What ASTM Standard B 456 & ISO Standard 1456 Teach Us About the Standardization Process & Decorative Electroplated Nickel-plus-Chromium Coatings

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Technical standards are tools for improving efficiency, reducing production costs, introducing new products and relating quality levels to actual requirements. They help expand existing markets and develop new ones by eliminating technical barriers to the circulation of goods and services across national boundaries. The criteria and commercial implications of the standardization process are described, along with the activities of national, global and regional standards bodies. Gaining access to the European standardization process is via ISO-the International Organization for Standardization. In the case of surface finishing, access has been ensured by AESF acceptance and support of the Secretariat of ISO Technical Committee 107 on Metallic and Inorganic Coatings. The technical basis of ASTM Standard B 456 and its international counterpart, ISO Standard 1456, is reviewed to provide concrete examples of the types of standards that are developed when the standardization process meets the highest criteria.

ASTM Standard B 456, and its international equivalent, ISO Standard 1456, teach us how to specify requirements for decorative, electroplated nickel-plus-chromium coatings, and how to determine that the requirements have been met. As a result of reviewing and updating those standards for more than 25 years, I have learned something about the standardization process and the requirements for electrodeposited nickel-plus-chromium coatings.

The first part of this paper discusses the standardization process, its commercial effects and its relevance to AESF, NAMF and MFSA. The second part explains how the requirements for decorative, electroplated nickel-plus-chromium coatings originated and how they have changed with time.

The Standardization Process

Standards are tools for improving efficiency, reducing production costs, introducing new products and relating quality levels to actual requirements. How the standardization process is conducted is the key to developing technically valid standards.

Criteria for Standardization

The majority of people who serve on standardization committees approach the standards-writing process objectively, attempting to draft specifications that are consistent with known technical facts. In addition to encouraging scientific objectivity, the process by which standards are created and maintained must meet the following criteria:

- The process must be open to all stakeholders.
- The standards developed must be universally applicable.
- The process must be managed by a respected developer of standards.
- The process must provide a means for dealing with negatives votes.
- The standards must be nondiscriminatory.

If producers, suppliers, users, consumers and other stakeholders are not encouraged to participate, divergent viewpoints will not be heard, and all the available facts may not come to light. If a standard can only be implemented in a particular region, it becomes a technical barrier to trade and may have a negative impact on the economy of countries outside the region. The standardization body must ensure that the process is administered openly and fairly. If negatives and comments are ignored, the standard is likely to be less than objective. If a standard specifies one specific product or process, then it may become discriminatory.

If the above criteria are *not* met, then the standardization process may become politicized and influenced by proprietary interests. To be effective, standards must be developed by voluntary consensus of all interested parties and must be based on facts. The process must be free, open and completely transparent.

Connercial Implication & Effects

Major corporations often have hundreds of people involved in the development of internal and external standards.¹ The reason for developing internal standards is to improve the quality of a company's products and, therefore, its competitive position. A reason for encouraging employees to participate in external standards development is to prevent the creation of competitive disadvantages. The most important reason for corporate involvement, however, is to enlarge existing markets and develop new ones by removing the technical barriers to the circulation of goods and services among countries. By doing that—and by improving the quality and reliability of materials and products-good technical standards promote market growth.

National, Global & Regional Standardization Bodies

The number of groups drafting and writing standards no doubt complicates the standards development process.

National bodies that develop country-specific standards include, for example, AFNOR, the French Standardization Association; ANSI, the American National Standards Institute; BSI, the British Standards Institute; DIN, the German Institute for Normalization; GOST, the Russian Federation National Standards Body and many others.

Global standards bodies include ISO, the International Organization for Standardization, and IEC, the

International Electrotechnical Commission, among others.

ANSI, the U.S.'s designated national standards body, coordinates the standardization activities of its domestic member bodies, is active on a global level and has authority to appoint delegates to ISO and other international bodies. The American Society for Testing and Materials (ASTM), the Society of Automotive Engineers (SAE) and other domestic groups are members of ANSI.

ASTM Committee B 8 and ISO Technical Committee (TC) 107 are responsible for developing national and international surface finishing standards, respectively, and have achieved distinction in that specialty. ASTM Committee B 8 has a permanent Technical Advisory Group (TAG) to ISO TC 107, and delegates from the TAG attend international standards meetings, along with delegates from other countries. The members of the TAG are also members of AESF. Most are also affiliated with companies that are members of NAMF or MFSA and, therefore, represent the interests of the U.S. surface finishing industry. The basic purpose of this international effort is to harmonize differences and develop international standards acceptable to the majority of ISO member countries.

The aim of *regional bodies* is similar: To eliminate differences that might become technical barriers to trade among the member states within the region. CANENA, for example, a NAFTA Regional Standards Body, is engaged in developing standards and regulations for Canada, the U.S. and Mexico. CEN, the European Committee for Standardization, is responsible for harmonizing national standards developed by the countries that comprise the European Community. Other regional groups include: COPANT, the Pan American Standards Commission; ICAITI, the Central American Regional Standards Body; and PASC, the Pacific Area Standards Congress.

If the standardization movement is to reach its ultimate goal—the creation of universal standards that foster free trade—then national, global and regional standards bodies must communicate and coordinate their efforts. The increase in the number of groups writing standards in the past 25 years has increased the

Dedication



This paper is dedicated to Boris B. Joffe and Allen W. Grobin, both of whom died in March. Both were chairmen of ASIM Committee B 8 and of ASIM Technical Advisory Group to Technical Committee 107 of the International Organization for Standardization (ISO TC 107). They were devoted to the development of national and international surface finishing standards, and their help, advice and friendship will be screlymissed.



need for cooperation, but has also made that coordination difficult and time-consuming.

Access to European Standardization

CEN, the European Committee for Standardization, is now actively engaged in harmonizing national standards developed by the countries that comprise the European community. CEN and other regional groups, *by definition*, exclude countries outside the region. The U.S., for one, has no vote or voice at regional standards meetings. How does the U.S. gain access² to the development of European technical standards so that its interests are not disenfranchised?

The realization that CEN's responsibilities overlapped those of ISO has led to changes in the European standardization process. There are only so many experts available to write standards in a particular field, and the people assigned to work on CEN standards were the same people working on ISO documents. To avoid duplication of effort and to utilize available resources efficiently, the European Parliament created "new approach" directives in 1987 "to ensure that products are sufficiently well-designed and built to be fit for the purpose for which they are sold." The new directives define only essential requirements. The technical details and specifications covering the production and marketing of products are to be defined by the private sector, that is, CEN.

The European Parliament also directed that CEN rely on existing standards, or standards under development, whenever possible, instead of starting from scratch. This subsequently led to agreements of understanding among ANSI, CEN and ISO to coordinate work programs, set priorities and deadlines, develop and vote on standards in parallel, and withdraw national standards when a European standard became available, with the intent of developing an International Standard identical to its European counterpart.

To ensure that U.S. electroplaters and surface finishers have access to the European standardization process, the ASTM TAG to ISO TC 107 recommended that the U.S. assume the Secretariats of TC 107 and TC 107, SC 3. The recommendation was accepted by the ISO Central Secretariat, and the first international meeting under the new Secretariat was held in Gaithersburg, MD, in 1995.

The cooperation between CEN and ISO has accelerated the development of European standards—there are now about 5,000 of them. ISO has 6,500 active work items, of which more than 1,000 are being developed in parallel with CEN. In the great majority of cases, the appropriate ISO committee is the one with the responsibility for review and revision of existing standards, or creation of a new one when none exists.

As a result of the changes and the agreements reached among ANSI, ISO and CEN, U.S. access to the European standardization process is *through* ISO and its technical committees. In the case of surface finishing, access has been further strengthened by U.S. acceptance of the Secretariats of TC 107 and TC 107/SC 3.

Relevance to Surface Finishing Organizations

The relevance to technical societies and associations that serve the surface finishing industry is similar to that of corporations, namely:

• To enlarge existing markets and create new ones by removing technical barriers to the circula-

Table 1 - Summary of ASIM Corrosion Performance Programs*

No. – Yær	Program Description	Findings
1-1945	Durability of decorative nickel-chromium	Nickel thickness was the determining factor; copper added little
	vs. copper-nickel-chromium coatings on steel.	to corrosion resistance, except at the early stages of exposure;
		applying a nickel coating in two steps was beneficial.
2 & 3 - 1947	Supplements to Program No. 1	Results did not agree with Program 1, leading to controversy
		over copper's role.
4 - 1956	Effects of copper and nickel strikes under	Nickel and copper strikes did not improve corrosion performance;
	bright nickel; type and thickness of chromium.	increasing chromium thickness was beneficial. Panels prepared with
		two different bright nickel processes differed in corrosion resistance.
5 - 1958	Effects of type and thickness of chromium with	Regular chromium gave best performance. Double-layer nickel was
	double-layer nickel	superior to buffed Watts and single-layer bright nickel.
6 - 1962	Corrosion performance of nickel coatings	Double-layer nickel was superior to buffed Watts nickel.
	on aluminum	Performance improved with increase in total nickel thickness; an
		increase in copper thickness did not improve performance.
7 - 1966	Performance of copper-nickel-chromium	Double-layer nickel coatings out-perform single layer nickel of
	coatings on zinc alloy die castings.	equivalent thickness. Substitution of copper for semi-bright nickel
0 10 60		was detrimental.
8 - 1968	Performance of thin multilayer nickel coatings	A minimum thickness of 25 mm of double- or triple-layer nickel
	with regular, microcracked and microporous	with microdiscontinuous chromium required for very severe service.
	chromium.	Excessive peeling of panels plated with regular chromium limited
	Deufermenne of common nickel sharewinne	The value of this program.
ASEP I $\propto 2$ -	performance of copper-mckel-chromium	P 604 1075 Decorative Electroplated Costings of Copper Plus
1908	coatings on plastics	B 604-1975, Decorative Electropiated Coatings of Copper Plus
0 1070	Substitution conner for nickel in coatings	With regular chromium, substitution of conner for all or part of the
9 - 1970	for very severe exposures (SC 4)	semi bright nickel laver reduces corrosion resistance. Nickel thick
	tor very severe exposures (Se 4).	ness specified in ASTM B 456 SC 4 is adequate only when
		microdiscontinuous chromium is employed
10 - 1972	Performance of decorative nickel chromium	Three commercial pre-treatments did not differ from each other, and
10 1772	coatings on aluminum as influenced by	were slightly better than standard zincate. Led to inclusion of
	pretreatment of the aluminum.	stannate, modified zincate, special nickel strikes in ASTM Standard
	r	B 253. Preparation of Aluminum Allovs.
11 - 1974	Study of the effects of reducing the thickness	Decreasing the thickness of semi-bright nickel was detrimental to
	of semi-bright nickel.	corrosion resistance when copper was substituted for part of the
		semi-bright nickel.
12 - 1980	Study of Single-Layer Bright Nickel vs Double-	Confirmed that double-layer nickel coatings 30 to 40 mm thick with
	Layer Nickel With & Without Copper Underlayers	microporous or microcracked chromium prevent rusting of steel for
		longer than 10 years.
13 - 1980	Thermal Cycle Performance of ABS Plastics	Copper underlayer is essential to achieve thermal cycle resistance.
		Results were used to harmonize the differences between ASTM 604
		and ISO Standard 4525.
14 - 1982	Study of Corrosion Performance of Electroless	Corrosion resistance depends on the phosphorus content and
	Nickel Coatings on Steel	surface roughness of the steel, and is better than that of dull electro-
		deposited nickel of equal thickness.

* The information in this table was re-constructed from information and reports in my files. The results of many of these programs were published in the Proceedings, ASTM.

Table 2 - Nickel	Plus Chroniu	n Coatings on	Steel'
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Service	Classification No.	Nidel	Typical Applications
Condition No.		Thickness, µm	
SC 5	Fe/Ni35d Cr mp or mc	35	Components of vehicles; bumpers, wheels
extended very severe (outdoors)			
SC 4	Fe/Ni40d Cr r	40	Components of automobiles; boat fittings
very severe (outdoors)	Fe/Ni30d Cr mp or mc	30	
SC 3	Fe/Ni30d Cr r	30	Outdoor furniture; bicycles; hospital goods
severe (outdoors)	Fe/Ni25d Cr mp or mc	25	
SC 2	Fe/Ni20b Cr r	20	Where moisture condenses; e.g., bathrooms/kitchens
moderate (indoors)	Fe/Ni15b Cr mp or mc	15	
SC 1	Fe/Ni10b Cr r	10	Exposures in warm, dry atmospheres; offices
mild (indoors)			

* based on ASTM B 456-1995

tion of goods and services among countries.

- To develop standards of excellence that improve the quality and reliability of materials, products, systems and services.
- To prevent the creation of competitive disadvantages.

Organizations such as AESF. NAMF and MFSA have unique missions, but they also have a common goal: To ensure that surface finishing products, processes and services continue to be improved so that the surface finishing industry will grow and prosper. It is justified for those organizations to promote and support the development of quality metal finishing standards for the economic well-being of its members, as well as themselves. As a result, AESF has provided funds to support the administrative costs of the Secretariat of TC 107 and will, hopefully, continue to do so.

The Technical Basis Of ASTM Standard B 456

The processes by which ASTM Standard B 456 and ISO Standard 1456 were developed and continue to be improved meet the criteria discussed at the beginning of this paper.

What makes ASTM Standard B 456 unique, however, is that the specifications on thickness, corrosion testing and other requirements have been verified by programs, studies and inter-laboratory testing conducted by committee members. What follows is a summary of some of that work.

ASIM Corrosion

Performance Programs The corrosion performance programs conducted by ASTM Committee B 8,

Subcommittee 3, are summarized in Table 1. The first program was initiated in

1945 to settle the controversy over the relative durability of nickel-pluschromium vs. copper plus nickel-pluschromium coatings. That controversy had begun in the early 1920s and had remained unresolved. The results of ASTM Program 1 were conclusive and convincing—copper underlayers were detrimental to the corrosion performance of electrodeposited nickel coatings, except in the early stages of exposure. Attempts to reproduce that result in supplemental Programs 2 and 3, however, were not successful, and the issue of copper's function remained controversial for years. The early standards, therefore, specified minimum nickel thickness and permitted the use of copper underlayers, only so long as the minimum nickel thickness was maintained. The programs conducted prior to the 1950s evaluated buffed Watts nickel coatings. Bright nickel electroplating processes, although invented in 1938, were not yet commercially available.

Program 4 was the first to include bright nickel deposited from solutions that contained organic additives and was the first to indicate that different proprietary processes might yield coatings with different corrosion characteristics.

Program 5 was the first to establish that double-layer nickel coatings on steel provide better corrosion resistance than buffed Watts and singlelayer bright nickel coatings.

Program 6 was initiated to evaluate the performance of decorative, electroplated nickel-plus-chromium coatings on aluminum alloys. The corrosion performance of electroplated aluminum in that program was not good. The subsequent work of Program 10 and related research³ established that the use of microdiscontinuous chromium, in combination with double-layer nickel, overcame the shortcomings observed with electroplated aluminum in Program 6. Program 7 was similar in scope, except that the substrate was zinc alloy die castings.

The results of Program 8 were inconclusive because of excessive peeling of the chromium layer on panels plated with regular chromium, but, for the first time, included microdiscontinuous chromium coatings deposited from commercially available processes (rather than from experimental ones). Despite its shortcomings, Program 8 came close to establishing that the thickness of double-layer nickel coatings should be at least 25 μ m for severe service conditions with microdiscontinuous chromium.

The question of substituting copper for a portion of the nickel was again investigated in Programs 9 and 11. The results of both programs indicated that substitution of copper for all or part of the semi-bright nickel layer reduced corrosion resistance. In addition, Program 9 was the first program to show that coatings specified in ASTM Standard B 456 for very severe service (SC 4) were not equivalent; those with regular chromium did not provide the same corrosion protection as those with microdiscontinuous chromium.

Program 12 was initiated to compare the performance of nickelplus-chromium coatings specified in ASTM vs. ISO Standards. Program 12 (still in progress) confirmed that double-layer nickel coatings 30–40 μ m thick, in combination with microdiscontinuous chromium, are capable of protecting steel from corrosion for longer than 10 years, and that the single-layer bright nickel coatings specified in the ISO standard were not suitable for severe service.

Program 13 established that copper underlayers are essential for obtaining maximum resistance to thermal cycling with electroplated plastics. The results of that program made it possible to eliminate differences between ASTM Standard B 456 and ISO Standard 4525, and thereby bring the standards covering copper plus nickel-plus-chromium coatings on plastics into virtual agreement.

Other programs that studied performance of electrodeposited copper plus nickel-plus-chromium coatings on plastics are ASEP Programs 1 and 2, originated by the American Society for Electroplated Plastics with the participation of ASTM Committee B 8 members. Those comprehensive studies included marine, industrial and mobile exposures, as well as accelerated corrosion and thermal cycle testing. The results of those programs helped establish the specifications and requirements included in ASTM Standard B 604.12

Program 14, on the corrosion performance of electroless nickel coatings on steel, was the first ASTM program to evaluate a nondecorative coating for engineering applications (although work to compare the outdoor performance of zinc coatings deposited from acid, alkaline and cyanide solutions has been performed). Some of the results of Program 14 have been described.⁴

ASTM Corrosion Performance Programs 1 through 13, therefore, document the development of decorative nickel electroplating technology from 1945 through the present. The results of those programs have been used to revise and update ASTM Standards B 456, ASTM Standard B 604 and ISO Standards 1456 and 4525. The requirements contained in those standards have been verified experimentally with the involvement of all interested parties.

Coating Thickness & Other Requirements

Some of the requirements for nickelplus-chromium coatings on steel are given in Table 2. The requirements are related to the corrosion performance programs discussed in the previous section as explained here.

Corrosion performance improves with increased nickel thickness. Five grades of coatings designated by service condition numbers are included in Table 2. As the service condition number decreases, the severity of the exposure and the minimum nickel thickness decrease. The standard, therefore, states that corrosion performance improves with increased nickel thickness. The correlation between nickel thickness and corrosion resistance has been confirmed repeatedly in most of the ASTM corrosion performance programs described in the preceding section.

Double-layer coatings are better than single-layer ones. Double-layer nickel coatings are more resistant to corrosion than equivalent thicknesses of single-layer bright nickel. To extract that bit of information from the table, we need to decipher the classification number. The classification number designates the substrate and the type and thickness of the coating. The symbol, Fe, means the substrate is made of steel. The symbols and numbers after the slash mark describe the coating. Ni35, for example, means the coating is nickel, minimum thickness, 35 µm. The lower case letters indicate the type of nickel (d for double-layer nickel and b for single-layer bright nickel). Double-layer nickel coatings are, therefore, specified for severe service (SC 5, SC 4, and SC 3), single-layer bright nickel for moderate and mild service (SC 2 and SC 1). The superiority of double-layer coatings was established in Programs 5, 6, 7, 11 and 12.

High-porosity chromium outperforms regular chromium. The type and thickness of the chromium deposited over the nickel is indicated by the symbol, Cr, followed by the lower case letters (r for regular or low porosity; mp or mc for microporous and microcracked chromium, respectively). The standard, minimum thickness of chromium is 0.25 µm; the number is not shown unless it differs from the standard value. The improvement in corrosion performance when micro-discontinuous chromium is applied over doublelayer nickel coatings was first documented in Program 8, and subsequently in Programs 9 and 12.

Extended Very Severe Service Outdoors(SC 5). The SC 5 category is a relatively new addition to the standard, and was introduced to satisfy the need for decorative coatings that provide *long-time* protection (minimum 10 years). It responds to the observation made in Program 9, that the nickel thickness specified in the SC 4 category is inadequate when regular chromium is specified. The SC 5 category, therefore, does not specify regular chromium, to emphasize the superior performance that can be achieved with microporous or microcracked chromium. This has been confirmed in Program 12, as well as in an independent study.⁵

STEP Test Requirements. STEP test requirements are included in ASTM B 456 and will be included in the latest revision of ISO Standard 1456 when approved. The origin of these requirements may be of interest.

Studies⁶⁻⁹ of the electrochemical characteristics of bright and semibright nickel coatings provided explanations for the improved performance of double-layer coatings. and for the observation made in ASTM Program 4 that nickel electrodeposits from different proprietary processes have different corrosion characteristics. The improved corrosion performance of double-layer nickel coatings was shown to be caused by the difference in potential between the bright and semi-bright nickel layer. The variations in corrosion performance were related to variations in the potential difference displayed by coatings prepared from different proprietary solutions.¹⁰

The electrochemical studies culminated in the development of the STEP test by Harbulak.¹¹ This test made it possible to measure potential differences between various layers in a multilayer nickel coating on actual electroplated parts, rather than on deposits detached from the substrate. STEP is an acronym for simultaneous thickness and electrochemical potential measurement. In the test, which is a simple, but brilliant modification of the well-known coulometric method of thickness testing, the electrochemical potential is monitored continuously as the coating is dissolved anodically. This is made possible by placing a reference electrode in the form of a silver wire in the coulometric cell used for stripping the coating. By recording the changes in potential with time, the potential differences, as well as the thickness, of the individual nickel layers can be measured. Unpublished work on the precision of the STEP test by ASTM Committee B 8 members indicates that potential differences and thickness can be measured with a standard deviation of

less than five percent on standard reference materials. The STEP test is described¹² in ASTM Standard B 767.

Although there are no universally accepted values for the optimum potential differences between nickel layers, ASTM Standard B 456 provides the following guidelines:

- The STEP potential difference between the semi-bright and bright nickel layer generally falls within the range of 100 to 200 mV, and in all combinations, the semi-bright nickel layer is more noble (cathodic) than the bright nickel layer.
- 2. The STEP potential difference between the high-activity layer and the bright nickel layer in triplelayer coatings has a potential range of 15 to 35 mV, and the highactivity layer is more active (anodic) than the bright nickel layer.
- 3. The STEP potential difference between the bright nickel and any thin layer applied just prior to chromium plating for producing microporous or microcracked chromium has a potential range of 0 to 30 mV, and the bright nickel layer is more active.

The last requirement minimizes the deterioration in surface appearance that may occur in severe outdoor conditions or during accelerated corrosion testing.

Thickness Specifications Then & Now

In 1945, the total recommended coating thickness was 50 µm with a minimum of 25 µm of buffed Watts nickel. Those coatings began to rust in two to three years. Today, the minimum nickel thickness in SC 5 is 35 μm and in SC 4, 30 μm. The nickel thickness has increased slightly, but the total coating thickness has decreased. What is significant, however, is that the life of these coatings has been tripled or quadrupled so that we can now say with great confidence that SC 5 coatings are capable of protecting steel, aluminum, stainless steel, zinc alloys and other substrates for extended periods of time-10 or more years.

Summary

By eliminating technical barriers to trade and by helping to improve the

quality of materials, products, systems and services, standards help enlarge existing markets and create new ones. Involvement in the development of technical standards is justified by their beneficial effects on business growth. To ensure that U.S. electroplaters and surface finishers have access to the European standardization process, AESF accepted the Secretariat of ISO Technical Committee 107, on Metallic and Inorganic Coatings, and members of the ASTM Technical Advisory Group to ISO TC 107 are active in the development of surface finishing standards. What makes ASTM Standard B 456 and its international counterpart, ISO 1456, unique is that the corrosion requirements for decorative, electroplated nickel-plus-chromium coatings have been verified in corrosion performance programs. Those standards are good examples of the types developed when the standardization process is objective and technically based. P&SF

References

- C.R. Camp, "Standards Management and Texas Instruments," ASTM Standardization News, 25, 24, (Dec. 1997).
- 2. "American Access to the European Standardization Process," ANSI website, www.ansi.org.
- G.A. DiBari, "Plating on Aluminum—Pretreatments and Corrosion Performance," *Plat. & Surf. Fin.*, **64**, 68 (1977); "Decorative Electroplated Aluminum," *Aluminum Finishing Seminar-Technical Papers*—Vol. II, The Aluminum Association, Washington, DC, p. 577, 1982.
- G.A. DiBari, "Marine Corrosion Performance of EN Coatings on Steel—Report on ASTM Corrosion Program 14," *Proceedings of EN 91*, Gardner Publications, Inc., Cincinnati, OH, pp. 2-1 (1991).
- 5. G.A. DiBari and F.X. Carlin, "Decorative Nickel Chromium Electrodeposits on Steel—15 Years of Corrosion Performance Data," *Plat. & Surf. Fin.*, **72(5)**, 1, (1985).
- 6. W.H. Flint and S.H. Melbourne, *Trans. Inst. of Metal Fin.*, **39**, 85 (1960).
- A.H. DuRose, Proc. of the AES 47th Annual Conf., 1960, p. 83;
 A.H. DuRose and W.J. Pierce, Metal Finishing, 57, 44 (1959).

- 8. W.H. Safranek, R.W. Hardy and H.R. Miller, *Proc. of the AES 48th Annual Conf.*, 1961, p. 156.
- J.V. Petrocelli, V. Hospadaruk and G.A. DiBari, "The Electrochemistry of Copper, Nickel and Chromium in the Corrodkote and CASS Test Electrolytes," *Plating*, 49, 1 (1962).
- G.A. DiBari, A.J. Dill and B.B. Knapp, Proc. of the First AES Decorative Plating Symp., Dearborn, MI, 1973, p. 93.
- E.H. Harbulak, "Simultaneous Thickness and Electrochemical Potential Determination of Individual Layers in Multilayer Nickel Coatings," *Plat. & Surf. Fin.*, 67(2), 49 (1980).
- 12. See: 1997 Annual Book of ASTM Standards, Vol. 02.05, American Society for Testing and Materials, West Conshohocken, PA, 1997, for standards on metallic and inorganic coatings cited in the text.

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