UNCLASSIFIED

AD NUMBER
ADB279562
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution: Further dissemination only as directed by Office of Scientific Research and Development, Washington, DC 20301, MAR 1943, or higher DoD authority.**
AUTHORITY
OTS index dtd Jun 1947

THIS PAGE IS UNCLASSIFIED

NDRC A-156

OSRD 1301

[redacted]

Classification ~~cancelled or changed to:~~ [illegible]

OTS

Initials of Officer making the change:

DoB/JBK

NATIONAL DEFENSE RESEARCH COMMITTEE

ARMOR AND ORDNANCE REPORT NO. A-156

DIVISION 2

BALLISTIC TESTS OF STS ARMOR PLATE, USING 37-mm PROJECTILES

DISTRIBUTION STATEMENT F: MAR 1943
Further dissemination only as directed by OSRD, WASHINGTON, DC or higher DoD authority. R0330

by

The Ballistic Research Group

Princeton University

[redacted]

Copy No. 48

NDRC A-156

[redacted]

UNCLASSIFIED

NATIONAL DEFENSE RESEARCH COMMITTEE

ARMOR AND ORDNANCE REPORT NO. A-156

DIVISION 2

BALLISTIC TESTS OF STS ARMOR PLATE, USING 37-mm PROJECTILES

by

The Ballistic Research Group

Princeton University

Approved on March 2, 1943
for submission to the Division Chief

Walker Bleakney
Walker Bleakney, Head
Princeton Research Station

Approved on March 8, 1943
for submission to the Committee

John E. Burchard
John E. Burchard, Chief
Division 2
Structural Defense and Offense

[redacted]

UNCLASSIFIED

Preface

The work described in this report is pertinent to the projects designated by the War Department Liaison Officer as CE-5 and CE-6, to the project designated by the Navy Department Liaison Officer as NO-11 and to Division 2 projects P2-101 and P2-402.

The work was initiated by H. P. Robertson. The main series of tests herein reported was performed by the group headed by L. A. Delsasso, the experiments being carried out by R. J. Emrich. The auxiliary tests at Palmer Physical Laboratory were performed by R. L. Kramer. The computations were carried out under the direction of, and this report was written by, R. J. Slutz, Technical Aide, Division 2. The experiments were performed under Contract OEMsr-260 with Princeton University.

The technical reports section of NDRC Divisions 1 to 4 -- Armor and Ordnance -- edited this report and prepared it for duplication.

Distribution of copies of this report. -- The initial distribution was as follows:

Nos. 1 to 24, inclusive, to the Office of the Secretary of the Committee for distribution in the usual manner;

No. 25 to R. C. Tolman, Vice Chairman, NDRC;

No. 26 to R. Adams, Member, NDRC;

No. 27 to F. B. Jewett, Member, NDRC;

No. 28 to J. E. Burchard, Chief, Division 2;

No. 29 to W. Bleakney, Deputy Chief, Division 2;

No. 30 to W. F. Davidson, Office of the Chairman, NDRC;

No. 31 to R. A. Beth, Member, Division 2;

No. 32 to H. L. Bowman, Member, Division 2;

No. 33 to C. W. Curtis, Member, Division 2;

No. 34 to C. W. Lampson, Member, Division 2;

No. 35 to W. E. Lawson, Member, Division 2;

No. 36 to H. P. Robertson, Member, Division 2;

No. 37 to F. Seitz, Jr., Member, Division 2;

No. 38 to A. H. Taub, Member, Division 2;

No. 39 to E. B. Wilson, Jr., Member, Division 2;

Nos. 40 and 41 to R. J. Slutz, Technical Aide, Division 2;

Nos. 42 and 43 to the Office of the Chief of the Army Air Forces (Attention: Brig. Gen. B. W. Chidlaw, Brig. Gen. E. L. Eubank);

No. 44 to the Office of the Chief of Engineers (Attention: Lt. Col. F. S. Besson, Jr.);

No. 45 to the Office of the Chief of Ordnance (Attention: Col. S. B. Ritchie);

No. 46 to the Office of the Chief of Engineers (Attention: Lt. Col. S. B. Smith, Construction Division, Operations Branch);

No. 47 to Watertown Arsenal (Attention: Col. H. H. Zornig);

No. 48 to Aberdeen Proving Ground (Attention: Col. L. E. Simon);

No. 49 to the Office of the Chief of Ordnance (Attention: S. Feltman);

Nos. 50 and 51 to Aberdeen Proving Ground (Attention: R. H. Kent, O. Veblen);

No. 52 to the U.S. Naval Proving Ground, Dahlgren (Attention: Lt. Comdr. R. A. Sawyer);

Nos. 53 and 54 to the Office of the Chief of the Bureau of Ordnance (Attention: Lt. Comdr. T. J. Flynn, A. Wertheimer);

No. 55 to the David Taylor Model Basin (Attention: Comdr. W. P. Roop);

No. 56 to the Office of the Chief of the Bureau of Yards and Docks (Attention: Capt. C. A. Trexel);

No. 57 to the Naval Research Laboratory (Attention: R. Gunn);

No. 58 to the Office of the Chief of the Bureau of Ordnance (Attention: Capt. G. L. Schuyler);

No. 59 to P. W. Bridgman, Consultant, Division 2;

No. 60 to D. S. Clark, Consultant, Division 2.

CONTENTS

List of Figures

BALLISTIC TESTS OF STS ARMOR PLATE, USING 37-mm PROJECTILES

Abstract

Data are reported concerning the ballistic limit of STS armor -- Brinell hardness 270 -- for 37-mm projectiles (M51 without cap and windshield). Armor plates of thicknesses from $\frac{1}{2}$ to 2 in. were used. Auxiliary tests with smaller caliber projectiles are also included; these tests were made on plates down to $\frac{1}{4}$ in. thick.

1. Introduction

The ballistic limit of armor plate will be affected not only by the characteristics of the plate, but also by those of the incident projectile. Thus a given plate might be impervious to a highly frangible projectile, whereas it would be holed at the same velocity by another projectile having the same characteristics as the first except for being less brittle. It is customary in proof testing of armor to specify that the armor will fail for a given projectile at a given velocity. The shattering characteristics of the projectile may be one of the factors determining the performance.

In studying the physical bases of the behavior of armor plate it is desirable to separate the factors influencing this behavior in so far as it is practicable. Accordingly, one of the projects undertaken by the Ballistic Research Group at Princeton University is that of determining the ballistic limit of plate for nondeforming projectiles. A previous report[1/] presented the results of measurements

---

1/ Ballistic Research Group, Princeton University, The ballistic properties of mild steel, NDRC Report A-111 (OSRD No. 1027).

made on mild steel at normal impact, using a wide range of projectile diameters and of thickness of plate. The present report is a record of an extension of that work to include measurements of the ballistic limit of STS plate for normal incidence by 37-mm projectiles. The study of the behavior of such plate at oblique incidence is at present delayed by a lack of 37-mm projectiles that will withstand such impact without shattering. Instead of waiting for the completion of the work at oblique incidence, we are reporting the data at present available for the information of those who are working on related problems. No attempt is made here to incorporate the data into a general physical theory of the behavior of armor; this report is a record of the carefully measured data needed for such a theory.

2. Plates

The armor tested consists of a series of STS plates obtained through the cooperation of the Naval Proving Ground at Dahlgren, Virginia. The plates are approximately 30 in. square and have thicknesses from $\frac{1}{4}$ to 2 in. They were especially selected to have very nearly the same hardnesses, as shown in Table I. The $\frac{1}{4}$-in. and 3/8-in. plates were taken from plates that had previously, at the Naval Proving Ground, passed acceptance tests against caliber .30 armor-piercing projectiles at 0° obliquity, and the remainder from plates that had passed acceptance tests against 6-in. or 8-in. projectiles at high obliquity.

Table I. Properties of plates tested. Tensile tests conducted at the Naval Proving Ground; Brinell hardness readings taken at Princeton.

Plate Number	Nominal Thickness (in.)	Yield Point ($lb/in.^2$)	Tensile Strength ($lb/in.^2$)	Elongation (percent)	Reduction of Area (percent)	Brinell Hardness Number
D-1	$\frac{1}{4}$	133 100	141 500	19.0	50.8	294
D-2	3/8	122 300	144 000	18.5	54	283
D-3	5/8	110 800	125 500	22	67	264
D-4	1	106 900	127 200	21	61	272
D-5	$1\frac{1}{4}$	107 300	129 300	22	62	257
D-6	$1\frac{1}{2}$	106 300	125 800	22	63	271
D-7	2	107 500	130 500	22	65	289

3. Experimental conditions

The main series of tests was made with standard 37-mm M51 projectiles from which the cap, windshield and tracer had been removed for the reasons discussed in detail in the report on mild steel.[2/] Certain auxiliary tests were also made, using caliber .244 smoothbore projectiles, Type 1, and caliber .50 E6 projectiles. These projectiles are also discussed in detail in the report on mild steel.

The 37-mm and caliber .50 tests were made at the NDRC range.[3/] The plates were hung with cables attached to the top corners; hence they can be considered as freely suspended. The residual velocity of the projectile was measured by a light-screen chronograph having a 1-ft base line.[4/] The striking velocity was measured both with a

2/ Reference 1.

3/ H. D. Smyth, Construction of the NDRC experimental firing range at Princeton University, NDRC Report A-6 (OSRD No. 10).

4/ R. J. Emrich and L. A. Delsasso, Short base line projectile velocity measurements, NDRC Report A-89 (OSRD No. 927).

spiral chronograph using 1-ft base-line light screens close to the plate and with an Aberdeen chronograph utilizing foil screens on a 50-ft base. The velocity measured by the Aberdeen chronograph was corrected for the loss of velocity between the screens and the target plate. This corrected value was then averaged with the value obtained from the light-screen chronograph to give the striking velocity of the projectile. The caliber .244 tests were made on the double ballistic pendulum in Palmer Physical Laboratory,[5/] using clamped 6 × 6-in. pieces cut from the larger plates.

In accordance with the method described in reference 1 on mild steel, the observed data were used to compute striking energy, residual energy, limit energy, Thompson F-coefficients, and so forth. In computing the striking and residual energies of a projectile it is customary to use the weight of the projectile as recovered after firing. This practice amounts to neglecting the energy of any soft parts of the projectile -- such as bands -- that shear off on impact. In this series of experiments, however, the projectiles shattered with sufficient frequency to make it necessary to use a different method in some cases. For the projectiles that shattered, then, the weight to be used in calculating the kinetic energies was determined by taking the projectile weight before firing and correcting according to the average loss of weight observed in the projectiles that did not shatter.

5/ G. T. Reynolds and R. L. Kramer, A double pendulum for use in studies of the ballistic behavior of armor, NDRC Report A-52 (OSRD No. 686).

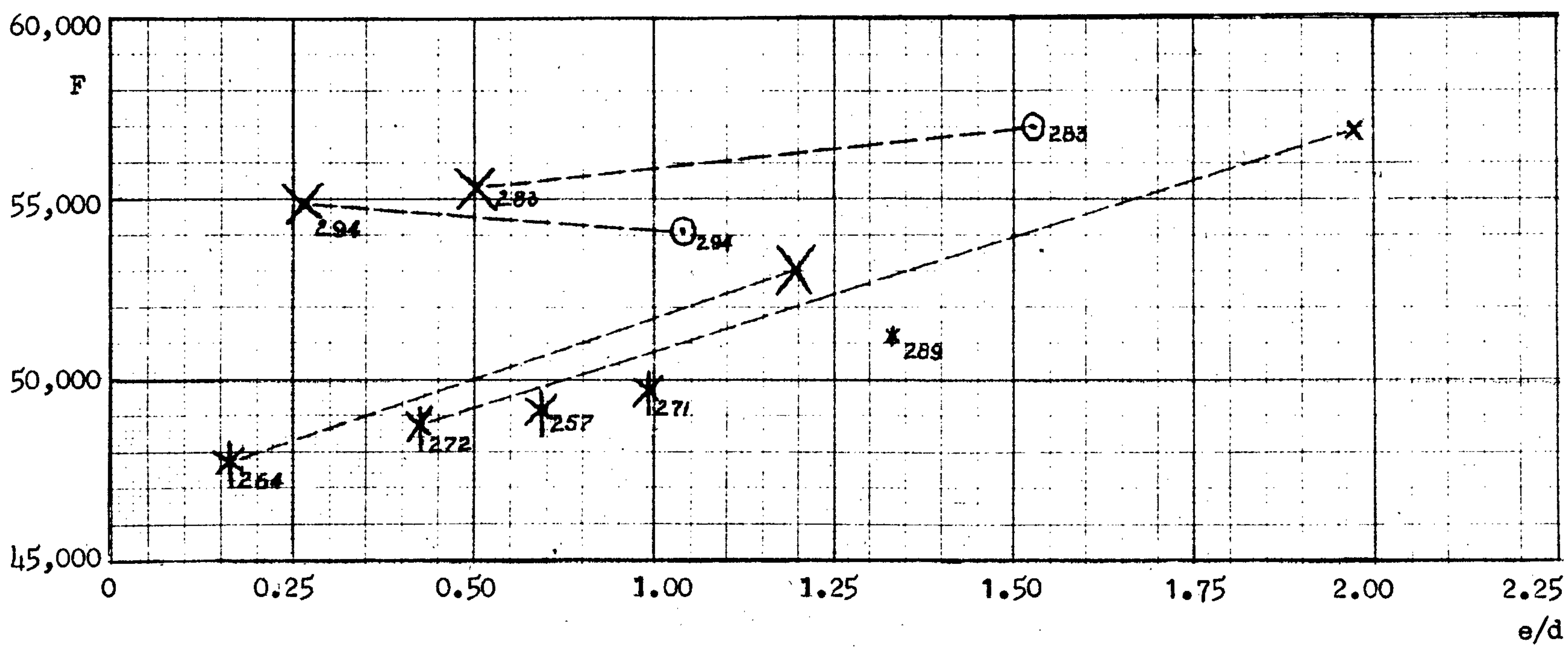

Fig. 1. Thompson F-coefficient versus e/d, where e is plate thickness and d is projectile diameter. ⊙, caliber .244 smoothbore cores, X, caliber .50 E6 and ✳, 37-mm AP M51. Numbers by the symbols indicate the Brinell hardness of the plate. Small symbols indicate less reliable data. Data taken from the same plate are connected by dashed lines. Data for the main series of tests are indicated by ✳.

4. Results

The results obtained are presented in Table II, and plotted in Fig. 1, which gives the results of the main series of tests and also the auxiliary results obtained. This figure is plotted to the same scale as was used in reference 1, thus facilitating comparison. The Brinell hardness number of each plate is indicated beside the point giving the ballistic limit.

The quantities listed in Table II are discussed in reference 1. Brief definitions of the symbols follow:

- e Average plate thickness.
- w Average projectile weight as recovered after firing.
- d Projectile diameter.
- E_l Limit energy, that is, the energy for which the residual energy is zero.
- P Average pressure between projectile and plate.
- v_l Limit velocity, associated with limit energy.
- F Thompson F-coefficient; $F = \sqrt{w/e}\, v_l/d$.
- a Parameter related to P by

$$a = P\frac{\gamma w'}{w}\left(e^{\frac{\gamma w'}{w}} - 1\right)^{-1}.$$

- w' Weight of a cylinder of diameter d and height e cut out of the target plate of thickness e.
- s Slope of the graph of residual versus striking energy.
- γ Dimensionless parameter related to s by the equation,

$$s = e^{-\gamma w'/w}.$$

5. Discussion

Attempts to obtain satisfactory data for the ballistic limit of 37-mm projectiles on the two thinnest plates proved fruitless.

For the $\frac{1}{4}$-in. plate, projectiles having high velocity were observed to lose approximately the amount of kinetic energy that would

Table II. **Ballistic data for STS plates.**

Plate			Projectile		Energy		Velocity		Poncelet Parameters			No. of Shots[a]	Quality[b]
No.	B_H (kg/mm²)	e (in.)	w (gm)	e/d	E_l (ft lb)	P (10^3 lb/in.²)	V_l (ft/sec)	F (10^3 units)	a (kg/mm²)	s	γ		
Caliber .244 smoothbore cores, d, 0.244 in. (Type 1 of reference 1)													
D-1	294	0.255	5.252	1.04	399	402	1 490[c]	54.1	279	0.972	0.10	4	G
D-2	283	.373	5.258	1.53	650	447	1 900	57.0	305	.944	.14	4	G
Caliber .50 E6, d, 0.495 in. (Type 20 of reference 1)													
D-1	294	0.254	29.45	0.512	1 680	412	1 289	54.8	-	1.020	-	4	G
D-2	283	.372	29.85	.751	2 504	420	1 565	55.3	294	0.992	0.03	4	G
D-3	264	.596	29.02	1.20	3 696	387	1 928	53.0	265	.949	.10	4	F
D-4	272	.978	29.02	1.976	6 965	444	2 647	56.9	-	1[d]	-	2	P
37-mm, d, 1.448 in. (Type 23 of reference 1)													
D-3	264	0.596	754.2	0.411	25 500	312	994	47.7	-	1.009	-	4	G
D-4	272	.976	755.6	.674	43 720	326	1 300	48.7	-	1.023	-	5	G
D-5	257	1.223	756.4	.844	55 600	332	1 465	49.1	229	0.968	0.09	5	F
D-6	271	1.435	759.8	.991	66 900	340	1 603	49.7	235	.966	.09	5	G
D-7	289	1.932	728.9[e]	1.334	95 700	361	1 957	51.2	247	.948	.10	2	P

[a] The number of shots used in reduction of data.

[b] G, good; F, fair; P, poor.

[c] Bullets slightly blunted.

[d] Value s = 1, assumed.

[e] Projectile weight taken without band.

caliber .244 data, but also because of the scale effect, which would indicate that even for the same value of e/d the smaller caliber projectiles would have larger F-coefficients. We have no satisfactory explanation of this result, but more recent work indicates that the hardness of these plates is in the vicinity of the "hardness limit," above which is observed a decided drop in the ballistic limit of a plate. If the hardness at which this effect occurs were different for the different calibers, this might possibly serve as an explanation of the apparent discrepancy. More considerations along this line must wait for further experimentation. In any case, it will be seen that the remainder of the data are in definite agreement with the observations reported in reference 1, both in the dependence of the F-coefficient on the ratio e/d and in its dependence on the scale of the experiment.

The main series of tests -- using 37-mm projectiles -- is plotted in Fig. 1, the points being indicated by stars. It will be seen that these tests gave the customary slight increase of F with increase in the ratio e/d. The bullets were found to shatter with increasing frequency as the thickness of the plate was increased, until on the thickest plate -- 2-in. -- only 2 out of 10 shots gave acceptable measurements of both the striking and residual velocities. The F-coefficient for this plate is indicated by a small star in order to indicate that its value is somewhat less reliable than the values for the thinner plates.

Data taken with caliber .50 projectiles on the 5/8-in. and 1-in. plates are also shown in Fig. 1. For these projectiles on the

~~CONFIDENTIAL~~

TITLE: Ballistic Tests of STS Armor Plate, Using 37-MM Projectiles

U

ATI-	25200
REVISION	(None)
ORIG. AGENCY NO.	(None)
PUBLISHING AGENCY NO.	OSRD-1311

AUTHOR(S): (Not known)

ORIGINATING AGENCY: Princeton Univ., Princeton, N. J.

PUBLISHED BY: Office of Scientific Research and Development, NDRC, Div 2

DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
March '43	Conf'l	U.S.	Eng.	14	tables, graph

ABSTRACT:

Tests were conducted on the ballistic limits of STS armor plate of 270 Brinell hardness and varying from 1/2 to 2 in. in thickness for 37 mm projectiles (M51 without cap and windshield). The tests with 37 mm ammunition gave the customary slight increase in the Thompson F-coefficient with increase in the ratio of average plate thickness over projectile diameter. The bullets were found to shatter with increasing frequency as the thickness of the plate was increased. Detailed data obtained from tests are given in graphs and tables. Auxiliary tests with smaller caliber projectiles were also made on plates down to 1/4 in. thick.

DISTRIBUTION: Copies of this report obtainable from Air Documents Division; Attn: MCIDXD

DIVISION: Ordnance and Armament (~~22~~) 22

SECTION: Armor (~~5~~) 2

SUBJECT HEADINGS: Armor plate - Gunfire resistance (11455); Armor plate - Penetration theory (11503)

ATI SHEET NO.: C-22-5-2

R5

~~Declassified per Auth: List from~~
~~E. A. Albrecht, Tech. Aide, NDRC Div. 15.~~
~~by ... dtd 1 Aug. 1949.~~

R5

[illegible]

CLASSIFICATION CHANGED

TO Unclassified

AUTH OSRD LIST #33 dated 9-27 Sept 1946.

BY George R Jordan, USCO

DATE JUL 25 1950