 55.5	OK
Continental	C-65	266 282	Fc 1/2	33.4 21.0	OK
Continental	B-48	266 269	Fc 1/3 D	29.1 17.1	NG
Continental	B-46	255 269	FD	31.2 29.5	NG
Scullin	S-48	234 255	Fc 1/2	37.4 22.0	NG

RESTRICTED

Appendix A - Page 12

COPY

C. D. Reg. No.
06-84-ME-0C

RESTRICTED

ARMOR BRANCH
ORDNANCE RESEARCH AND DEVELOPMENT CENTER
ABERDEEN PROVING GROUND, MARYLAND

SUBJECT: Development of a Shock Test for
1" and 2" Cast Armor.

Report No.: Ar-16241
Date of Test: 9 April 1945
Sheet 1 of 6
Related F.R. No.: 3965
Project No.: 2220(113-Ar3-305)
References: OOM 470.5/APG(10 Feb
45)R; SPOME-EE
APG 470.5/1161

OBJECT: To Obtain Shock Test Data with
the 105 mm. Proof Projectile on a
Total of Fifteen 2" Cast Acceptance
Plates Received from Erie Proving
Ground.

COMMENTS:

1. Fifteen 2" cast plates, received from Erie Proving Ground after passing acceptance tests for penetration, were shock tested with 105 mm. proof projectiles in order to obtain data to establish a required velocity for Specification AXS-492.
2. In this test, one round was placed against the center of the plate at a required velocity of 1100 f/s. If the plate withstood the impact without excessive cracking, a second round was fired at a velocity 100 f/s higher. If the plate cracked as a result of the first impact, the second round was fired at a velocity 100 f/s lower. Failure was considered to have occurred when cracking extended greater than 8-1/2" and/or Army complete penetration was obtained (light visible through impact).
3. A summary of this test is given on sheet 2. A list of test facilities is given on sheet 3. The detailed results are on sheets 4 through 6.
4. This is the first report on test data on this project. Testing will continue.

APPROVED:

G. G. EDDY
Col., Ord Dept
Director

BY:

(s) H. J. Rouse Sr. Eng.
for JOHN W. CAVE
Col., Ord Dept
Chief, Arms & Ammun.
Division

(s/t) G. H. OSHRY
Metallurgist, P-4
Proof Director

Distribution of this report:

Commanding General, Office, Chief
of Ordnance-Detroit, Attention: SPOME-EE

1 copy

COPY

////// RESTRICTED ////

Report No.: Ar-16241
Sheet 3 of 6

Test Facilities:

a. Guns Used:

Howitzer, Field, 105 mm., M2A1, No. 347, Mf'd. by the Vilter M'fg. Co.

b. Projectiles Used:

Projectile, Proof, T8, 105 mm., Lot FA-E-75.

////// RESTRICTED ////

COPY

////////// RESTRICTED //////////

ABERDEEN PROVING GROUND, MARYLAND
ARMOR BRANCH

DATE OF FIRING 9 April 1945
ARMOR TEST REPORT NO. Ar-16241
SHEET 4 OF 6
RELATED F.R. NO. AF 3965

PLATE NO.	HEAT NO.		THICKNESS & TYPE				RESULTS - ARMOR AND PROJECTILE
RD. No.	PROJECTILE	OBLIQ.	AVG. THICK.	REQ. VEL.	ACT. S.V.	PP CP PTP	
1	Symington-Gould-(D); Plate No. L333-1; Heat 4380; BHN 261	0°	1.98	1090	1109	PP(Δ)	MB - no cracking; Mushroomed & intact 5-1/4", 5-1/4", 4-3/8" cracks; Mushroomed & intact
2	105mm PP T8	"	"	1199	1202	CP(Δ)	
1	Symington-Gould-(D); Plate No. 330-1; Heat 3719; BHN 252	0°	2.00	1100	1084	PP(Δ)	MB - no cracking; Mushroomed & intact MB - 3 1/2", 3-3/8" crack; Mushroomed & intact
2	105mm PP T8	"	2.00	1200	1198	PP(Δ)	
1	Symington-Gould-(D); Plate No. L340-1; Heat 4422; BHN 267	0°	2.02	1110	1117	CP(Δ)	9 1/2", 7 1/2", 7 1/2" to prev. impact; Mushroomed & intact 3-1/4", 2 1/2" cracks; prev. ck. extended 16"; Mushroomed & intact
2	105mm PP T8	"	2.00	1000	989	PP(Δ)	
1	Continental Fdry. & Mach. Co.(W); Plate No. 2; Heat 2508 Sq 178; BHN 252	0°	2.10	1150	1149	PP(Δ)	MB - no cracking; Mushroomed & intact 4 1/2", 3-5/8" cracks; Mushroomed & intact
2	105mm PP T8	"	2.10	1250	1259	CP(Δ)	
1	Symington-Gould-(D); Plate L335-1; Heat 3746; BHN 242		1.98	1090	1095	CP(Δ)	5-1/4", 5", 3-3/4" cracks; Mushroomed & intact MB - No cracking; Mushroomed & intact
2	105mm PP T8		1.95	975	995	PP(Δ)	
1	Union Steel; Plate No. 842; Heat 401A; BHN 267	0°	1.86	1030	1031	CP(Δ)	8-5/8", 8 1/2", 6 1/2" cracks; Mushroomed & intact 8-3/4", 7 1/2", 5-3/4" cracks; Mushroomed & intact
2	105mm PPT8	"	1.85	925	910	CP(Δ)	

CP - Complete Penetration	PTP - Passed through plate
PP - Partial Penetration	PIP - Projectile in plate
CIP - Core in plate	FPTP - Failed to pass thru plate.
PUN S' - Punching started	
BS - Back spall	ND - Nose destroyed
FS - Face spall	BD - Base destroyed
SC - Star cracking	NI - Nose intact
MI - Misregard	BI - Base intact
CR - Cratering	PC - Partial cratering
PF - Petaling on face	

////////// RESTRICTED //////////

COPY

////////// RESTRICTED //////////

ABERDEEN PROVING GROUND, MARYLAND
ARMOR BRANCH

DATE OF FIRING 9 April 1945
ARMOR TEST REPORT NO. Ar-16241
SHEET 5 OF 6
RELATED F.R. NO. AF 3965

PLATE NO.

HEAT NO.

THICKNESS & TYPE

RD NO.	PROJECTILE	OBLIQ.	AVG. THICK.	REQ. VEL.	ACT. S.V.	PP CP PTP	RESULTS - ARMOR AND PROJECTILE
	Symington-Gould-(D); Plate L-336-1; Heat 4397; BHN 245						
1	105mm PP T8	0°	1.98	1090	1095	PP(A)	LB - no cracking; Mushroomed & intact
2	"	"	1.92	1160	1164	PP(A)	LB - no cracking; Mushroomed & intact
	Union Steel; Plate 837; Heat 373A; BHN 264						
1	105mm PP T8	0°	1.96	1080	1094	CP(A)	4 1/2", 4 1/2", 4"; Mushroomed & intact
2	"	"	2.01	1005	989	PP(A)	MB - no cracking; Mushroomed & intact
	Continental Fdry. & Mach.(C); Plate No. 145; Heat 5928; BHN 245						
1	105mm PP T8	0°	2.03	1115	1112	PP(A)	MB - no cracking; Mushroomed & intact
2	"	"	2.03	1215	1226	PP(A)	LB - 3/4" crack; Mushroomed & intact
	Symington-Gould-(D); Plate L-334-1; Heat 3741; BHN 245						
1	105mm PP T8	0°	2.01	1105	1106	PP(A)	4", 2-1/4", 3-3/4" cracks, Mushroomed & intact
2	"	"	1.99	1195	1205	CP(A)	6-3/4", 6", 5", 5-3/4"; Mushroomed & intact
	Union Steel; Plate No. 833; Heat 639B; BHN 267						
1	105mm PP T8	0°	2.05	1125	1124	CP(A)	4-3/4", 4-1/4", 5", 4-3/4" cracks; Mushroomed & intact
2	"	"	2.00	1000	991	PP(A)	2 1/2", 2-3/4", cracks; Mushroomed & intact
	Continental Fdry. and Mach. Co.(W); Plate No. 2; Heat L367 Sq. 183; BHN 245						
1	105mm PP T8	0°	2.16	1180	1200	PP(A)	MB - no cracking; Mushroomed & intact
2	"	"	2.15	1275	1283	PP(A)	Cracks off bulge 5-1/4", 5-1/4"; Mushroomed & intact

CP - Complete Penetration
PP - Partial Penetration
CIP - Core in plate
PUM S - Punching started
BS - Back spall
FS - Face spall
SO - Star cracking
D - Disregard
C - Cratering
P - Petaling onface

PTP - Passed through plate
PIP - Projectile in plate
FPTP - Failed to pass through plate
ND - Nose destroyed
BD - Base destroyed
NI - Nose intact
BI - Base intact
PC - Partial cratering

////////// RESTRICTED //////////

////////// RESTRICTED //////////

ABERDEEN PROVING GROUND, MARYLAND
ARMOR BRANCH

DATE OF FIRING 9 April 1945
ARMOR TEST REPORT NO. Ar-16241
SHEET 6 OF 6
RELATED F.R. NO. AF 3965

PLATE NO. HEAT NO. THICKNESS & TYPE

RD. NO.	PROJECTILE	ORIG.	AVE. THICK.	REQ. VEL.	ACT. S.V.	PP CP PTP	RESULTS - ARMOR AND PROJECTILE
	Union Steel; Plate No. 844; Heat 657B; BHN 267						
1	105mm PP T8	0°	1.98	1090	1091	CP(A)	8-3/4", 8 1/2", 3" cracks; Mushroomed & intact
2	"	"	1.87	935	919	PP(A)	5-1/4", 2"; Mushroomed & intact
	Symington-Gould(D); Plate 328-1; Heat 3705; BHN 259						
1	105mm PP T8	0°	1.93	1065	1078	PP(A)	LB - no cracking; Mushroomed & intact
2	"	"	1.91	1155	1159	CP(A)	6 1/2", 5-1/4", 6" cracking; Mushroomed & intact
	Continental Fdry. & Mach. Co.-(D); Plate No. SC-147; Heat 5951; BHN 240						
1	105mm PP T8	0°	2.11	1155	1156	PP(A)	LB - 1-1/2" crack; Mushroomed & intact
2	"	"	2.16	1280	1271	CP(A)	4-3/4", 4" cracks; Mushroomed & intact

CP - Complete Penetration
PP - Partial Penetration
CIP - Core in plate
PUM & P - Punching started
BS - Back spall
FS - Face spall
SC - Star cracking
D - Disregard
G - Gratering
P - Petaling on face

PTP - Passed through plate
PIP - Projectile in plate
FPTP - Failed to pass through plate.
ND - Nose destroyed
BD - Base destroyed
NI - Nose intact
BI - Base intact
PC - Partial cratering

COPY

C. D. Reg. No.
06-84-ME-OC

RESTRICTED

ARMOR BRANCH
ORDNANCE RESEARCH AND DEVELOPMENT CENTER
ABERDEEN PROVING GROUND, MARYLAND

SUBJECT: Development of a Shock Test
for 1" and 2" Cast Armor.

Report No.: Ar-16242
Date of Test: 10 April 1945
Sheet 1 of 6
Related F.R. No.: AF 3967
Project No.: 2220(113 Ar3-305)
References: OOM 470.5/APG(10 Feb
45)R; SPOCE-EE
APG 470.5/1161

OBJECT: To Obtain Shock Test Data with
the 57mm. Proof Projectile on
a Total of Seventeen 1" Cast
Plates received from Erie Proving
Ground

COMMENTS:

1. Seventeen 1" cast plates, received from Erie Proving Ground after passing acceptance tests for penetration, were shock tested with the 57 mm. proof projectile in order to obtain data to establish a required velocity for Spec. ~~AMS-192~~.
2. In this test, one round was placed against the center of the plate at a required velocity of 1000 f/s. If the plate withstood the impact without cracking excessively, a second round was fired at a velocity 100 f/s higher. If the plate cracked excessively on the first impact, the second round was fired at a velocity 100 f/s lower. Failure was considered to have occurred when cracking extended greater than 4-1/2" (two calibers) and/or an Army complete penetration was obtained (light visible through impact).
3. A summary of this test is given on sheet 2. A list of test facilities is given on sheet 3. The detailed results are on sheets 4 through 6.
4. This is the second report of test data on this project. Testing will continue.

APPROVED:

BY:

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

(s) H. J. Rouse Sr. Eng
for JOHN W. CAVE (s/t) G. H. OSHRY
Col., Ord. Dept. Metallurgist, P-4
Chief, Arms & Ammn. Div. Proof Director

Distribution of this report:

Commanding General, Office, Chief of
Ordnance-Detroit, Attention: SPOCE-EE

1 copy

RESTRICTED

COPY

RESTRICTED

SUMMARY OF RESULTS

<u>Company</u>	<u>Plate No.</u>	<u>Heat No.</u>	<u>Avg. BHN</u>	<u>Required Vel. 900 f/s + 15 f/s</u>	<u>Required Vel. 1000 f/s + 15 f/s</u>	<u>Required Vel. 1100 f/s + 15 f/s</u>
American Radiator	L3352	J43	325	Passed	Passed	Passed
"	L3355	J160	331	Passed	Passed	Passed
Ordinance Steel Fdry.	2	B412	321	Failed*	Failed*	Failed
Pratt & Letchworth	2216	E154	316	Passed	Passed	Failed
"	2218	E157	316	Passed	Passed	Failed
"	2244	E138	311	Passed	Passed	Failed
"	2250	E162	316	Passed	Passed	Failed
"	2252	E167	316	Passed	Passed	Failed
"	2254	E170	311	Passed	Passed	Failed
"	2259	E183	311	Passed	Failed	Failed
"	2261	E186	311	Passed	Passed	Passed
"	2263	E188	316	Passed	Passed	Failed
Symington-Gould(D)	L330	3719	252	Passed	Passed	Failed
"	L332	4375	266	Passed	Passed	Failed
"	L333	4380	216	Passed	Passed	Failed
"	L334	3741	245	Passed	Failed	Failed
"	OB329	B4576	321	Passed	Passed	Failed

NOTES: *This plate broke in 3 pieces; all other plates failed because of ARMY complete penetrations (light visible through impact). No plate produced cracking greater than 4-1/2", except Ordnance Steel Foundry plate #2 that broke.

RESTRICTED

COPY

RESTRICTED

Report No.: Ar-16242
Sheet 3 of 6

Test Facilities:

a. Guns Used:

Gun, A.T., 57 mm, M1, No. 726, Mf'd. by A.T.F.
Tube, A.T., 57 mm, M1, No. 1019, Mf'd by A.T.F.

b. Projectiles Used:

Projectile, Proof, T1, 57 mm. AK 3-1

RESTRICTED

COPY

////////// RESTRICTED //////////

ABERDEEN PROVING GROUND, MARYLAND
ARMOR BRANCH

DATE OF FIRING 10 April 1945
ARMOR TEST REPORT NO. Ar-16242
SHEET 6 OF 6
RELATED F.R. NO. AF 3967

PLATE NO.	HEAT NO.		THICKNESS & TYPE				RESULTS - ARMOR AND PROJECTILE
RD. NO.	PROJECTILE	ANGLE	AVG. VELOCITY	REQ. VEL.	AOT. S.V.	PP CP PTP	
Pratt & Letchworth; Lot Z263-1; Heat B188; BHN 316							
1	57mm FP T1	0°	.99	992	991	PP(A)	2-1/4", 2-1/4" cracks; Mushroomed and intact
2	"	"	1.00	1100	1119	CP(A)	4", 4-1/4", 3-1/4" cracks; Mushroomed and intact
Symington-Gould; Plate L332A; Heat 4375; BHN 266							
1	57mm FP T1	0°	.97	976	988	PP(A)	LB; No cracking
2	"	"	.97	1076	1071	PP(A)	LB; No cracking
Symington-Gould; Plate 334; Heat 3741; BHN 245							
1	57mm FP T1	0°	.98	984	975	CP(A)	3", 2-7/8", 1-3/4" cracks; Mushroomed and intact
2	"	"	.98	884	Est. PP(A) 884(Lost)		2-3/4", 1-1/4", 1" cracks; Mushroomed and intact
American Radlater; Plate No. LB352; Heat J43; BHN 325							
1	57mm FP T1	0°	1.10	1080	1098	PP(A)	MB; No cracking
2	"	"	1.11	1188	1181	PP(A)	LB; "
Symington-Gould (R); Plate GB 329; Heat 4576; BHN 321							
1	57mm FP T1	0°	1.04	1032	1035	PP(A)	MB; 3/4" cracks; Mushroomed and intact
2	"	"	1.05	1140	1163	CP(A)	3-1/4", 3", 2-1/8" cracks; Mushroomed and intact

CP - Complete Penetration
FP - Partial Penetration
CIP - Core in plate
FUM S - Punching started
BS - Back spall
FS - Face spall
SC - Star cracking
D - Disregard
P - Penetration
PC - Penetration on face

PP - Passed through plate
PIP - Projectile in plate
FPP - Failed to pass through plate
ND - Nose destroyed
BD - Base destroyed
NI - Nose intact
BI - Base intact
PC - Partial cratering

WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT NO. WAL 710/760

First Partial Report on Problem B-4.78

28 June 1945

Metallurgical Examination of 1" and 2" Thick
Cast Armor Used for the Development of
57 MM and 105 MM Proof Projectile Shock Tests

Abstract

Except for a few cases, the ballistic performance of 1" and 2" thick cast armor shock tested at velocities of 1000 and 1100 ft./sec. with 57 mm. and 105 mm. proof projectiles respectively does not correlate with the shock properties of the armor as revealed by metallurgical tests. There is evidence that low hardness is the factor responsible for the failure of 1" thick plates during the shock test. In general, the ballistic failures resulted from complete penetrations (Army criterion) rather than from breakage or excessive cracking. Complete penetrations are not considered reliable indices of the shock resistance of armor. As presently conducted, the subject ballistic shock tests are not considered satisfactory for inclusion in Specification AXB-492-5.

1. At the request of the Ordnance Research Center, Aberdeen¹, a metallurgical examination of seventeen 1" and eleven 2" thick cast armor plates has been completed. These plates had been shock tested with 57 mm. and 105 mm. proof projectiles respectively in an attempt to establish required velocities for these tests for incorporation in Specification AXB-492-5.

2. Metallurgical examination and an evaluation of the results of the ballistic tests lead to the following observations and conclusions.

a. The 57 mm. proof projectile shock tests at velocities of 1000 ft./sec. and 1100 ft./sec. are not considered satisfactory as criteria of the shock resistance of 1" thick cast armor since metallurgical tests show, in general, no difference in shock properties between plates which

1. APO. 470.5/1476 - Wtn. 470.5/8735 dated 25 April 1945.

passed and plates which failed the test. Furthermore, plates generally failed the test because of complete penetrations (Army criterion) rather than cracking or breaking. Complete penetrations are not satisfactory indices of poor shock resistance.

b. The ballistic behavior of 2" thick cast armor shock tested at a velocity of 1000 ft./sec. with 105 mm. proof projectiles does correlate somewhat more satisfactorily with the shock properties as revealed by metallurgical tests. Complete penetrations (Army criterion) occurred, however, in some of the failing plates. The philosophy of failing plates as the result of complete penetrations during shock testing is open to severe criticism.

3. The metallurgical examination included the following tests:
 - a. Fibre fracture test.
 - b. Cross-sectional Brinell hardness survey.
 - c. V-notch Charpy impact tests.

The 6"x12"x2" and 4"x8"x1" sections were notched by flame cutting in from the middle of the two longer sides and were fractured under the impact of a steam forge hammer. One-half inch thick sections cut from the middle of one of the fractured halves were surface ground. Brinell hardness surveys were made on the cross-sectional surfaces, after which two V-notch Charpy impact specimens were machined from each section, from positions halfway between the surface and the center in the case of the 1" thick plates and from near the center of the 2" thick plates. One impact specimen from each plate was tested at +70°F. and the other at -40°F.

4. The details regarding the ballistic performance, hardness, fibre fracture rating, and notched bar impact values of the 1" and 2" thick plates are tabulated in Tables I and II respectively.

5. According to the ballistic data forwarded to this arsenal with the 2nd indorsement to the basic letter¹, all but a very few of the plates which failed the shock test at the various velocities failed because of complete penetrations (Army criterion). The fact that failure occurred through complete penetration rather than as a result of breakage or cracking of the test plates casts immediate doubt upon the success of 57 mm. and 105 mm. proof projectiles employed to shock test 1" and 2" thick cast armor respectively. A complete penetration cannot in itself be considered an adequate proof of poor shock properties. The one 1" thick plate, Ordnance Steel Foundry plate 2, heat B142, which did break up under the impact of a 57 mm. proof projectile was found to possess extremely poor impact properties, having an impact energy of 7.9 ft.lbs. at +70°F. and 4.1 ft.lbs. at -40°F. Likewise, two 2" thick plates which cracked in excess of $\frac{1}{2}$ ", Symington-Gould, heat

1. See reference on preceding page.

4422 and Union Steel, heat 401A, possessed relatively poor low temperature impact properties. Except for these three isolated cases, however, no correlation can be established between the ballistic performance and the shock properties as determined by metallurgical tests.

6. In order to more clearly demonstrate the lack of correlation between the results of the ballistic and the metallurgical shock tests, the data were rearranged as shown in Tables III and IV. The hardnesses, impact properties, and fibre fracture ratings of the plates which passed and those which failed the shock tests at velocities of both 1000 ± 15 ft./sec. and 1100 ft./sec. are arranged for purposes of comparison. The data in Table III indicate that at a velocity of 1100 ± 15 ft./sec., hardness rather than shock resistance determines whether plates pass or fail the 57 mm. proof projectile test. The hardness of the passing plates averages 340 ± 10 BHN and that of the failing plates 320 ± 7 BHN, whereas the impact energy of the passing plates at -40°F . averages 16.3 ± 5.8 ft.lbs. and that of the failing plates 17.2 ± 3.5 ft.lbs. No correlation whatsoever exists between the ballistic and metallurgical shock tests of the 1" thick plates tested at 1000 ± 15 ft./sec., except in the case of the previously described Ordnance Steel Foundry plate of extremely poor shock properties.

7. A further criticism of the 57 mm. proof projectile shock test arises from the fact that some 1" thick cast plates, which upon the basis of metallurgical tests would be considered of inferior quality, passed the shock test at striking velocities of both 1000 and 1100 ft./sec. American Radiator heat J160 and Symington Gould heat 4375 possess poor shock properties as measured by notched bar impact tests, yet these plates passed the shock test at both striking velocities.

8. The 105 mm. proof projectile shock test of 2" thick cast armor at a velocity of 1000 ± 15 ft./sec. does correlate somewhat better with the metallurgical shock tests in that the passing plates have an average impact energy at -40°F . of 38.2 ± 4.7 ft.lbs. whereas the failing plates average average 23.5 ± 2.1 ft.lbs., see Table IV. No similar correlation was found, however, at a velocity of 1100 ± 15 ft./sec. Of the three plates failing, one has the relatively low impact energy of 26.5 ft.lbs. but the other two failing plates have impact energies higher than those of some of the passing plates.

9. The results of the metallurgical examination show, in general, a very imperfect relation between the ballistic performance of the subject plates and their shock properties. The poor correlation between the ballistic and metallurgical shock tests in combination with the fact that ballistic failures for the most part resulted from Army complete penetrations, demonstrate beyond doubt that the 57 mm. proof projectile shock test for 1" thick cast armor and the 105 mm. proof projectile shock test for 2" thick cast armor as conducted at the Ordnance Research Center do not qualify as bona fide shock tests.

It is possible that these projectiles may yield more satisfactory results at an obliquity where the force of the impact would be spread over a larger area than at normal obliquity.

M. Yoffa

M. Yoffa
Physical Science Aide

A. Hurlich

A. Hurlich
Associate Metallurgist

APPROVED:

E. L. Reed

E. L. REED
Research Metallurgist
Chief, Armor Section

TABLE I

1" Thick Plates Tested with 57 MM Proof Projectiles

Company	Heat No.	Ave. BHN ^e	57 MM Proof Projectile Velocity		Fibre Fracture Rating ^g	V-Notch Charpy Data	
			900 ± 15 Ft./Sec.	1000 ± 15 Ft./Sec.		Ft.Lbs. at +70°F.	Ft.Lbs. at -40°F.
American Radiator	J43	334	Passed	Passed	F (shrinkage)	26.5	28.0
"	J160	359	Passed	Passed	Cbf 1/2	22.9	10.6
Ordinance Steel Fdry.	E142	341	Failed ^h		Fc 1/4	7.9	4.1
Pratt & Letchworth	E154	334	Passed	Failed	Fc (tr shrinkage)	34.2	15.5
"	E157	324	Passed	Failed	F (shrinkage)	24.7	18.1
"	E138	311	Passed	Failed	Fc 1/8	26.5	17.4
"	E162	328	Passed	Failed	F (shrinkage)	45.8	15.8
"	E167	328	Passed	Failed	F	17.4	12.1
"	E170	318	Passed	Failed	F	43.6	22.5
"	E183	334	Passed	Failed	Fc 1/8	23.2	13.3
"	E186	334	Passed	Passed	F (shrinkage)	29.5	13.0
"	E188	315	Passed	Failed	Cbf 1/4	28.0	10.6
Symington-Gould(D)	3719	324	Passed	Failed	Fc 1/8	28.0	15.1
"	4375	331	Passed	Passed	Fc trace	16.4	13.6
"	4380	301	Passed	Failed	F (shrinkage)	20.8	16.8
"	3741	299	Passed	Failed	F (shrinkage)	28.8	18.4
Symington-Gould(R)	B4576	321	Passed	Failed	F	35.8	28.0

^eAverage of 3 cross-sectional readings.

^fF = fibrous, Fc = fibrous matrix with spots of crystallinity, Cbf = bright crystalline patch surrounded by fibrous border. Fractions represent portion of crystalline area.

^gThis plate broke in 3 pieces. All other plates failed because of Army complete penetrations, none had cracking greater than 1/8".

TABLE II

2" Thick Plates Tested with 105 MM Proof Projectiles

Company	Heat No.	Ave. BHN ^a	105 MM Proof Projectile Velocity		Fibre Fracture Rating ^b	V-Notch Charpy Data	
			Ft./Sec.			Yt. lbs.	Yt. lbs.
			900 ± 15	1000 ± 15		at +70°F.	at -40°F.
Continental (W)	1367 (sq. 183)	264	Passed	Passed	Fc 1/8	32.6	35.0
"	2508 (sq. 178)	264	Passed	Failed	Fc 1/4	56.8	37.4
Continental (C)	5928	253	Passed	Passed	Fc trace	50.1	42.4
"	5951	255	Passed	Failed	Fc 1/4	40.7	26.5
Symington-Gould (D)	3705	250	Passed	Failed	Fc tr (shrinkage)	41.1	42.0
"	3719	264	Passed	Passed	Fc trace	29.5	37.4
"	3746	253	Failed	Failed	Fc 1/4	24.7	28.0
"	4397	248	Passed	Passed	F (shrinkage)	38.2	46.6
"	4422	253	Failed ^c	Failed ^c	Fc 1/10	23.6	23.6
Union Steel	373A	285	Passed	Failed	Fc 1/2	34.2	20.1
"	401A	272	Failed ^c (cracking in excess of 8%)	Failed ^c (cracking in excess of 8%)	Fc 1/4 (slight conchoidal)	47.5	22.2

^aBHN determined at Watertown Arsenal.

^bF = fibrous, Fc = fibrous matrix with spots of crystallinity. Fractions represent portion of crystalline area.
^cCracking in excess of 8% occurred on these plates as well as Army complete penetrations. All other failing plates failed on Army complete penetrations only.

TABLE III

Correlation Between Ballistic and Metallurgical Properties
of 1" Thick Cast Armor Shock Tested with 57 MM Proof Projectiles

<u>Required Velocity - 1000 ± 15 ft./sec.</u>		<u>Required Velocity - 1100 ± 15 ft./sec.</u>	
<u>Hardness of Plates</u>	<u>Hardness of Plates</u>	<u>Hardness of Plates</u>	<u>Hardness of Plates</u>
<u>Passing the Test</u>	<u>Failing the Test</u>	<u>Passing the Test</u>	<u>Failing the Test</u>
334	341	334	334
359	334	324	324
334	299	311	311
324		326	326
311		328	328
328		318	318
318		315	315
334		324	324
315		301	301
324		321	321
331			
301			
321			
Ave. - $\frac{326}{10}$ ± 10 BHN	Ave. - $\frac{325}{13}$ ± 13 BHN	Ave. - $\frac{340}{10}$ ± 10 BHN	Ave. - $\frac{320}{7}$ ± 7 BHN

TABLE III (Cont'd)

Required Velocity - 1000 ± 15 ft./sec.

Fibre Fracture Rating of Plates Passing the Test	Fibre Fracture Rating of Plates Failing the Test
F (shrinkage)	Fc 1/4
Cbf 1/2	Fc 1/8
Fc trace	F (shrinkage)
F (shrinkage)	
Fc 1/8	
F (shrinkage)	
F	
F	
F (shrinkage)	
Cbf 1/4	
Fc 1/8	
Fc trace	
F (shrinkage)	
F	

Required Velocity - 1100 ± 15 ft./sec.

Fibre Fracture Rating of Plates Passing the Test	Fibre Fracture Rating of Plates Failing the Test
F (shrinkage)	Fc trace
Cbf 1/2	F (shrinkage)
F (shrinkage)	Fc 1/8
Fc trace	F (shrinkage)
F	F
F	F
	Cbf 1/4
	Fc 1/8
	F (shrinkage)

F = fibrous.

Fc = fibrous matrix with scattered crystalline patches.

Cbf = Crystalline matrix with fibrous edges.

Fractions after rating refer to the amount of the fractured surface which is crystalline.

TABLE IV

Correlation between Ballistic and Metallurgical Properties
of 2" Thick Cast Armor Shock Tested with 105 MM Proof Projectiles

Required Velocity - 1000 ± 15 ft./sec.		Required Velocity - 1100 ± 15 ft./sec.	
Hardness of Plates Passing the Test	Hardness of Plates Failing the Test	Hardness of Plates Passing the Test	Hardness of Plates Failing the Test
264	253	264	264
264	253	253	255
253	265	264	250
255	272	248	Ave. - 256 ± 5 BHN
250	Ave. - 266 ± 13 BHN	Ave. - 257 ± 7 BHN	
264			
248			
Ave. - 257 ± 6 BHN			
V-Notch Charpy Impact at -40°F. of Plates Passing the Test - Ft.Lbs.		V-Notch Charpy Impact at -40°F. of Plates Failing the Test - Ft.Lbs.	
35.0	28.0	35.0	37.4
37.4	23.6	42.4	26.5
42.4	20.1	37.4	42.0
26.5	22.2	46.6	Ave. - 35.3 ± 5.9 ft.lbs.
42.0	Ave. - 23.5 ± 2.1 ft.lbs.	Ave. 40.4 ± 4.2 ft.lbs.	
37.4			
46.6			
Ave. - 38.2 ± 4.7 ft.lbs.			

TABLE IV (CONT'D)

Required Velocity - 1000 ± 15 ft./sec.

<u>Fibre Fracture Rating of Plates Passing the Test</u>	<u>Fibre Fracture Rating of Plates Failing the Test</u>
Fc 1/8	Fc 1/4
Fc 1/4	Fc 1/10
Fc trace	Fc 1/2
Fc 1/4	Fc 1/4 (slightly conchoidal)

Fc trace (shrinkage)

Fc trace

F (shrinkage)

Required Velocity - 1100 ± 15 ft./sec.

<u>Fibre Fracture Rating of Plates Passing the Test</u>	<u>Fibre Fracture Rating of Plates Failing the Test</u>
Fc 1/8	Fc 1/4
Fc trace	Fc 1/4
Fc trace	Fc trace (shrinkage)
F (shrinkage)	

//////////RESTRICTED//////////

C.D. Reg. No.
06-84-ME-0C

ARMOR BRANCH
ORDNANCE RESEARCH AND DEVELOPMENT CENTER
ABERDEEN PROVING GROUND, MARYLAND

SUBJECT: Development of a Shock
Test for 1" and 2"
Cast Armor.

Report No.: Ar-16646
Sheet 1 of 7
Date of Test: 6 July 1945
Related P.R. No.: AF-5453
Project No.: 2220 (113 Ar3-305)
References: OOM 470.5/APG
910 Feb 45)R SPOME-EE
APG 470.5/1161

OBJECT: To Obtain Shock Test
Data with the 105 mm
Proof Projectile on a
Total of Fifteen 2" Cast
Homogeneous Acceptance
Plates Received from
Gary Proof Range.

COMMENTS:

1. Fifteen 2" cast plates, received from Gary Proof Range after passing acceptance tests for penetration, were shock tested with 105 mm proof projectiles in order to obtain data to establish a required velocity for Specification AXS 492.

2. In this test, one round was placed near the center of the plate at a required velocity of 1100 fps (the velocity was corrected for thickness using a correction factor of 5 fps per .01" in thickness). If the plate withstood the impact without excessive cracking or was a Army partial penetration, a second round was fired at a velocity 100 fps higher. If the plate cracked or was a Army complete penetration as a result of the first impact, the second round was fired at a velocity 100 fps lower. Failure was considered to have occurred when cracking extended greater than 8-1/2" and/or Army complete penetration was obtained (light visible through impact).

3. A summary of this test is given on Sheet 2. A list of test facilities is given on Sheet 3. The detailed results are on Sheets 4 through 7.

4. This is the fourth report of test data on this project. Testing is completed and a formal report analyzing all results will be written.

APPROVED:

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

BY:
(s) C. J. YARGER, MAJ. OD
for STUART McLAIN
Lt. Col., Ord. Dept.
Acting Chief, Arms
& Amm'n Div.

(s/t) L.G. GRAPHER
T/4, Ord. Dept.
Proof Director

DISTRIBUTION:

Office, Chief of Ordnance-Detroit, Attn: SPOME-EE-----One Copy

//////////RESTRICTED//////////

COPY

RESTRICTED

1. Summary of Results:

Company	Plate No.	Heat No.	AVG. BHN	Required Velocity + 15 fps.		Result
				105 mm FP 78 - 0° Obliquity 1000 fps	1100 fps	
Continental Foundry & Mech. (E. Chi.)	08192-1 Sq B48	8192	259	Passed	Passed	Passed
	B2327-2 Sq B48	2327	266	Failed	Failed	Failed
	08227-2 Sq 064	8227	246	Passed	Passed	Passed
	08260-2 Sq 065	8260	266	Passed	Passed	Passed
American Steel Foundries (G)	B2256-1 Sq B46	2256	255	Passed	Failed	Passed
	0-7974-D-277	7526	251	Passed	Passed	Passed
" " " "	0-7974-D-256	7447	244	Passed	Passed	Passed
	0-7974-D-257	7454	245	Passed	Passed	Passed
	0-7974-D-266	7451	246	Passed	Passed	Passed
	0-7974-D-261	7463	242	Passed	Passed	Passed
Scullin Steel Co.	S-48	1-907	234	Passed	Failed	Passed
	S-50	1-915	232	Passed	Passed	Passed
	680	5-018	251	Passed	Failed	Failed
	681	5-023	248	Passed	Failed	Failed
"	682	2-177	250	Passed	Failed	Failed

*Cracking in excess of 2-1/2" was obtained on these plates as well as Army complete penetrations. All other plates that failed were on basis of Army complete penetrations only. Plate B48, submitted by Continental Foundry and Machine, broke into two pieces due to the second round on the plate.

RESTRICTED

COPY

//////RESTRICTED//////

Report No.: Ar-16646
Sheet 3 of 7

2. Test Facilities:

a. Guns Used:

Howitzer, Field, 105 mm, M2A1, No. 347, Mf'd by Vilter Mfg. Co.

b. Projectiles Used:

Projectile, Proof, TS, 105 mm, Mf'd by Frankford Arsenal,
Lot FA-N-100, Wt. 33.00 lbs.

//////RESTRICTED//////

COPY

||||| RESTRICTED |||||

Report No.: Ar-16647
Sheet 3 of 5

2. Test Facilities:

a. Guns Used:

Gun, A.T., 57 mm, M1, No. 726, Mf'd by American Type Founders.
Tube, A.T., 57 mm, M1, No. 1019, Mf'd by American Type Founders.

b. Projectiles Used:

Projectile, Proof, T1, 57 mm, Mf'd by Andover-Kent Co.,
Lot AK-3-1, Wt. 6.30 lbs.

||||| RESTRICTED |||||

COPY

RESTRICTED

1. Summary of Results:

1" Cast Homogeneous Armor
57 mm PP T1 - 0° Obliquity

Company	Plate No.	Heat No.	Avg. BHN	Required Velocity		Result
				500 fps	1000 fps	
ASF - Cast Armor Plant	026	3560	322	Passed	Failed*	Failed*
"	022	3540	326	Passed	Failed	Failed
Sivyer Steel (Chi.)	20B599	20B599	302	Passed	Passed	Passed
Scullin Steel Co.	48	3-333	286	Passed	Failed	Failed
"	49	5-020	290	Passed	Failed	Failed

*This plate failed due to excess cracking greater than 4-1/2" and Army complete penetration; all other plates failed because of Army complete penetrations (light visible through impact).

RESTRICTED

COPY

RESTRICTED

ABERDEEN PROVING GROUND, MARYLAND
ARMOR BRANCH

DATE OF FIRING 6 July 1945
ARMOR TEST REPORT NO. Ar-16647
SHEET 5 OF 5
RELATED F.R. NO. AP-5453

PLATE NO. HEAT NO. THICKNESS & TYPE

RD. NO.	PROJECTILE	OBLIQ.	AVG. THICK.	REQ. VEL.	ACT. S.V.	PP CP PTP	RESULTS - ARMOR AND PROJECTILE
	Scullin Steel	Co.					Plate No.: 49, Heat No.: 5-020, BHN 290
1.	57mm PP T1	0°	1.15	1120	1134	CP(A)	3", 3", 3", 2" Cracks, Mushroomed & Intact
2.	"	"	1.15	1020	1070	PP(A)	2", 2", 1-3/4" Cracks, Mushroomed & Intact

CP - Complete Penetration
PP - Partial Penetration
CIP - Core in Plate
PUN S - Punching started
BS - Back spall
FS - Face spall
SC - Star cracking
D - Disregard
C - Cratering
P - Petaling on face

PTP - Passed through plate
PIP - Projectile in plate
FPTP - Failed to pass through plate
ND - Nose destroyed
BD - Base destroyed
NI - Nose intact
BI - Base intact
PC - Partial cratering

COPY

LOG/dlf

////// RESTRICTED //

C.D. Reg. No.
06-84-NE-08

ARMOR BRANCH
ORDNANCE RESEARCH AND DEVELOPMENT CENTER
ABERDEEN PROVING GROUND, MARYLAND

SUBJECT: Development of a Shock
Test for 1" and 2" Cast
Armor.

OBJECT: To Obtain Shock Data
with the 57 mm Proof
Projectile on a Total
of Five 1" Cast Homogeneous
Plates Received from Gary
Proof Range.

Report No.: Ar-16647
Sheet 1 of 5
Date of Test: 6 July 1945
Related P.R. No.: AF-5453
Project No.: 2220 (113 Ar3-305)
References: OOM 470.5/APG
(10 Feb 45) RESPONSE-NE
APG 470.5/1161

COMMENTS:

1. Five 1" cast plates, received from Gary Proof Range after passing acceptance tests for penetration, were shock tested with the 57 mm proof projectile in order to obtain data to establish a required velocity for Specification AIS 492.
2. In this test, one round was placed near the center of the plate at a velocity of 1000 fps. The velocity was corrected for thickness using a correction factor of 8 fps per .01" in thickness. If the plate withstood the impact without cracking excessively or was a Army partial penetration, a second round was fired at a velocity 100 fps higher. If the plate cracked excessively or was a Army complete penetration on the first impact, the second round was fired at a velocity 100 fps lower. Failure was considered to have occurred when cracking extended greater than 4-1/2" (two calibers) and/or an Army complete penetration was obtained (light visible through impact).
3. A summary of this test is given on Sheet 2. A list of test facilities is given on Sheet 3. The detailed results are on Sheets 4 and 5.
4. This is the third report of firing data on this project. Testing will continue.

APPROVED:

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

BY:

(s) C. J. Yaeger, Maj. OD
for STUART McLAIN
Lt. Col., Ord. Dept.
Acting Chief, Arms &
Amm'n Div.

(s/t) L. G. GRAPER
T/4, Ord. Dept.
Proof Director

DISTRIBUTION:

Office, Chief of Ordnance-Detroit, Attn: SPOME-NE-----1 Copy

////// RESTRICTED //

COPY

////////// RESTRICTED //////////

ABERDEEN PROVING GROUND, MARYLAND
ARMOR BRANCH

DATE OF FIRING 6 July 1945
ARMOR TEST REPORT NO. AP-16646
SHEET 6 OF 7
RELATED F.R. NO. AP-5453
THICKNESS & TYPE

PLATE NO.

HEAT NO.

RD. NO.	PROJECTILE	ANGLE	AVG. THICK	REQ. VEL.	ACT. S.V.	PP CP PTP	RESULTS - ARMOR AND PROJECTILE
American Steel Foundries (G) Plate No.: G-7974-D-266, Heat No.: 7451, BHN 246							
1	105 mm PP T8	0°	2.04	1120	1126	PP(A)	Medium Bulge, No Cracking, Mushroomed and Intact
2	"	"	2.09	1245	1243	PP(A)	4 1/2", 2 1/2", 2" Cracks, Mushroomed and Intact
American Steel Foundries (G) Plate No.: G-7974-D-261, Heat No.: 7468, BHN 242							
1	105 mm PP T8	0°	2.00	1100	1119	PP(A)	Medium Bulge, No Cracking. Mushroomed and Intact
2	"	"	"	1200	1208	PP(A)	Large Bulge, 2 1/2", 2" Cracks. Mushroomed and Intact
Scullin Steel Co. Plate No.: S-48, Heat No.: 1-907, BHN 234							
1	105 mm PP T8	0°	1.92	1060	1064	CP(A)	5 1/2", 4 1/2", 3 1/2" Cracks, Mushroomed and Intact
2	"	"	"	960	947	PP(A)	2 1/2", 2-1/4" Cracks, Mushroomed and Intact
Scullin Steel Co. Plate No.: S-58, Heat No.: 1-915, BHN 232							
1	105 mm PP T8	0°	2.03	1115	1025	PP(A)	Medium Bulge, No Cracking, Mushroomed and Intact
2	"	"	"	1215	1200	PP(A)	Large Bulge, No Cracking, Mushroomed and Intact

CP - Complete Penetration
FP - Partial Penetration
CIP - Core in plate
PUN S - Punching started
BS - Back spall
FS - Face spall
SC - Star cracking
D - Disregard
C - Cratering
P - Petaling on face

PTP - Passed through plate
PIP - Projectile in plate
FPTP - Failed to pass through plate.
ND - Nose destroyed
BD - Base destroyed
NI - Nose intact
BI - Base intact
PC - Partial cratering

////////// RESTRICTED //////////