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Rolled Armor Report No. 44 Regraded *Declassified* by Auth
of C. O. Watertown Arsenal
in compliance w/Par 25, AR
390-5, dtd 6 June 1952

Watertown Arsenal

May 6, 1942

1 Dec 1952
date

W. A. Woods
W. A. Woods
Sec Adm

Types of Failure Occurring in the Shock Test of

1/2" Homogeneous Armor with Caliber .50 A.P. Projectiles

INTRODUCTION

This investigation was carried out in an effort to obtain information which may be of assistance to the armor manufacturers in overcoming the difficulty being encountered with large exit holes and back spalls on 1/2" homogeneous armor impacted with caliber .50 A.P. projectiles at high velocities.

Samples of several pieces of 1/2" homogeneous armor, all low in alloy content, were selected in the three hardness levels of 320, 360, and 388 Brinell. Armor rolled from induction furnace heats and having a minimum of nonmetallic inclusions and segregation was used as one type, and a steel of commercial quality and rolled straight-away from large ingots was utilized as the second type. Each plate was impacted with caliber .50 A.P. projectiles at approximately 2550 f/s and 2300 f/s striking velocities.

TEST PROCEDURE

Projectiles were fired at each plate with powder charges calculated to give 2550 and 2300 f/s striking velocities. The actual velocities were measured by means of the Aberdeen Chronograph.

The projectile core, back spalls, and other material which were rejected on the back side of the plate were caught in a cylindrical pipe section filled with sand. The jacket and other material rejected on the front of the plates were entrapped in a cylindrical, corrugated pipe section with a small aperture through which the projectile passed before impact.

The plates were sectioned in the longitudinal direction of the original ingot through the exact center of the penetration. The sections were then macroetched and photographed together with the

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material which passed through the plate and the material rejected from the face of the plate.

The following tabulation shows the chemistries and other details of the plates used:

Plate No.	Chemistry					Brinell	Figure No.
	C	Mn	Cr	Mo	Zr		
203	.28	.68	.69	.15	.06	320	1
657-2	.33	.57	-	.47	-	320	2
1000	.34	.63	.71	.19	.11	360	3
656-2	.35	.51	-	.48	-	352	4
900	.34	.63	.71	.19	.11	388	5
200	.28	.68	.69	.15	.06	388	6
656-1	.35	.51	-	.48	-	388	7

All the above plates were water quenched from 1600-1650°F and drawn to the Brinell hardnesses shown.

DISCUSSION

Difficulty is being experienced in the development of the new, low alloy armor compositions in meeting the shock test requirements specified for $\frac{1}{2}$ " homogeneous armor. The machine gun burst of caliber .50 APM1 projectiles fired at service velocity (2550 f/s approximate striking velocity) produces one of two types of failure which result in large exit diameters. In the first type of failure back spalls are formed which are of considerable size and produce a nonacceptable plate. This condition is most generally encountered in the hardness range from 340 Brinell up, which is most common for this thickness of material.

The second type of failure results when in an effort to avoid back spalling, the hardness is lowered to 310-330 Brinell and a conical exit hole is formed with large punchings being rejected from the back of the plate. Under these conditions the exit holes may or may not be acceptable under the two-caliber exit hole allowance. In any event, however, the punching type of failure is to be avoided because of the material rejected from the back of the plate and because at the 320 Brinell hardness level the margin of excess on ballistic limit is low and the plate is not heat treated to be most effective in defeating projectiles of the caliber which it is expected to resist.

Consideration of Figures 1 and 6 indicates that the two types of failure (punching shown in Figure 1 and back spalls illustrated in Figure 6) are associated with the high impact velocity and the resulting jacket effect. In both cases with a lowering of striking velocity to 2300 f/s, the jacket, in its entirety essentially, is rejected from the face of the plate and a small exit hole results. With the soft plate, there is a tendency for the jacket to "ball up" on its way through the plate and influence the formation of the punching. This condition is apparently a manifestation of the lower shear strength of the softer material.

Examination of Figure 6 shows that shear failure produced by the jacket effect is also a factor in the failure of the high hardness plate by back spalling. Apparently the tip of the core starts a back spall which decreases the effective plate thickness. Then the jacket proceeds to initiate shear failure in the remaining thickness and in doing so greatly enlarges the size of the back spall.

Reference to Figures 3 and 4 shows the satisfactory results obtained on both the induction furnace steel and the commercial quality steel at the hardness level of approximately 360 Brinell.

With respect to steel cleanliness, it will be noted that throughout the hardness series the comparatively clean and less segregated induction furnace steel gives satisfactory results when the commercial steel fails except at the 360 Brinell hardness level. A comparison of Figures 5 and 6, which illustrate the effect upon two pieces of commercial quality steel at the same hardness level, demonstrates that whether or not back spalling will result is dependent upon the degree of uncleanliness in the steel. Study of the macroetched sections reveals that Plate 900 is somewhat cleaner than Plate 200.

The general types of failures discussed above have been verified repeatedly at this arsenal recently during the testing of development and acceptance plates of $\frac{1}{2}$ " homogeneous, low alloy armor. At hardnesses of 310-340 Brinell the punching type of failure has been very common. At high hardnesses, namely 370-390 Brinell, back spalling has been common, but does not occur in all cases dependent upon steel cleanliness. Evidence obtained to date indicates that the optimum hardness range for this thickness of material is 350-370 Brinell.

CONCLUSIONS

1. With a given cleanliness condition in a $\frac{1}{2}$ " homogeneous armor, the most satisfactory hardness range appears to be 350-370 Brinell. At this hardness level less trouble with back spalling and large exit holes is experienced.

2. A steel may be sufficiently dirty so that under no conditions can satisfactory shock properties be obtained coincident with a satisfactory ballistic limit.

3. With a clean steel, properly cross rolled, a larger spread in hardness can be expected to be satisfactory with respect to back spalling tendencies.

4. The punching type of failure is undesirable and to be further avoided in that it is associated with soft plate which is relatively inferior with respect to ballistic limit.

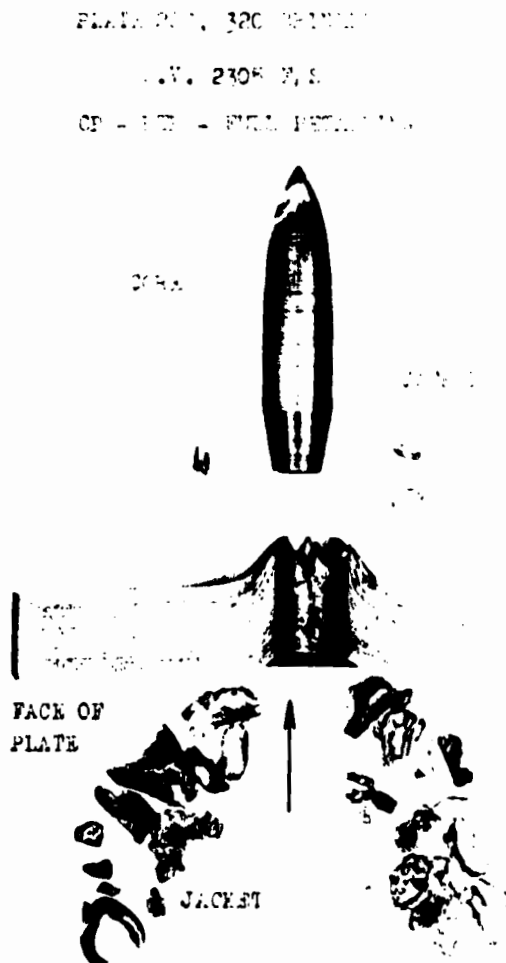
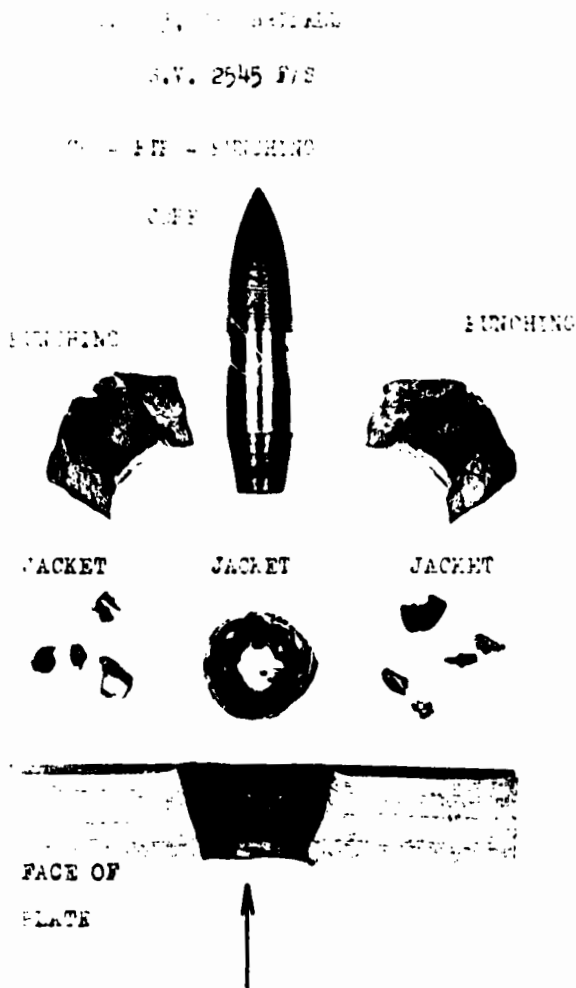
N. A. Matthews

N. A. MATTHEWS,
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Secretary, Subcommittee
for Rolled Armor.

G. L. COX,
Major, Ord. Dept.,
Acting Chairman, Subcommittee
for Rolled Armor.

FIGURE 1

COMMERCIAL STEEL QUALITY
LOW ABILITY HOMOGENEOUS (1) APMS



CALIBER .50 AP M2 PROJECTILES
MEASURED STRIKING VELOCITIES

FIGURE 2
INDUCTION FURNACE STEEL
LOW ALLOY HOMOGENEOUS 1/2" ARMOR

PLATE 657-2, 320 BRINELL

S.V. 2535 F/S

CP - PTP - FULL PETALLING

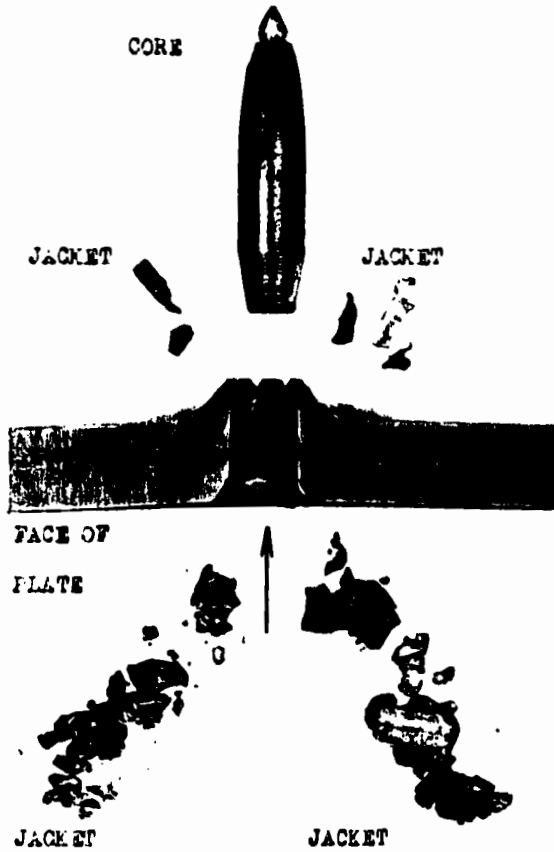
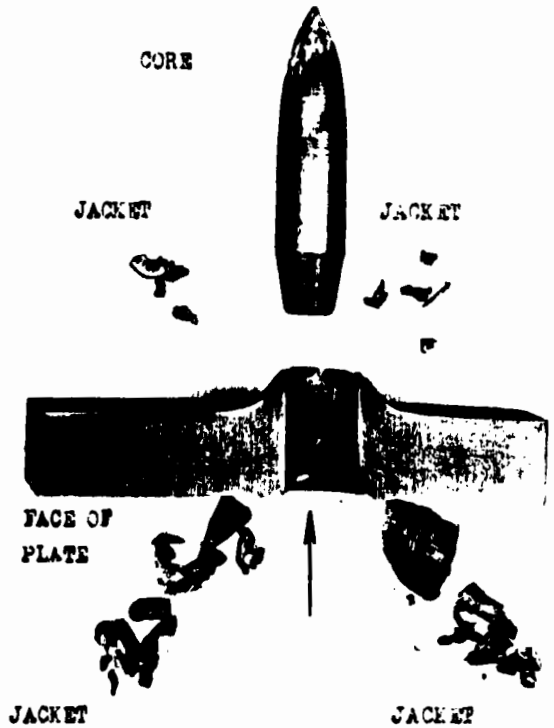


PLATE 657-2, 320 BRINELL

S.V. 2323 F/S

CP - PTP - FULL PETALLING



CALIBER .50 A.P. M2 PROJECTILES
MEASURED STRIKING VELOCITIES

FIGURE 5
COMMERCIAL STEEL QUALITY
LOW ALLOY HOMOGENEOUS 1/2" ARMOR

PLATE 1000, 360 BRINELL

S.V. 2535 F/S

CP - PTP - FULL PETALLING

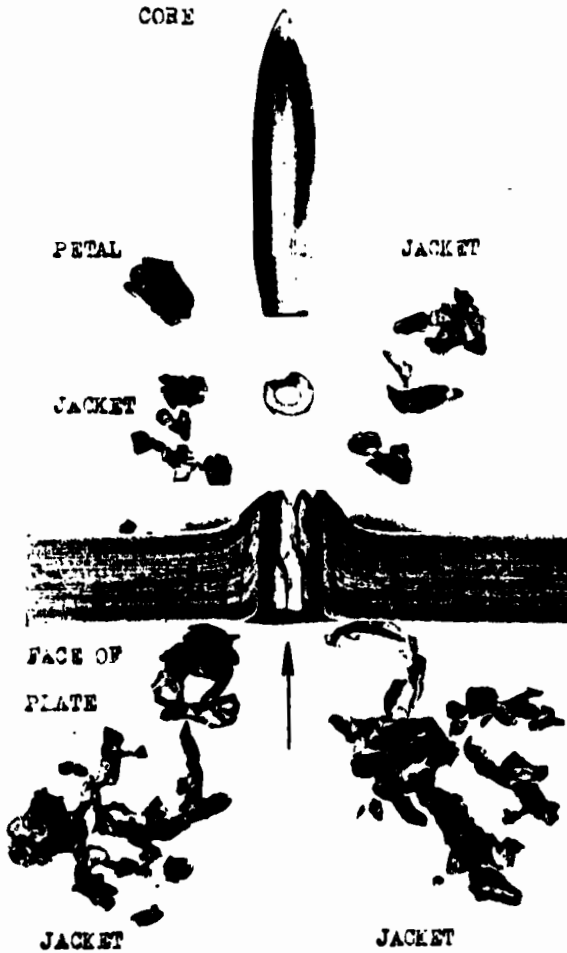
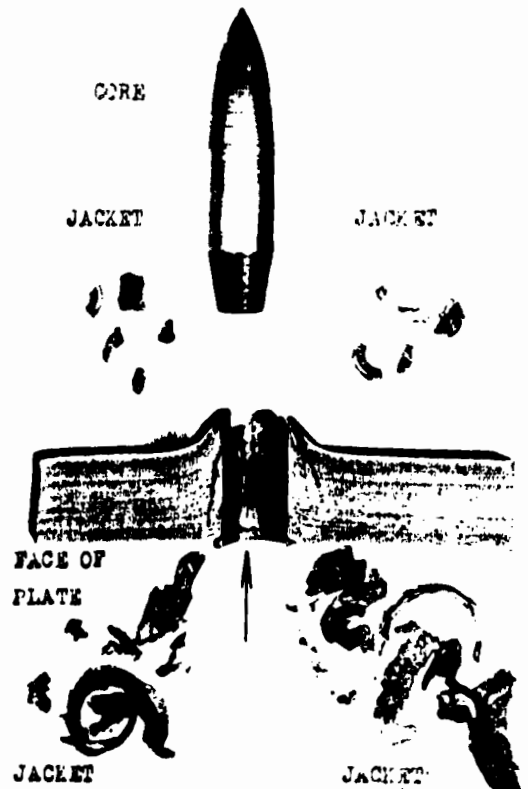


PLATE 1000, 360 BRINELL

S.V. 2320 F/S

CP - PTP - FULL PETALLING



CALIBER .50 A.P. M2 PROJECTILES
MEASURED STRIKING VELOCITIES

FIGURE 1.

INDUCTION FURNACE STEEL
LOW ALLOY HOMOGENEOUS 3/8" ARMOR

PLATE 656-2, 352 BRINELL

S.V. 2535 F/S

CP - PTP - FULL PETALLING

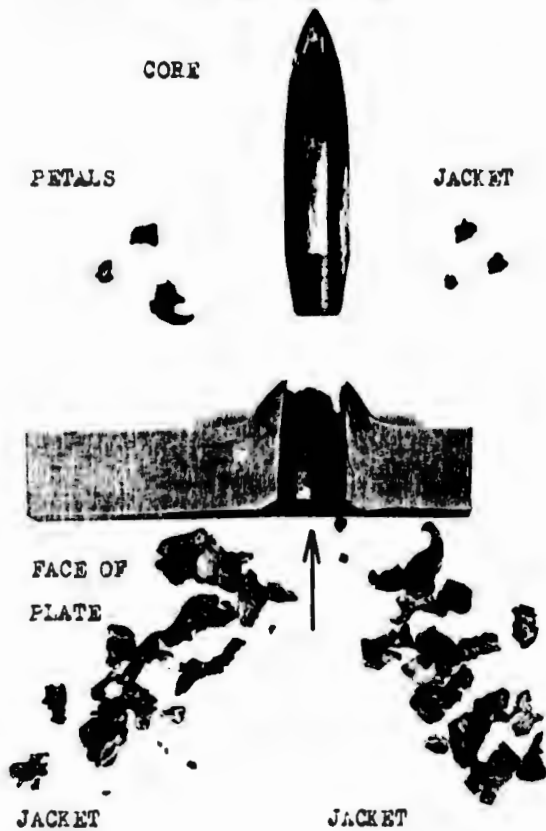
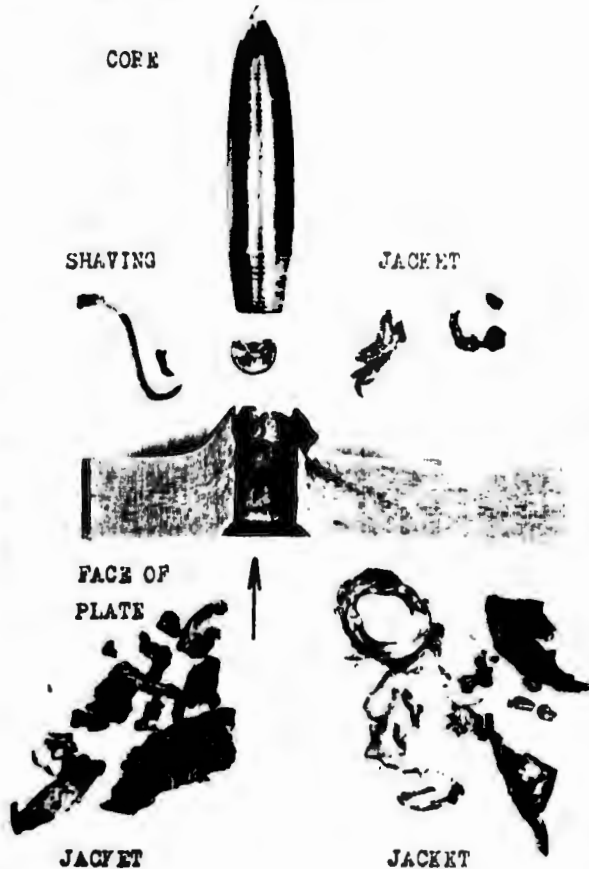


PLATE 656-2, 352 BRINELL

S.V. 2298 F/S

CP - PTP - FULL PETALLING



CALIBER .50 A.P. M2 PROJECTILES
MEASURED STRIKING VELOCITIES

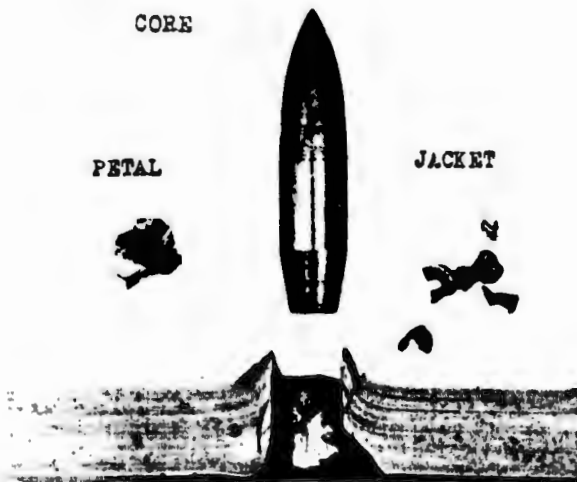
FIGURE 5
COMMERCIAL STEEL QUALITY
LOW ALLOY HOMOGENEOUS 1/2" ARMOR

PLATE 900, 388 BRINELL

S.V. 2535 F/S

CP - PTP - PETALLING

CORE



FACE OF
PLATE



JACKET



FACE SPALL



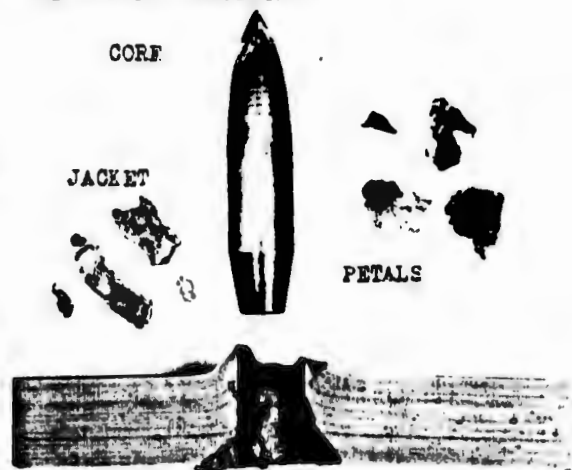
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PLATE 900, 388 BRINELL

S.V. 2285 F/S

CP - PTP - PETALLING

CORE



FACE OF
PLATE



JACKET



FACE SPALL



JACKET

CALIBER .50 A.P. M2 PROJECTILES
MEASURED STRIKING VELOCITIES

FIGURE 6
COMMERCIAL STEEL QUALITY
LOW ALLOY HOMOGENEOUS 1/2" ARMOR

PLATE 200, 388 BRINELL

S.V. 2550 F/S

CF - PTP - BACK SPALL 1 1/2" x 1-1/4"

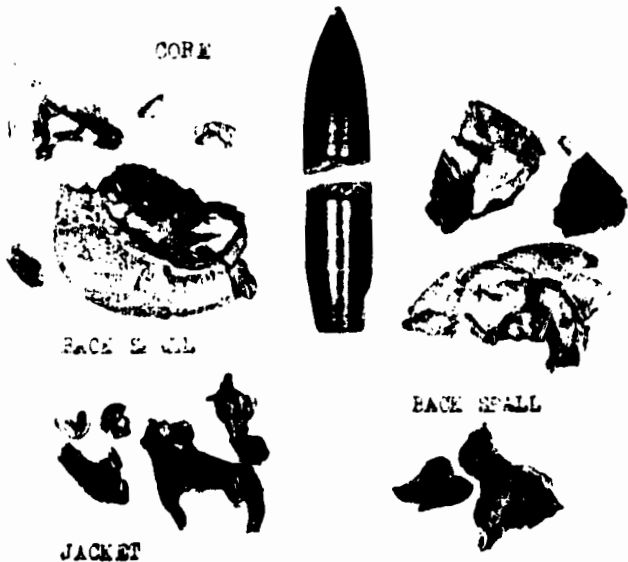
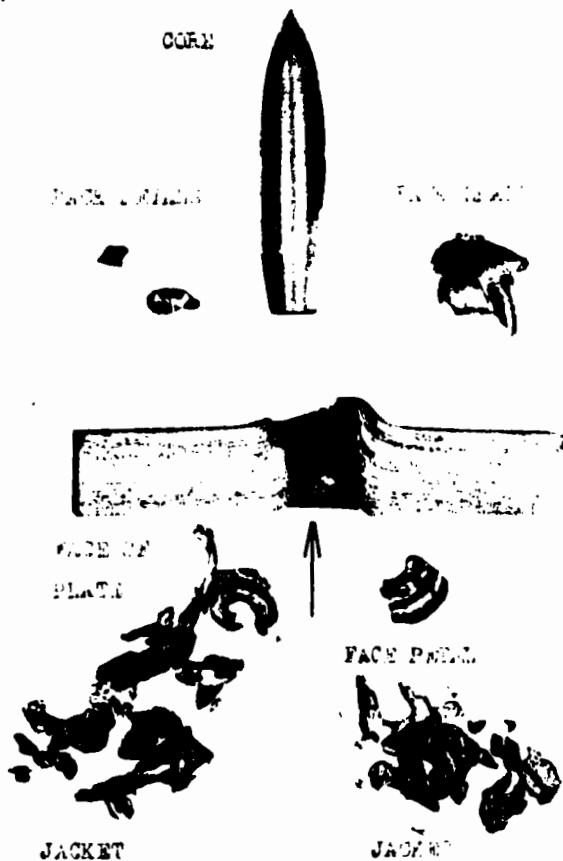


PLATE 200, 388 BRINELL

S.V. 2700 F/S

CF - PTP - BACK SPALL 1 1/2" x 1-1/4"



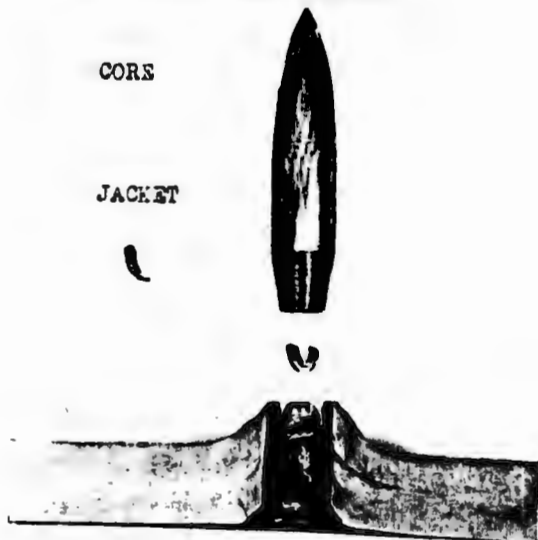
CALIBER .50 A.P. M2 PROJECTILES
MEASURED STRIKING VELOCITIES

FIGURE 7
INDUCTION FURNACE STEEL
LOW ALLOY HOMOGENEOUS 1/2" ARMOR

PLATE 656-1, 388 BRINELL

S.V. 2545 F/S

CP - PTP - FULL PETALLING



FACE OF
PLATE

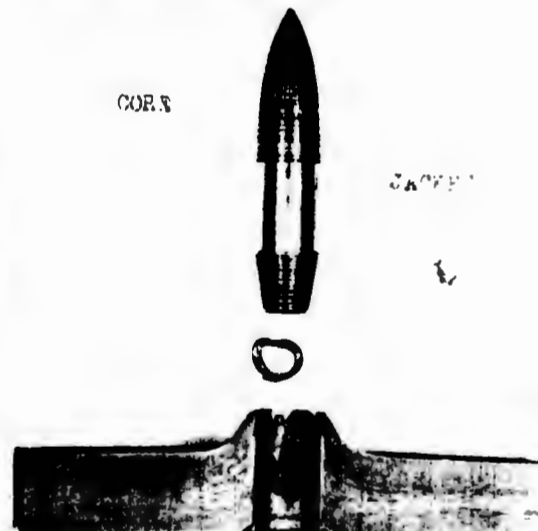
JACKET

JACKET

PLATE 656-2, 387 BRINELL

S.V. 2238 F/S

CP - PTP - FULL PETALLING



FACE OF
PLATE

JACKET

JACKET

CALIBER .50 A.P. M2 PROJECTILES
MEASURED STRIKING VELOCITIES