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REPORT R-1177

PENETRATION PERFORMANCE vs PROJECTILE NOSE HARDNESS

PROJECT TAI-5002

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OBJECT

To investigate the effect of projectile nose hardness upon penetration performance.

SUMMARY

Projectile penetration performance was investigated as a function of projectile nose hardness. The 20 mm model of the 90 mm AP M318 (T33) monobloc steel shot was tested for four different Rockwell C hardnesses (63 to 64, 61 to 62, 56 and 49). These hardnesses were obtained by tempering at 250°, 350°, 550°, and 800° F, respectively. Targets investigated included: 3/4 inch (0.95 caliber) plate at 55° and 60° obliquities, 7/8 inch (1.11 caliber) plate at 20°, 30° and 55° obliquities and 1 1/8 inch (1.43 caliber) plate at 20° and 30° obliquities. Protection ballistic limits of each one of these homogeneous armor targets were compared for the four shot hardnesses.

For shattering projectiles in the hardness range of 56 to 64 Rockwell C there were no significant differences among the various ballistic limits. The main effect of hardness was to alter the velocity at which shatter occurred, which made softer shot less effective against certain targets. Hard shot provided a low and a high ballistic limit for certain low obliquity targets, whereas soft shot provided only the high ballistic limit. The softer intact shot in the 56 to 64 Rc range were slightly inferior to the hardest intact shot presumably because the softer shot deformed more and required more energy to defeat the same targets. Shot as soft as 49 Rockwell C generally were quite inferior to the harder shot against overmatching targets at low and high obliquities. Shot hardness was more critical for overmatching low obliquity targets than for matching high obliquity targets.

AUTHORIZATION

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INTRODUCTION

Since World War II, conventional armor piercing shot developed for attack of tank armor have generally been as hard as reasonably possible (60 to 64 Rc). Shot of high hardness are more resistant to deformation and shatter than soft shot and better for the defeat of overmatching armor plate at low and intermediate obliquities. However, some of the current tank targets, which consist of matching and undermatching armor at high (55° to 70°) obliquities, have on occasion been defeated as easily and sometimes even more easily with soft (55 Rc) shot than with very hard shot. For these conditions of attack it is more desirable for the shot to deform and shatter early in the penetration process than to remain intact and tend to ricochet. By shattering, the shot punch through the armor and eject plugs. In order to investigate this situation more thoroughly, the subject firings were conducted.

MATERIALS AND METHODS

Projectile Type and Composition

The 20 mm model of the 90 mm monobloc AP M318 (T33) shot was used in these firings. A picture and drawing of this shot are included in Figures 1 and 2. All shot (Lot 2165) were machined from 13/16 inch diameter bar stock of one heat of manganese molybdenum (MnMo, Fed Spec 57-107-33) steel. Each shot weighed approximately 1800 grains. The composition is listed in Table I.

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Figure 1. 20 mm model of 90 mm AP M318 (T33) shot

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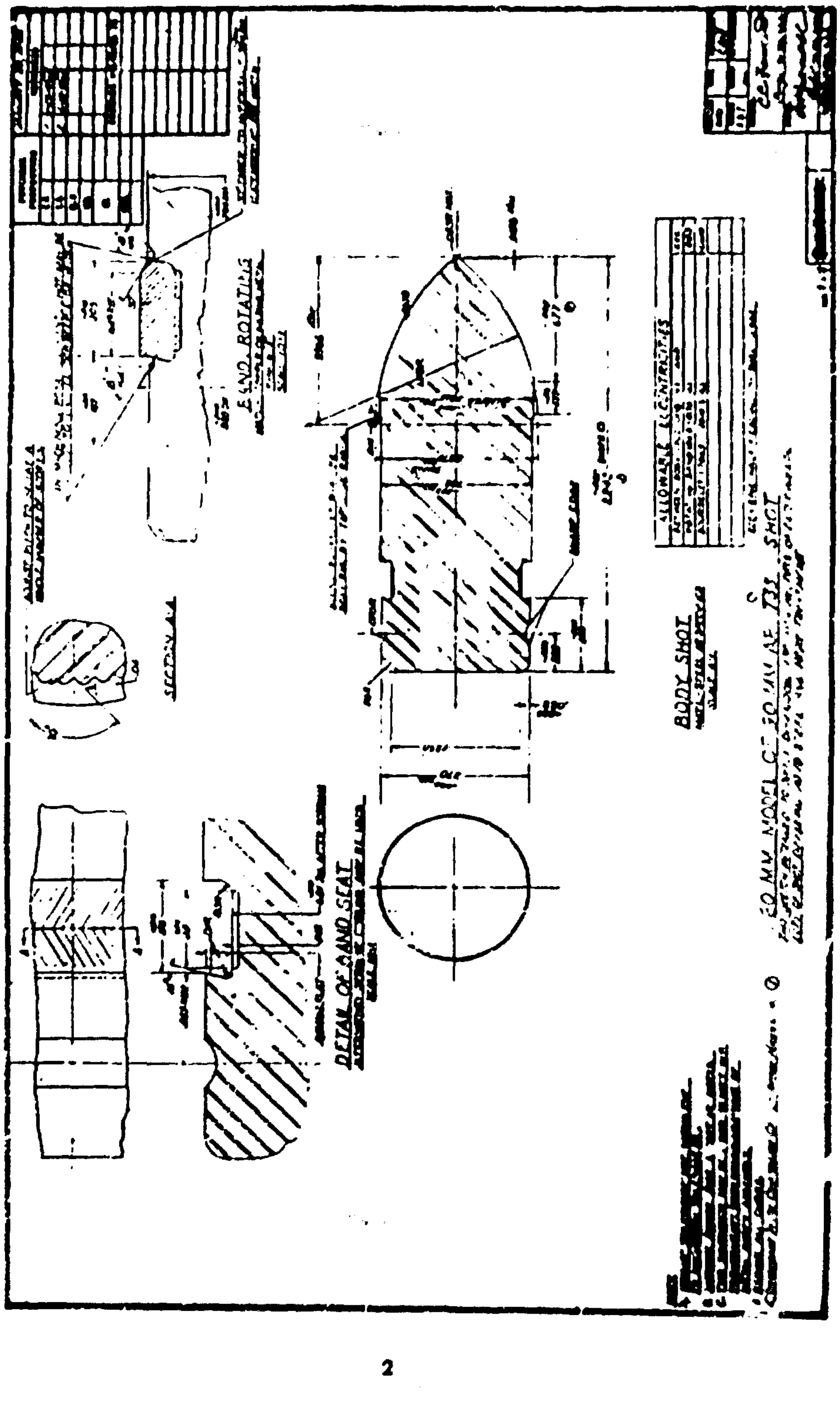

Figure 2. Detail drawing of 20 mm model of 90 mm AP M318 (T33) shot

Table I. Per Cent Composition

C	Mn	Mo	P	S	Si	Ni	Cr	V
0.74	0.90	1.04	0.02	0.04	0.33	0.05	0.15	0.02

Heat Treatment

All shot were austenitized in salt at 1550° F and quenched into brine. After dividing them into four groups, one group was tempered at 250° F, one at 350° F, one at 550° F and one at 800° F. All shot were then base tempered by induction. These treatments produced tempered martensitic structures. Hardness patterns for the various tempering temperatures are included in Figure 3.

Plate

All firings were conducted against rolled homogeneous armor. The various plate thicknesses, hardnesses and obliquities are included in summary Table II. Plates of different hardnesses were chosen for the 3/4 inch- and 7/8 inch-plate firings at high obliquity to investigate the effect of shot hardness more thoroughly.

Firing

A 20 mm Mann type barrel chambered for the T20 (.60/20 mm) case was used for all firings. For velocities in excess of 3000 fps a special chamber extension was screwed onto the above barrel to accommodate a two piece, double length case. The distance from the muzzle to the plate was 215 feet. Velocities were measured on counter chronographs actuated by three pairs of solenoids, the base line centers of which were 32, 87 and 132 feet from the plate. Three pairs of solenoids were used in order to correct the measured velocities to actual striking velocities.

Evaluation

Protection ballistic limits were used as a criterion for comparing the penetration performance of the various shot groups. Most of the limits were obtained by averaging the velocities of the highest partial and lowest complete penetrations of each group of firings. For firings where a zone of mixed partial and complete penetrations occurred the ballistic limit was obtained by averaging the velocities in the zone. Limited firings were conducted for some test conditions so that more conditions could be

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250° F	350° F	550° F	800° F
63.5	61.5	56.0	46.8
63.5	61.5	55.3	48.8
63.8	61.7	56.0	49.0
63.9	61.3	56.0	48.8
63.8	61.5	55.9	48.8
63.9	61.0	[illegible]	48.8
63.8	61.5	55.8	48.8
63.8	61.5	56.[illegible]	49.2
63.5	61.5	56.0	49.0
63.0	61.2	56.0	49.0
62.8	61.5	56.0	49.0
63.1	61.7	56.0	49.0
[illegible]	[illegible]	56.0	49.0
63.3	60.5	56.0	49.0
62.8	61.0	56.2	49.2
62.8	61.0	55.0	48.8
61.3	61.0	56.1	49.2
59.9	60.2	56.0	49.0
58.0	59.0	56.1	49.2
55.8	57.1	56.1	49.2
53.1	54.9	55.8	49.2
52.[illegible]	52.8	53.0	48.9
50.2	50.9	50.1	47.8
47.0	49.0	48.0	46.2
46.0	47.3	47.2	[illegible]
45.2	46.5	46.0	44.0

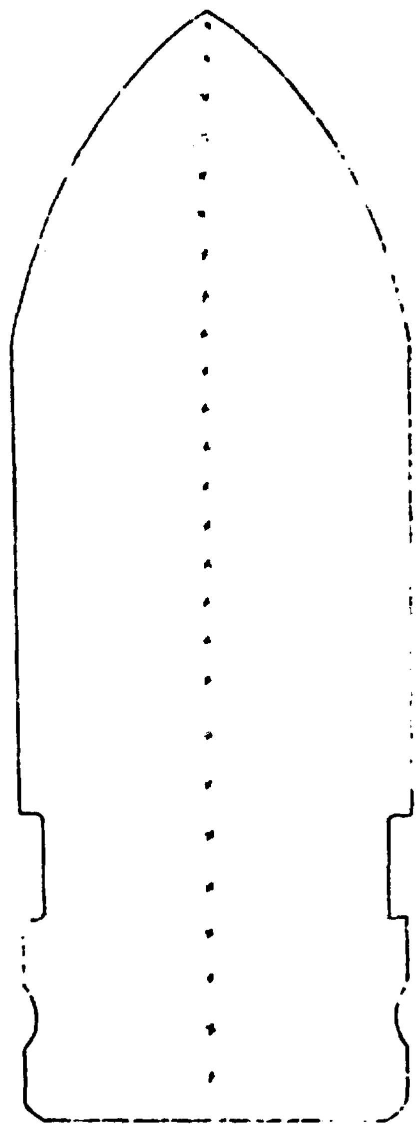

Figure 3. Rockwell C hardness patterns at center of shot for various tempering temperatures.

Table II. Summary - Protection Ballistic Limit Variation with Projectile Nose Hardness of 20 mm AP T33 (Lot 2165)

Plate Thickness (in.)	Plate Thickness (cal)	Plate Hardness (Bhn)	Obliquity (deg)	PBL vs Projectile Hardness (Rc) 63 - 64 (Temp at 250° F)	61 - 62 (Temp at 350° F)	56 (Temp at 550° F)	49 (Temp at 800° F)
3/4	0.95	352-356	60	2915*(Sh)	3025*(Sh)	2790*(Sh)	299[illegible] (Sh)
3/4	0.95	293-302	55	2980 (Sh)	>2980 (Sh)	2965 (Sh)	3020 (Sh)
7/8	1.11	[illegible]	55	3355 (Sh)	3300 (Sh)	3275 (Sh)	3620 (Sh)
7/8	1.11	293-302	30	2165*(Fr) 2670 (Sh)	2260*(I) 2640 (Sh)	2635 (Sh)	2740 (Sh)
7/8	1.11	293-302	20	1930 (I) (CP to 2800)	2055 (I)	2185 (I) 2515*(Sh)	2610 (Sh)
1 1/8	1.43	321-331	30	3335 (Sh)	3320 (Sh)	3260 (Sh)	>3565 (Sh)
1 1/8	1.43	321-331	20	2405 (I) 3050 (Sh)	2505 (I) 3225 (Sh)	3000 (Sh)	34[illegible]0 (Sh)

*Approximate protection ballistic limits
>Greater than
See Appendix for abbreviations

investigated. For the majority of ballistic limits the velocity difference between the highest partial and the lowest complete penetrations was less than 50 feet per second. All projectiles were recovered in plywood and were examined for the extent of deformation and failure. A description of the recovered projectile for each round is included in the Appendix.

RESULTS and DISCUSSION

Table II summarizes the protection ballistic limits for each projectile hardness group and for each target condition investigated. The condition of the recovered projectile at each ballistic limit velocity is also included. Figures 4 to 10, inclusive, represent plots of all rounds fired for the four tempering temperatures as a function of striking velocity. The protection ballistic limit for each target condition is indicated between the partial and complete penetration velocities along with the condition (intact or shattered) of each recovered shot.

It may be noted that for shattered shot, generally, there were no significant differences in ballistic limits for shot in the hardness range of 56 to 64 Rockwell C. Some of the results seem to indicate that the softer shot were slightly superior to the hardest shot for conditions where both shattered in defeating the plate. For the 3/4 inch (0.95 caliber) plate firings the softest (49 Rc) shot were practically as efficient as the hardest (63 to 64 Rc) shot. Since conventional shot shatter in defeating high obliquity matching and slightly undermatching plates which usually fail by means of punching or plugging, these targets are not particularly sensitive to shot contour and hardness. However, for the thicker, overmatching plates at high and low obliquities, the softest shot were much inferior to the harder ones. Furthermore, ballistic limits obtained with intact soft shot were slightly higher than those obtained with intact hard shot because the softer ones presumably deformed more and required more velocity and energy to defeat the same targets. To defeat these targets the shot must push the plate material aside during most of the penetration.

The differences among the ballistic limits of the harder 3/4- and 7/8-inch plates at 60° and 55° obliquities generally were no greater for the various nose hardnesses than those of plates of lower hardness. Furthermore, the limits of the hard 3/4-inch plate at 60° obliquity were practically equal to those of the softer plate at 55° because punchings or plugs were ejected more easily from the hard plate than from the softer plate. Ordinarily, for plates of the same thickness and hardness, 60° obliquity targets are more difficult to defeat with conventional shot than 55° targets.

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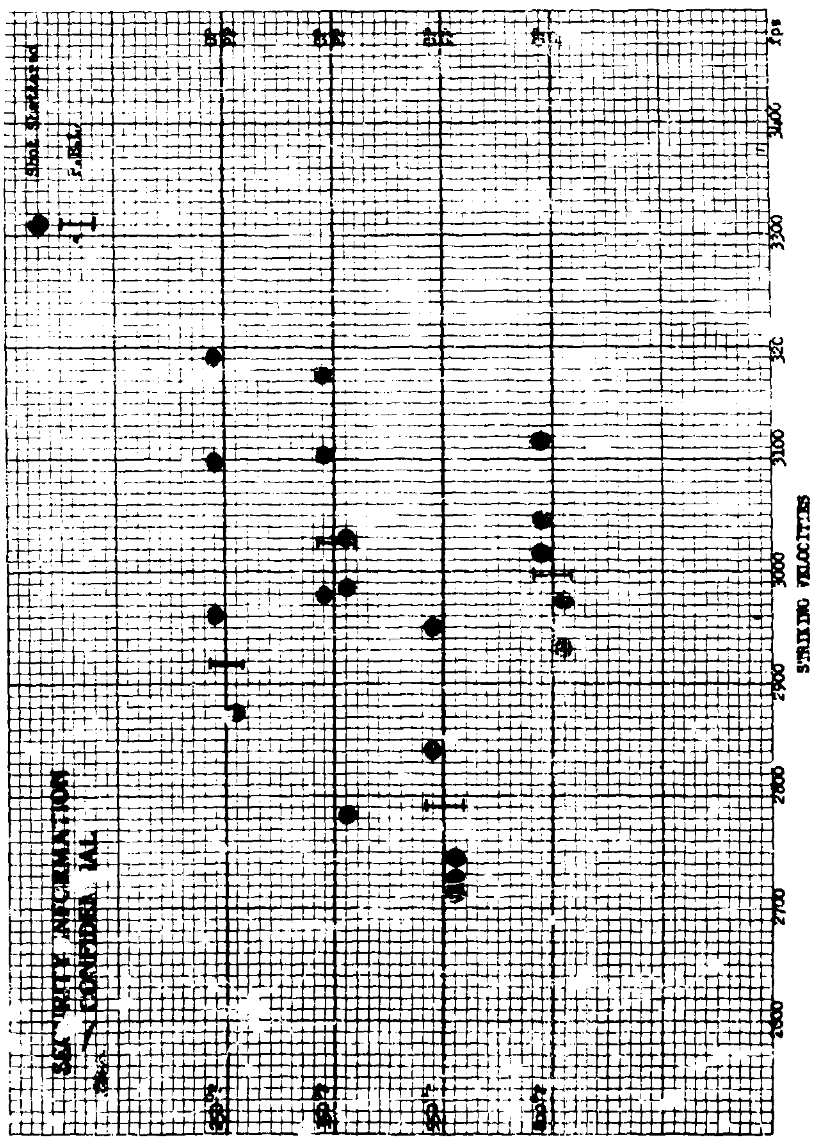

Figure 4. Rounds of various tempering temperatures vs 3/4 inch 352-356 Bhn) plate at 60° obliquity

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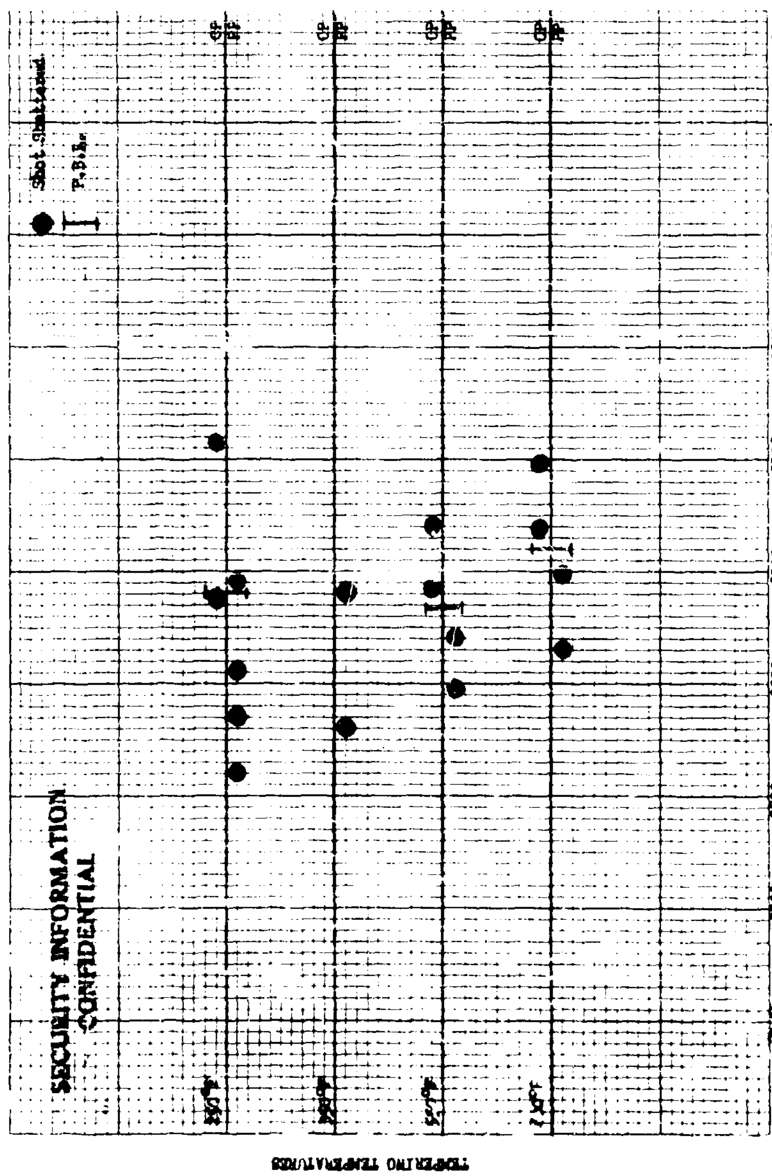

Figure 5. Rounds of various tempering temperatures vs 3/4 inch (293-302 Bhn) plate at 55° obliquity

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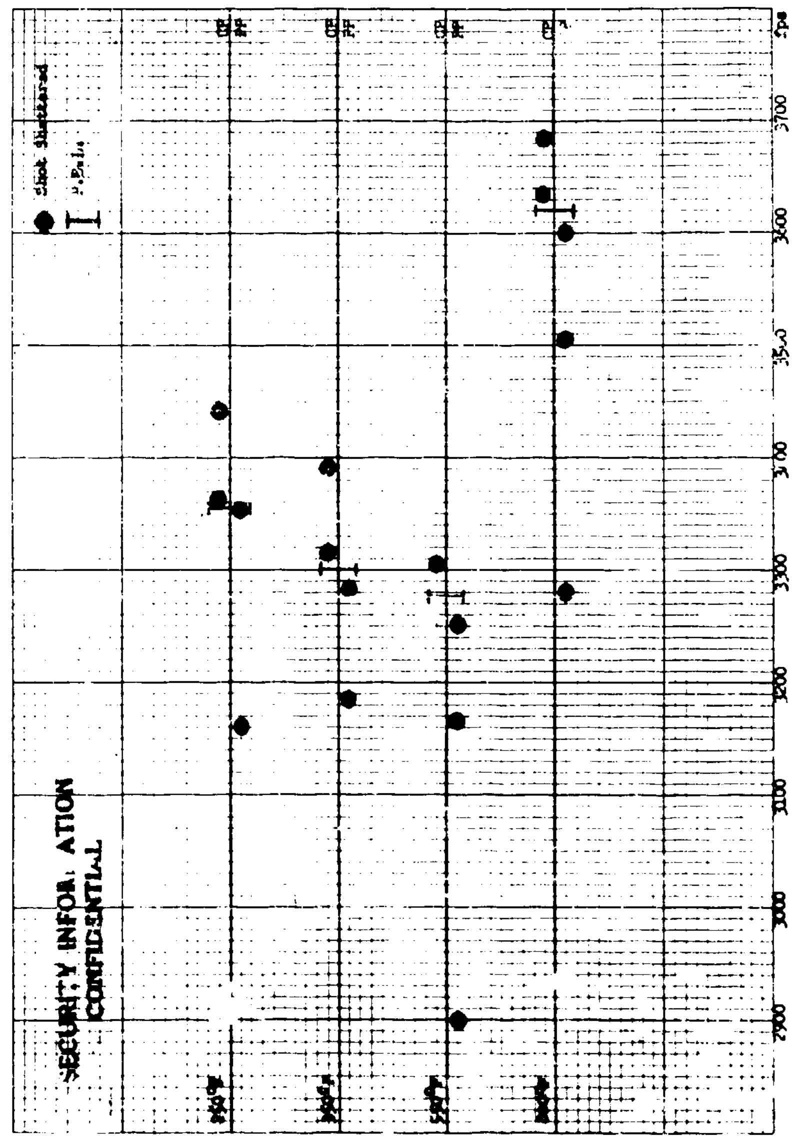

Figure 6. Rounds of various tempering temperatures vs 7/8 inch (429 Bhn) plate at 55° obliquity

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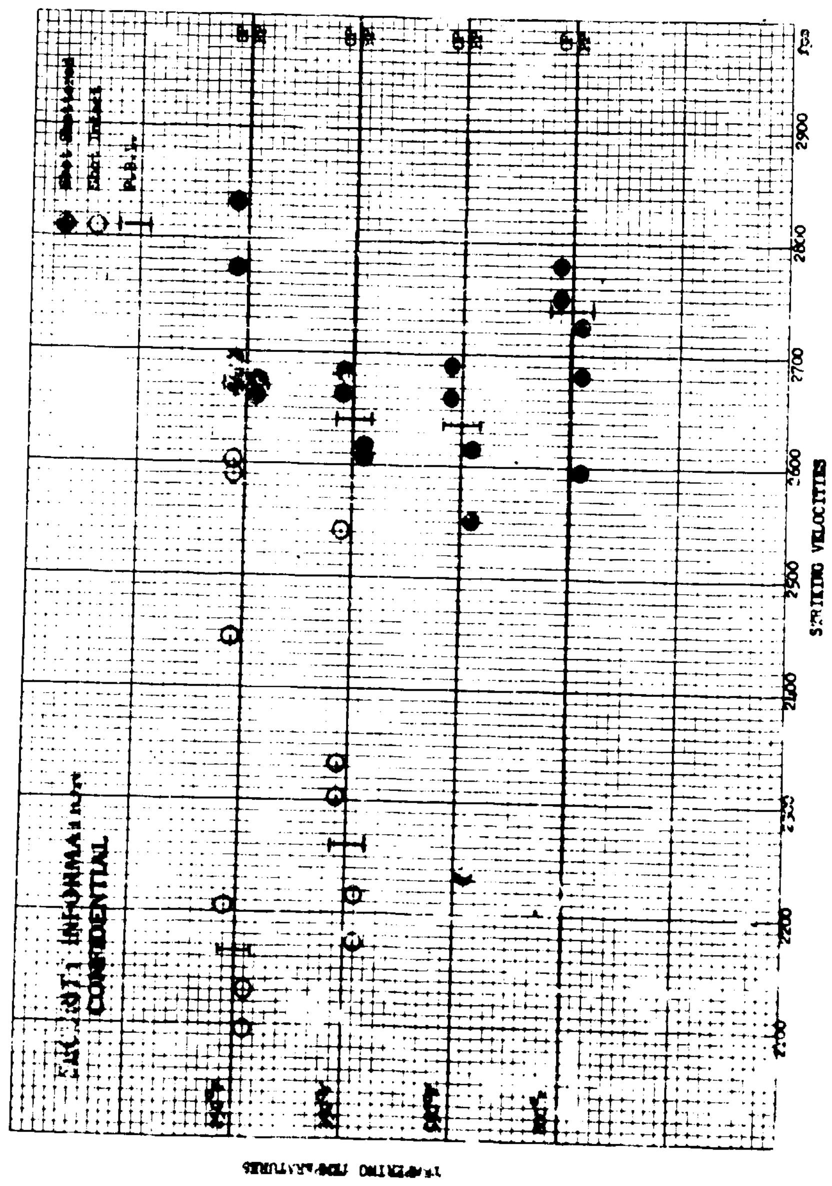

Figure 7. Rounds of various tempering temperatures vs 7/8 inch (293-302 Bhn) plate at 30° obliquity

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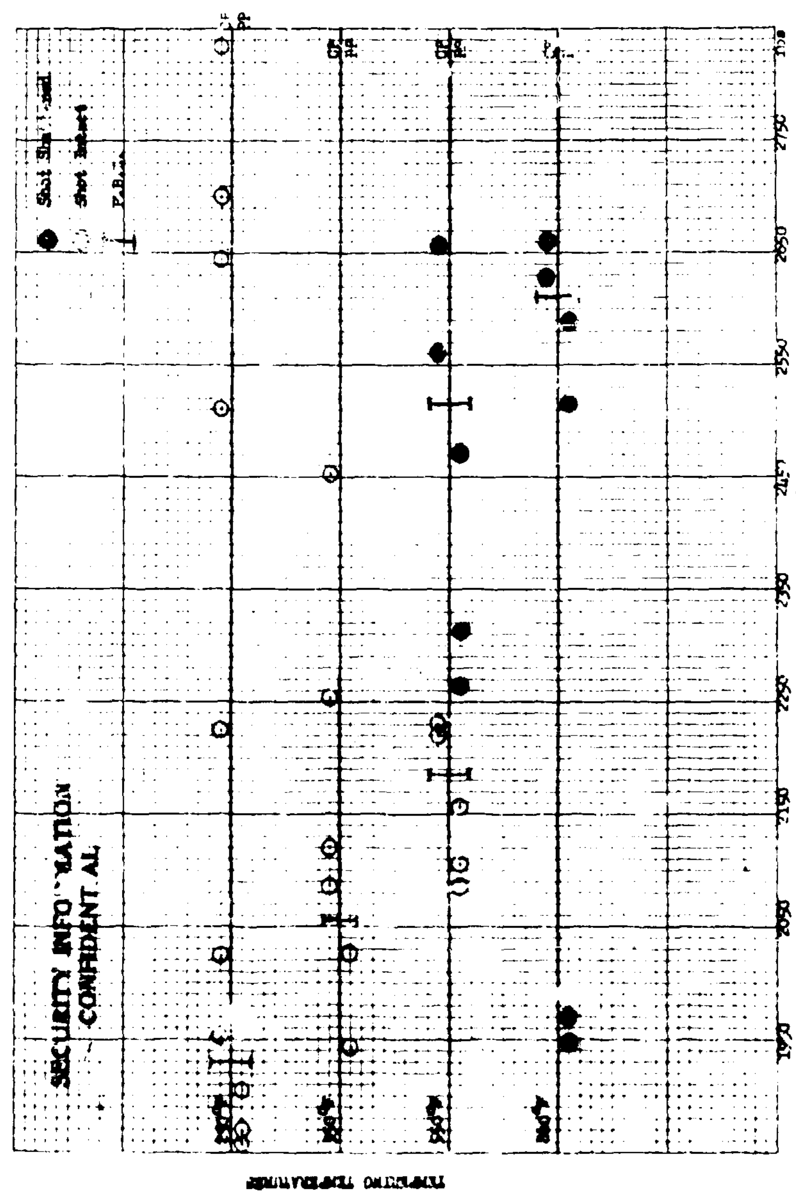

Figure 8. Rounds of various tempering temperatures vs 7/8 inch (293-302 Bhn) plate at 20° obliquity

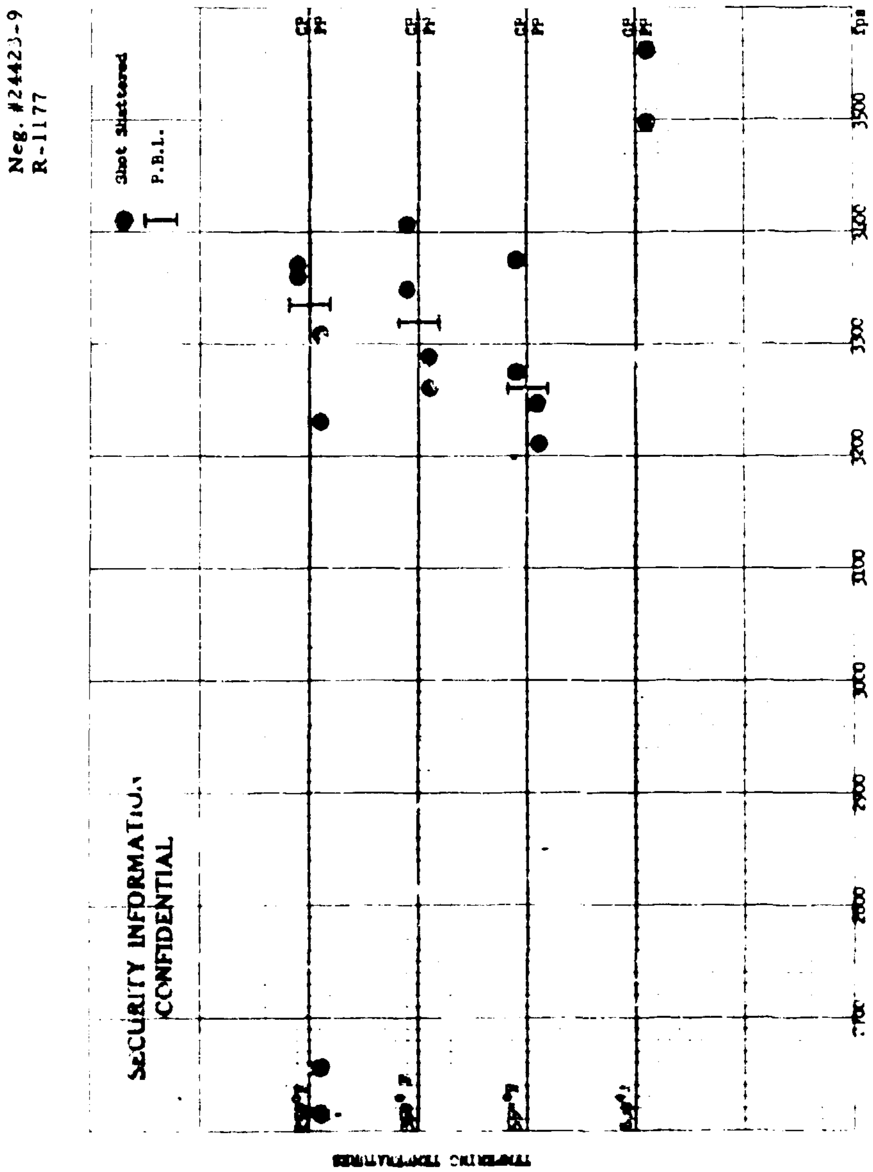

Figure 9. Rounds of various tempering temperatures vs 1 1/8 inch (321-331 Bhn) plate at 30° obliquity

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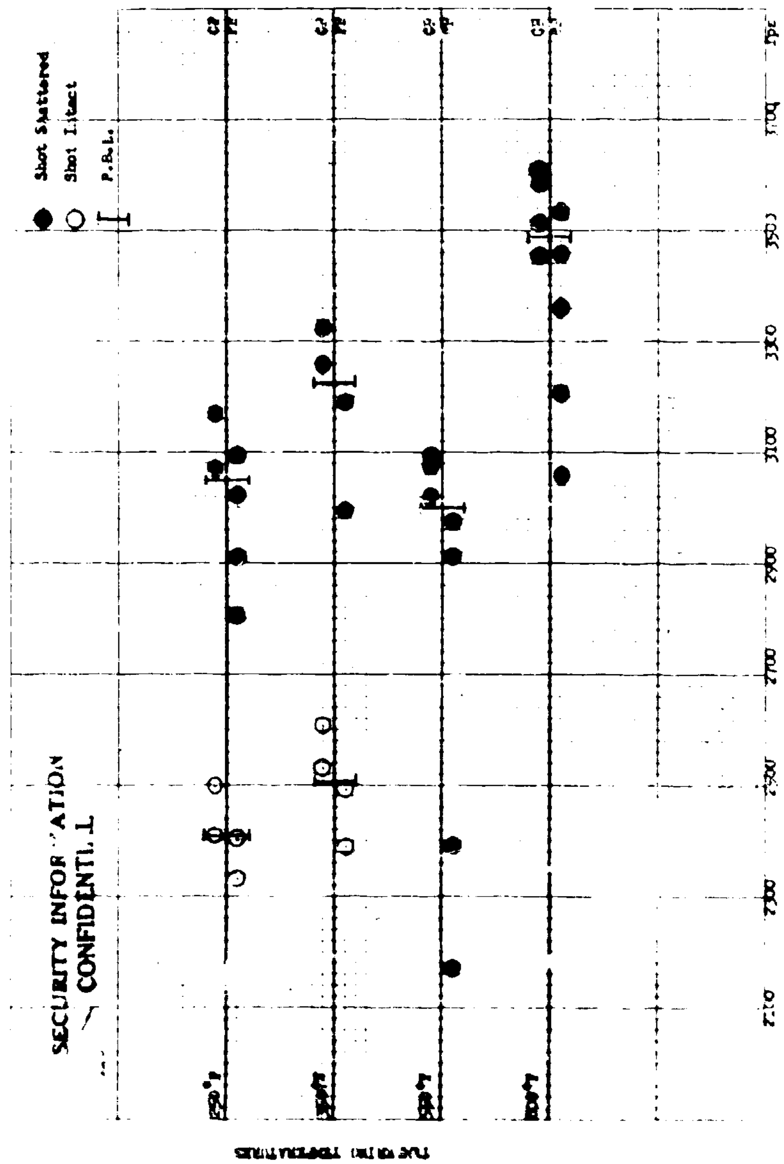

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Figure 10. Rounds of various tempering temperatures vs 1 1/8 inch (321-331 Bhn) plate at 20° obliquity

Shatter Gap

It may be noted in Table II and Figures 7, 8 and 10 that two ballistic limits, one with intact and one with shattered shot, were obtained for some of the overmatching low obliquity firings. In these cases a shatter gap resulted in which plate perforation could be obtained above and below but not within a certain velocity interval. Perforation below this velocity range was obtained with intact shot and above the range with shattered shot. Within the range the shot shattered and did not have enough energy to perforate the plate.

Shatter gaps were not observed for the harder (61 to 64 Rc) shot fired against 7/8 inch (1.11 caliber) plate at 20° obliquity but a shatter gap was observed for the softer (56 Rc) shot. The softest (49 Rc) shot also did not demonstrate a shatter gap and only provided the high ballistic limit. This performance was in marked contrast to the behavior with the harder shot which did not exhibit a shatter gap because it was able to remain effective in defeating the target at all velocities above that of the low limit. In addition, against 7/8-inch plate at 30° obliquity and 1 1/8-inch plate at 20° obliquity, only the harder shot could perforate both in an intact and a shattered condition, whereas the softer shot could perforate only in a shattered condition. This shows that shot hardness is critical for the overmatching low obliquity targets. Also, conventional monobloc shot should not be softer than approximately 55 Rockwell C in order to be able to defeat overmatching targets similar to those of this investigation.

CONCLUSIONS

1. When all conventional shot remain intact or when all shot shatter in defeating a target, there is little difference in their penetration performance due to shot hardness in the range of Rockwell C 56 to 64. The main effect of hardness is to alter the velocity at which shatter occurs, which may make softer shot less effective against some targets.

2. Hard shot provide a low and a high ballistic limit for certain low obliquity targets, whereas soft shot provide only the high ballistic limit.

3. Shot approximately as soft as Rockwell C 50 generally are inferior to harder shot.

4. Soft shot, remaining intact during penetration, require slightly more energy to defeat a target than harder shot which remain intact and deform less.

5. Shot hardness is more critical for overmatching low obliquity plate targets than for matching high obliquity plate targets.

FUTURE WORK

Additional tests are being planned to investigate the effect of shot nose hardness on penetration performance against thinner, undermatching plate. Investigations also will be conducted to determine further the effect of steel composition and microstructure upon shot penetration performance. The results of these tests at the 20 mm scale will be compared with those obtained at full scale.

APPENDIX

ABBREVIATIONS AND NOTES USED IN FIRING TABLES

PP - Partial penetration
CP(A) - Complete penetration - Army criterion*
CP(P) - Complete penetration - Protection criterion*
CP(NI) - Complete penetration - Navy criterion, shot intact*
CP(NF) - Complete penetration - Navy criterion, shot fractured*
CP(NS) - Complete penetration - Navy criterion, shot shattered*
SB - Small bulge
MB - Medium bulge
LB - Large bulge
Ck Crack
NCk - No crack
PO - Plug out
POS - Plug out started
BS - Back spall
BSS - Back spall started
BP - Back petals
FP - Face petals
NI** - Nose intact
BI*** - Base intact
Sh - Shatter
Fr - Fracture
LS - Local shear
BIP - Base (projectile) in plate
BNR - Base (projectile) not recovered
QCk - Shot cracked during quenching
SI - Shot intact
SIIP - Shot intact in plate
NIIP - Nose intact in plate
VSB - Very small bulge
NShIP - Nose shatter in plate

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* Defined according to Ordnance Department Bulletin No. 24-44.
** Fractions following NI indicate approximate ratio of nose fragment to total length of shot body.
*** Fractions following BI indicate approximate ratio of base fragment to total length of shot body.
a Approximate value for protection ballistic limit.
b Bracketing velocities used to obtain protection ballistic limit.
c Velocities in zone of mixed results averaged to obtain protection ballistic limit.
d Plate [illegible] extent in inches.

FIRING RECORD

I. Firing with 20 mm AP T33 Shot (Lot 2165) against [illegible]-inch Thick Homogeneous Armor at 60° Obliquity

Striking Velocity	Plate	Penetration Results Shot	Scoop[a]
	A. 250° F Temper vs Plate No. 70 (352 to 356 Bhn)		
3190	CP(NS)-PO	BI 2/5-Sh-Fr-LS	(2.0 x 1.1)
3098	CP(A&P)-PO	BI 1/4-Sh-Fr-LS	(1.8 x 1.1)
2960b	CP(A&P)-PO	BI 1/4-Sh-Fr-LS	(1.9 x 1.1)
2873b	PP-SB-NCk	BI 1/4-Sh-Fr-LS	(2.1 x 1.1)
	PBL = 2915 fps		
	B. 350° F Temper vs Plate No. 70 (352 to 356 Bhn)		
3175	CP(A&P)-PO	BI 1/4-Sh-Fr-LS	(2.2 x 1.1)
3104c	CP(A&P)-PO	BI 1/4-Sh-Fr-LS	(2.0 x 1.3)
3028c	PP-MB-Ck	BI 1/5-Sh-Fr-LS	(2.0 x 1.1)
2984c	PP-LB-Ck	BI 1/5-Sh-Fr-LS	(2.1 x 1.1)
2978c	CP(A&P)-PO	BI 1/5-Sh-Fr-LS	(1.8 x 1.1)
2782	PP-LB-Ck	BI 1/4-Sh-Fr-LS	(2.2 x 0.9)
	PBL = 3025 fps		
	C. 550° F Temper vs Plate No. 70 (352 to 356 Bhn)		
2949	CP(A&P)-PO	Sh-Fr-LS	(2.1 x 1.2)
2840b	CP(A&P)-PO	Sh-Fr-LS	(1.9 x 1.1)
2745b	PP-SB-NCk	BI 1/4-Sh-Fr-LS	(2.0 x 1.0)
2720	PP-SB-NCk	BI 1/4-Sh-Fr-LS	(2.0 x 1.1)
2715	PP-SB-NCk	Sh-Fr-LS	(1.9 x 1.0)
	PBL = 2790 fps		
	D. 800° F Temper vs Plate No. 70 (352 to 356 Bhn)		
3115	CP(A&P)-PO	BI 1/3-Sh-LS	(2.1 x 1.0)
3045	CP(A&P)-PO	BI 1/3 Sh-LS	(2.1 x 1.0)
3016b	CP(A&P)-PO	BI 1/3-Sh-LS	(2.1 x 1.0)
2972b	PP-MB-NCk	BI 2/5-Sh-LS	(2.2 x 1.0)
2930	PP-MB-NCk	BI 2/5-Sh-LS	(2.0 x 1.0)
	PBL = 2995 fps		

II. Firing with 20 mm AP [illegible] Shot (Lot 2165) against 3/4-inch Thick Homogeneous Armor at 55° Obliquity

Striking Velocity	*Plate*	*Penetration Results* *Shot*	*Scoop*[a]
	A. 250° F Temper vs Plate No. 38 (293 to 302 Bhn)		
3115	CP(A&P)-PO	BI 1/4-Sh-Fr-LS	(1.8 x 1.4)
2985b	PP-LB-Ck	BI 1/4-Sh-Fr-LS	(2.0 x 1.3)
2975b	CP(NS)-PO	BIP-Sh-LS	(1.7 x 1.2)
2910	PP-LB-POS	BI 1/3-Sh-Fr-LS	(1.9 x 1.0)
2870	PP-LB-NCk	BNR-Sh-Fr-LS	(1.9 x 1.1)
2820	PP-LB-Ck	BI 1/3-Sh-LS	(1.9 x 1.2)
	PBL = 2980 fps		
	B. 350° F Temper vs Plate No. 38 (293 to 302 Bhn)		
2980	CP(A)-POS	BI 2/3-Sh-Fr-LS	(2.5 x 1.1)
2850	PP-LB-Ck	BI 1/4-Sh-Fr-LS	(2.0 x 1.3)
	PBL > 2980 fps		
	C. 550° F Temper vs Plate No. 38 (293 to 302 Bhn)		
3040	CP(A&P)-PO	BIP-Sh-LS	(2.0 x 1.0)
2985b	CP(A&P)-PO	Sh-Fr-LS	(1.9 x 1.2)
2940b	PP-LB-POS	Sh-Fr-LS	(2.0 x 1.3)
2895	CP(A)-POS	BI 1/3-Sh-Fr-LS	(1.9 x 1.3)
	PBL = 2965 fps		
	D. 800° F Temper vs Plate No. 38 (293 to 302 Bhn)		
3096	CP(A&P)-PO	BI 1/3-Sh-LS	(2.1 x 1.1)
3038b	CP(A&P)-PO	BIP-Sh-LS	(1.9 x 1.0)
[illegible]	PP-POS	BI 1/3-Sh-LS	(1.9 x 1.1)
[illegible]	PP-LB-NCk	BI 1/3-Sh-LS	(2.2 x 1.2)
	PBL = 3020 fps		

III. Firing with 20 mm AP T33 Shot (Lot 2165) against 7/8-inch Thick Homogeneous Armor at 55° Obliquity

Striking Velocity	*Plate*	*Penetration Results Shot*	*Scoop*[d]
	A. 250° F Temper vs Plate No 29 (429 Bhn)		
3442	CP(A&P)-BS	BI 1/4-Sh-Fr-LS	(1.8 x 1.4)
3362b	CP(A&P)-PO	Sh-Fr-LS	(1.7 x 1.2)
3353b	PP-LB-BSS	Sh-Fr-LS	(1.8 x 1.3)
3160	PP-SB-NCk	Sh-Fr-LS	(2.5 x 1.2)
	PBL = 3355 fps		
	B. 350° F Temper vs Plate No. 29 (429 Bhn)		
3390	CP(A&P)-PO	Sh-Fr-LS	(1.6 x 1.3)
3315b	CP(A&P)-PO	Sh-Fr-LS	(1.5 x 1.[illegible])
3282b	PP-LB-POS	BI 1/5-Sh-Fr-LS	(1.6 x 1.3)
3185	PP-LB-Ck	Sh-Fr-LS	(1.7 x 1.2)
	PBL = 3300 fps		
	C. 550° F Temper vs Plate No. 29 (429 Bhn)		
3305b	CP(A&P)-PO	Sh-Fr-LS	(1.5 x 1.3)
3250b	CP(A)-POS	Sh-Fr-LS	(1.6 x 1.3)
3166	PP-LB-Ck	Sh-Fr-LS	(1.6 x 1.1)
2900	PP-SB-NCk	Sh-Fr-LS	(1.4 x 1.1)
	PBL = 3275 fps		
	D. 800° F Temper vs Plate No. 29 (429 Bhn)		
3685	CP(A&P)-BS	BI 1/3-Sh-LS	(1.8 x 1.2)
3635b	CP(A&P)-[illegible]	BI 1/3-Sh-LS	(1.8 x 1.3)
3600b	PP-MB-BSS	Sh-Fr-LS	(1.8 x 1.3)
3505	PP-MB-Ck	BI 1/3-Sh-LS	(1.8 x 1.2)
3280	PP-SB-NCk	BI 1/3-Sh-Fr-LS	(1.5 x 1.2)
	PBL = 3620 fps		

IV. Firing with 20 mm AP T33 Shot (Lot 2165) against 7/8-inch Thick Homogeneous Armor at 30° Obliquity

Striking Velocity	*Plate*	*Penetration Results Shot*	*Scoop*[d]
	A. 250° F Temper vs Plate No. 49 (293 to 302 Bhn)		
2833	CP(NS)-PO	BI 1/4-Sh-LS	(1.5 x 1.5)
2737	CP(NS)-PO	Sh-LS	(1.6 x 1.3)
2687	CP(NF)-BS	BI 1/3 Fr	(1.7 x 1.1)
2679c	CP(A)-POS	Sh-Fr-LS	(1.5 x 1.2)
2676c	CP(A&P)-PO	Sh-Fr-LS	(1.5 x 1.4)
2670c	CP(A&P)	BI 1/4-Sh-Fr-LS	(1.4 x 1.4)
2660c	PP-POS	Sh-Fr-LS	(1.5 x 1.3)
2600	CP(NI)-PO	SI	(1.5 x 1.1)
2590	CP(NF)-PO	NI 2/3-BI 1/3-Fr	(1.6 x 1.2)
2443	CP(NF)-PO	BI 1/3-Fr	(1.7 x 1.2)
2205b	CP(A&P)-PO	BI 1/3-Fr	(1.8 x 1.2)
2130b	PP-LB-Ck	BI 3/5-Fr	(2 x 1.1)
2097	PP-LB-Ck	SI	(2 x 1.2)
	PBL ≙ 2165 (Fr); = 2670 (Sh)		
	B. 350° F Temper vs Plate No. 49 (293 to 302 Bhn)		
2682	CP(A&P)-PO	Sh-Fr-LS-BIF	(1.7 x 1.4)
2663b	CP(A&P)-PO	Sh-Fr-LS	(1.5 x 1.4)
2615b	PP-LB-POS	Sh-Fr-LS	(1.7 x 1.3)
2610	PP-LB-Ck	BI 1/3-Sh-Fr-LS	(1.7 x 1.3)
2540	CP(NI)-PO	SI	(1.8 x 1.3)
2333	CP(NF)-PO	NI 2/3-Fr	(1.8 x 1.2)
2302b	CP(NF)-PO	NI 2/3-BI 1/3-Fr	(1.9 x 1.2)
2215b	PP-LB-Ck	SI	(2.2 x 1.4)
2172	PP-LB-Ck	SI-Ck	(2.0 x 1.2)
	PBL ≙ 2260 (I); = 2640 (Sh)		
	C. 550° F Temper vs Plate No. 49 (293 to 302 Bhn)		
2688	CP(A&P)-PO	BI 1/3-Sh-Fr-LS	(1.6 x 1.4)
2660b	CP(A&P)-PO	BI 1/3-Sh-Fr-LS	(1.6 x 1.3)
2514b	PP-LB-Ck	BNR-Sh-LS	(1.5 x 1.4)
2551	PP-LB-Ck	BI 1/3-Sh-Fr-LS	(1.4 x 1.4)
2233	PP-SB-NCk	Sh-Fr-LS	(1.5 x 1.3)
	PBL = 2635 (I)		

IV. Firing with 20 mm AP T33 Shot (Lot 2165) against 7/8-inch Thick Homogeneous Armor at 30° Obliquity (Cont'd)

Striking Velocity	Plate	Penetration Results Shot	Scoop[d]
	D. 800° F Temper vs Plate No. 50 (302 to 311 Bhn)		
2779	CP(A&P)-PO	BI 1/3-Sh-Fr-LS	(1.1 x 1.5)
2749b	CP(A&P)-PO	BI 2/5-Sh-Fr-LS	(1.6 x 1.4)
2726b	CP(A)-POS	BI 1/3-Sh-Fr-LS	(1.5 x 1.4)
2680	PP-LB-Ck	BI 2/5-Sh-Fr-LS	(1.4 x 1.4)
2597	PP-LB-NCk	BI 2/5-Sh-Fr-LS	(1.5 x 1.4)

PBL = 2740 fps

V. Firing with 20 mm AP T33 Shot (Lot 2165) against 7/8-inch Homogeneous Armor at 20° Obliquity

A. 250° F Temper vs Plate No. 49 (293 to 302 Bhn)

2835	CP(NF)-PO	BI 1/3-Fr	(1.3 x 1.2)
2644	CP(NF)-PO	BI 1/3-Fr	(1.3 x 1.2)
2510	CP(NI)-BP	SI-Ck	(1.4 x 1.1)
2224	CP(NI)-PO	SI	(1.4 x 1.1)
2025	CP(A&P)-PO	BI 1/3-Fr	(1.2 x 1.1)
1952b	CP(A&P)-PO	SIIP	(1.3 x 1.1)
1905b	CP(A)-POS	SI	(1.3 x 1.1)
1865	PP-LB-Ck	SI	(1.3 x 1.2)
1860	PP-LB-Ck	SI	(1.3 x 1.1)

PBL = 1930 fps

B. 350° F Temper vs Plate No. 50 (302 to 311 Bhn)

2700	CP(A&P)-BS	SI	(1.4 x 1.2)
2453	CP(NF)-BS	BI 1/4-Fr	(1.3 x 1.2)
2253	CP(NI)-PO	SI	(1.3 x 1.2)
2120	CP(NF)-BS	NI 2/3-BI 1/3-Fr	(1.1 x 1.0)
2087b	CP(NI)-BS	SI	(1.3 x 1.2)
2026b	CP(A)-POS	NI 2/3 BI 1/3 Fr	(1.3 x 1.0)
1943	CP(A)-POS	SI	(1.3 x 1.2)

PBL = 2055 fps

V. Firing with 20 mm AP T33 Shot (Lot 2165) against 7/8-inch Homogeneous Armor at 20° Obliquity (Cont'd)

Striking Velocity	*Plate*	*Penetration Results* Shot	Scoop[d]
	C. 550° F Temper vs Plate No. 49 (293 to 302 Bhn)		
2657	CP(NS)-PO	BI 1/3-Sh-Fr-LS	(1.5 x 1.4)
2560b	CP(NS)-PO	Sh-Fr-LS	(1.5 x 1.3)
2470b	CP(A)-POS	BI 1/3-Sh-Fr-LS	(1.7 x 1.2)
2312	PP-LB-Ck	NI 1/4-BI 1/2-Sh-Fr-LS	(1.7 x 1.2)
2263	PP-LB-Ck	NI 1/3-BI 1/4-Fr-LS	(1.7 x 1.3)
2225	CP(NI)-PO	SI-Ck	(1.5 x 1.1)
2210b	CP(A&P)-PO	NIIP-BI 1/3-Fr	(1.5 x 1.2)
2157b	PP-LB-Ck	NI 2/3-BI 1/3-Fr	(1.6 x 1.2)
2105	PP-LB-Ck	NI 2/3-BI 1/3-Fr	([illegible] x 1.1)
2085	CP(A)-LB-Ck	SI	(1.5 x 1.2)
	PBL = 2185 (I); 8 2515 (Sh)		
	D. 800° F Temper vs Plate No. 50 (302 to 311 Bhn)		
2658	CP(NS)-PO	BI 2/5-Sh-Fr-LS	(1.6 x 1.3)
2628b	CP(A&P)-PO	BI 2/5-Sh-Fr-LS	(1.6 x 1.3)
2588b	PP-LB-Ck	BI 2/5-Sh-Fr-LS	(1.5 x 1.4)
2516	PP-LB-Ck	BI 2/5-Sh-Fr-LS	(1.5 x 1.3)
1969	PP-VSB-NCk	BI 2/5-Sh-Fr-LS	(1.3 x 1.2)
1948	PP-VSB-NCk	BI 2/5-Sh-Fr-LS	(1.3 x 1.3)
	PBL = 2610 fps		

VI. Firing with 20 mm AP T33 Shot (Lot 2165) against 1 1/8-inch Homogeneous Armor at 30° Obliquity

	A. 250° F Temper vs Plate No. 16 (321 to 331 Bhn)		
3370	CP(NS)-PO	NShIP-LS	(1.6 x 1.8)
3361b	CP(A[illegible])-PO	NShIP-LS	(1.8 x 1.7)
[illegible]	PP-L[illegible]-Ck	BI 1/3-Sh-Fr-LS	(1.8 x 1.7)
[illegible]230	PP-LB-NCk	Sh-Fr-LS	(1.7 x 1.7)
2655	PP-MB-NCk	BI 1/3-Sh-Fr-LS	(1.5 x [illegible].5)
2615	PP-MB-NCk	Sh-[illegible]-LS	([illegible].5 x 1.5)
2490	PP-SB-NCk	BI 2/5-Fr	(2.4 x 1.3)
2255	PP-SB-NCk	BI [illegible]/3-Fr	(2.5 x 1.4)
	PBL = 333[illegible] fps		

VI. Firing with 20 mm AP T33 Shot (Lot 2165) against 1 1/8-inch Homogeneous Armor at 30° Obliquity (Cont'd)

Striking Velocity	Plate	Penetration Results Shot	Scoop[d]
	B. 350° F Temper vs Plate No. 16 (321 to 331 Bhn)		
3405	CP(NS)-PO	BI 1/4-Sh-Fr-LS	(1.5 x 1.6)
3349b	CP(NS)-PO	Sh-Fr-LS	(1.[illegible] x 1.8)
3287b	CP(A)-POS	Sh-Fr-LS	(1.8 x 1.7)
3260	PP-LB-NCk	Sh-Fr-LS	(1.6 x 1.7)
	PBL = 3320 fps		
	C. 550° F Temper vs Plate No. 15 (321 to 331 Bhn)		
3375	CP(NS)-PO	NShIP-Fr-LS	(1.6 x 1.7)
3274b	CP(NS)-PO	NShIP-Fr-LS	(1.8 x 1.7)
3248b	PP-LB-Ck	Sh-Fr-LS	(1.7 x 1.6)
3210	PP-LB-Ck	BI 2/5-Sh-Fr-LS	(1.8 x 1.6)
	PBL = 3260 fps		
	D. 800° F Temper vs Plate No. 15 (321 to 331 Bhn)		
3563	CP(A)-POS	BI 1/3-ShIP	(1.7 x 1.6)
3498	PP-LB-Ck	BI 1/3-ShIP	(1.8 x 1.7)
	PBL > 3565 fps		

VII. Firing with 20 mm AP T33 Shot (Lot 2165) against 1 1/8-inch Homogeneous Armor at 20° Obliquity

Striking Velocity	Plate	Penetration Results Shot	Scoop
	A. 250° F Temper vs Plate No. 16 (321 to 331 Bhn)		
3168	CP(NS)-PO	BI 1/3-Sh-Fr-LS	(1.7 x 1.7)
3096	PP-LB-Ck	BI 1/3-Sh-Fr-LS	(1.7 x 1.5)
3073b	CP(NS)-PO	BI 1/3-Sh-Fr-LS	(1.6 x 1.5)
3020b	PP-LB-POS	Sh-Fr-LS	(1.7 x 1.7)
2913	PP-LB-Ck	BI 1/4-Sh-Fr-LS	(1.7 x 1.5)
2904	PP-LB-POS	BI 1/2-Sh-Fr-LS	(1.6 x 1.5)
2498	CP(A&P)-PO	BI 1/4-Sh-Fr-LS	(1.3 x 1.3)
2412b	CP(A&P)-PO	NI 2/3-BI 1/3-Fr	(1.6 x 1.2)
2403b	PP-LB-Ck	NI 3/5-BI 2/5-Fr	(1.6 x 1.2)
23[illegible]4	PP-LB-NCk	SI	(1.5 x 1.2)
	PBL = 2405 (I); = 3050 (SI)		

VII. Firing with 20 mm AP T33 Shot (Lot 2165) against 1 1/8-inch Homogeneous Armor at 20° Obliquity (Cont'd)

Striking Velocity	*Plate*	*Penetration Results Shot*	*Scoop*[d]
	B. 350° F Temper vs Plate No. 15 (21 to 331 Bhn)		
3321	CP(A&P)-PO	BI 2/3-Sh-Fr-LS	(1.6 x 1.6)
3259b	CP(NS)-PO	BI 1/3-Sh-Fr-LS	(1.6 x 1.6)
3191b	PP-LB-POS	BI 1/4-ShIP	(1.6 x 1.6)
2996	PP-LB-Ck	BI 1/4-ShIP	(1.6 x 1.7)
2606	CP(A&P)-PO	SIIP	([illegible].4 x 1.[illegible])
2528b	CP(A&P)-PO	SIIP	(1.4 x 1.3)
2487b	CP(A)-POS	SIIP	(1.[illegible] x 1.3)
2388	CP(A)-POS	SICk	(1.4 x 1.1)
	PBL = 2505 (I); = 3225 (Sh)		
	C. 550° F Temper vs Plate No. 16 (321 to 331 Bhn)		
3084	CP(NS)-PO	BI 1/3-Sh-Fr-LS	(1.7 x 1.6)
3080	CP(NS)-PO	BI 1/3-Sh-Fr-LS	(1.7 x 1.6)
3020b	CP(A&P)-PO	BI 1/2-Sh-Fr-LS	(1.7 x 1.5)
2977b	PP-LB-Ck	BI 1/3-Sh-Fr-LS	(1.6 x 1.5)
2910	PP-LB-NCk	Sh-Fr-LS	(1.7 x 1.5)
2390	PP-SB-NCk	BI 1/2-Sh-Fr-LS	(1.5 x 1.3)
2170	PP-VSB-NCk	BI 1/3-Sh-Fr-LS	(1.7 x 1.2)
	PBL = 3000 fps		
	D. 800° F Temper vs Plate No. 15 (321 to 331 Bhn)		
3605	CP(A&P)-BS	BI 1/3-Sh-LS	(1.8 x 1.7)
3589	CP(NS)-BS	Sh-LS	(1.7 x 1.6)
3538c	CP(A)-POS	Sh-LS	(1.8 x 1.7)
35[illegible]3c	CP(A&P)-BS	BI 1/3-Sh-LS	(1.7 x 1.7)
3459c	CP(A)-POS	BI 1/3-Sh-LS	(1.8 x 1.6)
345[illegible]c	CP(A&P)-BS	BI 1/3-Sh-LS	(1.8 x 1.7)
3360	PP-LB-POS	BI 1/3-Sh-LS	(1.7 x 1.6)
3205	PP-LB-POS	BI 1/3-Sh-LS	(1.7 x 1.7)
3060	PP-LB-POS	BI 1/3-Sh-LS	(1.7 x 1.7)
	PBL = 34[illegible]0 fps		

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