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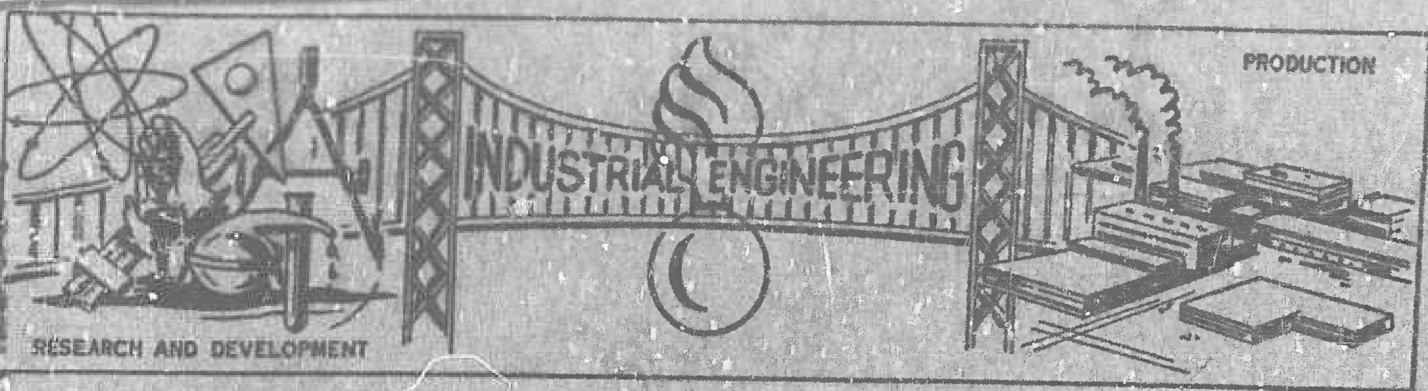

TECHNICAL REPORT

DC-TR: 2-58

METALLURGICAL TESTING AND PENETRATION PERFORMANCE OF THIN-NOSED 750-POUND T54E3 DEMOLITION BOMBS MANUFACTURED BY THE WALSH CONSTRUCTION COMPANY OF PORTLAND, MAINE

BY
W. R. GRAY

COPY NO. 15 OF 55

JUNE 1958

INDUSTRIAL ENGINEERING DIVISION

PICATINNY ARSENAL—DOVER, NEW JERSEY

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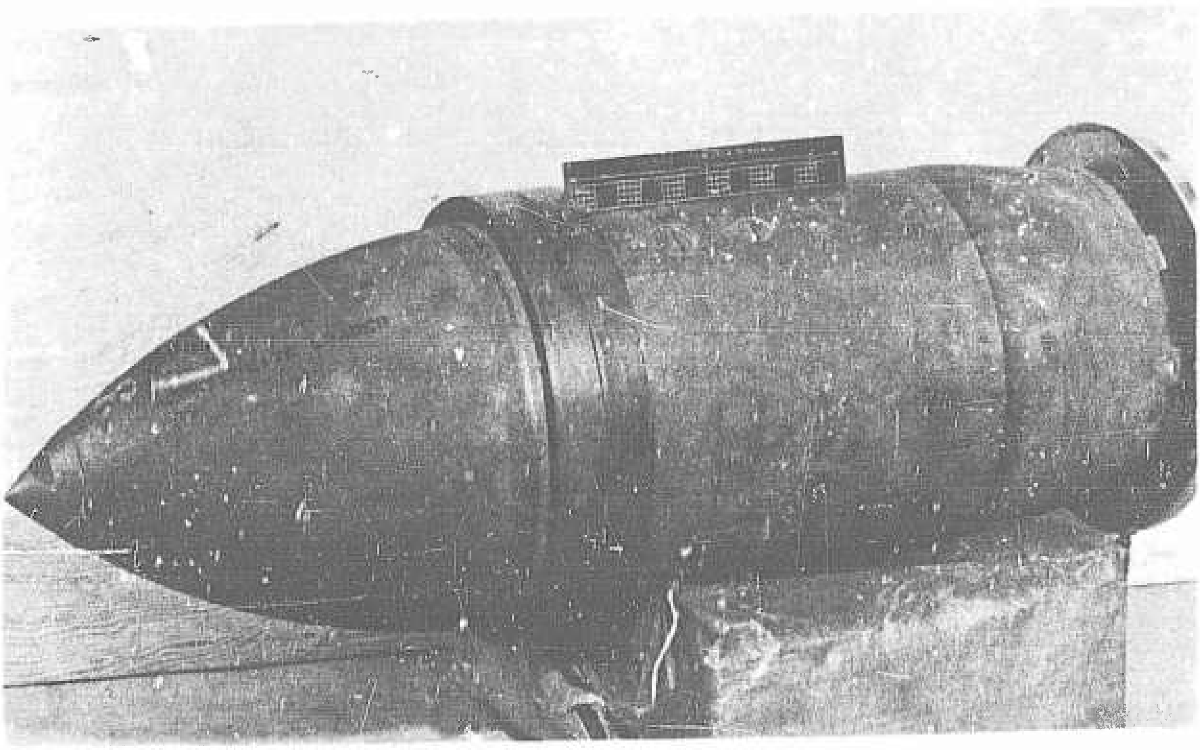

FRONTISPIECE: Walsh 750-Pound, T54E3, Demolition Bomb, Modified for Gun-Firing Tests by Addition of Two Cloth Tape Bourrelets and an Aluminum Pusher Plate.

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METALLURGICAL TESTING AND PENETRATION PERFORMANCE OF THIN-NOSED 750-POUND T54E3 DEMOLITION BOMBS MANUFACTURED BY THE WALSH CONSTRUCTION COMPANY OF PORTLAND, MAINE

BY

W. R. GRAY

PROJECT NO: PA-2-1C5

REPORT NO: LC-TR: 2-58

JUNE 1958

SUBMITTED BY: J. LONGOBARDO
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ACKNOWLEDGMENT

Drawing upon material contained in a Watertown Arsenal report ("Examination of Casings and Lug Insert Weldments from 750-Pound General Purpose Bomb, T54E3, Manufactured by Walsh Construction Company of Portland, Maine," by C. A. Riddle and W. L. Warner), and a U. S. Naval Proving Ground report ("Reinforced Concrete Penetration Test of 750-Pound Demolition Bomb, T54E3, Manufactured by Walsh Construction Co., Portland, Maine," by L. E. Wills), is hereby duly acknowledged.

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OBJECT

Work described in this report was designed primarily to determine whether the first 60,000 bombs, with less than specified wall thickness in the ogive area, manufactured by the Walsh Construction Company would meet penetration requirements of the 750-pound T54E3 demolition bombs. Another purpose of the evaluation was to determine the reason for cracks which appeared adjacent to the lug insert welds in the casings of a small percentage of the bombs. This investigation also included evaluation of the effectiveness of repair welding the cracks.

SUMMARY

Evaluation of thin-nosed, 750-pound, T54E3 demolition bombs made by the Walsh Construction Company was accomplished through thorough metallurgical testing and gun-firing tests.

Three bomb casings, one "as forged" with "as welded" inserts, another, welded and heat-treated, and a third, repair-welded and tempered, were metallurgically tested to establish what properties assure intact casings after target penetration at reduced temperatures.

The test program included chemical analysis, hot-acid microetching, microscopic study, tensile property check, and hardness surveys of each ogive and body, also radiographic examination of lug insert welds, and microscopic examination of welds and cracked areas.

Thin-nosed 750-pound, T54E3 demolition bombs manufactured by the Walsh Construction Company were gun-fired at an average velocity of 1000 ft/sec against reinforced targets set at 15-degree obliquity. Examination of the

targets and bombs recovered behind the targets revealed that the T54E3 bomb effectively penetrated both 16-inch single-thickness concrete, reinforced with two spaced layers of steel bar lattice, and 24-inch laminated concrete in 8-inch slabs, each reinforced with one layer of steel lattice at the rear.

CONCLUSIONS

According to test results, the penetration ability of the Walsh bomb was not limited by the thin ogival walls, but rather by the base closure construction and insert weld.

Cracking which occurred at the lug insert welds was associated with the stress pattern imposed by welding a relatively massive insert into a thinner casing wall. Snugness of the lug insert against the inside of the casing wall will affect the strength of the weld. A small space between lug insert and wall could act as a "triggering mechanism" for cracking. The contour of the toe of the weld reinforcement should be smoothly curved.

Repair welding was effective, and the tempering treatment after weld repair did not appreciably affect tensile properties of the ogive, whereas yield and tensile strengths of the bomb body were reduced slightly (about 10 percent and 5 percent, respectively).

RECOMMENDATIONS

The lug insert should be made to fit snugly against the casing wall during manufacture. The welding process should also be studied and a method established which will increase the weld penetration in width. The weld should extend to the edge of the insert boss, completely filling the space between the lug insert boss and the wall body, thereby eliminating one possible "triggering mechanism" for cracking.

There should be an investigation of base closure construction, and development of a design capable of withstanding the impact of the bomb against a concrete target. Parenthetically, it should be noted that failure in this area is not limited to the design herein considered. It is recommended that repair welding be considered acceptable, provided the repair weld is examined carefully by radiographic or other means to assure complete closure of the crack.

ACTION TO BE TAKEN ON RECOMMENDATIONS

A note will be added to the bomb drawing, calling for the weld of the lug insert boss to extend to the edge of the boss. The process is to be qualified and the qualification requirements will be placed in the specification. The specification will be changed to permit repair welding of cracks and call for inspection of the repair.

The base closure constructions has been referred to Research and Development for investigation.

INTRODUCTION

1. The Walsh Construction Company of Portland, Maine, in early 1954, contracted to manufacture 133,600 T54E3, 750-pound demolition bombs; however, the only available supplier of butt-welded tubing did not have the plant capacity to produce a sufficient amount. Therefore, the Walsh Company used seamless tubing and developed a new method to form the ogive and base taper. The new method, a swaging process, utilizing one small (400-ton) press instead of the usual five heavy presses, could produce bombs much faster and cheaper than by competing methods.

2. Because the drawings were made for another manufacturing process and the seamless tubing had a wall thickness tolerance of $\pm$ 12½ percent, the Walsh Company was unable to achieve the ogival wall thickness specified. However, since special heat treating and swaging of the seamless tubing produced bomb casings with 25 percent more structural strength, OCO granted waivers for Walsh to manufacture 60,000 bombs with minimum ogival wall thickness of 1.200, 0.700, 0.500, and 0.400 inch instead of the specification dimension of 1.295, 0.786, 0.575, and 0.425 inch.

3. Several bombs, each loaded by the manufacturer with 694 pounds of wet sand, were dropped by a mobile crane from heights of 55 and 110 feet. No major deformation occurred; nevertheless, Picatinny Arsenal initiated studies to determine the maximum performance that could be expected from these thin-nosed bombs.

4. As the first step in evaluation of T54E3 Bombs, Watertown Arsenal was requested to have its laboratories conduct metallurgical tests on three

bomb casings, labeled A, B, and C. Casing A had welded inserts, but was without subsequent heat treatment; B was processed through full heat treatment and had body wall cracks adjacent to the inserts; and C was similar to B, except for repair-welded cracks and subsequent tempering treatment.

5. The three casings were subjected to chemical analysis, hot acid macro-etching, microscopic study, tensile property determination, hardness surveys, and radiographic, macroscopic, and microscopic examination of lug insert welds.

6. Following analysis of metallurgical examination results, 30 Walsh-manufactured bombs were selected at random for measurements of wall thickness according to standards of A. O. Smith Company, producers of the original T54 Bomb Casing.

7. Of the 30 bombs, the 10 with the greatest variation in wall thickness were chosen for additional testing. Seven of the 10 were used for gun-firing penetration tests (Table 1); the remaining bombs were used to test the adapter booster impact.

TABLE 1

Wall Thickness of Bombs Gun-fired at Naval Proving Ground

Bomb	Measurement Position			
No.	No. 1	No. 2	No. 3	No. 4
3	1.280	.700	.450	.350
	1.260	.780	.460	.370
	1.400	.810	.450	.360
	1.360	.800	.450	.350
7	1.250	.700	.450	.350
	1.300	.690	.500	.400
	1.300	.690	.450	.410
	1.300	.670	.450	.370
8	1.580	.720	.520	.350
	1.350	.650	.450	.370
	1.400	.650	.470	.400
	1.600	.700	.500	.400
9	1.400	.700	.490	.380
	1.460	.660	.490	.390
	1.490	.710	.490	.400
	1.450	.700	.490	.400
11	1.500	.750	.480	.410
	1.590	.710	.460	.400
	1.570	.680	.500	.380
	1.520	.710	.470	.380
15	1.450	.740	.470	.390
	1.450	.710	.450	.350
	1.500	.750	.450	.380
16	1.380	.650	.450	.370
	1.390	.650	.480	.390
	1.370	.670	.480	.390
	1.350	.710	.450	.350

METALLURGICAL RESULTS

8. Visual examination showed the casings were similar, except that Casing A had a 0.45-inch wall thickness, while Casings B and C each had 0.375-inch.

9. Because the casings were manufactured from seamless tubing by hot forging, there were no longitudinal or circumferential weld joints.

10. Chemical analysis of specimens obtained from the body of each casing yielded the following results:

Casing	C	Mn	Si	S	P	Ni	Cr	Mo	V
A	0.305	0.84	0.26	0.020	0.015	nil	0.031	Trace	Trace
B	0.38	1.02	0.25	0.025	0.018	nil	0.021	nil	Trace
C	0.37	0.98	0.22	0.032	0.013	nil	0.021	nil	Trace

11. Although Casing A originated from a different heat of steel than either B or C, all three were manufactured from steel meeting chemical composition requirements of Picatinny Arsenal tentative Purchase Description No. PA-PD-613. The composition of this steel was inadequate to transform completely to martensite in the section thickness present in the casing ogives. **This condition was even worse with the standard, thicker section.**

12. Macroscopic Examination: Longitudinal sections were machined from the ogive and body of each casing, then surface-ground and etched in a hot solution of HCl and H_2O. The resulting macrostructures (Figs. 1 and 2) were typical of good quality hot-rolled steel. In Casings B and C the flow pattern of the forged ogive sections was more pronounced than in Casing A. Numerous fine cracks (resulting from the ogive-forming operation) were on both the interior and the exterior surfaces of the B and C casing ogives.

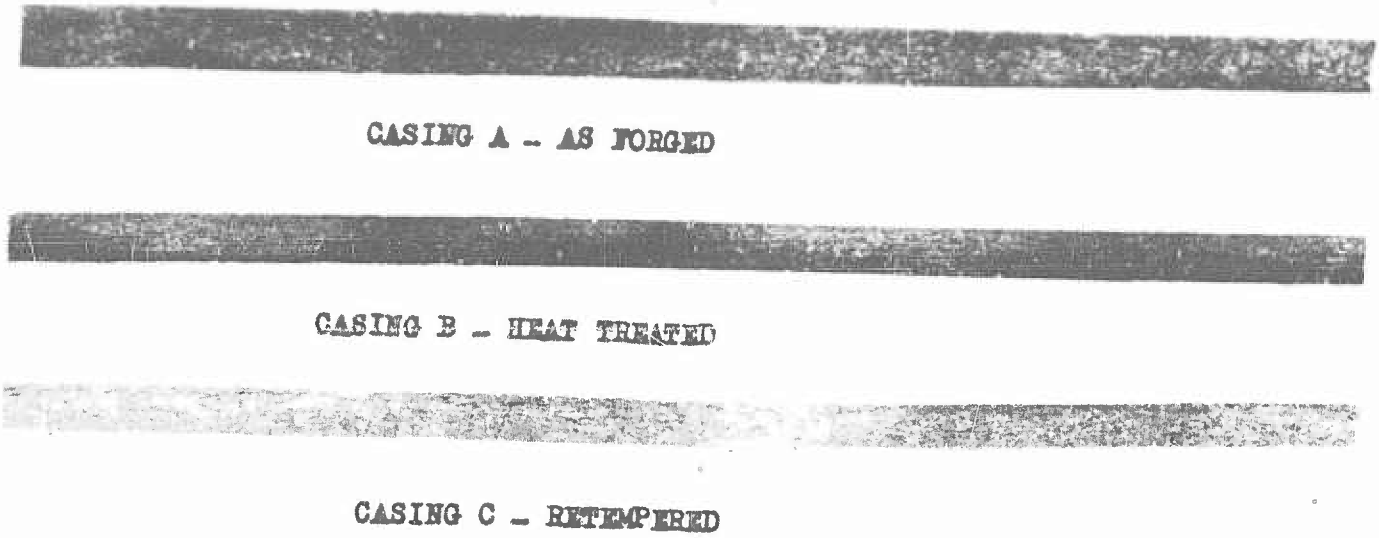


Fig. 1. Hot-Acid Macroetched Sections from Bodies of T54 Bomb Casings A, B, and C, Manufactured by the Walsh Construction Company.

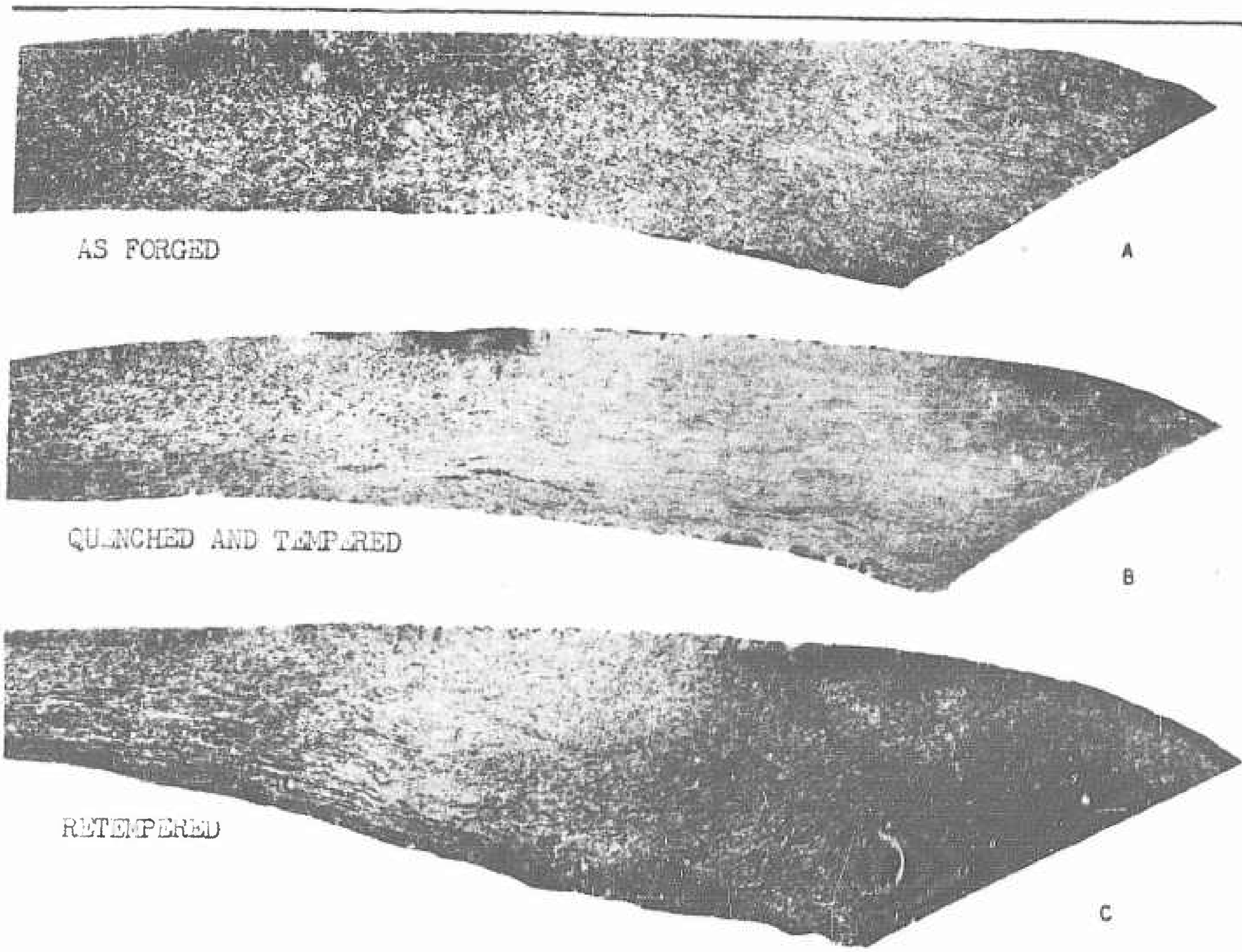


Fig. 2. Hot-Acid Macroetched Sections from Ogives of T54 Bomb Casings A, B, and C, Manufactured by the Walsh Construction Company.

Figure 3 shows how these cracks appeared on the interior surface of the ogives. The most severe cracks, found in Casing C, were 1/32 inch wide by 1/8 inch deep. Comparison of the three sections (Fig. 1) showed considerable variation in the ogive wall thickness of Casings A, B, and C.

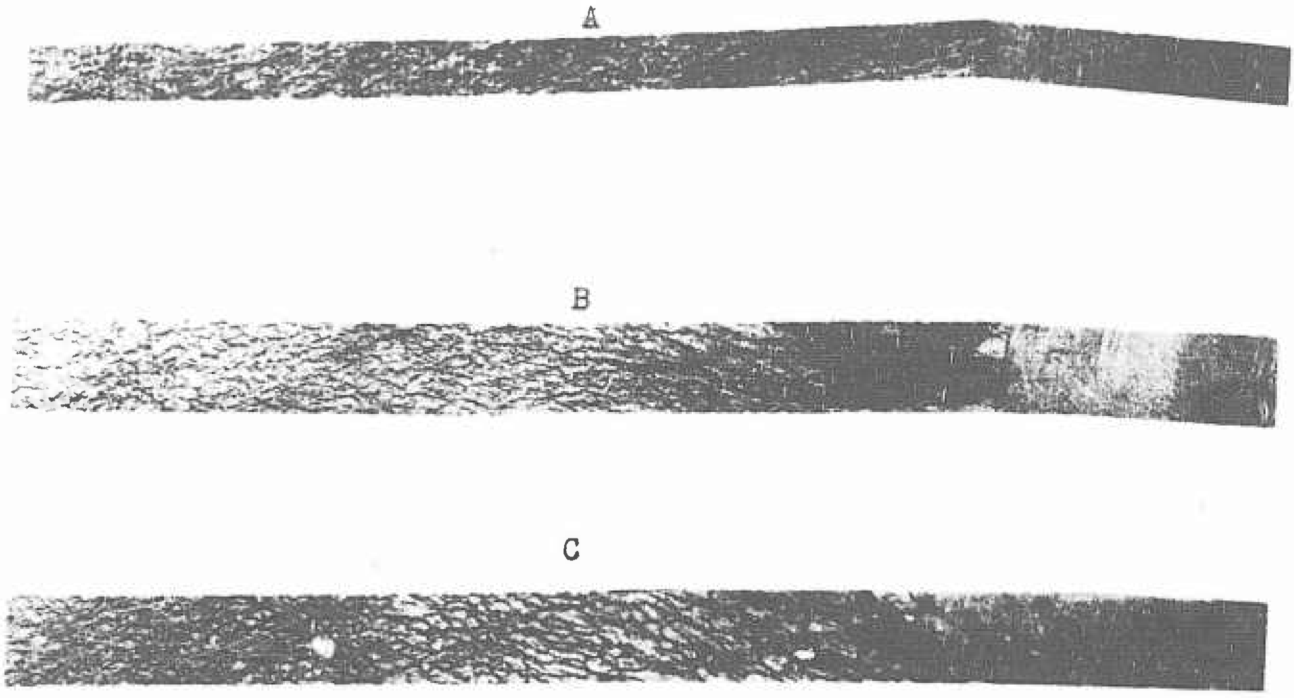
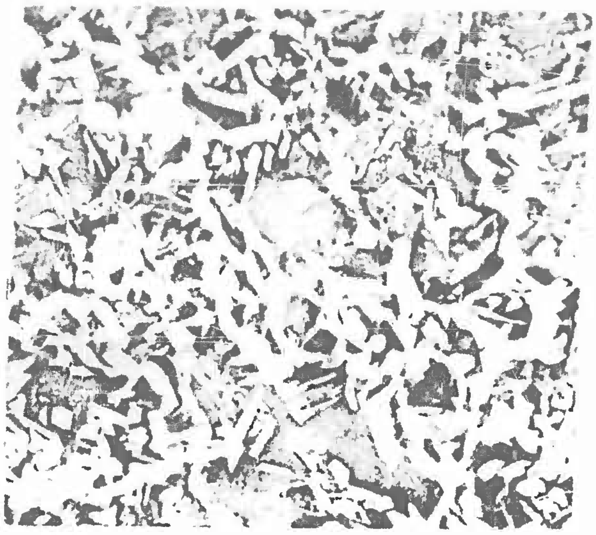


Fig. 3. View of Interior Surfaces of Ogives from 750-Pound T54 Bomb Casings A, B, and C Manufactured by the Walsh Construction Company.

13. Microscopic Examination: Specimens were machined from the ogive and body of each casing. In Casing A (Fig. 4), microscopic examination revealed very little difference in the microstructure in either location; both areas consisted of fine pearlite and ferrite. The structures were typical of hot-worked steel, slowly cooled from the forging temperature in air. Casings B and C had structures in the body consisting of tempered bainite, with some traces of martensite in B and considerable rejected

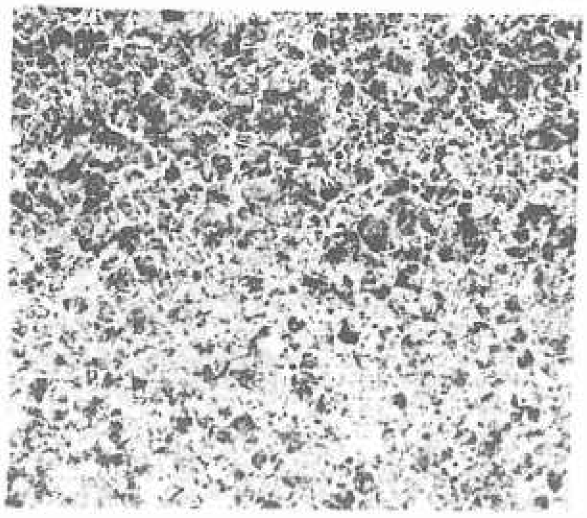
CASING A



X100 -A-
Coarse-Grained Structure of Hot-Worked Steel.

X1000 -B-
Fine Pearlite and Ferrite in Same Area as -A-.

CASING B

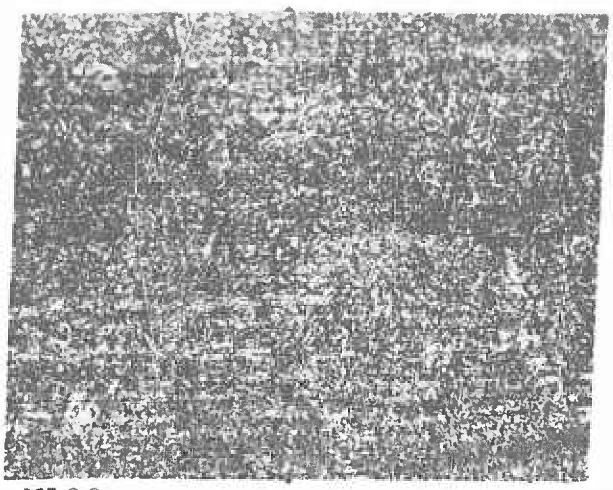
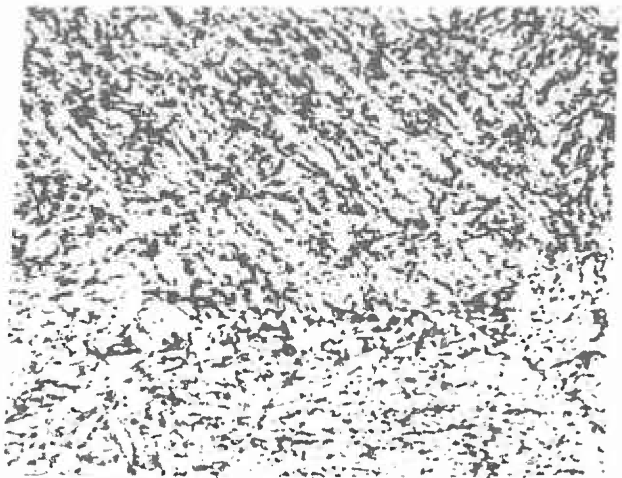


X100 -C-
Moderate Grain Size.

X1000 -D-
Ferrite, Bainite, and Fine Pearlite in Same Area as -C-.

Fig. 4. Microstructures of Ogive Sections From Casings A, B, and C.

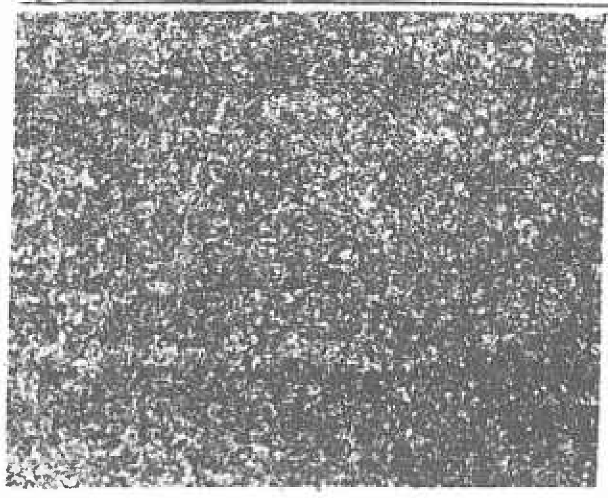
ferrite in C (Fig. 5). Both casings had similar ogive structure which consisted of bainite, pearlite, and ferrite. The nose structure was consistent for steel of the composition employed which would not be expected to quench-harden fully through the heavy wall section at this location.

CASING B

X100 — Fine-Grained, Slightly Banded Structure.

X1000 — Tempered Structure of Bainite and Some Martensite.




CASING C

X100 — Fine Grained Structure with Some Elongated Non-Metallic Inclusion.

X1000 — Tempered Bainite and Grain Boundary Ferrite.

Fig. 5. Microstructures from Bodies of Bomb Casings B and C.

14. Tensile Properties: Specimens for determination of tensile properties were taken from the ogive and body sections (in longitudinal and transverse directions) of all three casings. Four specimens were obtained for each position. Data contained in Table 2 show that yield and tensile strengths were higher in the casing sidewall than in the forged ogive area, with the difference more pronounced in heat-treated Casings B and C.

TABLE 2

TENSILE PROPERTIES OF 750-LB T54 BOMB CASINGS

Location	Direction	Temp. (°C)	Yield Strength, PSI 0.1% Offset	Yield Strength, PSI 0.2% Offset	Tensile Strength PSI	Elon. %	R.A. %	% Inc. at -65°C Y.S. 0.1%	% Inc. at -65°C T.S.
CASING A									
Ogive	T	+24	40,300	40,300	77,000	25.5	41.5		
Ogive	T	+24	41,000	41,800	78,400	26.0	47.6		
Ogive	T	-65	55,000	53,500	89,200	27.0	39.7	35	15
Ogive	T	-65	54,500	53,000	90,000	27.5	45.1		
Body	T	+24	44,500	44,750	83,000	26.5	56.5		
Body	T	+24	45,750	46,250	82,000	23.4	55.0		
Body	T	+24	45,750	45,750	82,500	23.4	55.0		
Body	T	+24	45,000	45,000	83,000	29.6	56.5		
Ogive	L	+24	42,500	42,500	78,500	28.0	54.6		
Ogive	L	+24	42,600	43,500	79,000	28.5	55.1		
Ogive	L	-65	56,600	55,000	91,100	29.0	48.4	31	16
Ogive	L	-65	55,500	53,750	91,500	30.0	50.2		
Body	L	+24	47,250	47,500	85,500	26.5	58.5		
Body	L	+24	44,250	43,750	85,250	26.5	59.0		
Body	L	+24	45,000	45,000	85,250	26.5	58.5		
Body	L	+24	46,500	46,500	85,250	29.6	58.5		
CASING B									
Ogive	T	+24	75,500	76,000	111,700	12.0	28.3		
Ogive	T	+24	81,800	81,800	114,800	15.7	*		
Ogive	T	-65	86,000	84,000	124,000	13.5	26.0	10	9
Ogive	T	-65	88,000	90,000	126,200	9.3	26.0		
Body	T	+24	112,250	113,750	133,500	14.1	46.3		
Body	T	+24	113,250	114,500	132,750	14.1	44.5		
Body	T	+24	110,000	111,250	132,500	14.1	46.3		
Body	T	+24	109,500	111,250	132,500	14.1	48.0		
Ogive	L	+24	72,500	71,800	109,000	20.0	48.5		
Ogive	L	+24	71,000	71,000	107,600	22.0	51.2		
Ogive	L	-65	84,200	82,200	121,300	23.0	49.5	17	13
Ogive	L	-65	84,500	83,000	123,500	21.0	47.4		
Body	L	+24	105,000	107,000	127,500	21.9	56.5		
Body	L	+24	104,250	105,750	126,500	17.2	56.5		
Body	L	+24	106,250	107,500	127,500	17.2	55.0		
Body	L	+24	105,250	106,750	127,250	17.2	59.0		
CASING C									
Ogive	T	+24	81,300	82,300	113,800	14.3	31.5		
Ogive	T	+24	86,500	86,500	116,000	17.9	41.1		
Ogive	T	-65	88,300	86,800	126,100	14.5	23.2	3	8
Ogive	T	-65	84,500	84,500	123,000	11.5	14.0		
Body	T	+24	107,500	108,750	127,500	15.6	44.5		
Body	T	+24	104,250	105,750	127,500	12.5	41.5		
Body	T	+24	98,500	100,500	128,000	12.5	46.3		
Body	T	+24	98,750	101,250	126,000	14.1	43.5		
Ogive	L	+24	70,000	70,600	106,500	19.0	45.7		
Ogive	L	+24	69,800	70,000	105,250	19.0	44.5		
Ogive	L	-65	85,500	83,300	118,000	20.0	39.7	17	12
Ogive	L	-65	84,100	82,100	120,300	20.0	42.7		
Body	L	+24	91,250	92,500	126,000	18.8	59.0		
Body	L	+24	87,500	88,750	118,750	21.9	60.0		
Body	L	+24	90,000	89,250	118,750	21.9	59.0		
Body	L	+24	96,250	97,500	121,750	15.6	58.5		

15. Casing A, unheat-treated, had yield and tensile strengths somewhat lower in the transverse direction; the opposite was true in Casings B and C, which had been heat-treated by quench and temper operations. Casing A had an average transverse yield strength of 41,000 psi in the forged ogive, and 45,000 psi in the body. Transverse sections of the heat-treated casings exhibited 81,000 psi yield and 114,000 psi tensile in the ogive, and 106,750 psi yield and 130,000 psi tensile in the body.

16. At -65°C (-84°F) the strength of the ogive section showed an increase over ambient temperature properties. This was more pronounced in the unheat-treated casing, which increased 30 to 35 percent in yield strength and approximately 15 percent in tensile. At the low temperature, quenched-and-tempered Casing B increased from 10 to 17 percent in yield strength and from 9 to 13 percent in tensile. An increase of 3 to 17 percent in yield and 8 to 12 percent in tensile strength was obtained in Casing C when the test temperature was lowered from room temperature to -65°C. No appreciable effect was noted in the elongation and reduction of area values of any of the casings.

17. Hardness Tests: Rockwell hardness readings were obtained on surface-ground longitudinal sections from the ogive and body of each casing. Table 3 contains readings on the ogive sections; body section readings were uniform and not tabulated. Casing A, as forged, was slightly higher in hardness at the outer surface of the ogive (84 Rockwell B average) with the hardness decreasing toward the interior (81 Rockwell B average).

18. Near the outer surface of the ogive, the other two casings showed higher readings (19 to 28 Rockwell C) which decreased toward the midwall (15 to 16 Rockwell C) and increased again slightly at the outer surface (18 to 21 Rockwell C).

TABLE 3

HARDNESS READINGS ON OGIVE SECTIONS OF 750-POUND BOMB CASINGS

Casing A (Rockwell "B")				Casing B (Rockwell "C")			Casing C (Rockwell "C")			
¼-Inch Below Surface		½-Inch Below Surface		¼-Inch Below Surface		Center of	¼-Inch Below Surface		½-Inch Below Surface	
Outer	Inner	Outer	Inner	Outer	Inner	Section	Outer	Inner	Outer	Inner
83.5	----	80.5	- - -	20.0	- - -	- - -	19.0	- - -	17.5	- - -
83.0	- - -	81.0	80.0	18.0	- - -	17.5	18.5	- - -	17.0	- - -
84.5	- - -	81.0	80.5	18.0	21.5	17.0	18.5	- - -	16.5	14.5
84.0	79.0	82.0	81.0	18.0	23.5	15.5	18.0	19.0	17.0	14.5
84.5	80.0	81.0	81.5	18.5	21.5	16.0	19.0	21.0	16.5	15.0
84.0	- - -	81.0	81.5	17.5	23.0	16.0	19.0	20.0	17.0	17.0
83.5	- - -	82.0	81.5	19.0	23.0	16.5	19.5	20.5	17.0	17.0
84.5	- - -	81.5	82.0	18.0	23.5	18.0	18.5	21.0	17.0	17.0
85.0	- - -	82.0	82.5	17.5	24.0	17.5	18.5	22.0	17.0	18.0
84.0	- - -	82.0	81.5	18.0	23.0	17.5	18.5	23.0	17.0	18.0
84.0	- - -	82.0	- - -	18.0	24.0	18.5	18.5	- - -	16.5	20,0
83.0	- - -	81.5	- - -	18.5	- - -	20.5	19.0	- - -	17.0	- - -
83.0	- - -	81.5	- - -	19.0	- - -	22.0	18.5	- - -	18.0	- - -
83.0	- - -	82.0	- - -	19.0	- - -	21.0	19.0	- - -	19.0	- - -
83.5	- - -	82.0	- - -	18.5	- - -	21.5	19.0	- - -	20.0	- - -
82.0	- - -	82.0	- - -	20.0	- - -	26.0	18.5	- - -	20.5	- - -
82.5	- - -	82.0	- - -	19.0	- - -	28.0	18.5	- - -	20.0	- - -
84.0	- - -	82.0	- - -	19.5	- - -	28.5	18.5	- - -	18.5	- - -
				21.0	- - -	28.5	19.0	- - -	18.5	- - -

19. Hardness readings obtained every half-inch apart on a section from Casing A's sidewall were similar to those obtained near the outer surface of its ogive. Readings obtained on sections of B and C casing sidewalls were fairly uniform and averaged 25 and 23 Rockwell C, respectively.

20. Radiographic Examination of Cracked Areas: Radiographs, covering an approximate 12-inch by 18-inch casing area, were taken of both lug inserts in each of the three casings. No cracks or other defects were observed in either the rear insert welds (circular inserts) or the forward insert weld of Casing A. In Casing B (visible without X-ray), an 11-inch long crack was shown tangent to the forward edge of the insert weld and extending into the casing metal an equal distance on each side of the insert (Fig. 6). The radiograph of Casing C revealed a repair weld of a crack which extended into the casing metal approximately seven inches to the left and 3/4 inch to the right of the insert. A 1/4-inch section at the end of the crack on the right side of the insert was not filled completely by the repair welding operation.

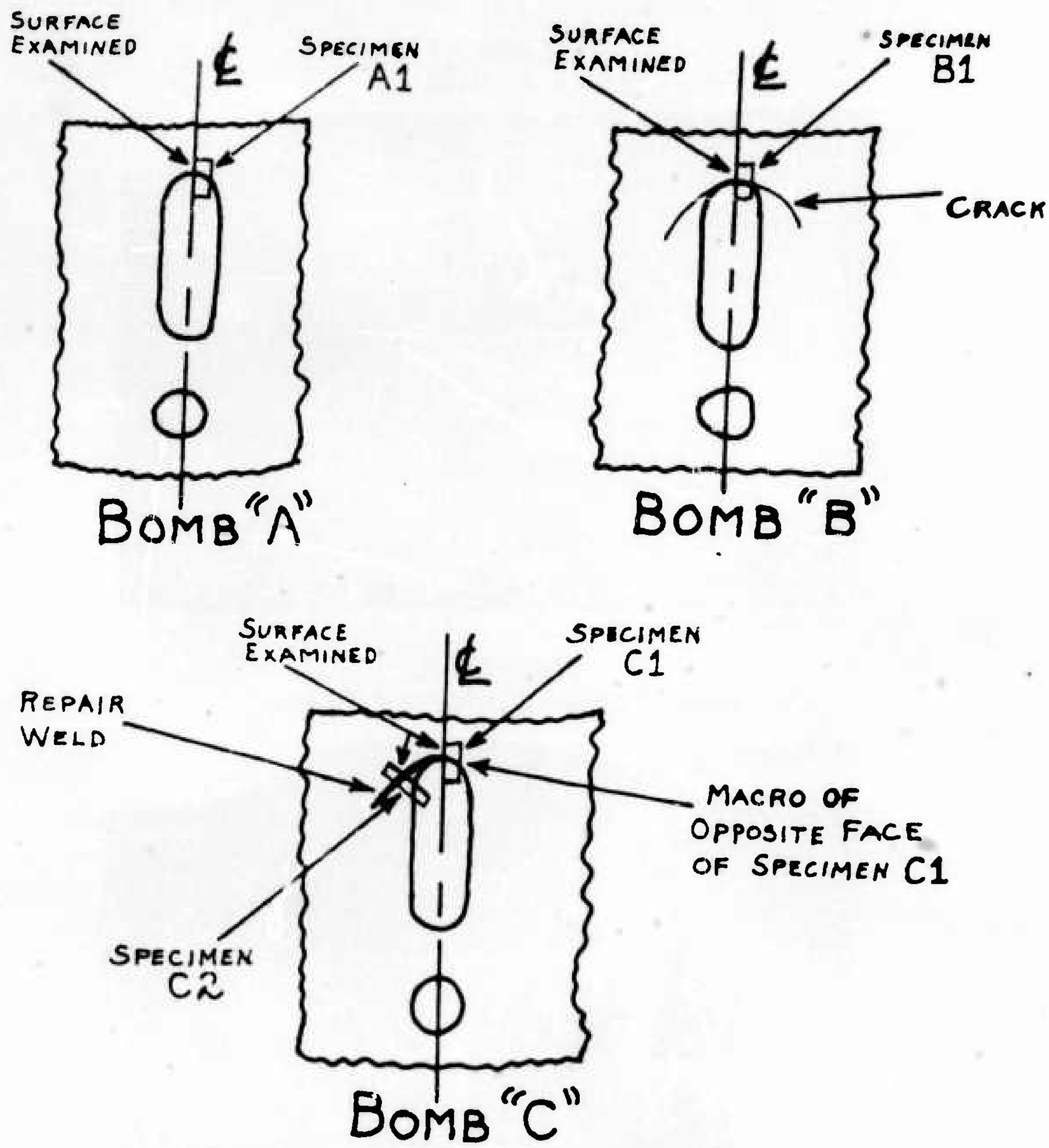
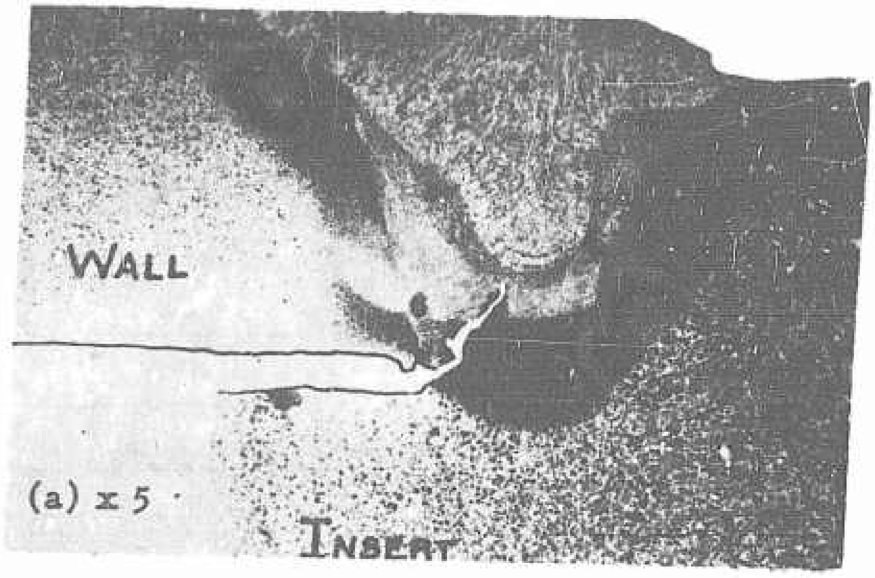


Fig. 6. Lug Insert Welds of Test Bomb Casings A, B, and C.

21. Examination of Lug Insert Welds: Sections of lug insert welds were taken from the three bomb casings (Fig. 6) so that in each case the section of Specimen No. 1 examined was approximately in the centerline of the lug insert. Macrographs of these sections are shown in Figures 7 and 8. As a point of interest, a macrograph of the opposite face of Specimen C1 is shown in Figure 8.

SPECIMEN A1
Bomb A As Welded



SPECIMEN B1
Bomb B After Quench and Temper

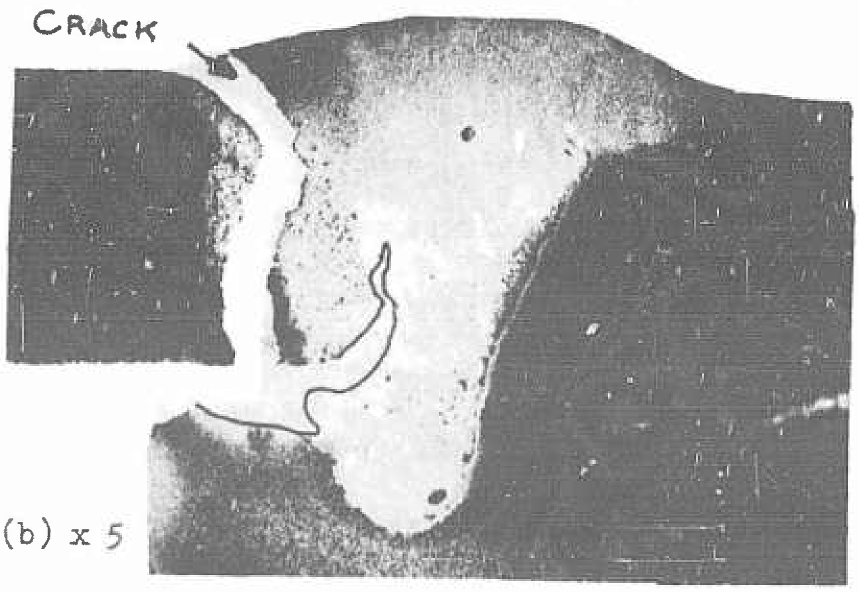
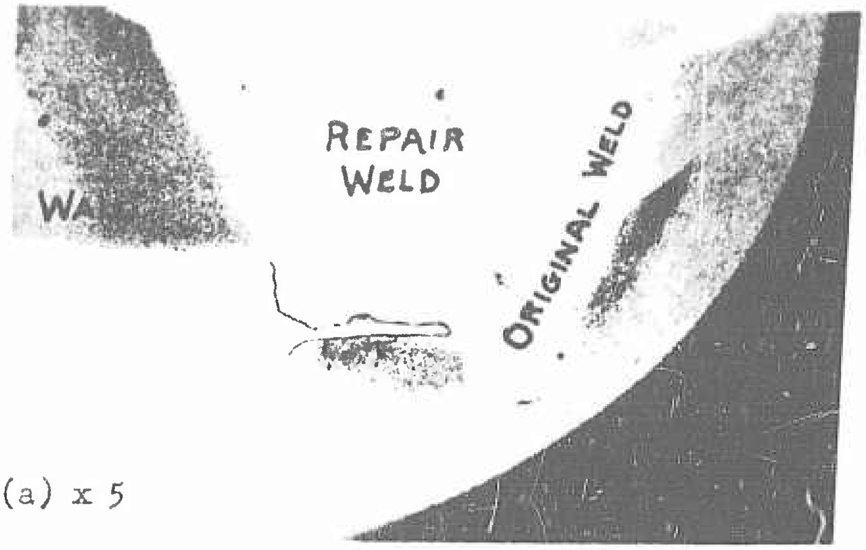


Fig. 7. Lug Insert Welds of Casings A and B, Showing Cracks in Casing Wall.

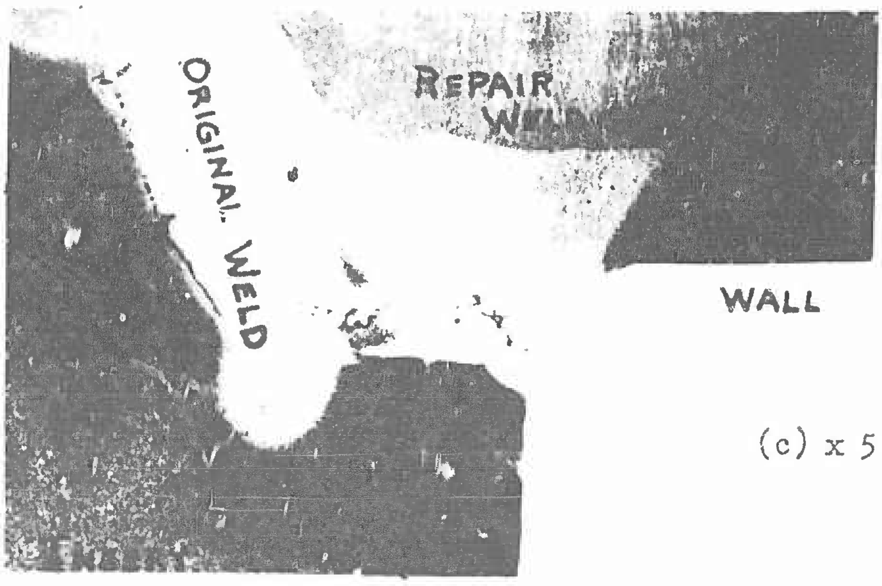
22. A second specimen, C2, was taken from Bomb C to give a cross section of the repair weld and a section of the insert weld. The black dots in the macrographs indicate approximately where photomicrographs were taken.

SPECIMEN C1



(a) x 5

SPECIMEN C1



(c) x 5

Fig. 8. Bomb Casing C with Lug Insert Weld Repaired.

23. Photomicrographs in Figure 9 were taken from the location on Bomb A, shown in Figure 7, to show the "as welded" condition. The bomb casing wall was a hot-worked metal with a banded, coarse pearlitic structure, and the weld metal had a coarse dendritic structure with some pearlite. Figure 9E shows the coarse pearlite of base metal in the heat-affected zone was refined considerably by successive heat applications of the two weld layers.

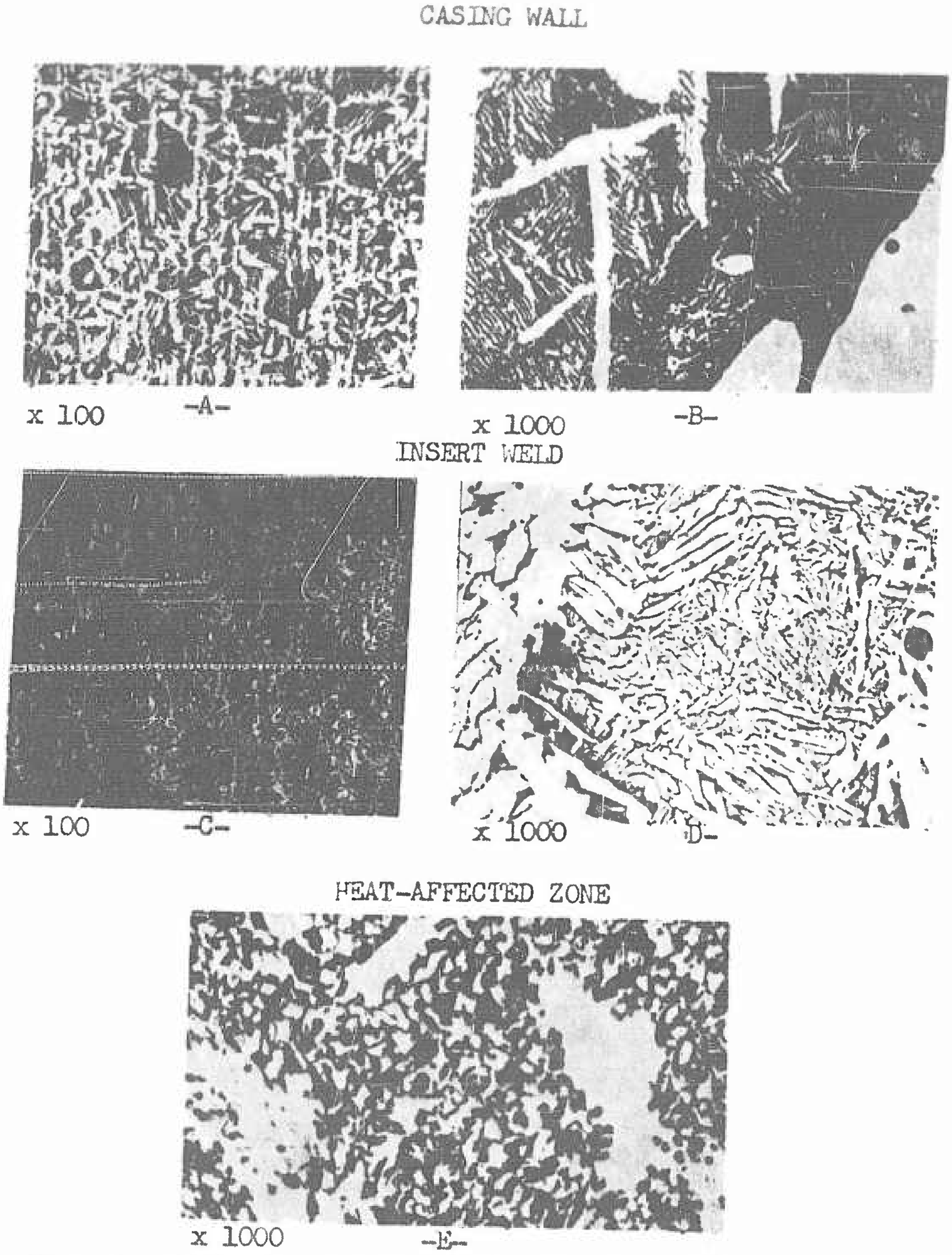


Fig. 9. Photomicrographs of the "As Welded" Condition of Lug Insert Section of Test Bomb Casing A.

24. In the quench- and temper-treated bomb casing, the coarse pearlite was refined considerably and had been transformed largely to tempered bainite. Coarse dendritic structures of the weld were eliminated by heat-treatment which left a structure of fine-grained pearlite with some bainite. The

heat-affected zone, as such, disappeared, and the structure reverted to that of the heat-treated casing wall.

25. Casing C's wall exhibited a structure of tempered bainite with a small amount of tempered martensite. The repair weld was dendritic, similar to the lug insert welds, but much finer grained because of alloy content and because specimens for the photomicrographs were in a layer of weld metal below the surface.

26. Casing C's lug insert weld showed a structure of fine-grained pearlite with some bainite, plus a slight iron carbide precipitation due to tempering. The repair weld showed that the structure in the surface layer was not reheated by a subsequent layer.

27. As shown in Figure 6, a typical example, quench cracking occurred approximately at right angles to the centerline of the lug insert, and the crack was tangent to the weld at the centerline of the lug insert. Except for a short distance in the region of tangency, the crack was not associated with the lug insert weld but extended into the bomb casing away from the weld.

GUN-FIRING RESULTS

28. All the seven bombs fired penetrated their respective targets, and all bombs were recovered after firing. Three were in an effective condition and four, in an ineffective, bursting condition.

29. In general, nose ends of recovered bombs were in very good condition. Conical nose plugs and the areas around them were only slightly deformed. All impacts were at a velocity of about 1000 ft/sec which roughly corresponded to a free fall from 25,000 feet altitude. In each case the concrete target was at 15 degrees obliquity from the line of fire (the angle at point of impact, between the line of fire and the normal to the plate).

30. The first bomb, with a mean velocity of 1010 ft/sec, was fired 29 March 1956, against 16-inch, single-thickness reinforced concrete, instead of the 18-inch requested by Reference B. An 18-inch target was not available and previous results had indicated that this bomb would not penetrate 20 inches of concrete and remain effective. Nose plug and nose area were in good condition. Figure 10 shows that the body was uncracked and, except for a 180-degree fold around the base, was in good shape. However, the bomb base was torn open, the explosive cavity exposed, and the base well broken and deformed (Fig. 11).

Fig. 10. Target Penetration and Fold at Ogive Base of First Bomb.

31. The second bomb was fired on 4 April 1956, against 20-inch, single-thickness reinforced concrete at a velocity of 1025 ft/ sec. Nose plug and nose area remained in good condition,

but the body fractured along the weld for the multiple lug insert (Figs. 12 and 13), and a heavy 300-degree fold appeared around the main base of the ogive (Fig. 14). The external base ring was partially separated from the body of the bomb as shown in Figure 12.

Fig. 11. Base of Recovered Bomb, Showing Broken External Base Ring, Missing Base Plug, and Distorted Fuze Cavity Liner.

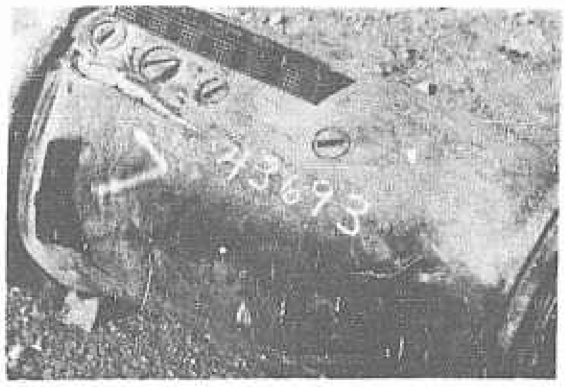


Fig. 12. Second Bomb, Showing Fold at Junction of Ogive and Body, Split Along Multiple Insert Weld, and Separation of External Base Ring.

32. The third bomb, fired 11 April 1956, against 20-inch, single-thickness reinforced concrete, had a mean velocity of 1005 ft/sec. Nose plug and nose area were in good condition, but the body had a fracture along the weld for the multiple lug insert and, at the ogive base, two heavy folds, one of

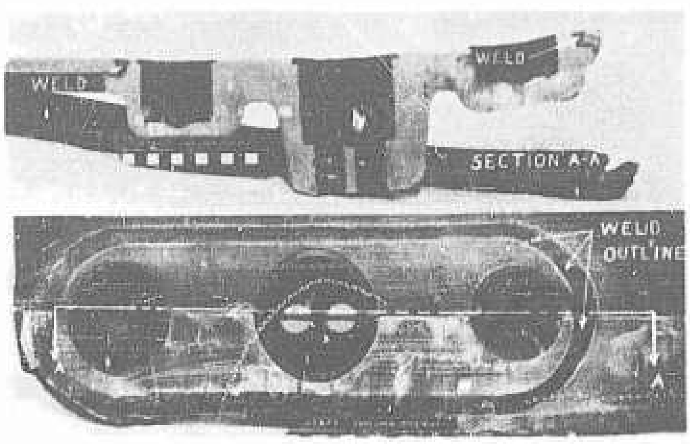


Fig. 13. Sectioned Multiple Lug Insert From Second Bomb, Showing Metal Failure Along Weld.

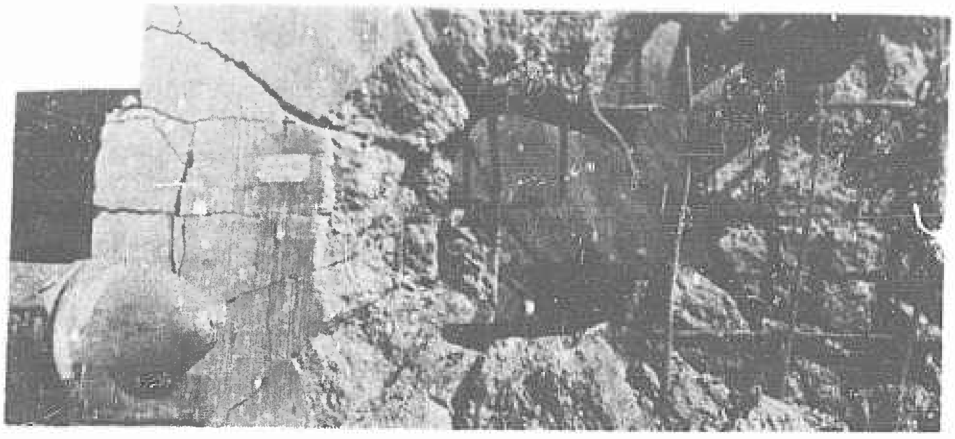


Fig. 14. Photo of Second Bomb Fired, Showing Fold at Base of Ogive and Penetration Through 20 Inches of Concrete.

which extended 360 degrees around the body (Fig. 15). The external base ring was partially separated from the body (Fig. 16), and the body section had a fracture along the weld for the multiple lug insert (Fig. 17).

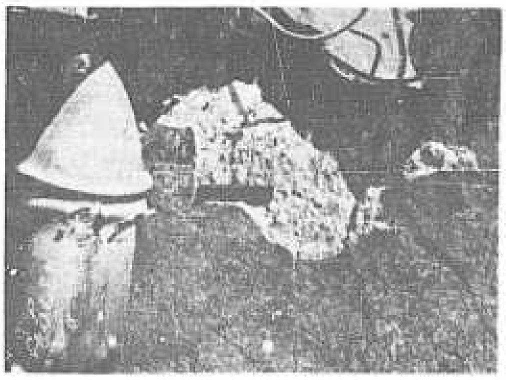


Fig. 15. Third Bomb Fired, Showing Heavy Folds Around Body.

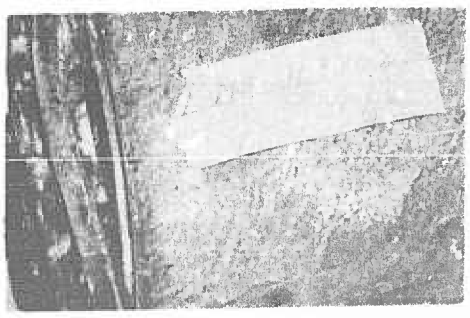


Fig. 16. Closeup of 3rd Bomb Base Showing Separation of External Base Ring and Exposed Cavity.

33. The fourth bomb was fired 18 April 1956, against 16-inch reinforced concrete. Mean velocity was 1013 ft/sec. The nose plug, nose area, and body were in good condition; the body had no folds

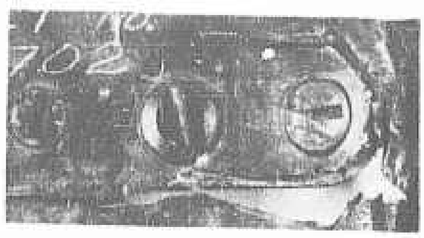


Fig. 17. Metal Failure Along Lug Insert Weld of Third Bomb Fired.

or bulges (Fig. 18). The external base ring in this bomb was broken and deformed, nevertheless, as shown by Figure 19, the explosive cavity was not exposed. The bomb remained effective.

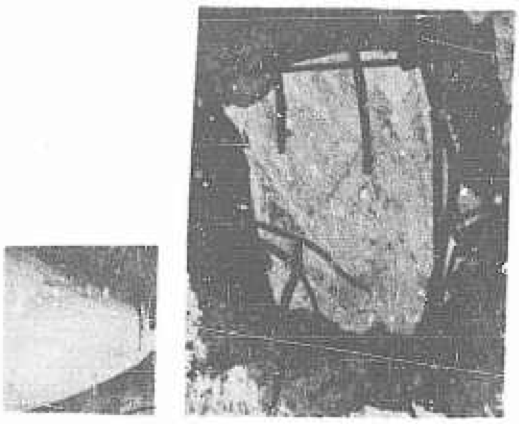


Fig. 18. Nose of Fourth Bomb Appears in Good Condition Following Target Penetration.

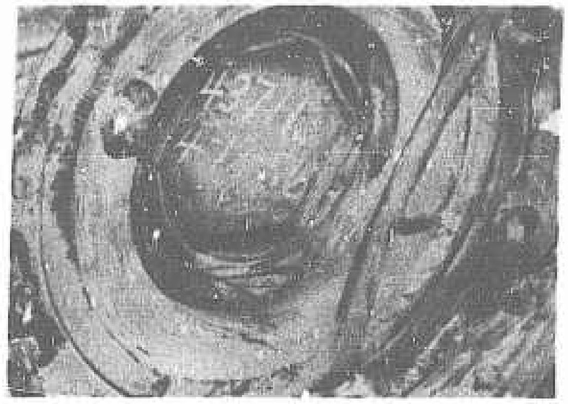


Fig. 19. Base of Recovered Fourth Bomb, Showing Broken External Base Ring and Sheared Rim on Base Plug.

34. The fifth bomb was fired 26 April 1956, against 24-inch, laminated (three 8-inch slabs stacked together) reinforced concrete. Mean velocity was 988 ft/sec. The nose plug was in poor condition and had been forced into the nose fuze well, although the surrounding nose area was in good condition. The body was not damaged, except for a slight 180-degree bulge around the base of the ogive.(Fig. 20). A slight separation appeared between the external base ring and the body.

35. The sixth bomb was fired 2 May 1956, against 24-inch, laminated (two 12-inch slabs stacked together) reinforced concrete. Mean velocity was 1016 ft/sec. Although the nose plug was in good condition, the surrounding area was fractured (Fig. 21). The body was badly fractured but the bomb base was in good shape, and no cracks appeared near the insert weld (Fig. 22).

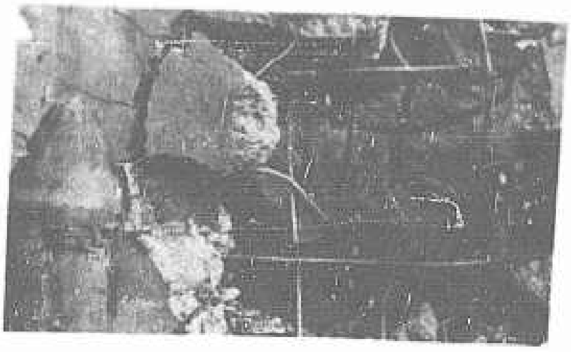


Fig. 20. Fifth Bomb Fired, Showing Penetrated Target and Bulge Around Base of Ogive.

36. The seventh bomb was fired 10 May 1956, against 24-inch, laminated (three 8-inch slabs stacked together) reinforced concrete. Mean velocity was 978 ft/sec. Nose plug and ogive were in good condition, except for a dent that

Fig. 21. Sixth Bomb Fired, Showing that Area Surrounding Nose Plug was Fractured, Although Plug was in Good Condition and Target was Penetrated.

Fig. 22. Sixth Bomb Fired with Base in Good Condition and Lug Insert Weld Area Free from Cracks.

resulted from secondary impact (Fig. 23). The base of the seventh bomb was in good condition and so was the body. However, as shown in Figure 24, a 180-degree fold appeared at the base of the ogive.

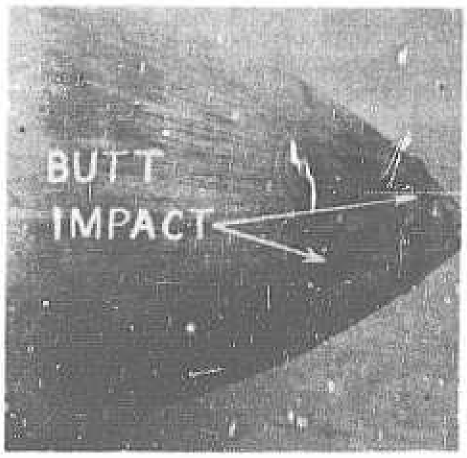


Fig. 23. Seventh Bomb Fired, Showing Dent from Secondary Impact.

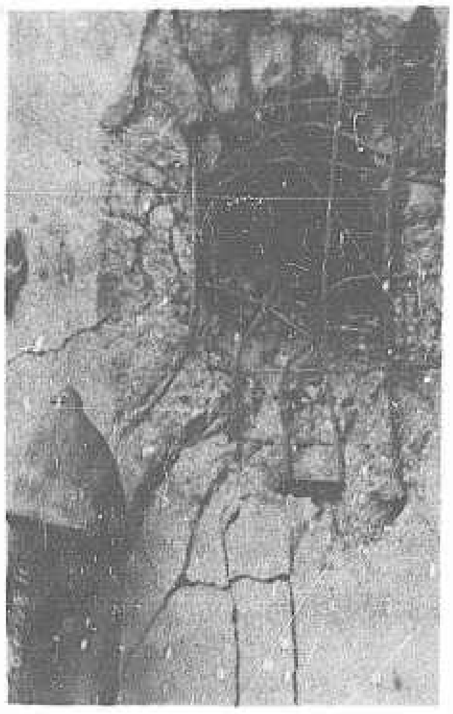


Fig. 24. Photo Showing How Seventh Bomb Penetrated Target.

DISCUSSION OF RESULTS

37. Although chemical analysis indicated incomplete transformation to martensite (refer to par. 11), a fully martensistic structure was probably not essential for use in the T54E3 Bomb.

38. It appears that in Casing A, fabricated from .45-inch-thick tubing, the flow pattern was less distinct than in Casings B and C because less forging was required to increase wall thickness from .45-inch to the required dimensions of the nose.

39. Microscopic examination indicated that the ogive and body structure of Casing A was consistent with the mechanical properties of the casing which had approximately a 55-percent yield to tensile strength ratio. The structure of the body of Casing C indicated that the austenitizing treatment was not performed with as drastic a quench as employed for Casing B. This accounts for the ferrite rejection. Again, the yield to tensile strength ratios are consistent with the microstructures of Casings B and C.

40. The lower ogival strength levels in the unheat-treated casing, shown by tensile strength tests, resulted from slow cooling from the forging temperature. In the heat-treated casings, lower strengths in the ogives were attributed to insufficient hardenability of the steel composition employed and the slower cooling rate in the thicker sections during quenching.

41. The variation in hardness (shown by Rockwell tests) existed from both the interior and exterior surfaces to the center of the heat-treated ogive sections. It demonstrated the lack of "through-hardening" qualities of the steel employed, and also revealed that the casings were cooled on both the exterior and interior surfaces during the quenching operation.

It appeared that the interior quench was more efficient than the exterior, because of higher hardness values obtained near the interior.

42. The slightly higher readings in the sidewall of the heat-treated casings (refer to par. 18) resulted from the more rapid cooling of the thinner sections during quenching from the austenitizing temperature. Because of their uniformity, individual readings obtained on the sidewall sections were not presented.

43. The repair weld on the lug insert showed that the structure in the surface layer was not reheated by a subsequent layer. This indicated that the tempering had a negligible effect on weld metal structure.

44. Review of lug insert examination results indicates that the lug insert did not fit the opening in the casing wall accurately enough to fit snugly against the inside of the casing wall prior to welding. This condition caused a tendency to the root cracking of the weld metal. A root crack was present in the first, or root layer of weld metal. The peculiar nature of the welding process was also a contributing factor to the root cracking because the process gave a penetration great in depth but restricted in width. This condition resulted in a constriction of the weld metal, at the root of the joints where the poor fit of the back-up produced a sharp re-entrant angle on the side of the casing wall, that was believed to be a contributing factor to root cracking upon cooling of the weld.

45. Root cracking was not associated with cracking of the casing wall during the heat treatment cycle, since the casing cracked through the heat-affected zone, contiguous to the toe of weld reinforcement and away from the bond line, over the inner half of the casing wall thickness. This indicated that cracking was "triggered" by restraint of the lug insert mass and weld

reinforcement, upon cooling from the quench. Small variations in snugness of fit of the lug insert against the inside of the casing wall, the height of weld reinforcement, or contour of the toe weld can cause "triggering".

46. It will be noted that quench cracking occurred approximately at right angles to the centerline of the lug insert, tangent to the weld at the centerline of the insert. Except for a short distance in the region of tangency, the crack was not associated with the lug insert weld but extended into the bomb casing away from the weld.

47. It is possible that quench-cracking of the bomb casing (about one percent of production) was associated with the stress pattern imposed by the relatively massive insert welded solidly into the thinner casing wall. The weld reinforcement could act as an effective stress raiser from longitudinal shrinkage of the bomb casing during the quench. It was not evident that variation in welding techniques would affect the incidence of cracking, except, possibly, insofar as the amount of weld reinforcement would be affected by such variations.

48. The first bomb fired was considered ineffective because the base closure failed. A body fracture and resulting exposure of the explosive cavity made the second bomb ineffective. Separation of the external base ring from the body, exposure of the explosive cavity, and a fracture along the weld rendered the third bomb ineffective.

49. Although its external base ring broke and deformed, the fourth bomb was considered effective because its explosive cavity was not exposed. The fifth bomb was also deemed effective because the body remained in good condition with the explosive cavity unexposed.

50. A badly fractured body made the sixth bomb ineffective; however, it should be noted that this bomb was fired against a target heavily reinforced (in a cubic fashion) with 3/8-inch bars on six-inch centers.

51. The seventh bomb was in an effective condition because both body and base were in very good shape.

52. Examination of recovered bombs indicated that two areas lacked adequate strength; the weld for the multiple lug insert, and the base closure. Only one bomb out of seven failed because of body fracture; the other failures were results of weld or base construction weaknesses. Refer to Table 4 for complete data.

TABLE 4

Summary of Firing Conditions and Results

Date Fired 1956	Bomb Wt Lbs.	Inert Filler Spec. Grav.	Velocity Ft/Sec*	Target Type	Target Thickness Inches	Through Opening Inches	Condition Of Bomb	Remarks
3/29	750	1.71	1010	S	16	26 x 27	Ineffective	Body deformed; base ring broken off; explosive cavity exposed.
4/4	776	1.73	1025	S	20	31 x 33	Ineffective	Body deformed and split along weld; base ring loose.
4/11	775	1.72	1005	S	20	26 x 27	Ineffective	Body deformed and split along weld; base ring broken.
4/18	775	1.71	1013	S	16	25 x 27	Effective	Body intact; base ring broken, but explosive cavity unexposed.
4/26	786	1.76	988	L	8+8+8	26 x 28	Effective	Body slightly deformed; base ring loose.
5/2	751	1.76	1016	L	8+8+8	22 x 28	Ineffective	Body badly fractured; base ring intact.
5/10	749	1.74	978	L	12+12	22 x 31	Effective	Body deformed; base ring intact.

* Figures listed are striking velocities obtained; bomb was designed for a velocity of 1000 ft/sec.
NOTE 1: Under "Target Type" S = single-thickness, L = laminated.
NOTE 2: All bombs penetrated the target, and all targets were at 15° obliquity.

DESCRIPTION OF TEST BOMBS

53. Walsh Company 750-pound demolition bombs used in the gun-firing tests were identical to the T54E3 Bomb shown in Figure 25, except that the ogive wall thickness was below specification requirements. The Walsh bomb had a maximum diameter of 16.13 inches and an overall length of 50.94 inches. All lug inserts, fuze charging tubes, and fuze wells were included in the bombs. Sample bombs were prepared from seamless tubing, with the ogive and base taper formed by a swaging process. The lug inserts were formed separately and welded into the bomb body.

54. The bombs were inert-loaded with a mixture of Pearlite (volcanic glass, specific gravity 0.125), Portland cement and water to simulate the density of tritonal high explosive. This inert filler was allowed to harden a minimum of ten days before firing.*

55. To increase the diameter of the bombs to gun bore diameter and seal against the escape of propellant gases, an aluminum pusher plate (Fig. 26) and a four-inch cloth tape bourrelet were placed on each bomb. The pusher plate, attached with four ½-inch bolts, was designed to strip off upon target impact without damage to the bomb body. The bombs were provided with regular conical steel nose plugs, and the fuze wells were left empty.*

TEST EQUIPMENT

56. An 18-inch/4417 Mk A, No. 1L (Rifled Bore) gun was used to fire the test bombs. The propellant, Index SPDN 10546, in 40-pound charges, was used

* NOTE: Bomb labeled "Vermiculite" on Frontispiece typifies description in paragraph 55, and does not pertain to loading described in paragraph 54.

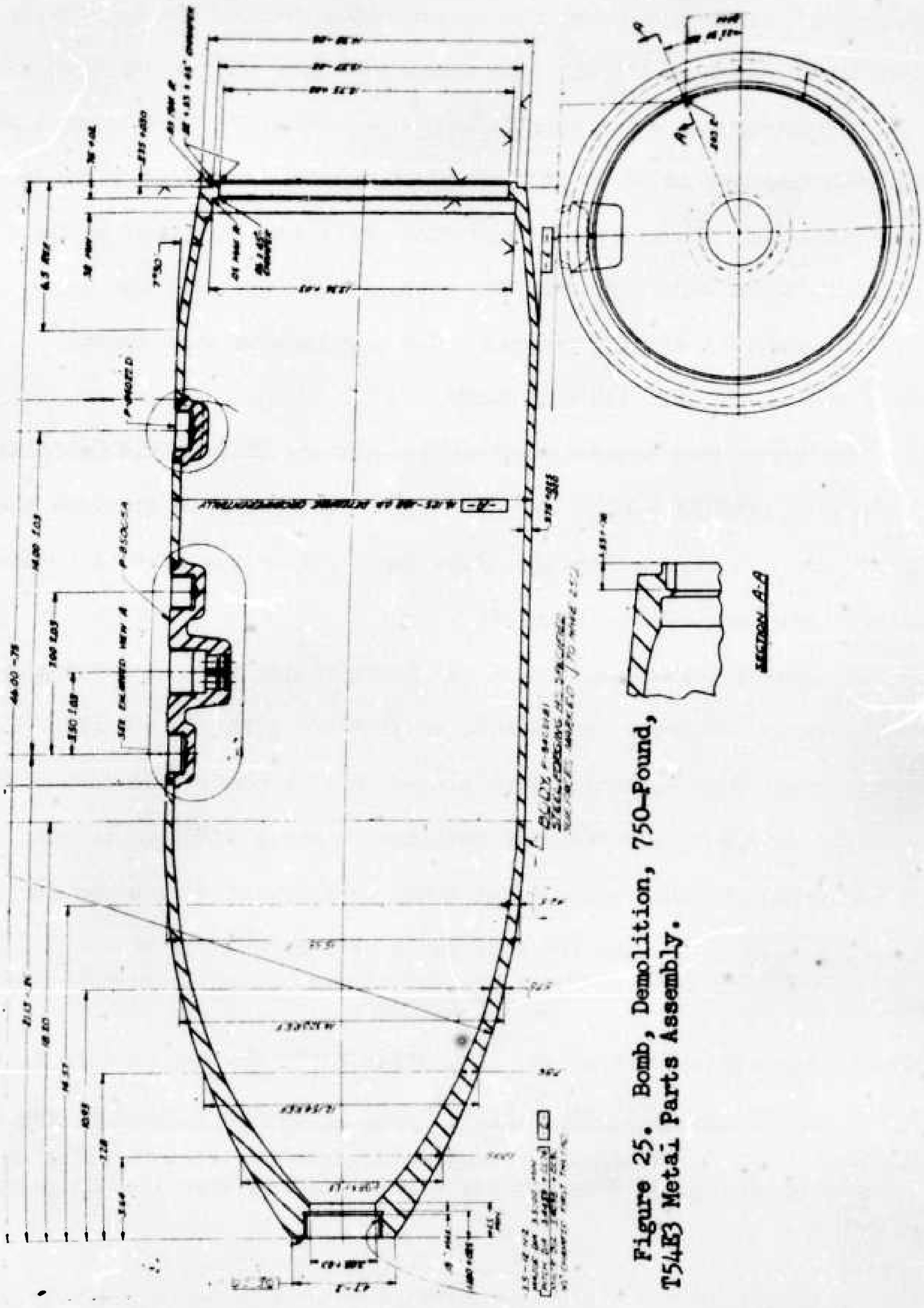


Figure 25. Bomb, Demolition, 750-Pound, T54E3 Metal Parts Assembly.

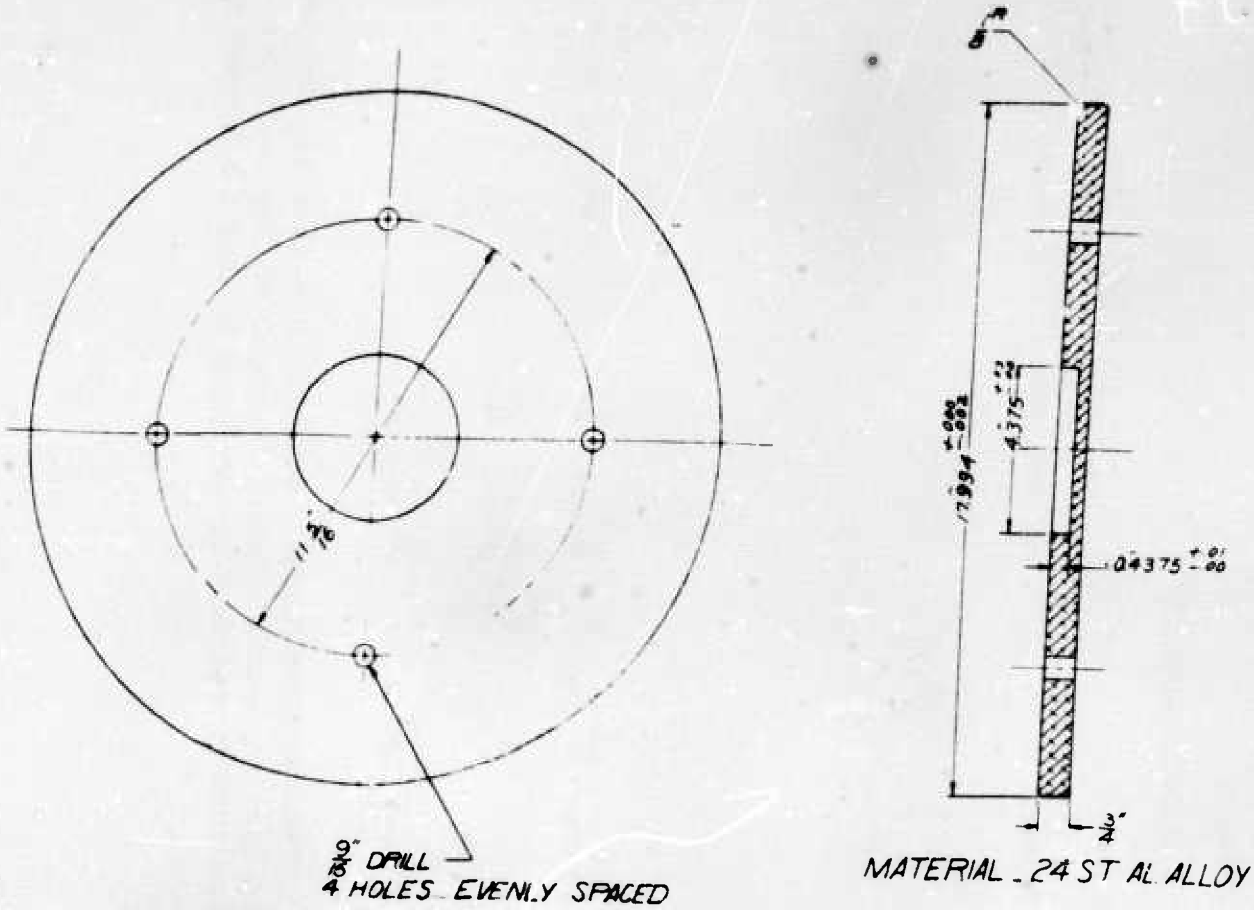


Fig. 26. Pressure Plate for 750-Pound Bomb.

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with Combination MK 15-2, Lot 2M10, 1952, primer. The powder was packed in 6-inch/52, three-section, raw silk bags. Targets were of various thicknesses of reinforced concrete with 5000 psi compressive strength. Refer to Table 5 for complete details.

TABLE 5

SUMMARY OF DATA ON CONCRETE TARGETS USED

Date Fired 1956	Concrete Target Thickness - Inches: Single	Laminated	Concrete Target Reinforcing - Round Steel Bar Lattice Work Arranged in Layers: Single-Thickness Target: Horizontal	Vertical	Layers	Laminated-Thickness Target (Slabs Stacked Together - One Behind the Other)* First Slab: Horizontal	Vertical	Layers	Second Slab: Horizontal	Vertical	Layers	Third Slab: Horizontal	Vertical	Layers
3/29	16	-	1/2" - 12" Ctrs.	3/4" - 12" Ctrs.	2	-	-	-	-	-	-	-	-	-
4/4	20	-	3/4" - 13" Ctrs.	3/4" - 13" Ctrs.	2	-	-	-	-	-	-	-	-	-
4/11	20	-	3/4" - 12" Ctrs.	3/4" - 12" Ctrs.	2	-	-	-	-	-	-	-	-	-
4/18	16	-	1/2" - 12" Ctrs.	3/4" - 12" Ctrs.	2	-	-	-	-	-	-	-	-	-
4/26	-	8+8+8	-	-	-	3/4" - 12" Ctrs.	3/4" - 12" Ctrs.	1	3/8" - 12" Ctrs.	3/8" - 12" Ctrs.	1	1/2" - 12" Ctrs.	3/4" - 12" Ctrs.	1
5/2*	-	12+12	-	-	-	3/8" - 6" Ctrs.	3/8" - 6" Ctrs.	2	3/8" - 6" Ctrs.	3/8" - 6" Ctrs.	2	-	-	-
5/10	-	8+8+8	-	-	-	1/2" - 10" Ctrs.	3/4" - 10" Ctrs.	1	1/2" - 10" Ctrs.	3/4" - 10" Ctrs.	1	1/2" - 10" Ctrs.	3/4" - 10" Ctrs.	1

* In addition to the horizontal and vertical reinforcing, each 12-inch slab had front-to-rear reinforcing of 3/8-inch round bars on 6-inch centers (connecting the two layers of 3/8-inch bars). This cubic lattice work of reinforcing produced a concrete target of great strength.

EXPERIMENTAL PROCEDURE

57. After a minimum of 10 days for curing of the inert filler, the bombs were prepared for firing by addition of the tape bourrelet and aluminum pusher plate.

58. Each bomb, seated 127.5 inches from the mushroom face of the closed breech block of the 18-inch gun, was fired by a charge adjusted to produce a muzzle velocity of 1000 ft/sec. The range was approximately 45 feet to the reinforced target, secured at 15-degree obliquity in a butt backed by a large amount of sand.

59. Velocities were measured by counter chronographs, and pressures, by copper crusher-cylinder gages. After each bomb was fired, it was recovered, examined, and photographed.

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