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A RESEARCH INVESTIGATION OF POSSIBILITIES
FOR OBTAINING HOT-HARD ELECTRODEPOSITED
CHROMIUM OR CHROMIUM-BASE ALLOYS FOR
CANNON

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September 15, 1951

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INTERIM TECHNICAL REPORT

on

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FOR OBTAINING HOT-HARD ELECTRODEPOSITED
CHROMIUM OR CHROMIUM-BASE ALLOYS FOR
CANNON

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WATERTOWN ARSENAL

September 15, 1951

by

J. Edwin Bride, Cloyd A. Snively, and Charles L. Faust

Contract No. DA-33-019-ORD-9

W. A. L. File No. 691.1/25-39

O. O. Project No. TR3-3003B

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INTERIM TECHNICAL REPORT

Contractor: Battelle Memorial Institute

Agency: Office, Chief of Ordnance, ORDTR - Cannon

Ordnance District: Cleveland, Ohio

Contract Number: DA-33-019-ORD-9 W. A. L. File No. 691.1/25-39

O. O. Project Number: TR3-3003B

Priority: War Department 2B

Title of Project: "A Research Investigation of Possibilities for Obtaining Hot-Hard Electrodeposited Chromium or Chromium-Base Alloys for Cannon"

Authors: J. Edwin Bride, Cloyd A. Snavely, and Charles L. Faust

Object: To investigate possibilities for an erosion-resistant chromium or chromium-alloy electroplate for lining gun tubes.

Summary: Experiments were continued on the application of 94% chromium - 6% iron alloy plate to the bore surfaces of cannon. An extended series of tests was unsuccessful in pointing a way for plating full-length gun tubes with moving anodes. Good plate was obtained only at the initial position of the anode. Areas plated after the anode travel began received a poorly adherent plate. The plating solution etched these areas before plating began, and the effect of the etching was to prevent plate adherence.

Several erosion-gage weapon inserts were plated using full-length stationary anodes. Firing tests showed these plates to lack sufficient adherence for erosion resistance. However, the full-length anode system offered advantages over a moving anode.

Plating tests were begun with four-foot lengths of simulated smooth-bore 40-mm gun tubes. These tests had not reached a conclusive stage when the contract period ended. *Additional layers: W/A report* ←

Conclusions and Recommendations

The work reported herein shows that the chromium-iron alloy plating process is not yet ready for full-scale application to gun tubes. The need for additional beaker-scale work on the plating process was clearly indicated. The good plates obtained showed considerable promise and

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additional work is needed to allow production of uniform good plates each plating trial. The firing-test results showed that adhesion of the plate is not satisfactory. More work is needed on the adhesion problem.

Report Period

This report covers the period from September 1, 1950, to February 9, 1951.

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INTERIM TECHNICAL REPORT

on

**A RESEARCH INVESTIGATION OF POSSIBILITIES
FOR OBTAINING HOT-HARD ELECTRODEPOSITED
CHROMIUM OR CHROMIUM-BASE ALLOYS FOR CANNON**

to

WATERTOWN ARSENAL

from

BATTELLE MEMORIAL INSTITUTE

by

J. Edwin Bride, Cloyd A. Snavely, and Charles L. Faust

September 15, 1951

INTRODUCTION

This final technical report describes work on the application of chromium-iron alloy to interior surfaces of gun tubes. The 94 per cent chromium-6 per cent iron alloy plating process was developed on a previous Army Ordnance contract⁽¹⁾. That work showed that the alloy plate has properties superior to those of conventional chromium plate, and can be deposited at greater rates and current efficiency. The 40-mm cannon has been selected for firing tests for the new alloy plate. The present work relates to the development of techniques for applying the chromium-iron alloy plate to the bore surfaces of the 40-mm cannon. Initial work in this direction was described in a previous Interim Technical Report⁽²⁾.

(1)Contract W33-ORD-6397. Results are reported in the "Final Technical Report on a Research Investigation of Possibilities for Obtaining Hot-Hard Electrodeposited Chromium or Chromium-Base Alloys for Cannon", Battelle Memorial Institute, November 15, 1949.

(2)Contract DA-33-019-ORD-9. Interim Technical Report on "A Research Investigation of Possibilities for Obtaining Hot-Hard Electrodeposited Chromium or Chromium-Base Alloys for Cannon", September 1, 1950.

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EXPERIMENTAL WORK*Method of Attack

The first experiments during the report period were a continuation of the series of tests begun in the previous report period. These tests were designed to show optimum conditions for plating tubes with moving anodes. This work was done first with 18-inch lengths of simulated smooth-bore 40-mm tube and then with 4-foot lengths. These tests did not give encouraging results, so full-length anode tests were begun. The report period ended before conclusive tests were completed.

The details of the work with moving anodes and with full-length anodes are described in the following sections.

Moving-Anode Tests With 18-Inch Tube SectionsTests 5389-56A to -58A

The object of this group of tests was to determine the optimum diameter and length of an active moving anode (up to 1/2-inch diameter by 7 inches long) that could be used in plating simulated smooth-bore 40-mm tubes. The pertinent data for these tests are given in Table 1. The apparatus used has been described previously⁽²⁾. In Test 5389-56E, the plated 18-inch-long steel tube was sectioned in the region of initial plate and, secondly, from an area plated after anode travel was begun. The moving anode in this test was 5/16-inch diameter by 7 inches long.

Metallographic examination of a cross-sectional area of the deposit from the region of initial plate showed both good structure and good bond. The thickness of the deposit, measured with the aid of a micrometer eye-piece, was found to be 0.0025 to 0.0030 inch. The deposit taken from the area plated after anode travel began was poorly bonded to the steel base, but the deposit was structurally sound and 0.002 to 0.003 inch in thickness. In Test 5389-57, a 1/2-inch-diameter by 7-inch-long, 90 per cent lead - 10 per cent tin coated copper rod was used as the moving anode.

Metallographic examination indicated that slightly better bond and equally as good structure could be obtained with the 1/2-inch-diameter anode as with the 5/16-inch-diameter anode.

*Experimental data obtained in this work are recorded in Laboratory Record Book No. 5389, pages 53-99.

These test results indicated that the rate of deposition when plating bore surfaces of steel tubes was much slower than when plating small flat cathodes. A 1-liter sample of bath from the pilot plating unit was used in beaker plating tests. A 1-square-inch area of a flat cathode was plated at a rate of 0.009 inch per hour at 400 amp/sq ft. This proved that the bath was in good condition and that the operation of plating in the tube was responsible for any lowering of current efficiency.

Tests 5389-58A to -68A

A series of tests was performed to determine the rates of plating in tubes when the flow of electrolyte was varied from 500 ml/min to 2500 ml/min. Cathodes were SAE 4130 1-inch x 18-inch x 0.125-inch steel. These cathodes were placed on the inside of a 1-3/4-inch-diameter x 18-inch-long glass tube through which the electrolyte flowed at a given rate. The lead-tin-coated 1/2-inch copper-rod anode* was held stationary in the center of the glass tube and current was applied at 400 amp/sq ft for 20 minutes. The results of separate tests with rates of flow from 500 ml/min to 2500 ml/min showed very little effect on the rate of deposition, which was unusually low in these tests. The plates were only 0.0001 inch in thickness. Up to this time, the pilot-cell Bath 4662-94A of 16-liter volume had 153 ampere-hours of electrolysis per liter. A new bath (-59A) was prepared to continue the tests.

Cathodes for the new plating tests were 1-1/2-inch-ID by 12-inch-long steel tube sections. Anode arrangements were the same as in the preceding tests which permitted a 7-inch length of bore surface to be plated. Electrolyte flows of 450 ml/min, 1020 ml/min, and 2660 ml/min were used.

Current density, bath temperature, and length of test were held constant during the three tests. Upon completion of each test, a mark was placed on the outside of the tube to indicate the exact position of the top of the 7-inch anode. The tube was then sawed so that short circular sections from various positions could be obtained for metallurgical examination and a check for thickness. The saw cuts were made 1 inch, 3-1/2 inches, and 6 inches from the top line. Examinations for plate thickness were made in the same position for each of the three tubes. Data from these studies are listed in Table 1 and plotted on Figure 1. The results indicate very little change in the over-all deposition; however, the slowest rate of flow gave a relatively thin deposit at the top and a heavy build-up of deposit on the tube wall opposite the bottom of the anode. Increasing the rate of electrolyte flow had a tendency to level off this difference, so that with 2660 ml/min of electrolyte flow the deposit at the top

*For photograph of anode, see Item 4 in Figure 4, Reference 2.

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of the 7-inch tube was almost as thick as that at the bottom. The rate of deposition was approximately 0.007-inch thickness per hour at this particular rate of flow. This is a slightly lower plating rate than is normal for still plating from this bath. However, it is much better than was indicated by the earlier tests.

Tests 5389-68A to -72A

Test 5389-68A represents the first attempt at plating a 4-foot length of simulated smooth-bore 40-mm gun tube. In preparation for this test, the flexaframe* anode-support structure was increased in height to ten feet above floor level. The rack-and-pinion mechanism for lowering the anode was discarded in favor of a more flexible arrangement consisting of a pulley-cord-hook attachment from which the anode and electrolyte suction tubing were suspended. The 1/2-inch x 7-inch insoluble anode was lowered through the steel tube at a rate of 10 inches per hour. The hexavalent chromium ion in the pilot-cell bath was reduced before the plating began. The test continued for 3-3/4 hours and no additions of hydrogen peroxide** were made during the test. The results for the top eight inches of tube were very good, but the remainder of the plate was poor. Thin circular slices from each 12-inch length of the tube were examined under a microscope for structure, bond, and measurement of thickness. As the anode progressed down the tube, the bond between the Cr-Fe alloy and the steel bore surface worsened until, at 3 feet from the top, very little deposit was found and the steel surface was severely etched. In a subsequent test, hydrogen peroxide was added to the plating bath continuously to prevent the accumulation of hexavalent chromium in the bath. This test was also unsuccessful, as the bottom 1-foot section of the tube had brown film on the bore surface instead of the desired alloy deposit.

Test 5389-71A was a rerun on this same tube. The brown film was removed by dipping in dilute hydrochloric acid. The anode was then lowered into the bottom of the tube and, with the pilot-cell bath flowing up past this freshly prepared surface, it was possible to obtain a very good adherent deposit on the portion of the tube that had not received a plate in the previous test.

*See Figure 1 of Reference 2.

**The use of H₂O₂ in the bath is described on page 18, Reference 2.

Summary and Discussion of Facts Pertinent to Plating
4-Foot Tubes With a Moving Anode

Prolonged exposure of the steel bore surface to the Cr-Fe alloy electrolyte results in a severely etched bore surface that usually is covered with a brown film. Results of tests indicate that it is practically impossible to deposit the Cr-Fe alloy on this etched and filmed surface.

Removal of this film permits a good-adhering plate to be deposited on the etched surface.

It appears that successful plating of the Cr-Fe alloy on a steel bore surface by means of the moving-anode system could be accomplished only by keeping the bath from coming in contact with the unplated bore surface, or by having a strike plate inert to the electrolyte.

Of several ways studied for preventing contact of electrolyte with unplated surfaces, the use of tetrachlorethylene appears the most promising.

Tetrachlorethylene is immiscible with the bath and has greater specific gravity. Therefore it displaces the bath in the tube to any level desired. A plating method is suggested whereby the anode is lowered into the tube during plating and the tetrachlorethylene level is lowered accordingly, so that the unplated bore surface is not overly exposed to the chemical action of the bath. This scheme has numerous engineering difficulties and will be useful only if other and simpler methods fail.

Erosion-Gage Weapon-Insert Tests

Tests 5389-77A to -94A

Preliminary plating tests were carried out on two rifled erosion-gage weapon inserts that had been supplied by Watertown Arsenal for this particular use. The tests were made with a full-length anode. Fixtures designed to fit both breech and muzzle ends served to center the lead-tin-alloy-coated copper-rod anode. The anode was 1/4 inch in diameter. The electrolyte flowed by gravity from the plating tank through a rubber tube into an opening in the bottom fixture. Rate of flow was controlled by an adjustable clamp on the rubber tube. Electrolyte was removed through the top fixture by a positive-displacement-type pump and was then returned to the plating tank.

Results of the tests carried out in this particular type of setup were not entirely satisfactory. Continuous addition of hydrogen peroxide was required during plating to prevent accumulation of hexavalent chromium in the bath.

Reaction of the hydrogen peroxide with the hexavalent chromium ion caused gas to form in pockets in the inlet tubing, thereby restricting the flow of electrolyte. To counteract this trouble, a new plating tank was made by removing the bottom of a 5-gallon Pyrex glass carboy and inverting it. Electrolyte was fed directly from the bottom of the glass tank to the entrance port of the bottom plating fixture. Electrolyte pumped from the plating cell (in this case the erosion-gage weapon insert plus bottom and top fixtures) was fed into the top of a glass tower filled with ceramic rings. Hydrogen peroxide (30 per cent) was added to the top of the tower. The purpose of the tower was to allow completion of the reduction of the hexavalent chromium ion before the electrolyte was returned to the plating unit. Electrolyte from the bottom of the mixing tower was pumped into the inverted glass carboy tank.

The smooth-bore erosion-gage Weapon Inserts Numbers 59X and 60X were both plated, stripped, and replated a number of times in the above plating setup. Deposits were thin and usually contained blistered areas. Table 2 gives the data for these tests.

As a third and final attempt at finding the proper apparatus to plate the erosion-gage weapon inserts, it was decided to suspend them in a 10-inch-diameter by 18-inch-high glass tank equipped with a lead steam coil for heating. A fixture originally used for electrocleaning the inserts was modified to hold an erosion-gage weapon insert for plating in the glass tank. A small stream of electrolyte was pumped from the bottom of the tank into the mixing chamber, where the hydrogen peroxide was added as required.

Dimensions of the inserts before and after plating are listed in Table 3.

The actual plate thickness was approximately 0.002 to 0.003 inch greater than indicated by the figures in Table 3, as each insert was plated and stripped several times before a satisfactory plate was obtained. The plate on Insert 59X appeared to be blistered, as inspected by looking through the end of the insert. Unfortunately, a boroscope was not available for this inspection. The situation was complicated by the fact that the base metal had about the same appearance before plating. The base metal was somewhat affected by the hydrochloric acid stripping and light electropolishing operations used to remove unsatisfactory plates and to prepare the surface for replating. Firing tests at Watertown Arsenal showed that adhesion of the plate on these inserts was very poor.

Plating Tests on 4-Foot Tubes With Full-Length AnodesLead-Tin Alloy Plating of Anodes

Experience with plating the inserts showed that chances for a successful plate were better when using full-length anodes than when using moving anodes. Therefore, tests were begun using full-length anodes in 4-foot sections of simulated smooth-bore 40-mm gun tube. For satisfactory electrical conductivity, the anode cores were 3/4-inch-diameter copper rod. These were plated with 90 per cent lead-10 per cent tin alloy using a fluoborate type of solution*. The plating bath was held in a neoprene-lined tank, 10 inches in diameter and 5-1/2 feet tall. Cast alloy bars containing 90 per cent lead and 10 per cent tin and measuring 3/4 inch in diameter by 60 inches in length were available at Battelle and were ideally suited for use as anodes. While this plating setup was assembled, two copper-rod anodes were coated with the lead-tin alloy. One was reserved as a spare.

Pilot-Cell Tests 5389-94A Through -98A

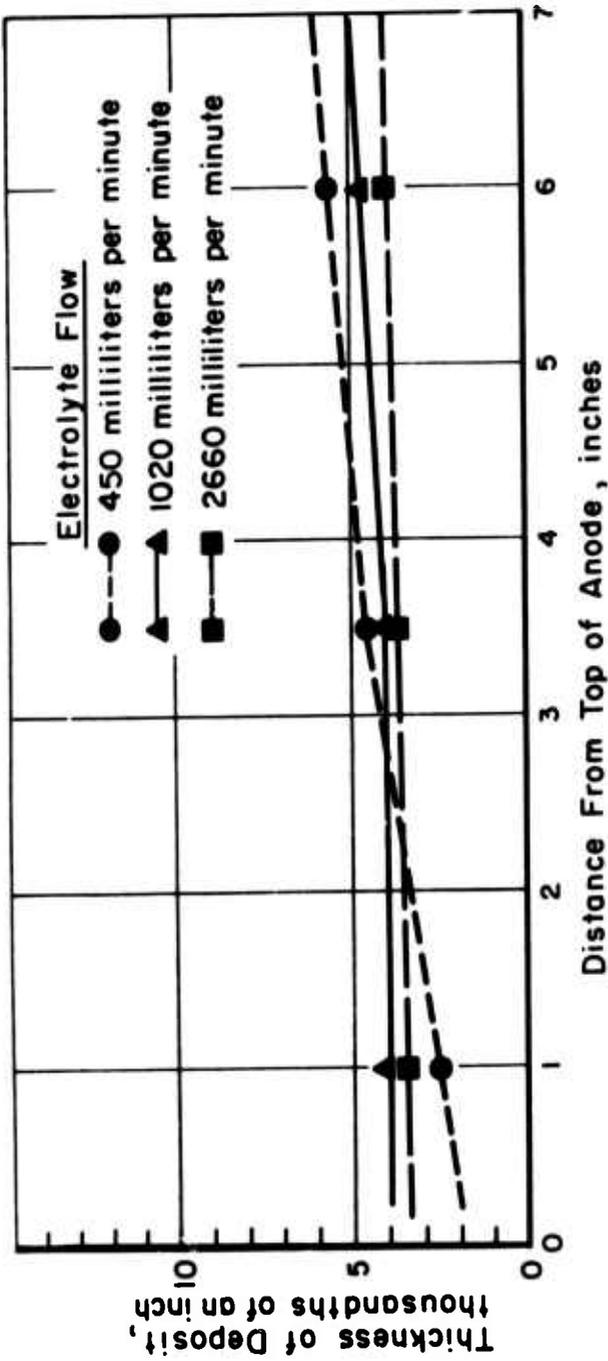
In this group of tests, a full-length insoluble anode was used in plating simulated 40-mm smooth-bore gun-tube sections four feet long. Considerable change in the equipment used for the moving-anode tests was necessary. A 50-liter rubber-lined tank, equipped with an electrically operated thermoregulator and lead-sheathed heating coil, was used to contain the pilot-cell bath. The bath was pumped from the tank into the bottom of the 4-foot tube being plated. Special fixtures mounted on the top and bottom of the tube served to center the lead-tin-coated copper anode rod. Electrolyte pumped up through the smooth-bore tube left the pilot cell through the top fixture, through a 2-inch-diameter Saran tube, and returned to the plating bath proper. Electrical connections and wiring to the anode and cathode were built to carry 400 amperes for an extended period of time. The capacity of the pump used to circulate the electrolyte was increased from 3 liters per minute to 16 liters per minute, or approximately 260 gallons per hour for these tests.

The preparatory treatment for steel tubes for Cr-Fe alloy plating is given in Appendix II. The data for the plating tests are given in Table 4. The current-density range covered in this group of tests varied from 150 amp/sq ft (238 amp total current) to 240 amp/sq ft (400 amp total current). The chromium-ammonium sulfate concentration of the pilot-cell bath was

*The plating-solution composition and plating conditions are given in Appendix I.

TABLE I. DATA FOR MOVING-ANODE PLATING TESTS

Test No.	Bath No.	Time, hours	Cathode Material	Cathode Current Density, amp/sq ft	Electrolyte Conditions			Description of Anode	Description of Deposit
					Flow, ml/min	pH	Temperature, F		
5389-56A	94A	1/2	Steel tube, 1-1/2" ID x 18" long	400	1700	1.4	142	Pb-Sn-coated 5/16" x 7" Cu rod	Blistered in small area
-56B	94A	1/2	Ditto	400	1700	1.4	142	Pb-Sn-coated 5/16" x 2" Cu rod	Good, adherent deposit
-56C	94A	1/2	"	400	1700	1.4	142	Pb-Sn-coated 5/16" x 4" Cu rod	Ditto
-56D	94A	1/2	"	400	1700	1.4	142	Pb-Sn-coated 5/16" x 6" Cu rod	
-56E	94A	1/2	"	400	1700	1.4	142	Pb-Sn-coated 5/16" x 7" Cu rod	Good bond for 7" length; metallographic study showed decreasing adherence of deposit to cathode as anode progressed down inside tube
-57	94A	1/2	"	400	1700	1.4	145	Pb-Sn-coated 1/2" x 7" Cu rod	Ditto
-58A	94A	1/2	SAE 4130, 1" x 18" x 0.125" steel	400	500	-	-	Ditto	Deposit only 0.0001" thick
-58B	94A	1/2	Ditto	400	1500	-	-	"	Ditto
-58C	94A	1/2	"	400	2500	-	-	"	Ditto
5389-59A	59A	3/4	60 ml/1 NH ₄ OH (28%), 700 g/l Cr ₂ (SO ₄) ₃ (NH ₄) ₂ SO ₄ ·24H ₂ O, 13.5 g/l FeSO ₄ (NH ₄) ₂ SO ₄ ·6H ₂ O, 20.0 g/l MgSO ₄ ·7H ₂ O, 50.0 g/l (NH ₄) ₂ SO ₄ , 0.125 g/l Duponol M.E., 0.5 g/l Na ₂ SO ₃ ; pH as made up, 1.4 at 140 F, 16-1 volume	400	450	1.4	140	Pb-Sn-coated 1/2" x 7" Cu rod	Thickness, top 0.0027" Thickness, middle 0.00465" Thickness, bottom 0.0055" Thickness, top 0.0040" Thickness, middle 0.0043" Thickness, bottom 0.0047" Thickness, top 0.0036" Thickness, middle 0.0039" Thickness, bottom 0.0041" Structure O.K., bond O.K., 0.0054" thick - 7" down from starting point; structure O.K., bond not as good, 0.0045" - 19" down from starting point; very little deposit, 0.0004" - 31" down from starting point; no deposit, surface etched 43" down from starting point
5389-64A	59A	1/2	Steel tube, 1-1/2" ID x 7" long	400	1020	1.4	140	Ditto	No deposit on last 1-foot length of tube; brown film in bore surface, 1 foot from end
-65A	59A	1/2	Ditto	400	1020	1.4	140	Ditto	Very good appearing deposit; bore surface easily plated with Cr-Fe after brown film from previous test was removed
-66A	59A	1/2	"	400	2660	1.4	140	"	
-68A	59A	3/4	Steel tube, 1-1/2" ID x 4 foot long	400	1100	-	-	Pb-Sn-coated 1/2" x 7" Cu-rod anode moving down 9 1/2"/hr	
-69A	59A	3/4	Ditto	400	1100	-	136-140	Ditto	
-71A	59A	1/2	"	400	1100	-	Ditt.	Pb-Sn-coated 1/2" x 7" Cu-rod anode moving down 9 1/2"/hr, but stationary at bottom of tube	



Plating Conditions : Standard - formulation Cr-Fe alloy plating bath (see Table I.)
 pH 1.4, temperature of bath 143 F, current density 400 amp/sq ft,
 8.0 volts, time of test 30 minutes each. Stationary anode 7" X 1 1/2",
 diameter copper rod, coated with 0.015" 90 per cent lead - 10 per cent
 tin alloy.

Thickness Measurement: Made with micrometer eye piece on microscope.

FIGURE 1. EFFECT OF ELECTROLYTE FLOW ON RATE OF DEPOSITION OF 94 PER CENT CHROMIUM -6 PER CENT IRON ALLOY

TABLE 2. PLATING TESTS FOR EROSION-GAGE WEAPON INSERTS

Test No.	Bath No.	Time, hours	Cathode Material	Cathode Electrolyte Conditions				Description of Anode	Description of Deposit
				Current Density, amp/sq ft	Flow, ml/min	Temperature, F	pH		
5389-72A	59A	1	Erosion-gage weapon insert (rifled)	300	1300-700	140		Pb-Sn-coated 3/16" x 18" copper rod	Sound deposit except at breech and muzzle ends; 1" from muzzle end - 0.003", 1" from breech end - 0.0035"
-77A	59A	1 1/2	Ditto	300	700	140		Ditto	Deposit in middle good
-78A	59A	1	Erosion-gage weapon insert	300	1200	140		"	No deposit
-78B	59A	1	Ditto	300	500	140		"	Very thin deposit
-79A	59A	1	"	400	700	140		"	Thin blistered deposit
-79B	59A	1/2	"	300	700	140		"	Deposit 0.002", poor at both ends
-80A	59A	2 1/2	"	300	-	-		"	0.0075" muzzle end, 0.012" breech end
-80B	59A	1 1/2	"	300	-	-		"	0.006" thickness, blistered spot near breech end
-81A	59A	1	"	300	-	-		"	0.005" thickness at muzzle end, blistered area
-81B	59A	1 1/2	"	300	-	-		"	Good-appearing deposit; final deposit for 59X
-82A	59A	1 1/2	"	300	-	-		"	Small blistered area
-82B	59A	1 1/2	"	300	-	-		"	Good-appearing deposit; final deposit for 60X

TABLE 3. DIMENSIONS OF EROSION-GAGE WEAPON
INSERTS BEFORE AND AFTER PLATING

Location of Measurement	Insert 59X Bore Diameter, inches	Insert 60X Bore Diameter, inches
	<u>Before Plating</u>	
3/4 inch from muzzle end	0.6141	0.6175
2 inches from breech end	0.6174	0.6145
	<u>After Plating</u>	
3 inches from muzzle end	0.611	0.615
3 inches from breech end	0.605	0.606

TABLE 4. PLATING TESTS - STEEL TUBE - STATIONARY ANODE

Test No.	Bath No.	Time, hours	Cathode Material	Electrolyte Conditions			Description of Anode	Description of Deposit
				Current Density, amp/sq ft	Flow, gal/hr	Temperature, F		
5389	93A	2	Steel tube, 1-1/2" ID x 48" long	144	150	125	Pb-Sn-coated 3/4" x 58"-long Cu rod	Tube plated about 15" up; tube was not sawed in sections; top half of tube not plated
-95A	93A	2	Ditto	150	150	128	Ditto	Good-appearing deposit where plated; tube sawed in 6" sections; deposit within 2" of bottom and up approximately 18"; remainder or top half of tube was not plated
-95B	93A	6	"	240	150	130	"	0.025" to 0.030" deposit at bottom; deposit had crack lines. Tube sawed in 6" sections; no deposit 2" from bottom, then thick deposit up 8"; remainder of tube showed no deposit
5389	97A	2	Steel tube, 1-1/2" ID x 48" long	240	260	130	Pb-Sn-coated 3/4" x 58"-long Cu rod	Small area plated near bottom of tube; bottom 2"-no deposit; small area-probably a quiescent area - good deposit; next 6" up - good deposit; next 6" up - iron deposit; rest of tube - no deposit
5389-94A	93A	2	Steel tube, 1-1/2" ID x 48" long	144	150	125	Pb-Sn-coated 3/4" x 58"-long Cu rod	Tube plated about 15" up; tube was not sawed in sections; top half of tube not plated
5389	93A	2	Steel tube, 1-1/2" ID x 48" long	144	150	125	Pb-Sn-coated 3/4" x 58"-long Cu rod	Tube plated about 15" up; tube was not sawed in sections; top half of tube not plated

NO. 1000

APPENDIX I

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APPENDIX I

90% Lead - 10% Tin Fluoborate Plating Bath

Bath Composition, Preparation, and Operating Instructions

	Grams/Liter	Ounces/Gallon
Total Tin	10.0	1.3
Stannous Tin	8.5	1.1
Tin Fluoborate Conc.	50.3	6.7
Lead	90.0	12.1
Lead Fluoborate Conc.	297.8	39.7
Free Fluoboric Acid	40.0	5.4
Free Boric Acid	25.0	3.4
Glue	0.5	0.067

Bath Make Up. (1) 50% of required water placed in tank; (2) add lead fluoborate concentrate; (3) add tin fluoborate; (4) dissolve boric acid in hot water; (5) add fluoboric acid; (6) add glue; (7) add water to make required volume.

Glue Preparation. Add minimum of cold water to dry hide glue. When glue has completed swelling action, stir, correct volume, and heat to 140 F until all the glue is dispersed.

Bath-Operating Temperature. 60-100 F.

Agitation. Mild agitation is recommended, but agitation did not seem to help in inhibiting the growth of trees during plating of 3/4-inch x 58-inch copper rods for insoluble anodes.

Current Density. 30 amp/sq ft was recommended, but best results were obtained by using 18 amp/sq ft.

Plating Procedure. The copper anode rod was plated for 3/4-to 1-hour intervals. After each interval the rod was removed from the plating tank, rinsed in cold water, and pumice scrubbed to remove any trees or nodules that had formed on the surface. Following this treatment, the rod was brushed again during a cold-water rinse to remove any traces of pumice. This process was continued until approximately 0.018 inch of lead-tin alloy had been deposited. At this stage, the plated rod was sanded lightly to remove any high spots on the surface. Plating was then continued until 0.020 inch of the lead-tin alloy had been deposited. The first rod plated was used for Tests 5389-94A through -98A and still shows no sign of any break through the insoluble lead-tin coating.

APPENDIX II

APPENDIX II

Preparatory Treatment Used on 4-Foot Simulated 40-mm Smooth-Bore Steel Tubes in Full-Length Anode Tests

1. Degrease.
2. Pickle in 6N HCL (50% dilution of conc. HCL).
3. Cold water rinse.
4. Electroclean (anodic) 3 min at 50 amp, using centered steel-rod cathode.
5. Hot water rinse.
6. Cold water rinse.
7. Pumice scrub.
8. Cold water rinse.
9. Mount and apply top and bottom fixtures; insert anode. Make cathode connections on tube and bottom anode connection. Make connection from pump to lower fixture.
10. Remove cap on top fixture and fill tube with 10% H₂SO₄ solution.
11. Replace cap on top fixture, tighten tension nut for anode, and make top anode electrical connection.
12. Drain 10% H₂SO₄ solution from tube and pressure side of pump.
13. Start flow of Cr-Fe electrolyte through tube by starting pump.
14. Apply current as soon as possible after starting flow of electrolyte.

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