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FIRST PROGRESS
REPORT

March 1, 1947

to

w33-019-019-6267

UNITED STATES OF AMERICA
(Cleveland Ordnance District)

A Research Investigation of
Fundamental Factors Governing the
Ductility and Hot Hardness of
Electrodeposited Chromium.

G-1149

BATTELLE
MEMORIAL INSTITUTE
505 King Avenue
COLUMBUS 1, OHIO

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TO INSURE PROMPT ATTENTION
IN REPLYING REFER TO

No. _____

ATTENTION OF _____

Laboratory

8 April 1947

Battelle Memorial Institute
505 King Avenue
Columbus 1, Ohio

ATTENTION: Mr. C. L. Faust

Gentlemen:

The First Progress Report dated 1 March 1947 (BMI G-1149) entitled, "A Research Investigation of Fundamental Factors Governing the Ductility and Hot Hardness of Electrodeposited Chromium", in compliance with Contract W33-019-ORD-6267, RAD-ORDTR 7-8454, has been received and studied with interest. The occurrence of the hydrides of chromium seem to play an important influence on the properties of the deposit. The discussion did not mention whether the mechanical agitation due to the bubbling off of hydrogen was an important factor upon the properties of the cathode film. It is understood that some investigators do not consider the mechanical agitation important. It would also appear valuable to describe the structure of the trivalent chromium in the dispersoid. If available as a simple ion, deposition should not be complicated, but if available as a complex ion, the deposition of it, if it contains oxide, may have to be taken into consideration. Undoubtedly these questions will be considered in your study of the electrophoretic properties of the dispersoid.

In connection with the factors affecting the hardness and hot hardness of the plate, the time for softening at any particular temperature may be of importance. Also, the codeposition of another metal with the chromium may have an appreciable effect on the hardness of the deposit. These two factors should also be included in your plans for future work.

FOR THE COMMANDING OFFICER:

Very truly yours,

D. G. LUDLAM
Col, Ord Dept
Assistant

CC: ORDTR-Cannon
Cleveland Ord Dist

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BATTELLE MEMORIAL INSTITUTE

INDUSTRIAL AND SCIENTIFIC RESEARCH

COLUMBUS 1, OHIO

April 16, 1947

Commanding Officer
Watertown Arsenal
Watertown 72, Mass.

Dear Sir:

Watertown Arsenal letter to Battelle
Memorial Institute, WTM No. 461/3041
(N), P. F. Kosting/eck/481, dated 8
April 1947.

Dr. Faust has asked me to reply to your letter, referenced above, concerning the chromium plating work. Answers to some of the questions brought up in your letter are available and are presented in the following paragraphs.

The mechanical agitation of the cathode film by the hydrogen gas released at the cathode is considered to be of importance. The pH of the cathode film is maintained above that of the solution proper, ~~because of the~~ lowered ionic diffusion rates for hydrogen and hydroxyl ions in the medium around the cathode. The violent agitation caused by the hydrogen gas as it bubbles off must certainly tend to decrease the pH at the cathode. An increase in current density increases agitation by gassing, but concurrently removes an increased number of hydrogen ions from the cathode vicinity. The two effects are, therefore, compensating to some extent. The data available at present seem to indicate that the hydrogen ion impoverishment effect is somewhat more important than the agitation effect in **normal** bright chromium plating.

The structure of the dispersoid in the chromium plating bath, and of the components of the dispersoid, is a pertinent subject for study. Kasper's extensive work on this subject at the Bureau of Standards has provided most of the information now available. The electrophoretic studies now being conducted are really an indirect attempt to determine the structure as well as the properties of the dispersoid. A more direct method is needed, but cannot be devised during the current phase of the work.

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Commanding Officer

PAGE -2-

April 16, 1947

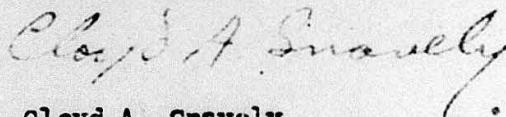
The material contained in the First Progress Report on this work will be considerably amplified by the doctoral dissertation. A copy of the dissertation will be forwarded to you as soon as it has been finally accepted at the Ohio State University.

The time for softening of chromium plate at any particular temperature can be studied during the present series of experiments, along with the study of the structural changes accompanying heating to extract hydrogen.

The study of the codeposition of another metal with chromium, and also the investigation of baths other than the chromic acid bath for chromium plating, will likely require considerable time for experimental effort. For that reason, the present phase of the work has not been directed along those lines. Our long-term view of the work to be done in chromium plating does include those two paths for investigation.

The Second Progress Report on this work will be mailed to you in the near future. Your comments on the work as it progresses will always be greatly appreciated by us.

Very truly yours,



Cloyd A. Snavely

CAS:LB

BATTELLE MEMORIAL INSTITUTE
INDUSTRIAL AND SCIENTIFIC RESEARCH
COLUMBUS 1, OHIO

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April 1, 1947

District Chief
Cleveland Ordnance District
6200 Riverside Drive
Cleveland 32, Ohio

Dear Sir:

Reference Contract W33-019 ord-6267
Electrodeposition of Chromium

Enclosed are two copies of the initial Progress Report on "A Research Investigation of Fundamental Factors Governing the Ductility and Hot Hardness of Electrodeposited Chromium". In accordance with Article 1, Paragraph G of the contract, other copies of the reports are being distributed to the following destinations:

- ✓ 2 copies to Watertown Arsenal Laboratory - Kosting, Watertown, Massachusetts
- 2 copies to Office of Chief of Ordnance, ORDTR, Cannon, Washington, D. C.
- 2 copies to Office of Chief of Ordnance, ORDTB, Materials, Washington, D. C.
- 1 copy to Bureau Ordnance, Navy Dept., Re5a, Washington, D. C.
- 1 copy to Watervliet Arsenal, Watervliet, N. Y.

This report covers the period of February 11, 1947, when the project was started, to February 28, 1947. Activities were related to analyzing the available information on chromium plating, summarizing it, and outlining the experimental program as discussed herein. Experimental work is expected to be under way in March.

This document has been approved for public release and sale; its distribution is unlimited.

Very truly yours,

Charles L. Faust

Charles L. Faust
Supervisor, Electrochemical
Engineering Research

CLF:LB
End. (2)

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FIRST PROGRESS REPORT

on

A RESEARCH INVESTIGATION OF FUNDAMENTAL FACTORS GOVERNING THE
DUCTILITY AND HOT HARDNESS OF ELECTRODEPOSITED CHROMIUM

(Contract No. W33-019 ord-6267)

to

UNITED STATES OF AMERICA
(Cleveland Ordnance District)

by

Cloyd A. Snavely, B. Agruss, and Charles L. Faust

Period Covered: February 11 to February 28, 1947

BATTELLE MEMORIAL INSTITUTE

March 1, 1947

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PROGRESS REPORT

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A RESEARCH INVESTIGATION OF FUNDAMENTAL FACTORS GOVERNING THE
DUCTILITY AND HOT HARDNESS OF ELECTRODEPOSITED CHROMIUM

to

UNITED STATES OF AMERICA
(Cleveland Ordnance District)

from

BATTELLE MEMORIAL INSTITUTE

by

Cloyd A. Snavely, B. Agruss, and Charles L. Faust

March 1, 1947

AUTHORITY FOR PROJECT

Work on this project is being conducted under U. S. Government
Contract No. W33-019 ord-6267, dated 1 January, 1947.

OBJECTIVE AND SCOPE OF PROJECT

The objective of this project is to develop further the
fundamental principles of chromium plating, and, in the light of these
principles, to modify the chromium plating process to produce an improved
type of plate for service on Ordnance materiel, and, in particular, on
gun tubes for hypervelocity firing.

The scope of the work to be performed is outlined as follows:

1. Identify factors governing the ductility and hot hardness of chromium plate;
2. Amplify and extend the data on the mechanism of chromium plating;
3. Conduct the research with an ultimate objective to recommend application of the principles developed to improving the chromium plating process to achieve crack-free hot-hard plate.

BACKGROUND

Hard-chromium plate has been extensively applied to the bore surfaces of gun tubes, particularly during World War II. Thick plate, that exceeding 0.0005 inch, showed benefit for extending the accuracy life of small-caliber guns only, i.e., up to 37 mm. Experiments with thick, hard-chromium plate were not successful on larger caliber guns, nor were results so good as desired on hypervelocity firing. The plate failed rapidly through cracking, which led to its breaking away in chunks. This was caused by undermining resulting from hot powder gases entering the cracks and attacking the steel.

"Soft" chromium was then tested on experimental gun tubes in the hope of avoiding the failure by cracking, which occurred in the hard plates. "Soft" plates, or high-temperature plates, are produced from plating baths at temperatures and current densities well above the normal plating range for hard chromium. The actual hardness of the soft plate is commonly found to be approximately 400 - 500 Knoop (100-g. load), while

hard plate may be expected to give hardness measurement values roughly twice as great. The soft plates failed by plastic deformation under the swaging action of the projectile driving bands. In other experiments, soft plate was demonstrated to be highly resistant to gas erosion at high temperatures.

The idea was conceived that a combination of the properties of hard and soft-chromium plates might be achieved by plating a layer of soft crack-free chromium on the gun-tube steel, then plating a layer of hard, wear and deformation resistant chromium over the soft plate. A limited amount of experimental work was done in the development of this "duplex" type of plate*. While the results were generally favorable, the amount of experimental work done was insufficient for a definite conclusion regarding the usefulness of the "duplex" plate as a gun-tube lining material.

Pure chromium has been described as a soft, ductile metal. The so-called soft chromium plate is soft as compared to hard-chromium plate, but is still hard as compared to most metals. As regards ductility, soft chromium plate is not known to be precracked as is hard chromium, and is ductile to a limited degree which has not been precisely defined.

*Battelle Report of June 28, 1946, Ord. Contract No. W-33-019 ord-6080, dated May 10, 1946

The chromium plating process, and the methods used in its application, have been developed, for the most part, in an empirical manner. Development of the theory for the mechanism of plating, and for the characteristics of the plate, was practically neglected during the past three decades while industrial exploitation of the process proceeded apace. For the past eighteen months, a fundamental research has been in progress to develop a theory of a usable nature for chromium plating on the basis of scientific principles. This research has just been completed. The work was carried out at Battelle Memorial Institute under the Battelle Research Education program*.

The theory, as developed in this fundamental research, explains the mechanism of chromium plating as now practiced, and gives fundamental reasons for most of the characteristics of chromium plate. Except for a few scattered points, the theory may now be considered to be "caught up" with the empirically developed plating process.

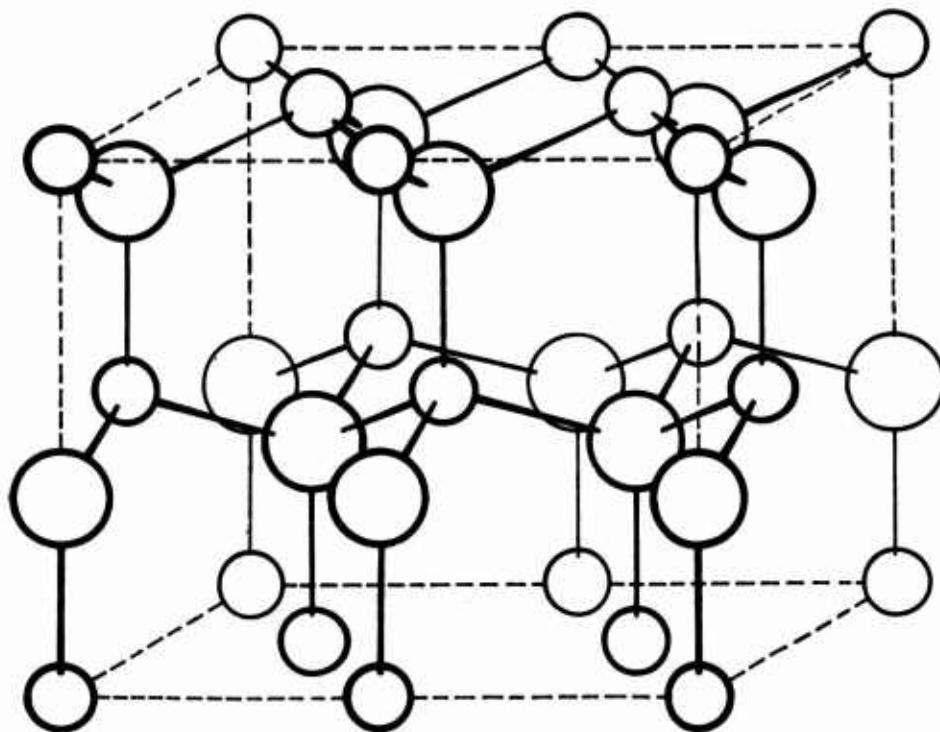
Research advances in any field may be expected to occur most rapidly when a fundamental approach is available. Such an approach is now available for research in chromium plating; involving extension and application of the basic theory for the process. The present investigation is, thus, logically projected into a continuation of the basic research project just completed, with special direction toward improvements in the chromium plating of gun tubes.

*Reported in a dissertation submitted to Ohio State University by C.A. Snively.

THE PRESENT STATUS OF THE THEORY FOR CHROMIUM PLATING
AND FOR THE CHARACTERISTICS OF CHROMIUM PLATE

The normal atomic structure for chromium metal is the body-centered cubic arrangement. However, chromium may be electrodeposited as a hexagonal close-packed hydride, or as a face-centered cubic hydride. Under normal commercial plating practices, the formation of one, or a combination, of these "structure compounds" generally occurs. These hydrides are interstitial solid solutions of hydrogen in a chromium lattice. They are unstable at atmospheric temperatures, and spontaneously decompose to form normal body-centered cubic chromium metal and uncombined hydrogen. Some of this hydrogen is normally occluded in voids in the plate during the decomposition. The remainder apparently escapes from the plate entirely.

The hexagonal close-packed chromium hydride has lattice parameters of: $a=2.71(7)\text{A}$, and $c=4.41(8)\text{A}$. In the decomposition of this structure to a normal body-centered cubic chromium metal structure of lattice parameter, $a_0=2.878(6)\text{A}$, the shrinkage in specific volume is 15.6 per cent. The hexagonal close-packed hydride adopts the Wurtzite structure, Figure 1, but may have only half the hydrogen atoms necessary to complete this structure. Thus, the formula for the hexagonal hydride may vary in the range of atomic proportions of Cr_2H to CrH . In terms of atomic per cent, these formulae include the entire range between 33 per cent hydrogen and 50 per cent hydrogen.



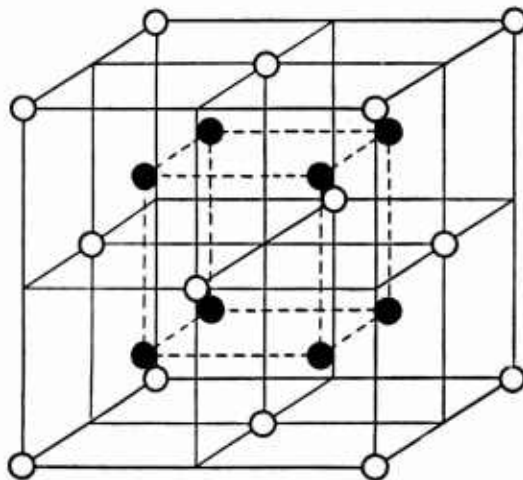
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Figure 1. Wurtzite-type structure. (Taken from Pauling, "Nature of the Chemical Bond", Cornell Univ. Press (1940).) The hexagonal close-packed hydride of chromium may assume this form. The large circles represent the positions assumed by chromium atoms, and the small circles give the positions of hydrogen atoms.

The face-centered cubic chromium hydride has a lattice parameter, in which $a_0 = 3.85(?)\text{A}$. When this structure decomposes to the normal body-centered cubic metal structure, a volume shrinkage of 16.4 per cent occurs. The face-centered cubic hydride adopts the fluorite structure, Figure 2, but may be deficient in hydrogen atoms, so that as many as half of the normally filled hydrogen positions may be empty. The extreme case of hydrogen deficiency is represented by the zinc blende-type structure, Figure 3. The formula for the face-centered cubic hydride may vary in the range of atomic proportions of CrH and CrH_2 , as illustrated by Figures 2 and 3. The range of compositions thus defined is between 50 and 67 atomic per cent hydrogen.

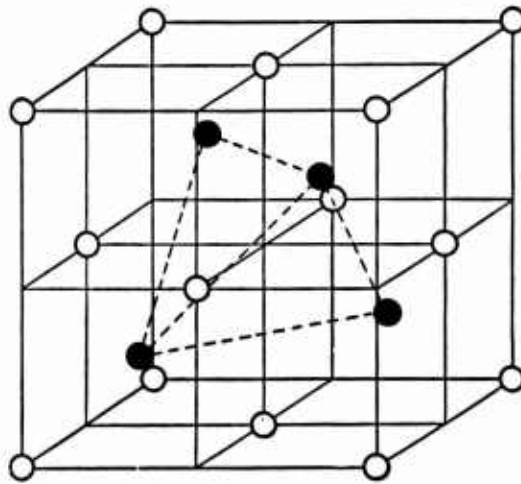
The type of atomic structure produced during chromium plating appears to be dependent on the pH of the solution film adjacent to the cathode. This relationship is schematically illustrated in Figure 4. As the pH at the cathode rises, structures produced are body-centered cubic chromium, the hexagonal hydride, and the face-centered cubic hydride. The deposition of mixtures of these various structural combinations is possible in intermediate pH ranges.

The pH of the solution film at the cathode is controlled by several factors. Chromic acid is a highly dissociated acid, and, therefore, the hydrogen ion concentration in the bath proper is very high. Upon electrolysis of the bath, hydrogen is evolved at the cathode(s) and oxygen at the anode(s). The cathode current efficiency of the chromium plating process is within the range from 10 to 20 per cent. The 80 to



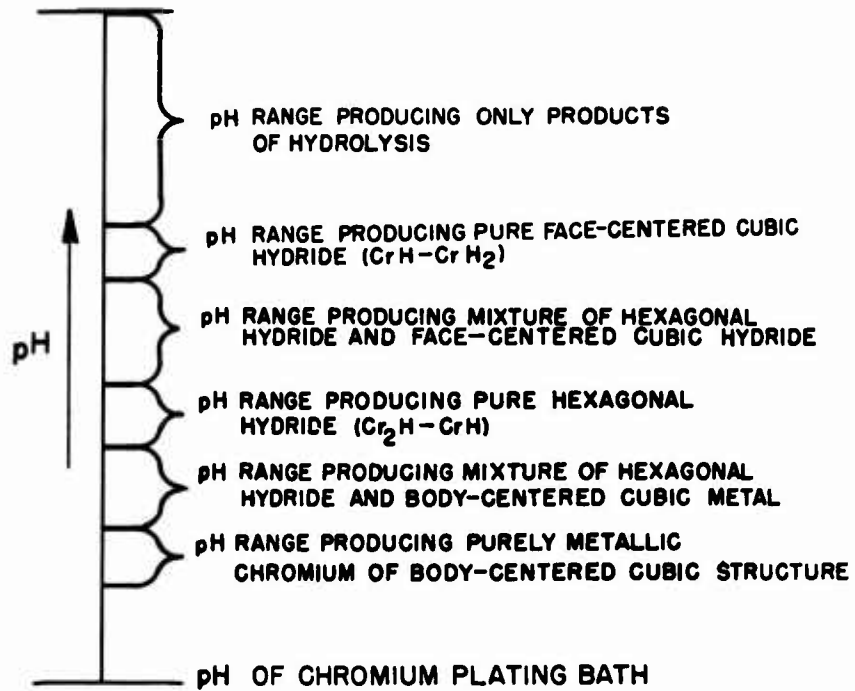
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Figure 2. Fluorite-type structure.
(Taken from Westgren, Jnl.
Franklin Inst., 212, 577
(1931).) The face-centered
cubic hydride of chromium
may assume this form. The
circles represent chromium
atoms, and the black dots
represent interstitially
placed hydrogen atoms.



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Figure 3. Zinc blende-type structure. (Taken from Westgren, Jnl. Franklin Inst., 212, 577 (1931).) The face-centered cubic hydride of chromium may assume this form. The circles represent chromium atoms, and the black dots represent hydrogen atoms.



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Figure 4. Schematic representation of the relation between cathode-film pH and the structure of the plate produced in the chromium plating process (actual pH values of all points except bottom of scale are unknown).

90 per cent of the current lost produces atomic hydrogen which largely combines to form molecular hydrogen, and escapes from the bath surface as a gas. This continual discharge of hydrogen ions at the cathode depletes the supply of these ions in the cathode region and so raises the pH of the cathode film. The pH of the cathode film is mainly dependent on the cathode current density, which defines the rate of hydrogen ion removal from the film, and on the bath viscosity, which controls the rate at which hydrogen ions may migrate into the cathode area to replace the ions discharged at the cathode.

The viscosity of the plating bath may be affected by several variables. A decrease in temperature increases the bath viscosity, decreases the migration velocity of hydrogen ion through the bath, and favors an increase of pH at the cathode. An increase in chromic acid concentration increases the bath viscosity and favors an increased pH at the cathode.

No mention has yet been made of trivalent chromium which exists in every used chromic acid bath, and which plays an extremely important part in the operation of the bath. The trivalent chromium is formed by partial reduction from the hexavalent state in the cathode area, and takes the form of an electropositively charged dispersoid in the bath. The plating bath is, therefore, a colloidal system consisting of a dispersoid in an electrolyte.

The effect of chromic acid concentration and of the partial reduction of hexavalent to trivalent chromium on the viscosity of the plating bath is illustrated in Figure 5. In a bath of given total

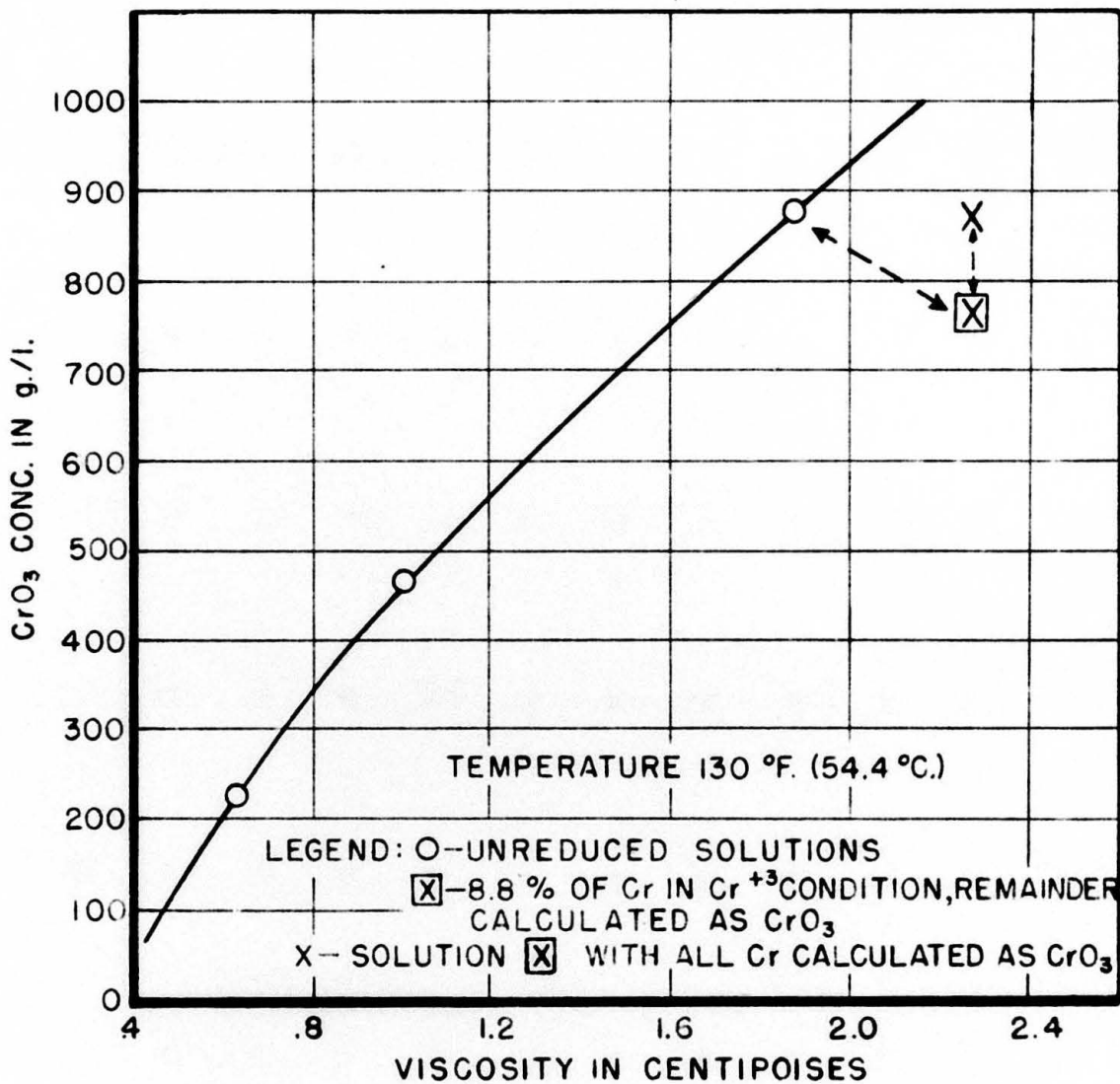


FIG. 5 — VISCOSITY OF AQUEOUS CHROMIC ACID SOLUTIONS

chromium concentration, the viscosity increases as the percentage of the chromium reduced to the trivalent state increases. Therefore, the pH of the cathode film is increased by an increase in the percentage of reduced chromium in a bath of given make-up composition.

The electropositive character of the trivalent chromium dispersoid accounts for a further affect on the pH of the cathode film. The electropositive dispersoid particles are drawn to the cathode during electrolysis, and thus are concentrated in the cathode area. In this way, the solution in the cathode area becomes much more viscous than the bath proper, and the migration of hydrogen ions into the cathode film is greatly impeded. Hydroxyl ions are similarly impeded from migrating out of the cathode area, although the comparative transfer numbers of hydrogen ion and hydroxyl ion would indicate that the migration of the hydroxyl ion is of minor significance.

The trivalent chromium dispersoid undergoes a reversal of charge (reaches its isoelectric point) when the pH of its environment exceeds a certain value. Therefore, when this critical pH is exceeded in the cathode film, the dispersoid migrates out of the film into a lower pH area, and the film becomes less viscous. This, in turn, favors more rapid replenishment of the hydrogen ion concentration of the film with a resultant lowering of pH. As the pH of the film is lowered, the dispersoid tends again to close in on the cathode. While the picture thus presented represents a cyclic performance, which is useful in explaining the phenomena involved, it is probably more accurate to consider a dynamic equilibrium condition at the cathode, with the dispersoid acting

to maintain the cathode film pH essentially constant for any given set of plating conditions.

An important constituent of the chromium plating bath is the sulfate ion, and it remains to explain the function of this ion in the bath. The sulfate ion is strongly adsorbed by the trivalent chromium dispersoid and effects a lowering of the isoelectric point of the dispersoid. This causes the dispersoid to control the cathode film pH at a value lower than that established by the dispersoid without adsorbed sulfate. The sulfate ion concentration of the chromium plating bath must be held within relatively close limits for good plating results. This is an indication that the cathode film pH must be held within relatively narrow limits for good results in terms of the type of chromium plate produced by present-day methods.

By drawing from the plating mechanism presented above, and from established metallurgical principles, most of the properties of chromium plate may be explained. The cracks found in all hard-chromium plates are formed because the plates are deposited as hydrides, or as a mixture of hydrides and chromium metal. The hydrides are extremely unstable in the plating bath environment, and decompose. The shrinkage attendant to the decomposition causes the plate to crack in the familiar "mud flat" pattern. Additional plate is deposited over the cracked plate, and this, in turn, decomposes and cracks.

The cracks form under the bath surface and extend from the plate surface to a depth at which shrinkage stresses are insufficient to propagate them further. As these cracks open up, the solution at the

cathode surface is drawn into them and fills them. The material found in the cracks in chromium plate is normally termed the "inclusions" in the plate. It is now apparent that this material is, in reality, a sample of the cathode film present during the plating process.

During the period when cracks are forming in the plate, shrinkage stresses are being relieved. This process continues until the stresses remaining are insufficient to continue existent cracks or to form new ones. The stresses then remaining in the plate must be just under the stress required to rupture the plate.

The grain size of chromium plate is very fine, as was shown by X-ray tests described in the literature some years ago. It is considered likely that this extraordinarily fine grain size is largely a result of the hydride decomposition. When a grain of hydride decomposes, the released hydrogen must escape from the structure at the grain surface. It is assumed that the decomposition occurs first at the grain surface. A phase change in any crystalline material is commonly thought to begin at the grain boundaries and to proceed toward the grain center. By this mechanism, a core of hydride is surrounded by a shell of body-centered cubic metal. However, the shell cannot completely surround the core, because of the shrinkage in the shell material during its decomposition from the original hydride form. Therefore, radial cracks must develop in the grain, growing from the surface to the grain center as the decomposition proceeds to the center. Upon completion of the decomposition, the radial cracks effectively divide the original grain into a number of smaller grains.

The hardness of chromium plate is extremely important in the present work, because it is this property, along with a low coefficient of friction, which are the principal factors accounting for the success of chromium plated gun tubes. The hardness of the plate is believed to be a result of the fine grain size of the plate. Published data indicate that stress in the plate is a minor factor in contributing to the hardness. Heat treatments, which might be expected to relieve any stress in the plate, were shown to have no appreciable effect on the hardness of hard chromium plate. Some other data do not entirely agree with this conclusion. It appears that the point bears further investigation.

The crack-free and soft character of chromium plates, produced from high-temperature ($\approx 185^{\circ}\text{F.}$) plating baths, may be explained on the basis of the pH and temperature, existing at the cathode in these baths. The high temperature decreases the viscosity of the bath, and favors increased diffusion of hydrogen ion into the cathode area. It is also likely that the isoelectric point of the dispersoid is altered somewhat from the value at lower temperatures. It is certain that any hydrides deposited at such elevated temperatures will be extremely unstable and decompose before growing to any appreciable grain size. The net result of these conditions is to produce a plate which is predominately body-centered cubic as deposited, or in which the hydride decomposes so quickly that shrinkage cracks are extremely minute.

Addition of iron or aluminum to the chromium plating bath was a war-time development to produce relatively soft, ductile plates. The plating is done at high temperatures or at normal plating temperatures.

It is believed that the iron or aluminum is taken into the trivalent chromium dispersoid in the bath and effects a lowering of the isoelectric point of the dispersoid. In this way, the deposition of hydrides is made less likely.

Data in support of the theory presented above are contained in a dissertation manuscript submitted at Ohio State University by one of the authors of this report*. It is planned to present these data in a publication of one of the technical societies in the near future.

THE PATH OF INVESTIGATION INDICATED BY THE THEORY

The theory, as presented in the previous section, is virtually complete. It is hoped to strengthen and extend certain points of the theory by obtaining additional experimental data. This work will be undertaken with the specific aim of broadening the usefulness of the theory for Ordnance applications.

A gun-tube lining must exhibit certain special properties, in order to function satisfactorily. Important among these properties are the following:

1. Hardness. This property is required to resist the swaging action of the projectile driving bands, and presumably also to provide wear resistance.

2. Hot hardness. This property is considered separately from ordinary low-temperature hardness. Gun tubes must operate at considerably elevated temperatures during repeated firing. Hardness is then

*C. A. Snavely

required for the same reasons as given under (1) above.

3. Resistance to cracking. Tube linings are subject to mechanical shock and heat shock. Both of these conditions must be withstood without cracking.

4. Freedom from cracks as plated. The potentialities for improvement of high-temperature operation will be greatly enhanced by having available a sound, crack-free chromium plate.

In the light of the theory as presented herein, chromium plate produced by conventional methods, cannot be expected to exhibit the required properties of hot hardness and resistance to cracking. The requirement of low-temperature hardness is satisfied. The theory does not indicate any way in which hot hardness of pure chromium can be achieved. Elevated temperatures may be expected to cause annealing and grain growth, thus eliminating the factors which cause the plate to be hard.

Since deposition of chromium by present methods produces unstable hydrides, and these hydrides shrink during decomposition, production of completely crack-free plate is likely to be achieved only by depositing the metal in the normal body-centered cubic arrangement. The high-temperature plate represents a step in this direction. Although lacking in hardness, the high-temperature plate contains few, if any, cracks of appreciable size. This plate is still relatively brittle and is too soft for gun-tube service without additional treatment.

The most logical approach to the improvement of chromium plate, in terms of the properties desired, appears to be in the direction of producing a softer, more ductile plate, and then devising a method of

hardening that plate. Such an approach is envisioned in the present work.

METHOD OF ATTACK

The work thus far planned may be separated into four subdivisions as follows:

1. A study of the electrophoretic properties of the trivalent chromium dispersoid in the plating bath, and the effect on these properties of various additions to the bath. In this work, it will be hoped to verify the theory as presented above, and to arrive at a method of controlling the cathode film pH in a range sufficiently low to deposit a ductile, soft-chromium plate.

2. A study of methods of hardening soft-chromium plate. The formation of chromium nitrides or borides (interstitial solid solutions of nitrogen or boron in a chromium lattice) in the plate would be expected to effect a pronounced hardening of the plate. It is hoped to form a hard, stable surface coating, which is in compression, and to have this coating backed up by a softer coating which is highly resistant to crack penetration.

3. An amplification of the data regarding the hardness of chromium. The theory presented above regarding the hardness of chromium is based, for the most part, on data gathered from a number of different literature sources. Since this information is being used to substantiate the conclusion that pure, untreated chromium plate will not be satisfactory for hypervelocity firing, it should be carefully checked for authenticity. It is believed that some experimental work is warranted to

check the literature. Measurements of grain size before and after decomposition of hydrides, of change in degree of preferred orientation during the decomposition, and of plate hardness before and after extraction of hydrogen from the plate, should provide the necessary information.

4. A study of the effect of the surface condition of the basis metal on the structure of the chromium deposited on it. Cold-rolled brass sheet was used as the basis metal in all of the experimental work leading to the development of the fundamental theory. A few experiments are planned to determine if the structures of chromium deposits on steel are identical with those on brass. Electropolished and surface ground steel specimens will be used, and any differences in the structural characteristics of deposits obtained on these two types of surfaces will be noted.

It is planned to carry on the investigation so that work is proceeding on several or all of the above subdivisions of the investigation at the same time. This is possible because pertinent information desired from any one of these subdivisions is largely independent of the other phases of the project.

CAS:BA:CLF/LB

March 21, 1947