The Plating Industry in World War II

Part 3: The Road to Victory

by
James H. Lindsay
Editor, Plating & Surface Finishing
Fenton, MI

Introduction
Over the last couple of months, we have been looking at the challenges that the surface finishing industry faced in the early years of World War II, as well as the time leading up to the active involvement of the United States prior to Pearl Harbor. With today's economy presenting a new set of challenges to the industry, it has been worthwhile to take a look at another period of unprecedented challenge.

In the first installment, it was pointed out that the tenor of the times was reflected in the atmosphere of the AES Annual Conventions of those years. In 1940, the goings-on at the Dayton, Ohio confab were characterized by business-as-usual, as the country continued to recover slowly from the depths of the Great Depression.

One year later, with Pearl Harbor still in the future, the war in Europe was raging across the pond, and despite strong isolationist currents, the handwriting was on the wall. The talk of the 1941 Convention in Boston was filled with uncertainty, as the future of the plating industry was in jeopardy. Critical materials were shifted from civilian to military use. The civilian activity of the plating business - chrome bumpers, jewelry and other decorative products - were considered "non-essential." Any critical materials would be diverted to military use. Government speakers felt that the use for plating in the war effort would be considerably less than in peace time and the opportunities for the plating business would shrink.

Then came Pearl Harbor, and American participation in all-out war would dominate the national consciousness for the next several years. As noted in the second installment last month, despite rationing and restrictions, AES Conventions continued, and in 1942, the talks in the opening "Victory Session" at the Grand Rapids meeting continued to sound pessimism for the plating industry. Indeed, the prospects for long-term survival were said to be worse, as the numbers put out there for audience consumption, foretold a shrinkage of the plating industry to 35% of its pre-war business.

Still, by 1943, the picture was changing, as the powers-that-be discovered that plating technology was indispensable to the war effort. Plating wasn't just for shiny baubles. Though it was no secret to those in the industry, it became obvious that the corrosion, wear and other engineering properties imparted by plated coatings were indispensable to the war effort. The amount of plating business was far beyond what government procurement agencies had predicted just a year earlier. By the end of the war, it was apparent that plating technology was indispensable to victory.

At the same time that plating technology boosted the war effort, the war effort in turn boosted plating technology, as ingenuity of the platers worked to meet unprecedented performance requirements that couldn't have been foreseen in peace time. For the postwar years, this gave the industry a boost to the prosperous times that followed, in the renewed automotive and electronics industries, to name two of the more visible sectors.

Fortunately, we have the records of those times, including the records of the Annual Conventions of the American Electroplaters' Society. In this final article of this series, you will read what was on the minds of the players in the industry and government as the war went on to victory in Europe and in the Pacific. The emphasis here will be on the advances in plating technology spawned by the war effort. Indeed, like the nation, the plating industry was transformed as it returned to civilian production, leading to a period of unprecedented prosperity.

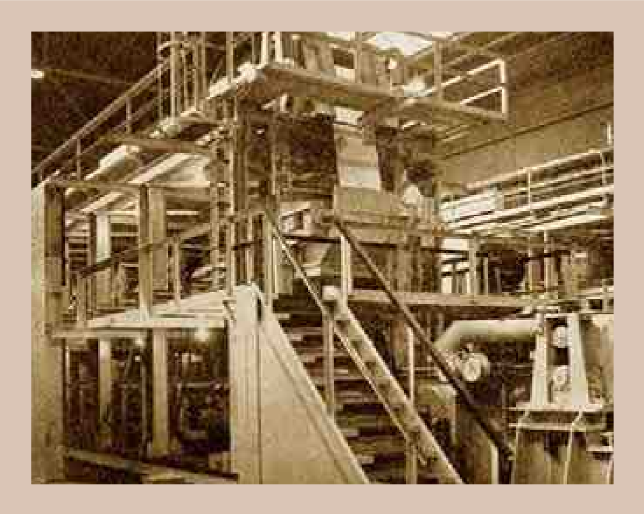
Through 1944, the AES had held its Annual Convention without interruption. Yet as the war effort increased in size and scope, the demands of the military effort required increased sacrifice for the nation as a whole. Much heavy manufacturing was converted to military production (notably automobiles). Even copper pennies were converted to steel. Rationing was a way of life, and for those who still had a car, severe rationing of gasoline strictly limited most civilian auto travel. Thus it happened that the 1945 AES Annual Convention, scheduled in Pittsburgh, Pennsylvania was strictly a meeting of the Council of Delegates. Only about 50 attended.

For the first time in AES history (and to date the only time), there would be no regular Annual Convention.

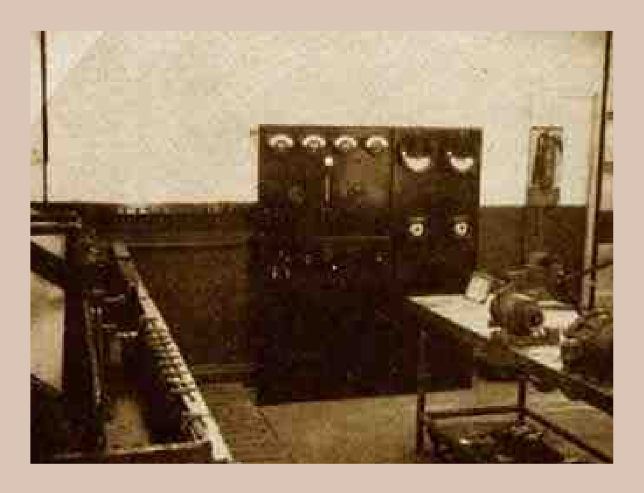
With victory in hand in 1945, 1946 was clearly a hopeful time. Because the 1945 meeting in Pittsburgh was not held, that city was the obvious choice for the 1946 AES Annual Convention. Optimism was in the air that Summer, and many of the presentations covered the advances in plating technology that had come about as a result of the war effort.

Foremost among these lectures was one given by the esteemed Dr. William Blum, of the National Bureau of Standards (now NIST), entitled "Summary of Wartime Research on Plating at the National Bureau of Standards." Although germane to the work at NBS, it was an accurate depiction of plating industry efforts as a whole. That was made evident in Dr. Blum's opening remarks:

"*This brief summary of the work of the Electroplating Section of the National Bureau of Standards during the past few years is written not so much to serve as a historical record, as to call attention to the relation between electroplating in peace and war, and to suggest ways in which the*



Electrotinning installation at Weirton Steel, built in 1938.



Hard chromium plating room at Delco-Remy Div. (GM), Anderson, Indiana (1944).

knowledge gained through military applications may be applied to industrial processes. It will be recalled that as late as 1942 grave fears were expressed regarding the continued existence of the electroplating industry. However, many new and important military applications of electroplating soon developed, and before V-J day the total volume of plating done in this country was at least equal to that in peace time, even though the types of coatings and products had greatly changed. The electroplating industry played an important part in the war both by meeting specific new demands and by making possible many substitutions for strategic metals.


William Blum

"*This review will include only those plating projects with which this Bureau has had some direct connection. It is by no means a comprehensive survey of the military applications of plating. For example, no further reference will be made here to such important projects as the use of electrodeposited silver-lead-indium coatings on aircraft bearings; the application of "porous chromium" to cylinders and piston rings in aircraft and Diesel engines, and the reported use of thick nickel coatings on equipment for the Manhattan Project, with all of which we have had only incidental contacts.*"

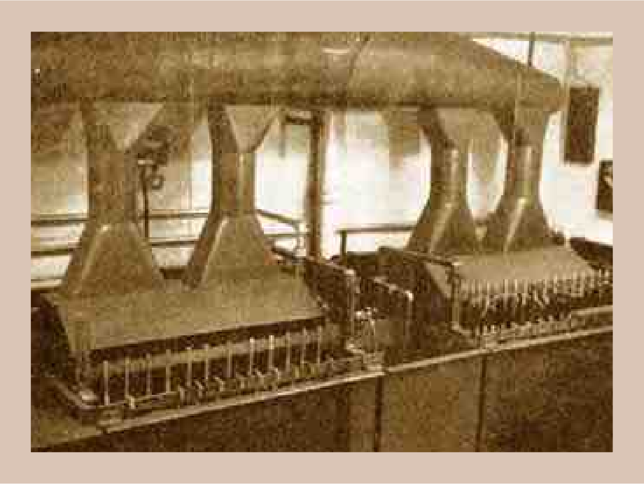
The size and power of the artillery used in the war was unprecedented, and it presented a number of technological challenges that had to be met if the war were to be won. The environment within the barrels during firing of the huge guns on naval ships for example, posed conditions on bores so severe as to be impractical as far as service life was concerned without added protection. Dr. Blum discussed how the challenge was met with new approaches to hard chromium plating.

"*The chief project of Division One of NDRC, with whom we cooperate, was the development of high-velocity rapid-fire guns. It soon became obvious that other materials than gun steel were necessary on the bore surface in order to achieve any-reasonable life under these conditions of service. Because chromium plating had been applied to small arms by Frankford Arsenal and to larger guns by the Washington Naval Gun Factory, it naturally received first consideration.*

"*Examination of plated guns after firing showed that the chromium coatings then used were less than 0.001 inch thick, and were very porous, especially after being heated. Erosion of the underlying steel occurred through the cracks. We then made a study of the properties of chromium deposits with a view to making them more nearly impervious.*

"*It is well known that the ordinary "hard" chromium coatings, such as are produced at 50°C (122°F) and 20 A/dm^2 (190 A/ft^2) are very hard (about 900 Brinell) and very brittle. As deposited, they have many cracks which increase in size and number if the coatings are heated. It was found some years ago that this type of chromium contracts as much as one percent when heated to or above 700°C (1300°F), which explains the increased cracking. It was also known that this chromium contains chromic oxide (Cr_2O_3). We found as much as 1 percent of Cr_2O_3 in certain deposits.*

"*A few years ago, G. E. Gardam of the British Armament Research Department, reported that "machinable" chromium can be deposited at 85°C (185°F) and 20 A/dm^2 (190 amp/ft^2) and that the cathode efficiency can be increased by adding iron or trivalent chromium to the bath. Our examination of chromium deposited at 85°C and at 40 to 120 A/dm^2 (370 to 1100 A/ft^2) showed that it is relatively soft (about 450 Brinell) and even though it is less brittle than the regular chromium, it cannot be called ductile. It has fewer cracks*


Army Air Force, Air Services Command, Hard Cr Plating Tanks, Kelly Field, San Antonio, Texas.


Convoy on D-Day (Wikipedia, US Gov. public domain).

and when heated it does not contract appreciably to produce additional cracks. It contains only about 0.2 percent of Cr_2O_3. This latter type of chromium was designated by us as "low-contraction" or "LC" chromium, in contrast to the regular "high-contraction" or "HC" chromium. Where moderate hardness and good resistance to corrosion are required, especially at high temperatures, the use of LC chromium warrants consideration.

"*Chromium plating of caliber-0.50 barrels, both those with nitrided-steel surfaces and those with stellite breech liners, was approved by the War Department and was conducted commercially by the Doehler-Jarvis Company of Grand Rapids. By V-J day several other plants were installing equipment for such plating. Studies on the chromium plating of guns of other calibers are being continued at this Bureau.*

"*Breech liners made of Stellite 21, an alloy of cobalt, chromium, nickel and molybdenum, are valuable because this alloy remains relatively hard at high temperatures. Electrodeposition of a coating with similar properties would be more convenient and economical than the present use of a cast, machined and rifled liner. Studies were therefore made on the deposition of alloys of tungsten or molybdenum with iron, nickel or cobalt. New types of baths were developed, and deposits with promising properties were obtained. When further details are completed we plan to publish these methods of deposition.*

In gun barrels then, the concern was friction and wear. Out on the battlefield itself, the concern was corrosion. Indeed, corrosion of the steel ammunition cartridge cases (*i.e.*, bullets) was the subject of considerable research and development at the Bureau of Standards.

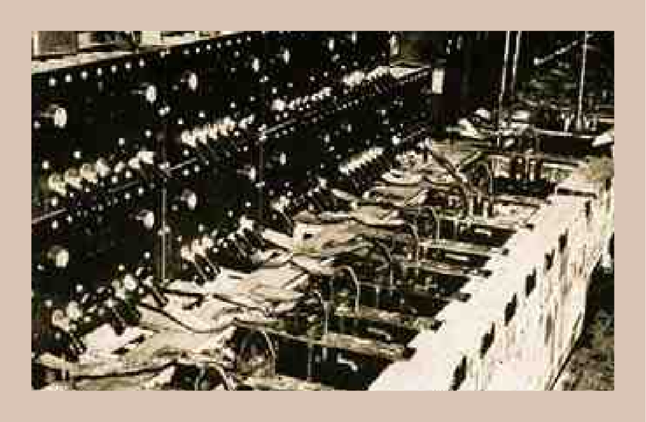
"*The scarcity of copper led to the production of steel cartridge cases that have the necessary physical properties, but which require protection against corrosion. In cooperation with Frankford Arsenal of the War Department we conducted studies on protective coatings for this purpose.*

"*Exploratory tests showed that the two most promising coatings on the steel cases were (a) electroplated zinc and (b) a baked phenolic varnish. The zinc coating protects the steel against corrosion even where it is exposed by scratches, but in humid or saline atmospheres the zinc acquires white corrosion products that may interfere with the extraction of the fired cases. Various chromate treatments of the zinc were found to retard the formation of the white corrosion products. The varnish coatings furnish very good protection so long as they are intact and continuous, but they permit corrosion of any steel that is exposed through pores or scratches.*

In our studies it was found that all types of zinc deposits with a given thickness furnish equal protection to each other, whether tested in the salt spray or in the atmosphere. Chromate films are more effective than phosphates in retarding corrosion of the zinc.

"*Studies on the application of paints to zinc coatings showed that on hot-dipped zinc, phosphate treatments result in better adhesion of paint than do chromates. On zinc-plated steel the adhesion of paints is good, and phosphate or chromate treatments, while beneficial, are less necessary. A zinc-chromate primer over either hot-dipped or electroplated zinc coatings improves the adhesion of subsequent paint coatings.*

"*Several thousand rounds of loaded 20-mm and 40-mm ammunition with brass cases, steel cases with a zinc-Cronak finish, or steel with a baked varnish coating, were subjected to salt-spray and salt-immersion tests to simulate severe marine exposure. They were then fired at the Army Proving Ground at Aberdeen, Maryland, or at the Naval Proving Ground at Dahlgren, Virginia. The results showed that ammunition with all types of case, even when severely corroded, can be fired successfully if, as is customary, they are lightly greased before firing. The application of a supplemental wax film does not prevent corrosion, but it yields less adherent corrosion products. Zinc-plated steel showed less leakage of water into the cases than did the brass or varnished steel.*



Army Air Force, Air Services Command, Cylinder Chromium Plating Plant, Kelly Field, San Antonio, Texas.

A-20 from the 416th Bomb Group making a bomb run on D-Day (Wikipedia, US Gov. public domain).

"*In connection with studies on plating of brass primer cups and anvils, some manganese deposits were applied. While these showed no advantage for this purpose, it is interesting to know that manganese coatings furnish good protection against corrosion of steel or brass.*"

The magnetic thickness gauge, developed by Dr. Abner Brenner of the Bureau of Standards before the war, became of great use in wartime plating applications.

"*Over 2,000 "Magne-gages" of the type developed in 1937 by Abner Brenner were calibrated at this Bureau. The fact that these measurements are non-destructive led to the wide use of these instruments in testing coatings on many military supplies. Special forms of the gage were designed and calibrated for measuring the thickness of very heavy nickel coatings on steel, and the thickness of coatings inside of tubes such as gun barrels of caliber-0.50. Efforts are now in progress to perfect a magnetic gage to determine the thickness of composite copper-nickel coatings on steel.*"

In the first two installments of this series, much was made of the scarcity of materials that were classified as critical to the war effort. Even within the military, scarce materials were allocated by critical need. Items as mundane as tableware for the mess halls faced materials availability problems (Keep in mind that plastic forks and spoons were off into the future.). This led to the development of substitutes, something that continues today, but for far different reasons - matters of environment and health.

"*The increased demands for metals such as copper, zinc, aluminum, chromium and tin, necessitated the substitution of steel for other metals in the production of both military and civilian supplies. Usually the steel required protection against corrosion, which in many cases could be furnished by electroplated coatings. Typical examples of such problems are:*

Lockheed P-38 Fighter - dependent on electroplatiang and metal finishing processes.

Plated steel tableware. "*The scarcity of nickel and chromium prevented the use of stainless-steel tableware or of silver-plated nickel-brass ware. Early experience of the War Department with silver-plated steel showed that the coatings were so thin and porous that they rusted quickly.*

"*Through the War Metallurgy Committee, a special committee, of which H.S. Lukens was chairman, planned tests of plated steel tableware in actual camp service. Many thousand steel forks were plated in commercial plants with coatings of different composition and thickness, and samples were analyzed at this Bureau. In addition accelerated corrosion tests and wear tests were made.*

"*The results of over a year's camp service showed that, under these severe conditions, failure occurred principally by wear and not by corrosion. In consequence it was found that hard chromium coatings applied directly to case-hardened steel yielded the best results. (This same conclusion was reached regarding chromium-plated steel mess trays, used in large quantities.) Relatively thick coatings of silver, or composite coatings of copper, nickel and chromium, yielded good service, provided the deposits had very good adhesion. No good method of measuring the relative adhesion of the coatings on the plated forks was found, though severe bending tests served to detect poor adhesion.*

"*This experience was instructive in showing that plated coatings must be adapted to the probable conditions of service and that then they can meet even very severe demands.*"

Steel one-cent pieces. **"***Laboratory studies showed that steel coins can be protected against corrosion by zinc coatings that need not cover the edges. Hence they could be stamped out of pre-plated sheets. Their white color, which could readily have been darkened, led to their confusion with dimes and caused the discontinuance of this coinage as soon as copper became more available. The saving of over 5,000,000 pounds of copper in a critical war year undoubtedly compensated for any inconvenience to the public.*"

Substitution of iron for copper and nickel in printing plates. **"***Studies conducted here early in the war showed that electrodeposited iron could be substituted for a large part of the copper and nickel normally used in electrotypes and on stereotypes. These methods were used successfully in three large plants which reported increased life of the plates. No extensive use was made of iron in the electrotyping industry because it was found possible to salvage and re-use a large part of the copper in the electrotypes.*

Finally, Dr. Blum alluded to how the war effort shifted the way of doing the work, including such matters as drafting specifications, and the shift of individual work assignments as the draft and enlistments sent so many employees overseas to fight the war. Many of these changes altered the way things were done in the postwar period.

"*In the above and numerous other activities we cooperated with the War Production Board and the Federal Specifications Board in efforts to meet the essential civilian needs with materials that were available. While some of the substitutions made were justified only in the emergency, the necessity of more clearly defining the requirements for many types of equipment was a salutary experience that will no doubt result in some changes in postwar practice.*

"*The large amount of testing of plated articles for use by the military agencies served to emphasize the need for definite specifications and tests. The specifications for plating adopted in recent years by the AES and ASTM served as a basis for many of the Government specifications, even though availability of materials and special requirements often prevented their literal adoption. It is safe to predict that many firms who found it necessary and possible to meet specifications (some of which they considered unreasonable) will do more testing and control of their peace-time products than formerly.*

"*To conduct the above studies and tests required the services of about 25 persons at one time and a total of nearly 50 persons in four years, owing to resignations and to draft by the Army and Navy. Although most of the employees, including a number of young women, had no previous experience in this field, they soon developed interest and ability in our problems, and made possible the work conducted by our section.*

"*Special credit should be given to Abner Brenner and Vernon A. Lamb, who directed a large part of these studies, and virtually conducted a training school for new employees. Thanks are also due for the cordial cooperation of a large number of persons in the War and Navy Departments, the War Production Board and other Government agencies, and the many firms associated with these problems.*"

Although Dr. Blum's talk was focused on the then-National Bureau of Standards, it is safe to say that any firm dealing with plating, including shops, suppliers, R&D facilities and users (*e.g.,* the auto companies who converted to war production), had similar stories to tell. The story told here is just the tip of the iceberg as production shifted from wartime to peacetime. In that vein, it is useful to read the transcript of the Q&A that followed Dr. Blum's paper.

Mr. Austin F. Fletcher (Brewer Titchener Corporation, Binghamton, NY): "*Dr. Blum, did I understand that you were chrome plating an alloy containing molybdenum, a stainless steel with a molybdenum content?*"

Dr. Blum: "*I am afraid, Mr. Fletcher, that in my haste to summarize quickly, I may have confused you. We did not study the plating of chromium on alloys. We did study the deposition of alloys of tungsten or molybdenum with iron, nickel or cobalt as possible substitutes for chromium in gun barrels. Such alloys are likely to have a greater hardness at high temperature than chromium.*"

Mr. Fletcher: "*I was wondering if you had run into the molybdenum oxide that seems to form after chrome plating. In other words, on high speed cutting tools, we could chrome plate them the first time and then if we have to go back for a rechroming, we usually put on a very thin film and then replate later on. After we have stripped it off, we seem to have some trouble in removing what we think is molybdenum oxide. Have you had any experience with that?*"

Dr. Blum: "*I am sorry to say we have not had any appreciable experience, and have made no study of methods of plating chromium on alloy steels. We may have done it occasionally, but only incidentally. We have not studied such conditions as Mr. Fletcher refers to.*"

Chairman W.M. Phillips (General Motors Research Laboratories, Detroit, MI) : "*I might say, Mr. Fletcher, in regard to your difficulty, that in plating of alloy steels, particularly if the alloy has any chromium in it, you have to be very careful to activate the surface or you cannot very well plate chromium on it. To do that, we generally treat with hydrochloric acid to the extent where you see a pronounced evolution of hydrogen. This is very helpful.*

Mr. Arthur W. Logozzo (Nutmeg Chrome Corp., Hartford, CT): "*On the chromium deposited at 85°C., you mentioned soft and stress-free deposits. It is only reasonable to assume that we can use this type of deposit on peace-time products as well as on the war products. May we have some of the operating conditions on that, namely, the current density factor and the type of solution as to chromic acid concentration and sulfate ratio?*"

Dr. Blum: "*Most of our work was done with the standard bath of 250 g/L of chromic acid and 2.5 g/L of sulfate, but there are indications that a higher content of sulfate, i.e., a lower ratio, is advantageous at these temperatures. At 85°C. we have plated at from 400 to 1000 A/ft^2, but for most pur-*

USS Pennsylvania moving into Lingayen Gulf (Wikipedia, US Gov. public domain).

poses we use a medium range of 750 A/ft^2, which happens to be 80 A/dm^2, and gives what we believe to be a typical low-contraction chromium of this type."

Mr. Logozzo: "*One more question along that line: I would like to know if you find it necessary to do any stress relieving before or after plating, or perhaps in both cases?*"

Dr. Blum: "*We have not made a special study of stress relieving in chromium plating. In connection with the gun barrel plating we had no occasion whatever to apply it. There was no indication of any embrittlement produced in the steel, either in the preparation or in the plating of the chromium.*"

Mr. Logozzo: "*Thank you, Dr. Blum. In answer to our friend, Mr. Fletcher, I think he will find the answer to his problem lies in the method of stripping. In stripping chromium for reworking, it is always desirable to strip so that the part is restored to the original surface without an accumulation of smut, or without a breakdown of any of the oxide that may be formed at the surface of that particular alloy. I think he will find it desirable to possibly strip in a high alkaline bath for just a long enough period of time to remove the chromium without additional work being done on the surface, because of reverse current, and then following Bill Phillips' advice of activating in a very mild muriatic so as to not again form a smut there.*"

Mr. Fletcher: "*Thanks, Art, but I think if you look up our Buffalo Convention Proceedings, you will find that you gave me the same solution to my problem as you did today and I cannot make it work.*"

Chairman Phillips: "*I have a little advice from long experience - you send for him and have him come up and show you.*"

Mr. Leonard E. Weeg (C. G. Conn Ltd., Elkhart, IN): "*I don't know whether I have the answer to this problem, because we don't do a lot of chrome plating on tools. However, from the small amount we have done and from some of the difficulties we have run into, we find that the difficulty is eliminated by giving the parts a vapor blast operation after stripping. Subsequently, we have no trouble in chrome plating. The vapor blast operation uses the method of blasting with abrasive in a liquid medium.*"

Large "Manodyz" installation (Mg anodizing).

Chairman Phillips: "*I might say that answer is very much along the line of Mr. Logozzo's advice — what he is trying to get rid of is oxide and smut.*"

The program then moved on to the next papers in the Session.

Looking back in history, much is noted of the alliance between the United States and Great Britain, and the personal alliance between President Franklin D. Roosevelt and Prime Minister Winston Churchill. Although it is a rather loose analogy, the opening session of the 1946 Annual Convention featured two speakers to discuss the technical advances resulting from the war. One of course was Dr. Blum. The other was Arthur W. Hothersall from the Armament Research Department, Ministry of Supply, London. Mr. Hothersall was located at the Royal Arsenal - Woolwich in south-east London, England, which carried out armaments manufacture, ammunition proofing and explosives research for the British armed forces.

In 1952, Mr. Hothersall's name was appended to the Hothersall Memorial Award, the prestigious award given by the Institute of Metal Finishing in Great Britain, given to an individual in recognition of their outstanding service to the metal finishing industry. The counterpart in the United States is the NASF Scientific Achievement Award and the William Blum Memorial Lecture associated with it, established in 1958.

Like the United States, Britain was of course subject to restraints in materials availability, and the military claim on resources took precedence over civilian uses. Obviously, the situation was more severe, as the British Isles were directly in the line of fire.

Although logistics prevented Mr. Hothersall from attending the Pittsburgh meeting, he sent a rather detailed paper, entitled "Wartime Plating Developments in England," which was read by Gustaf Soderberg, of the AES Philadelphia Branch. The paper was largely a review of published work, covering developments with which Mr. Hothersall was personally acquainted. Although it is too lengthy to include completely, some interesting highlights are well worth noting.

Mr. Hothersall began with a review of plating processes and deposit properties, including work during the war on brass, chromium, speculum (white alloys of copper and tin), tin, tin-zinc, rhodium, zinc and chromated zinc. A few excerpts on these topics are covered below:

Hothersall

***Brass plating**. "During the War, a new application for brass plating was to protect steel cartridge cases for medium caliber guns, and its use for plating steel to which rubber was to be bonded was much extended. One advantage of brass over zinc or copper for the cartridge cases in question was that fired cases could be reconditioned by annealing the mouth without spoiling the coating; brass also gave a case of similar appearance to what the gunners were already accustomed. Some difficulty was experienced in the bonding of rubber to steel owing to the lack of knowledge of reliable methods of controlling brass plating."*

***Tin plating**. "A method of tin plating steel sheets was developed during the War but was never carried beyond the pilot plant scale. In the course of this development, some interesting results were obtained which may possibly have an important bearing upon other electroplating processes. Since one object of plating steel with tin is to assist its soldering, Hothersall, Hopkins and Evans investigated the effect of plating conditions on strength of soldered joint using both the alkaline stannate and the acid sulfate bath developed by Hothersall and Bradshaw. It was found that the plate from the acid bath gave much weaker joints (sometimes only about half the strength) than the alkaline bath which gave joints as strong or stronger than hot-dipped tinplate; moreover, the relative strength was even less if the plates were stored, as for lacquering, before soldering. This anomaly could, however, be entirely removed by a modification in the cleaning technique before plating; it was due to adsorption of gelatin from the acid plating on the steel surface as it entered the bath and could be avoided by treatment of the steel in alkaline solution after acid pickling. Recommended methods of cleaning cold rolled steel, sheet or strip, consisted of anodic cleaning in hot alkaline solution, dipping in hot hydrochloric acid solution, and again anodic cleaning in hot alkaline solution; the time of treatment and the temperature and composition of the baths are best adapted to suit the speed of the strip and the size of the tanks; the conditions given in the original paper were developed for a 10 second time of immersion of sheet in each tank."*

***Rhodium plating of electrical contacts**. "Rhodium plate has the useful properties of resistance to tarnish combined with high hardness; its electrical resistivity (4.9 ohms per* cm^3*) is not unduly high. The diamond pyramid hardness number of electroplated rhodium is over 600 so that it is nearest to chromium of any of the metals commonly electroplated. For electrical contacts, it is usually plated over an undercoating of silver, the combination being analogous to that of nickel and chromium plate in that the silver provides protection from corrosion while the rhodium provides a non-tarnishing finish. ... One drawback of rhodium plating is that relatively little is generally known of factors affecting the properties of the deposit such as stress, hardness and adhesion. Rhodium plating has had many important applications in Great Britain during the War. With fuller knowledge of methods of controlling its properties, it should prove also important in peace time."*

***Chromate passivation of zinc**. "One disability of zinc is its tendency to rapid corrosion in damp air when condensed droplets can remain on the surface. Under suitable conditions, a chromate film can be formed on zinc plated articles by a short dip in a solution of a dichromate and sulfuric acid. One such process is the Cronak process of New Jersey Zinc Company; other proprietary processes have been developed both in Great Britain and America. …"*

Because of the incredible sense of urgency during the war, development of methods of testing coatings to meet evolving specifications was of high priority. Mr. Hothersall covered much ground in this critical area. It is remarkable to realize how elementary many of the "advanced" methods of the day actually were:

***Adhesion test**. "A number of attempts have been made to determine the adhesion of electroplated coatings and, whereas various tests of considerable value to the research worker or to the plater have been devised, nobody has yet succeeded in developing a universal test suitable for determining the degree of adhesion of a coating on any given article. An investigation was carried out … with the object of developing an inspection test suitable tor specification testing. The conclusion reached was that it was only possible to propose a universal test which would select a coating with little or no cohesion to the parent metal. The instrument proposed carried a vibrating hammer, 0.06 inch in diameter (actuated by an alternating magnetic field), which was to be applied to a local area of the coating. If the coating was non-adherent, it became extended and rose to form a blister. The principle of the test is similar to that of the well-known burnishing test which, however, is not capable of being standardized. The vibrating hammer test was applied to a variety of commercially chromium plated articles and was successful in revealing a number of non-adherent coatings on articles which to the eye appeared satisfactorily plated."*

***Drop test for thickness of chromium**. "Spencer-Timms worked on a drop test for thickness of decorative chromium plating and extended the information previously published in America by Blum and Olsen and others. This test consists of applying one drop of concentrated hydrochloric acid solution to the surface and timing the reaction as shown by the evolution of gas bubbles. One of the difficulties of this test is to define the end point. … To avoid variability in results it was necessary to maintain a suitable ratio of volume of acid to area of surface acted upon. If the drop of acid was allowed to spread, this ratio was liable to become too low and it was therefore recommended that wax rings* *should be drawn on the article to confine the drops of acid; a simple form of compass was described by means of which these rings could with a little practice readily be drawn.*”

Jet tests for silver and zinc. “*The BNF Jet Test, developed by Clarke and familiar in Great Britain for testing the thickness of nickel, copper and cadmium, has been extended by Hammond for testing silver coatings; the solution recommended contained 250 g of potassium iodide and 7.44 g of iodine per liter. The paper described the method of establishing the test using the standard BNF Jet Test apparatus. …*”

Magnetic thickness tester. “*A simple form of magnetic thickness tester for nonmagnetic coatings on steel has been developed by Spencer-Timms. A beam, pivoted near one end, carried a permanent magnet on its short arm whilst the long arm had a coarse thread along which a weight could be caused to travel until the attraction of the magnet was balanced; the position of the weight, which could be read on a scale attached to the arm, could be translated into thickness of coating by means of a calibration chart. The merits of the tester were simplicity of construction (cheapness) and robustness.*”

An interesting perspective on specifications for protective coatings, developed (or delayed) under wartime conditions was given:

“*Various Government specifications for protective coatings have been considerably amended and new ones have been drafted during the War. Apart from certain unpublished Service specifications, the following D.T.D. specifications have been revised or issued:*
DTD 901 Cleaning of metals (revised)
DTD 903 Zinc plating (revised)
DTD 904 Cadmium plating (revised)
DTD 910 Anodic oxidation of aluminum (revised)
DTD 916 Chromium plating (new)
DTD 923 Chromate treatment of zinc (new)”

Specification for nickel and chromium plate. “*The drafting of a British Standard specification for nickel and chromium plate was interrupted by the War but was resumed towards the end of the War and B.S. 1224*[17] *was issued as a provisional specification in August, 1945; it will probably be reviewed after experience of its results, by which time the abnormal conditions existing at the time of issue may have become relaxed. The main thickness requirements of this specification are reproduced in [the table]; these requirements should be read in conjunction with the text which states that “Articles shall be tested for thickness of coating at any desired number of places on significant surfaces which can be touched by a ball 1 inch in diameter by an approved local thickness test …” Coatings Ni 8S have also to withstand a porosity test and can be rejected if they show more than 6 pores per 6 sq. inch or less of significant surface. Chromium coatings must have an average thickness of not less than 0.00002 inch.*”

Thickness of nickel plating demanded by B.S. 1224, Table 1

Description	Standard Classification No.	Minimum thickness on significant surfaces, inch	
		Steel	Brass or Copper
Severe outdoor conditions or extra hard wear	Ni 8S Ni 6C	0.0008* ----------	---------- 0.0006
Normal outdoor conditions or hard indoor wear	Ni 5S Ni 3C	0.0005* ----------	---------- 0.0003
Ordinary indoor conditions	Ni 3S Ni 2C	0.0003 ----------	---------- 0.0002
*May be composite of nickel and copper, but the final nickel must be at least 50% of the whole.			

The final portion of Mr. Hothersall’s talk covered the engineering applications of electrodeposition that were critical to military success:

Salvage of worn or over-machined parts. “*The use of electrodeposition as a means of building up worn or over-machined surfaces was introduced during the First World War by British Army Repair Shops and it has been practiced in Britain since that time. Since the first World War, knowledge of methods of controlling the properties of electrodeposited metals and of means of securing strong adhesion to steel and other metals has been developed and widened with the result that the stage was set at the beginning of the second World War for a considerable expansion in the use of electrodeposition as a method of repair. Experience had also shown the value and limitations of hard chromium as a surface finish where high resistance to wear was needed.*

“*During the Second World War, the Armament Research Department (formerly the Research Department, Woolwich) was given the task of advising on the extension of facilities for this type of work to meet the need for electrodeposition repair plants near to the engineering shops producing or reconditioning the work. A number of new plants were installed or existing plating plants were adapted or expanded. In all, some sixty plants in the United Kingdom were approved by the Armament Research Department; in addition, other plants were engaged in hard chromium plating on parts of aircraft engines and control gear.*

“*Much repair work was done on new parts spoiled in manufacture by the removal of too much metal. The considerable expansion in the engineering industry which occurred during the War involved the use of much labor that was entirely new to engineering work. Thus it was not uncommon for a new factory or shop to spoil an appreciable quantity of work, especially where fine limits were being worked to on complicated parts; for example, one factory spoiled*

10 per cent of its first year's output by machining errors of various kinds. The value of a "putting-on tool", particularly for costly jobs, was obvious. One difficulty, especially in the early days of the War, was to get engineers to admit that mistakes were made but, though initially opposed by many engineers, the introduction of electrodeposition as a method of salvage came to be more generally accepted and often welcomed as the War progressed.

"*The two metals chiefly deposited were nickel and chromium. Nickel has the advantage of being similar to steel in many of its mechanical properties and it could therefore be finished by machining operations similar to those used for steel. Its superior throwing power to chromium and its greater rate of deposition made possible the use of thicker deposits. Thus, whilst it was rarely economical to deposit more than 0.010 - 0.015 inch of chromium, nickel was frequently applied in thicknesses of 0.02 -0.05 inch and occasionally 0.10 - 0.20 inch finished thickness was deposited.*

"*Precise data on the economic aspect of this process are not generally available but there is no doubt that components to the value of many millions of pounds sterling have been salvaged during the War. In one plant alone, the value of components salvaged during 15 months was £400,000 ($1,600,000). The actual savings in labor varied of course with the type of component treated. Figures are available for the 6 pr. gun barrel which show that the average net saving for each barrel was £50 ($200.00) or 70% of the total cost of the barrel; most of the saving was labor charge. In time of War, the savings made, although a direct contribution to easing the man power problem, are not the whole story; sometimes the production of the goods at the time required is even more important.*

"*One of the essential properties of an electrodeposit applied to a working surface is that of strong adhesion to the parent metal. In some applications, failure by flaking during use of the part is capable of putting the mechanism out of action or of doing so much damage that the use of the method can only be permitted if the satisfactory adhesion of the deposit is certain.*

"*The advantages of the use of electrodeposition for the repair and prevention of wear of automobile components has been fully dealt with by Wilson who has given interesting information on various applications of the process, including the Rolls Royce Company's method of local chromium plating of engine cylinders near the top of the piston travel. The plating of the cylinder in the area where wear chiefly occurs extends its life and the limited area of chromium renders unnecessary any special surface treatment to improve oil retention.*

"*A practical account of some of the uses of chromium plating in ordnance manufacture has been given by Howat. The examples which are discussed in detail, both as regards the methods used and the advantages obtained, are the chromium facing of dovetails of breech blocks (previously built up with nickel), the plating of tools and gauges both for salvage and to increase their resistance to wear, the plating of tools to prevent scaling during heat treatment, and the plating of profile milling copy plates to reduce the friction between the tool and the copy plate. The advantages of chromium plating the copy plate were to simplify and cheapen the manufacture and to extend the life.*"

Repair of cracked castings by electrodeposition. "*Cracked or leaky castings, such as cylinder blocks or heads of internal combustion engines, are sometimes difficult to repair by welding because of the risk of distortion. A process of repair by electrodeposition of copper was developed during the War when castings were difficult to replace; it has been successfully applied to engine blocks and heads both when dismantled and also in position. A trough of suitable insulating material is built up around the defect to serve as a container for the cleaning and plating solutions. The metal is first cleaned by grinding, the crack is plugged with plaster and the metal is cleaned and etched anodically in a sulfuric-nitric mixture. A thin nickel coating is electroplated, followed by copper from an acid sulfate solution. Copper plating is interrupted after several thousandths of an inch have been deposited, fresh plaster is placed in the defect and the surface of the plaster is metalized; after suitable cleaning, copper deposition is continued until a substantial thickness (0.10 inch or more) has been built up.*"

In summing up, Mr. Hothersall comments:

"*This review of developments in electrodeposition in Great Britain during the Second World War indicates a number of directions in which advances have been made. Knowledge of the properties of electrodeposited chromium, of the control of brass plating and of how to test and specify various coatings has been extended and developed. Methods for the plating of speculum and tin-zinc alloy have been developed and applied for the first time in Great Britain on a factory scale. The engineering applications of electrodeposited nickel, chromium and other metals have been considerably developed by the exploitation of the background of knowledge which was built up in time of peace on the control of the properties and the adhesion of this type of coating. The knowledge and experience gained has been considerable but the store of new information has been depleted and must be replenished if the advances made during the War in the uses of electrodeposition are to be consolidated and applied with advantage to peace-time manufacture.*"

This concludes this series on the story of the surface finishing industry during the extreme conditions of World War II. Beginning with darkness and foreboding, and predictions of doom for the survival of the industry, electroplating technology turned out to be indispensable to victory, and set the stage for all of the wonders in surface finishing applications in automotive, electronics and other applications for the rest of the 20th century and into the next.