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NATIONAL DEFENSE RESEARCH COMMITTEE

of

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

WAR METALLURGY DIVISION

Progress Report

on

EXAMINATION OF ENEMY MATERIEL: METALLURGICAL EXAMINATION OF GERMAN 80 MM. MORTAR SHELLS

(OD-113)

by

H. W. GILLETT, A. S. HENDERSON, L. H. GRENELL,
F. C. CROXTON, A. R. ELSEA, AND J. R. CADY
BATTELLE MEMORIAL INSTITUTE

OSRD No. 3115
Serial No. M-198
Copy No. 32

January 10, 1944

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January 10, 1944

To: Dr. James B. Conant, Chairman
National Defense Research Committee of the
Office of Scientific Research and Development

From: War Metallurgy Division (Div. 18), NDRC

Subject: Progress Report on "Examination of Enemy Materiel:
Metallurgical Examination of German 80 mm Mortar Shells"
(OD-113)

The attached progress report submitted by H. W. Gillett, Technical Representative on NDRC Research Project NRC-32, has been approved by representatives of the War Metallurgy Committee in charge of the work.

This report covers an examination of three inert German 80 mm malleable cast iron mortar shells for metallurgical properties, type and quality of raw material, workmanship, and method of manufacture.

I recommend acceptance as a satisfactory progress report under Contract OEMsr-722 with Battelle Memorial Institute.

Respectfully submitted,

Louis Jordan,
Technical Aide to the Chief
War Metallurgy Division, NDRC

Enclosure

PREFACE

This report is pertinent to the problems designated by the War Department Liaison Officer with NDRC as OD-113, and to the project designated by the War Metallurgy Division as NDRC Research Project NRC-32.

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PROGRESS REPORT NO. 29

on

NDRC RESEARCH PROJECT NRC-32, OEMsr-722

EXAMINATION OF ENEMY MATERIEL

Metallurgical Examination of German 80 mm. Mortar Shells

December 6, 1943

From:

BATTELLE MEMORIAL INSTITUTE

Report Prepared By:

L. H. Grenell
A. S. Henderson
F. C. Croxton
A. R. Elsea
J. R. Cady
Research Engineers

H. W. Gillett
Official Investigator

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ABSTRACT

Three inert German 80 mm. malleable cast-iron mortar shells were examined for metallurgical properties, method of manufacture, workmanship, and type and quality of raw materials.

FOREWORD

Three German 80 mm. malleable cast-iron mortar shells were received from Aberdeen Proving Ground for metallurgical examination. They were identified by the number FMAM-103. The markings stamped on this ammunition indicated that the shells and tail assemblies were made in 1939. The fuzes appeared to have been made in 1941 and the shells loaded and assembled in 1941. All of the shells were inert and unfired. A full description of the markings appearing on each shell is given on pages 20 to 22 in the Appendix.

SUMMARY

A malleable iron casting was used for the body of each of the three mortar shells. The heat treatment for malleablizing the iron was similar to the American black-heart process, but differed from the usual treatment in that all of the carbon was not graphitized. A microstructure that would be undesirable in castings subject to normal engineering service was produced by this treatment; however this structure may be desirable from a ballistic standpoint. A packing material of an oxidizing nature appeared to have been used to support the shells during heat treatment. A decarburized skin was produced on the castings as a result of this oxidizing condition. Like the abnormal microstructure, this skin would be undesirable for normal service but may be of value from a ballistic standpoint.

The fuze assembly was made of a number of aluminum parts, using both a strong duralumin alloy in the heat-treated condition and pure aluminum in sheet metal and extruded parts. The booster for the shells was made from a drawn low-carbon steel cup which was attached to a forged adaptor ring by welding in the case of two shells, and by brazing in the third shell. The tail assemblies were made of a central cartridge carrier machined from WD-1035 steel bar stock to which was attached, by spot welding, four double fins from WD-1010 steel sheet. The propelling charge had been packed in a paper tube fitted with a brass cap and a copper primer, and attached to the cartridge container with a soft steel set screw. The exterior of the shells had been painted with a common red lead paint. The explosive cavity was coated with a black asphalt base paint, and the booster cup was coated with a red alkyd-resin paint.

ECONOMIC CONSIDERATIONS

The production of cast malleable iron mortar shells is desirable from an economic standpoint because of the great ease in manufacturing as compared with either steel forgings or steel castings, and because the iron castings do not require the use of equipment of which there is a shortage. Ease and cost of manufacturing must be balanced against the quality of the part, which in this case depends upon the ballistic properties. Thus a comparison between different manufacturing methods used to produce mortar shells would necessarily be made on firing tests rather than on metallurgical considerations. If satisfactory castings could be made from malleable iron, their adoption would result in a more economical shell and a better distribution of war demands on industry.

The extensive uses of aluminum for small screw machine parts of the fuze is indicative of the availability of the metal in German economy. High-sulphur steel screw stock could be substituted for a number of these pieces. A redesign of the tail assembly to permit the use of seamless tubing in place of the solid bar used for the cartridge carrier would result in appreciable saving of steel, machine time, and labor. The method employed in fabrication of the tail fins, by stamping and spot welding steel sheet, is a desirable and time-saving procedure. Brass and copper used in the cartridge cap and primer and in the nose seal probably could be replaced by less critical sheet steel or aluminum. The change in the method of joining the booster cup to the adaptor from brazing to welding might result from a shortage of copper.

DISCUSSION OF RESULTS

Visual Examination

The nose, tail, and side views of the three mortar shells are shown in Figure 1. The disassembly of one shell is shown in Figure 2. Surface markings indicated that the shell bodies were produced by sand casting using a split core with no core wash or mold wash. They appear to have been cast in a vertical position with a single riser at the nose of the shell, although one shell (No. 111) had a longitudinal parting line mark indicating that it was molded, at least, on a horizontally split pattern. The remainder of the shells showed no parting marks and all may have been cast vertically. Shells No. 110 and 111 had a counter bore in the hole where the tail assembly was inserted. Shell No. 110 had a lead gasket in this counter bore. In general, the casting technique was

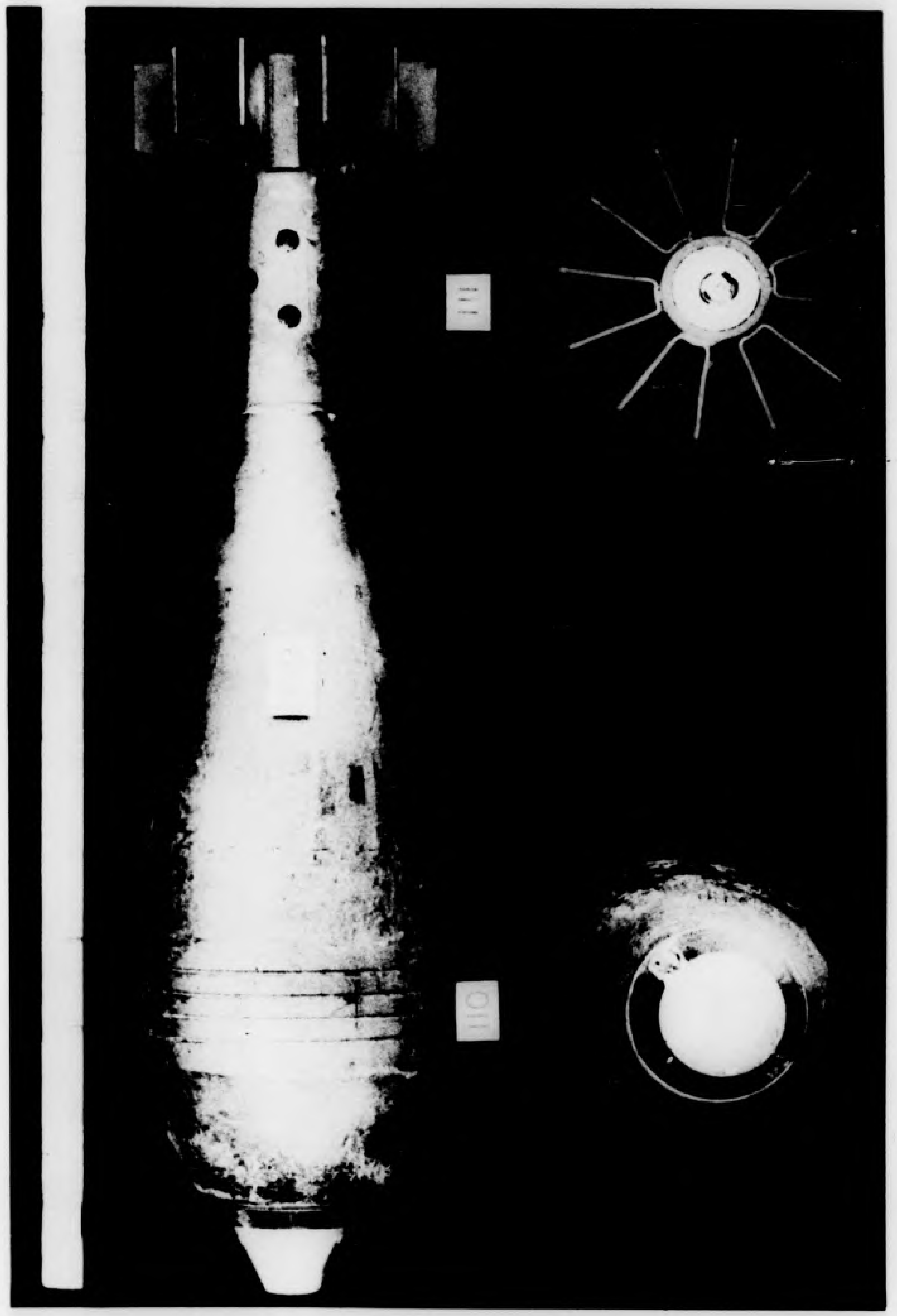

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Figure 1. Nose, Tail, and Side Views of Three German 80 mm. Mortar Shells. (FMAM-103)

DISASSEMBLY PART NUMBERS

1 - Body
2 - Booster
3 - Tail
4 - Detonator Window
5 - Detonator Window Holder
6 - Booster Liner
7 - Paper Cartridge
8 - Cartridge Cap
9 - Cartridge Seal
10 - Cartridge Wad
11 - Fuze Body
12 - Fuze Base Ring
13 - Firing Pin
14 - Safety Sleeve
15 - Safety Inertia
16 - Safety Sleeve Catch
17 - Safety Sleeve Catch Washer
18 - Detonator Cup
19 - Detonator Cup Cover
20 - Safety Bearings
21 - Firing Pin Spring Cover
22 - Firing Pin Spring
23 - Firing Pin Sleeve
24 - Safety Sleeve Spring

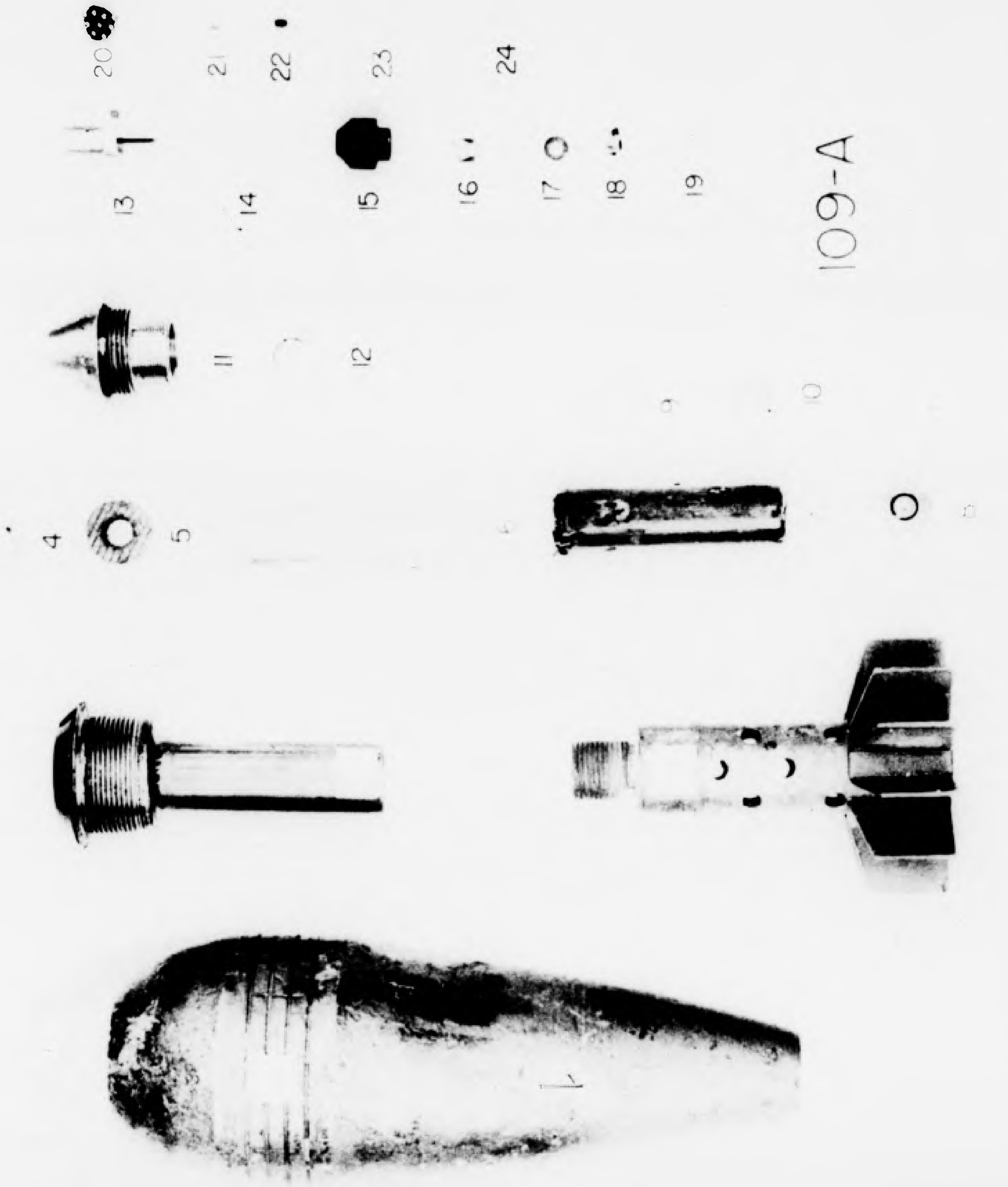

Figure 2. Disassembly of One of The German 80 mm. Mortar Shells.

24176
(FMAM-103)

good. The castings were sound and the surfaces were smooth. The alignment of the cores was good. Shell No. 110 was rough machined on the outside from the nose to the bourrelet. On one side the rough machining extended to a point about halfway between the tail and the bourrelet, while on the other side there was no machining. The location of the machining marks indicated that it was necessary to overcome unacceptable eccentricity in the original casting. All of the shells were machined at the bourrelet and threaded at the ends where the fuze and tail assemblies were inserted.

Protective Coatings

The shell body and the tail assembly were covered on the outside with a common red lead paint. Phenol coatings have been reported on similar ammunition, so a careful but unsuccessful search was made for this material in the paint. The inside of the shell body was coated with a black asphalt paint soluble in acetone. The booster cups and the adaptors were protected by a red alkyd resin containing iron-oxide pigment. A spot of green lacquer was used as a seal over the cartridge primer.

Type of Metal

Each of the shell bodies was cast from a hard, fluid, white cast iron and malleablized by heat treatment to produce the desired physical properties. A chemical analysis of the metal is given in Table 1. This analysis showed that one shell (No. 109) was cast from metal that would be considered normal for use in this country for engineering applications. The other two shells (Nos. 110 and 111) were cast from a very low carbon and high sulphur iron. Each of the shells showed normal phosphorus, silicon, and manganese contents. In general, the material as-cast was of

TABLE 1. CHEMICAL ANALYSIS OF 80 mm. GERMAN MORTAR SHELLS

Shell No.	Total C, %	% Mn	% Si	% S	% P	Acid Sol. Residual, Al, %
109	2.75	0.19	0.86	0.11	0.07	
110	1.62	0.36	0.65	0.14	0.07	
111	1.43	0.42	0.81	0.25	0.09	0.006

satisfactory composition and, with proper heat treatment, would have produced excellent physical properties. This is especially true of the two low-carbon irons.

It was noted that the sulphide inclusions did not appear normal but were somewhat modified as in the case when an addition of aluminum has been made to the material prior to casting. A qualitative analysis for acid-soluble aluminum run on Shell No. 111 indicated that an addition of aluminum was made to the metal. Aluminum is ordinarily not desired in malleable iron, but it is interesting to note that the British specify an addition of aluminum to their gray cast-iron mortar shells.

The mechanical properties of each of the shells was examined to determine the hardness, tensile strength, and elongation. These data are presented in Table 2. The strength and elongation of these shells would not be considered satisfactory by American standards for engineering purposes.

TABLE 2. MECHANICAL PROPERTIES OF 80 mm. GERMAN MORTAR SHELLS*

Shell No.	Hardness, Rockwell "B"	Tensile Strength, psi.	Yield Strength, psi.	Elongation, %
109	76	47,800	28,800	6.2
110	67	49,800	25,900	11.5
111	78	59,200	37,200	4.3

* All specimens 1-inch gage length, 1/4-inch diameter, standard sub-size A.S.T.M. tensile specimens.

Macrographic Examination

A sulphur print was made of the longitudinal section of each shell. Copies of these prints are shown in Figures 3, 4, and 5. In these prints the general contour of the shell is shown (note the counter bore in the tail of Shells No. 110 and 111). The degree of eccentricity is also indicated (note that the contour of the outside surface just below the bourrelet of Shell No. 110 is not symmetrical).

A section of a gray iron or malleable iron casting adjacent to a gate or feeder will usually contain a concentration of sulphide particles in the interdendritic areas; therefore, if the surface from which a sulphur print is made cuts through or near an area adjacent to a gate or feeder in the original casting, the proximity of such a gate or feeder is shown by dark needle-like areas in the sulphur print. The sulphur print of Shell No. 111 shows that the casting was properly gated at the bourrelet and was fed by some sort of shrink-bob at the nose. There is faint evidence that the other shells were also gated at the bourrelet.

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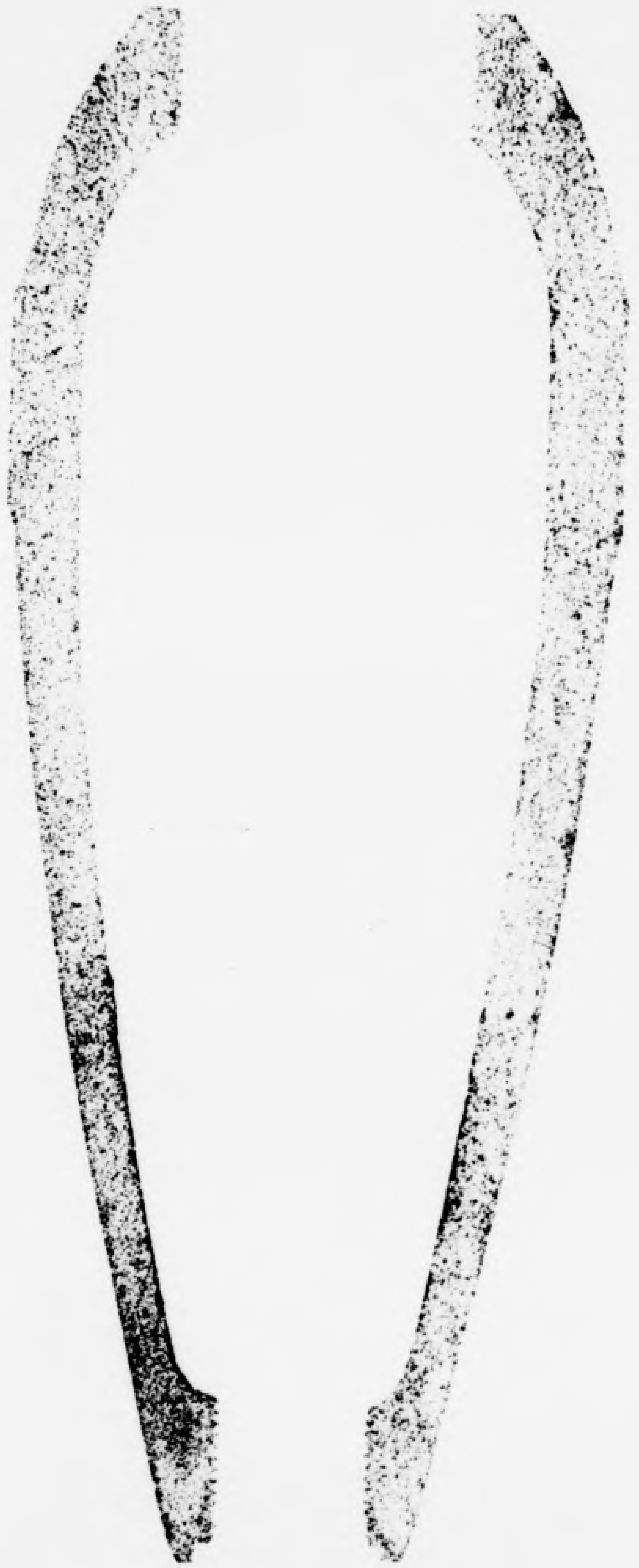
Figure 3. Sulphur Print of Shell No. 109.
Actual Size



24807
Figure 4. Sulphur Print of Shell No. 110.
Actual Size

24805
Figure 5. Sulphur Print of Shell No. 111.
Actual Size

Deep-etched sections of two booster cups and adaptors from Shells No. 109 and 110 are shown in Figure 6. Both booster cups were drawn from low-carbon steel sheet and attached to forged medium-carbon steel adaptors. The booster for Shell No. 109 was attached by brazing using a 60-40 Cu-Zn alloy. The boosters for Shells No. 110 and 111 were attached to their adaptors by manual fusion welding, probably with an oxyacetylene torch. Incomplete fusion was obtained in the case of the two welded assemblies and indicates that unskilled labor was used to form this joint. However, the assembly was not subject to high stress.

Heat Treatment

The type of microstructure produced by heat treatment of the three shell bodies is shown in Figures 7, 8, and 9. The heat treatment used in malleablizing is indicated by the type and distribution of the various structural components. A heavy deoxidized skin is shown on both the inner and the outer surfaces of each of the shell bodies, indicating an oxidizing atmosphere, or packing material used to support these shells, during heat treatment. This skin is thicker than is desirable for castings used in engineering structures, but it may be highly desirable from a ballistic standpoint by increasing the ductility of the metal at the surface of the shell walls. Reports of firing tests made upon other cast shells indicate that the type of fragmentation occurring on detonation may depend upon the ductility of the skin at the inner surface of the shell. The type of fracture in a cast-iron shell, whether brittle or ductile, may depend upon this skin effect. Some evidence substantiating this theory has been obtained from metallurgical study of fragments from cast-iron mortar shells made in this country. If this theory is correct, the decarburized skin (Figures 7, 8, and 9) is highly desirable.

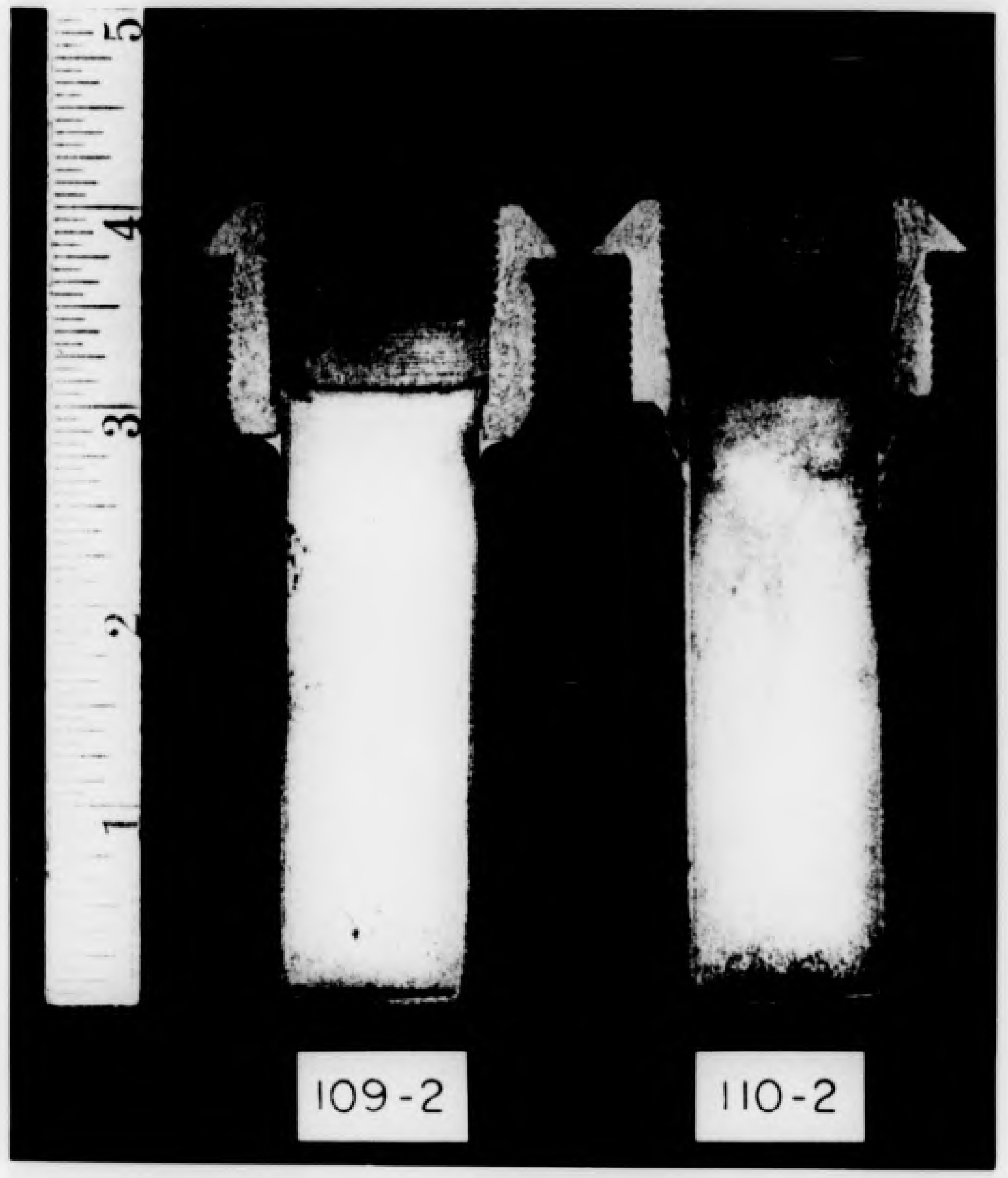


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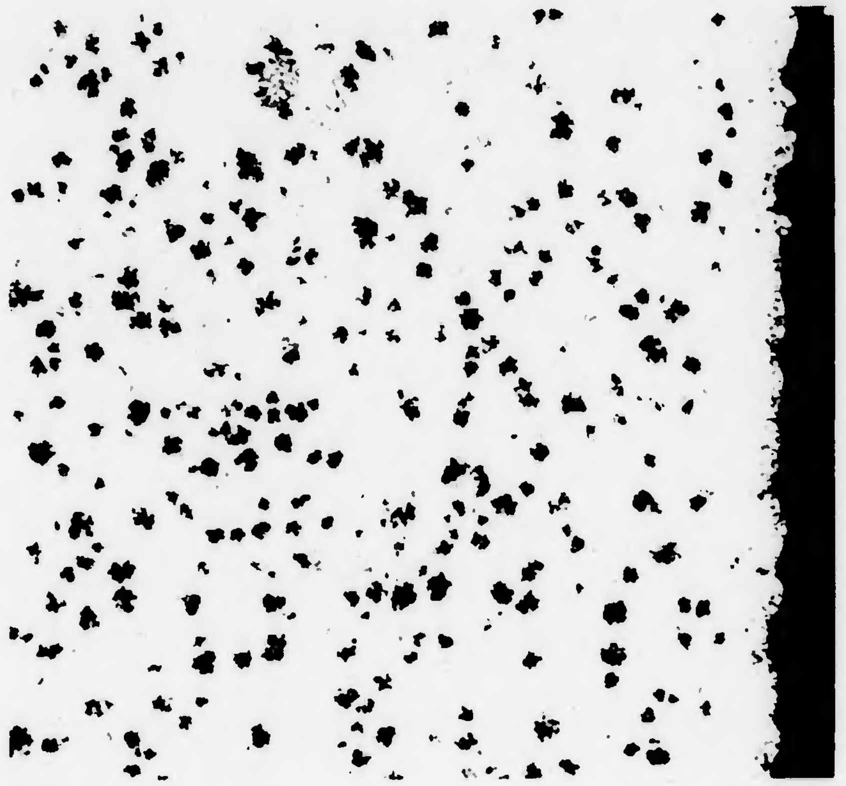
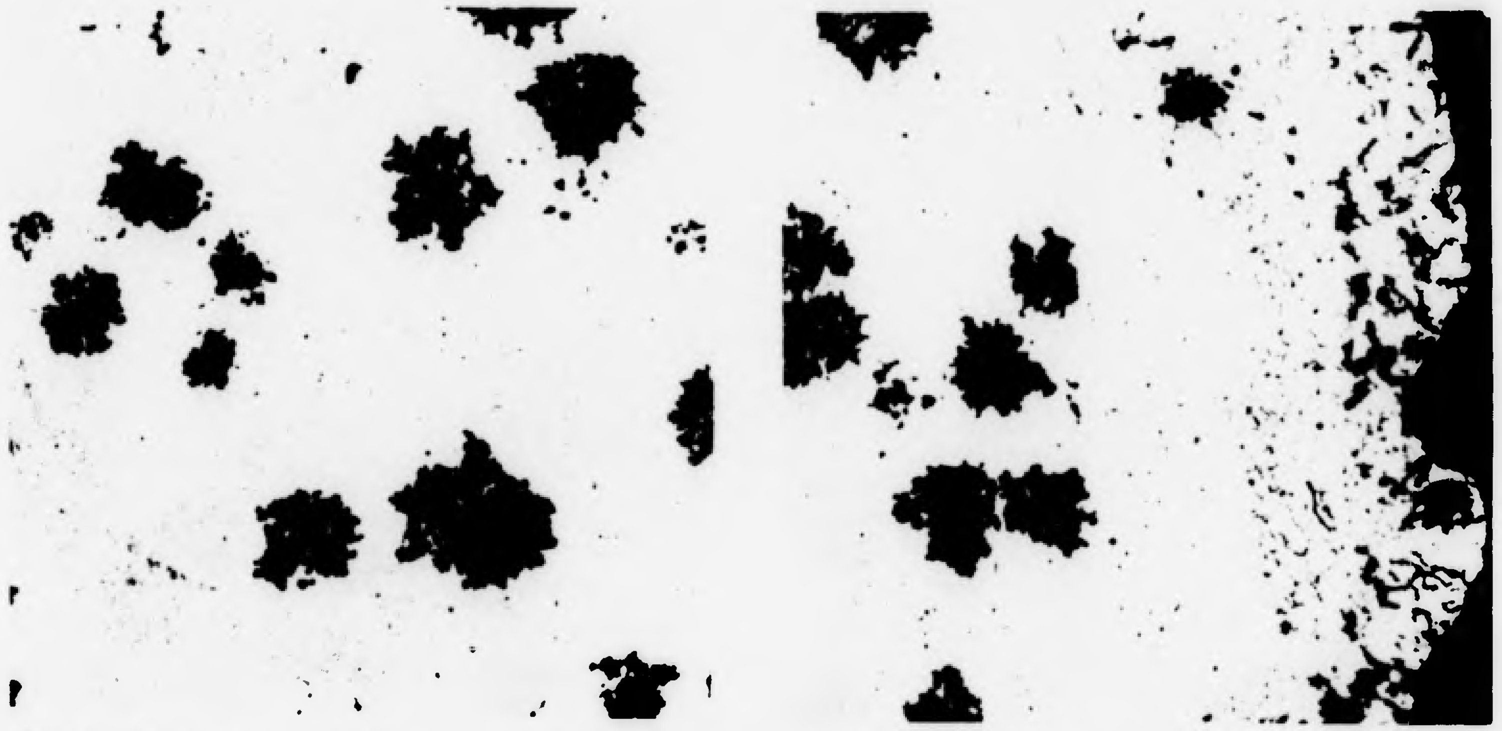
Figure 6. Deep-Etched Sections of Two Booster Cups and Adaptors.



Unetched - 20X 25439

Section of Shell Wall.



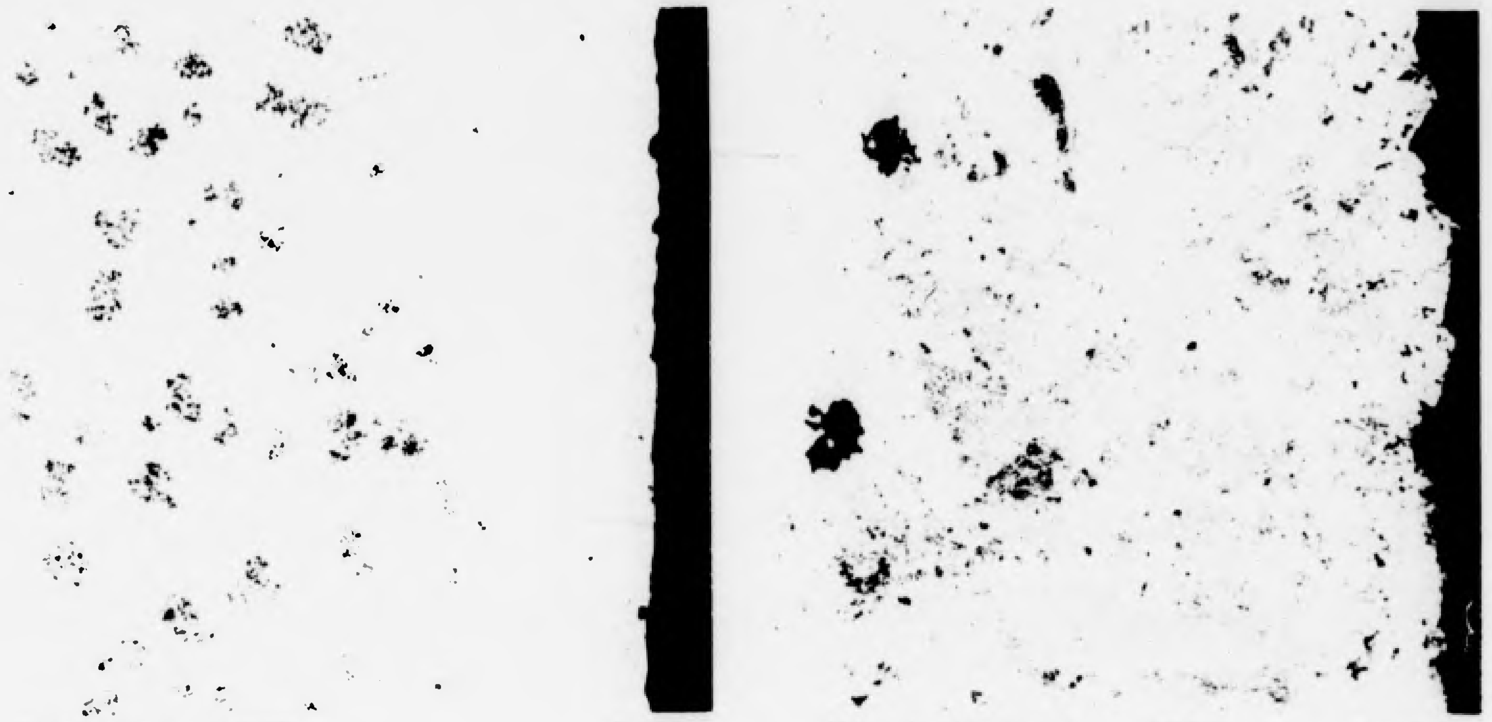
Nital Etchant - 100X 24549

Microstructure at Core of Shell Wall.

Nital Etchant - 100X 24548

Microstructure at Inside Shell Wall.

Figure 7. Type of Microstructure Produced by Heat Treatment of Shell Body No. 109.

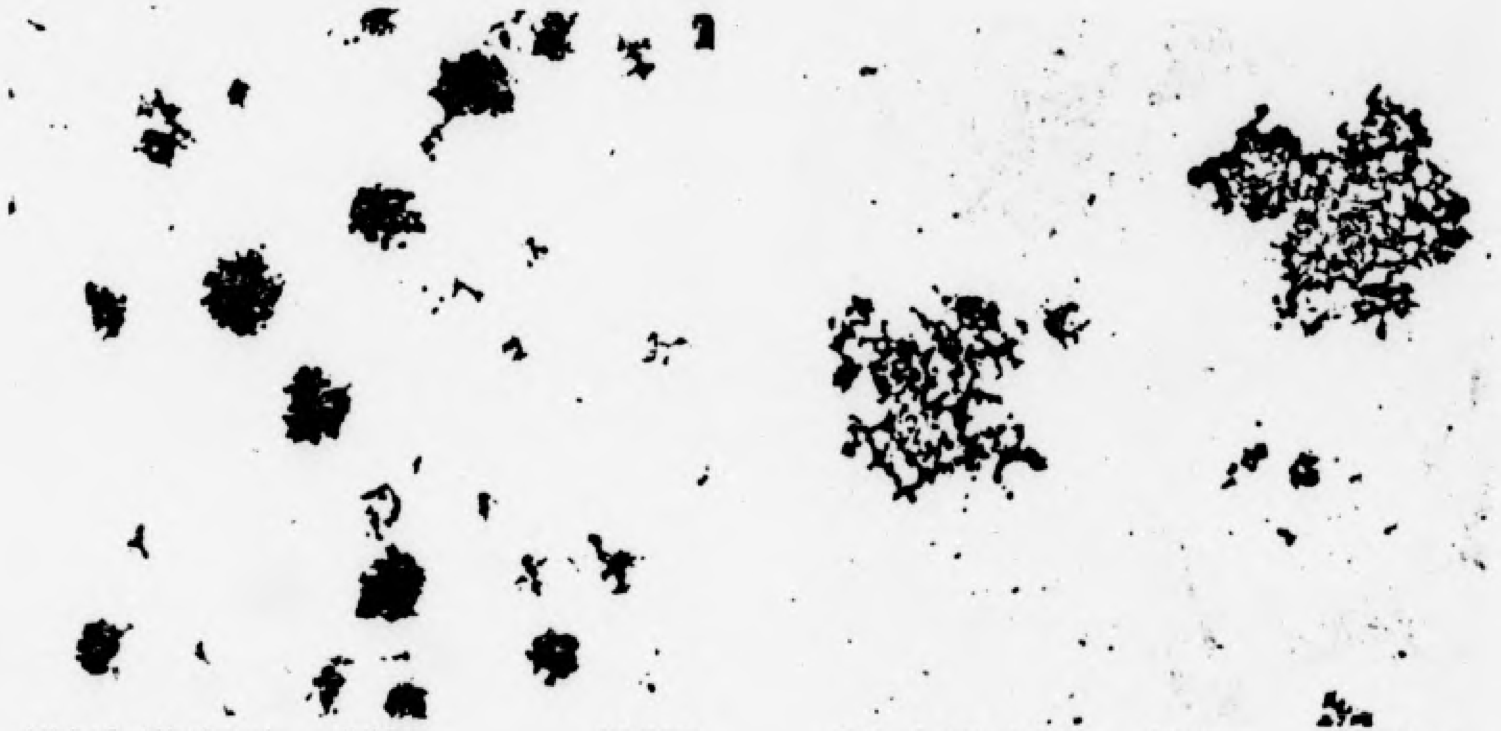


Unetched - 20X 24534

Section of Shell Wall.

Nital Etchant - 100X 24553

Microstructure at Inside Surface of Shell.



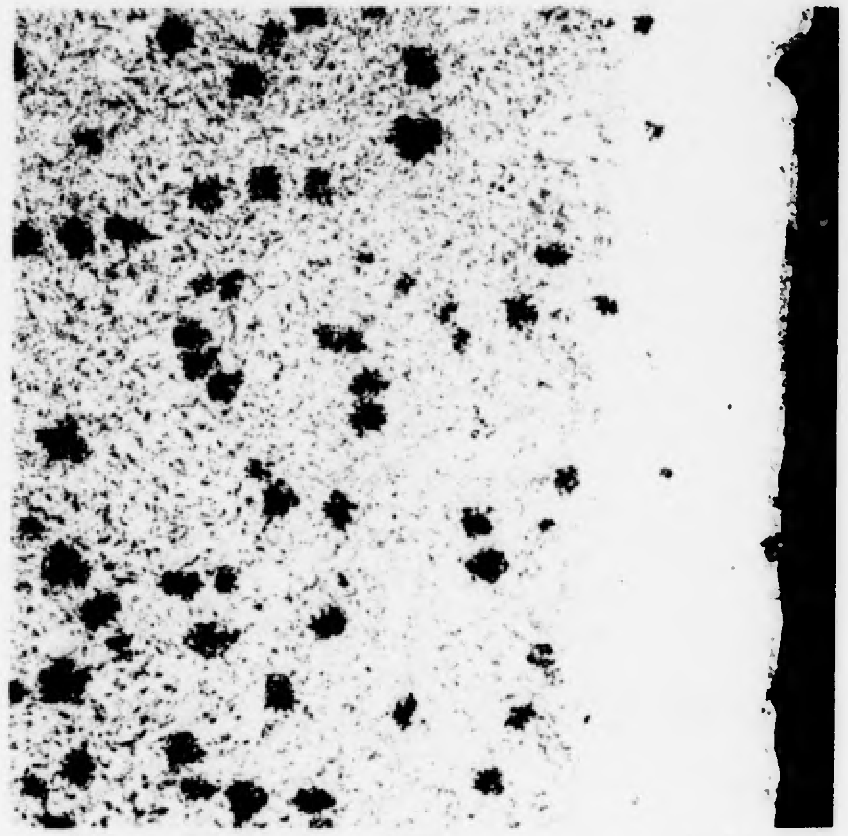
Nital Etchant - 100X 24550

Microstructure at Core of Nose and Bourrelet.

Nital Etchant - 100X 24554

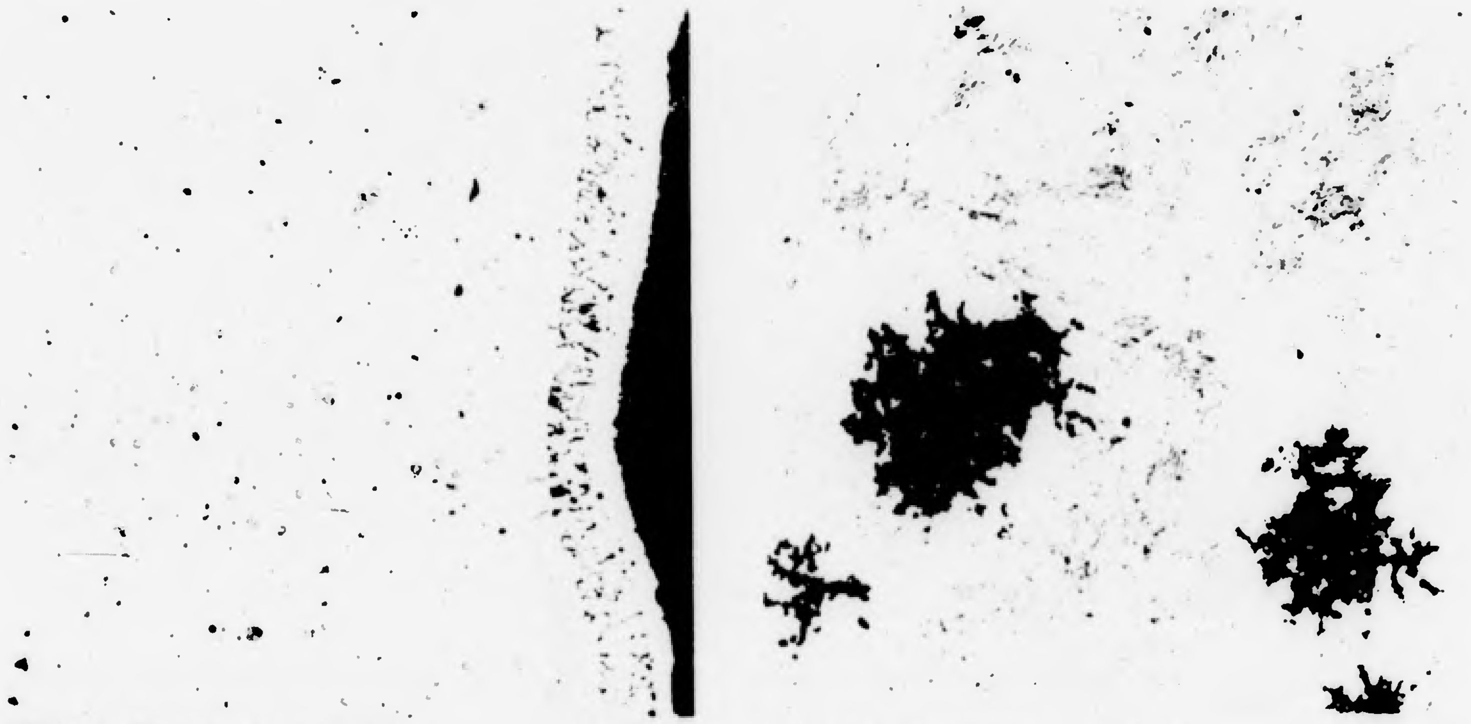
Microstructure at Core of Shell Body.

Figure 8. Type of Microstructure Produced by Heat Treatment of Shell Body No. 110.



Nital Etchant - 20X 24540

Section of Shell Wall.



Nital Etchant - 100X 24551

Microstructure at Inside Wall.

Nital Etchant - 100X 24552

Microstructure at Core of Wall.

Figure 9. Type of Microstructure Produced by Heat Treatment of Shell Body No. 111.

Shell No. 109 (Figure 7) has a pearlitic black-heart malleable iron microstructure showing a bull's-eye effect of decarburization around each graphite nodule. This shell has a skin several thousandths of an inch thick, containing primary flake graphite. Shell No. 110 (Figure 8) has a thick skin (.05") containing no graphite nodules and some iron oxide penetrating along the grain boundaries near the surface. This would indicate that the casting was packed in iron oxide, as for the white-heart process, but was subjected to a much shorter black-heart annealing cycle. The residual pearlite and the lacy graphite nodules shown indicate that the body of the shell was heated and cooled rapidly. Shell No. 111 (Figure 9) also has a thick skin (.05") on the inside and outside surfaces, and some penetration of oxide along the grain boundaries. The cooling rate through the critical range was rapid enough to prevent complete graphitization. The result is a pearlitic malleable iron showing a random distribution of the pearlite and ferrite.

Aluminum Fuze Parts

Microscopic examination of the aluminum fuze parts indicated that seven of nine pieces had been made from a dural-type alloy. This alloy is probably similar to the American Alloy 17S which is a strong Al-Cu-Mn-Mg alloy. The seven parts are all in the heat-treated condition. Several areas showing marked segregation of the copper constituent ($CuAl_2$) were observed. The fuze body had been machined from a heat-treated forging as indicated by the flow lines. The other six pieces of duralumin had been machined from extruded bar stock. The safety sleeve, through which the firing pin worked, had been made of pure aluminum and appeared to be of higher grade than the American Alloy 2S (99% Al). It appeared to have been machined from extruded tubing. The booster liner, which was also made from pure aluminum, had a very thin wall for extruded material and was probably produced by impact extrusion. The fuse shell was made of cold-worked sheet brass, probably of 80-20 Cu-Zn alloy.

Tail Assembly

The tail assembly for each shell consisted of the central tube containing the cartridge and primer to which was attached the fins necessary to prevent tumbling of the shell when fired. The tube was machined from medium carbon-steel bar stock. The microstructure showed normal ferrite and pearlite. The fins were stamped from very low carbon-steel sheet and attached to the tube by spot welding. The microstructure of the steel sheet in the fins was almost pure ferrite with some oxide-type inclusions. The heat effect of the spot-welding operation had distorted the structure of both parts near the weld, but a hard zone was not formed because of the comparatively low carbon content. The cartridge was held in the tube of the tail assembly by a low-carbon steel set screw.

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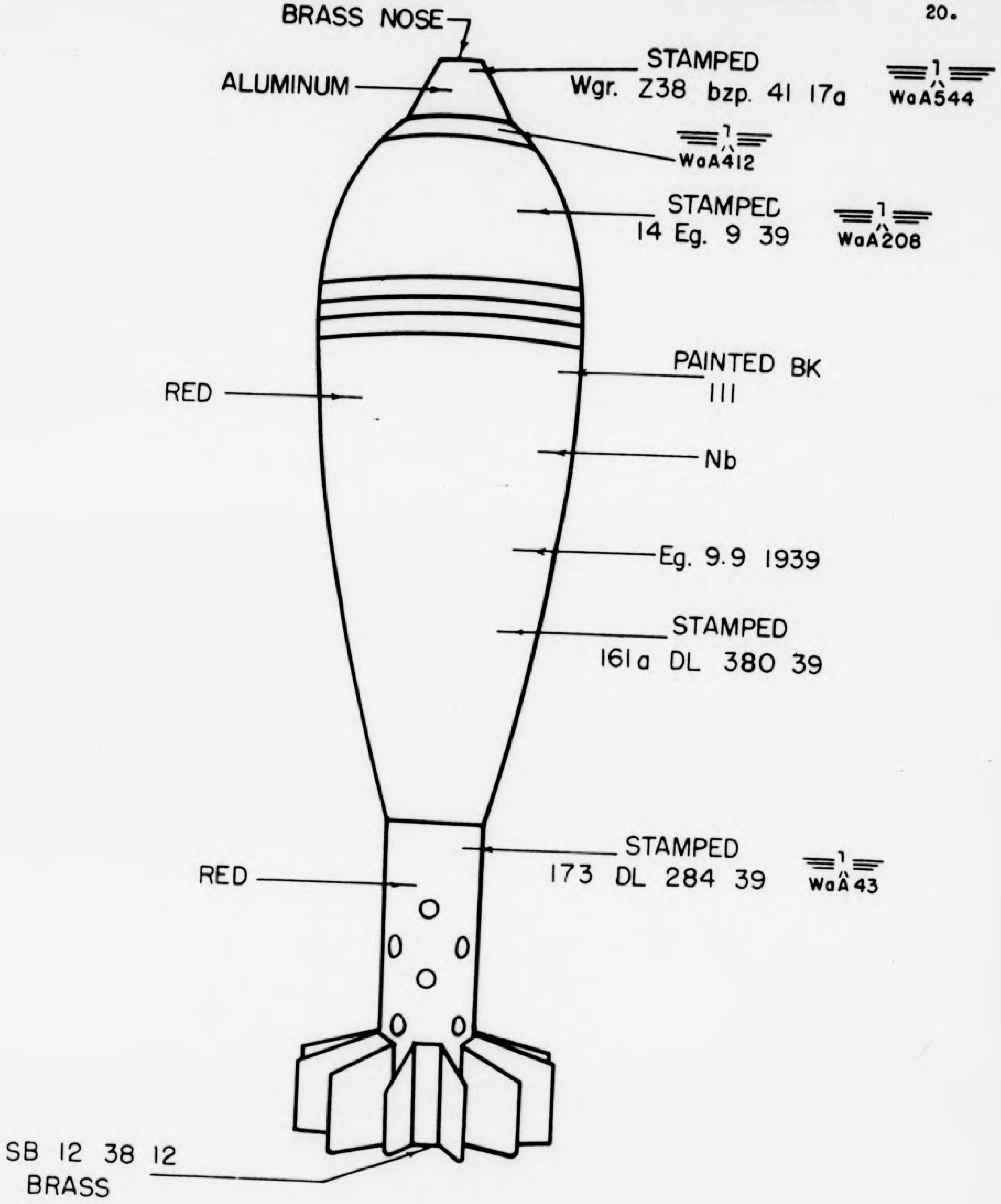
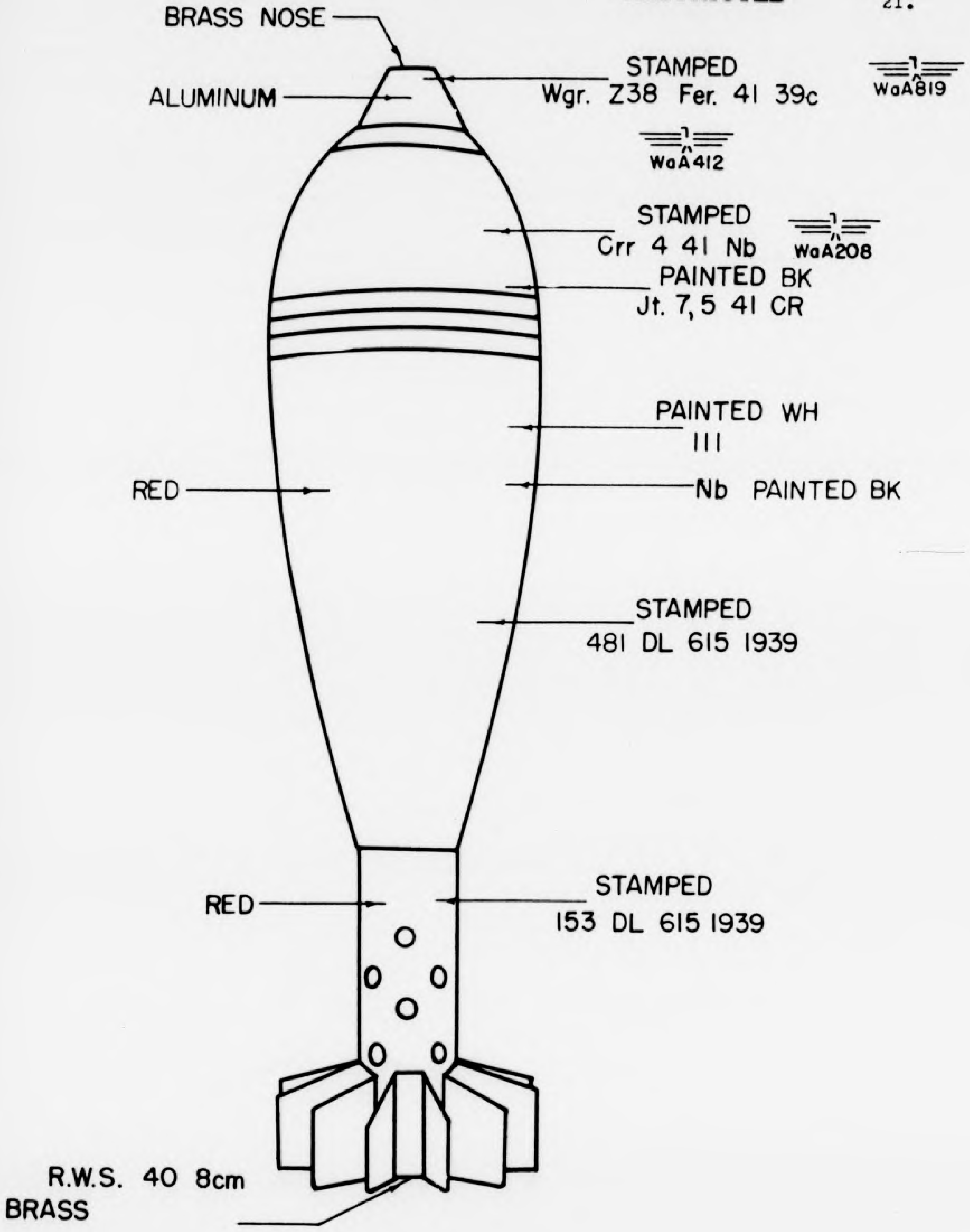
December 14, 1943



PART NO. 109

FMAM - 103 8 CM. GERMAN MORTAR SHELL 17a.

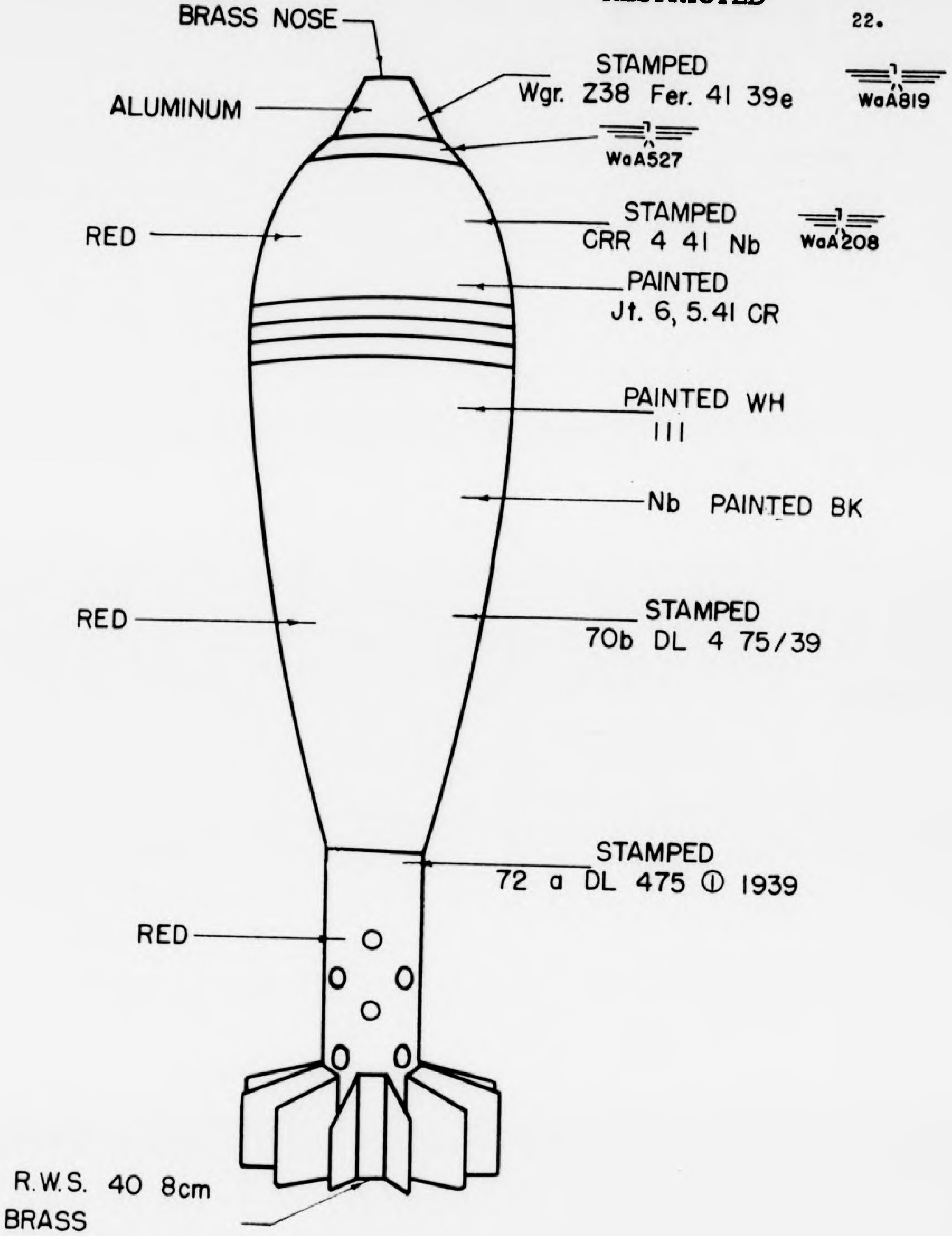
24128



PART NO. 110

FMAM-103 8 CM. GERMAN MORTAR SHELL 39c.

24127



PART NO. 111

FMAM-103 8 CM. GERMAN MORTAR SHELL 39e.

24126