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OUTDOOR EXPOSURE TESTS OF ELECTROPLATED NICKEL AND CHROMIUM COATINGS ON STEEL AND NONFERROUS METALS

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ABSTRACT

This paper includes the results and conclusions of extensive atmospheric exposure tests conducted since 1936 through cooperation of the American Electroplaters' Society, American Society for Testing Materials, and the National Bureau of Standards. Exposure tests of coatings of copper, nickel, or chromium, or combinations of these metals, plated upon steel, copper, brass, zinc, and zinc-base die-castings were made in six locations. The thickness of the nickel layers was found to be the most important factor in the value of the coatings for protection against corrosion.

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I. INTRODUCTION

In 1932, atmospheric exposure tests of plated coatings on steel were initiated by a joint committee of the American Electroplaters' Society, American Society for Testing Materials, and National Bureau of Standards.² In 1936, similar tests were started with plated coatings on various nonferrous metals,³ and in 1938 these were supplemented with some additional coatings.⁴ In the 1936 and 1938 exposures, some new plated steel specimens were also included in order to confirm and extend the earlier observations on steel. This paper summarizes the results obtained in these tests since 1936. While some of the specimens may be exposed for longer periods, especially in the milder locations, it is believed that subsequent observations upon them will not materially alter the conclusions based upon the exposures up to the present time.

II. PREPARATION OF SPECIMENS

1. BASIS METALS

All of the specimens were flat sheets or plates 4 by 6 in. (10 by 15 cm). Most of the rolled metals were No. 22 gage (0.031 in., or 0.78 mm), and the cast metals were from 0.1 to 0.2 in. (2.5 to 5 mm) thick. The types and compositions of all the basis metals are listed in table 1.

² W. Blum, P. W. C. Strausser, and A. Brenner, *Protective value of nickel and chromium plating on steel*, J. Research NBS **13**, 331 (1934) RP712.

P. W. C. Strausser, A. Brenner, and W. Blum, *Accelerated tests of nickel and chromium plating on steel*, J. Research NBS **13**, 519 (1934) RP712.

W. Blum, P. W. C. Strausser, and A. Brenner, *Corrosion protective value of electrodeposited zinc and cadmium coatings on steel*, J. Research NBS **16**, 185 (1936) RP867.

³ Report of joint committee, Proc. Am. Soc. Testing Materials **36**, pt. 1, 212 (1936).

⁴ Report of joint committee, Proc. Am. Soc. Testing Materials **38**, pt. 1, 250 (1938).

TABLE 1.—Composition of base metals

Number	Basis metal	Number of sets	Description of basis metal	Composition, by analysis							
A. FERROUS METALS											
				Carbon	Man- ganese	Phos- phorus	Sulfur	Silicon			
				%	%	%	%	%			
I	Steel	12	Cold-rolled (SAE No. 1010) ^a	0.10	0.43	0.006	0.017	0.01			
II	do	2	Full cold-rolled	.07	.39	.013	.034	b .01			
III	do	2	Spring, rolled	.83	.66	.023	.026	.17			
IV	Iron	2	Gray, cast	3.46	.48	.64	.08	2.82			
V	do	2	Malleable, cast	1.64	.27	.12	.13	0.93			
B. COPPER AND COPPER ALLOYS											
				Copper	Lead	Tin	Alumi- num	Manga- nese	Nickel	Iron	Zinc
				%	%	%	%	%	%	%	%
VI	Copper	4	Deoxidized, sheet	99.9						b 0.01	
VII	Brass	7	Cast high (ASTM B65-28) ^a	60.9	2.6	1.0	0.32		b 0.05	b .05	35.1
VIII	do	3	Cast low-ounce metal (ASTM B62-28) ^d	55.4	5.5	4.7				b .01	4.4
IX	do	3	Extruded (ASTM B16-29) ^e	62.3	2.9	b 0.05			b .05	b .1	34.6
X	do	18	Rolled high (ASTM B36-33) ^f	65.7	b 0.1					b .01	34.2
XI	do	4	Rolled low (alloy L, Com. B-3) ^g	55.0						b .01	15.0
XII	Nickel-brass	5	Rolled (Fed. Spec.) ^h	64.6				0.23	18.2	b .2	16.8
XIII	do	5	Cast (Fed. Spec.) ^h	65.5	3.7	3.4			18.9	b .2	7.2
C. ZINC AND ZINC ALLOYS											
				Zinc	Copper	Aluminum	Iron	Lead	Magnesium		
				%	%	%	%	%	%	%	%
XIV	Zinc	6	Rolled	98.4	0.99		0.017	0.62			
XXI	Zinc alloy	7	Die-cast (ASTM alloy No. XXI) ⁱ	93.8	2.2	4.0	.009				0.02
XXIII	do	21	Die-cast (ASTM alloy No. XXIII) ⁱ	96.1		3.9	.005				.04

^a SAE Handbook, Soc. Auto. Engrs., p. 254 (1936).^b Less than.^c Standard Specifications for Yellow Brass Sand Castings for General Purposes (ASTM designation B 65), 1933 Book of ASTM Standards, pt. 1, p. 597.^d Standard Specifications for Composition Brass or Ounce Metal Sand Castings (ASTM designation B 62), 1933 Book of ASTM Standards, pt. 1, p. 612.^e Standard Specifications for Free-Cutting Brass Rod for Use in Screw Machines (ASTM Designation B 16), 1933 Book of ASTM Standards, pt. 1, p. 719.^f Standard Specifications for Sheet High Brass (ASTM Designation B 36), 1933 Book of ASTM Standards, pt. 1, p. 728.^g Report of Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys, Proc. Am. Soc. Testing Materials, 32, pt. 1, 218 (1932).^h Federal Specification for Builders' Hardware, Lock and Lock-Trim (FF-H-106).ⁱ Zinc was determined by difference.^j Tentative Specifications for Zinc-Base Alloy Die Castings (ASTM designation B86-34T) Proc. Am. Soc. Testing Materials, 34, pt. 1, 706 (1934); also 1935 Book of ASTM Tentative Standards, p. 369.

2. PREPARATION FOR PLATING⁵

The basis metals were received from the manufacturers with one or both sides polished, and generally were not subjected to further polishing. However, the zinc-base die-castings were given a light "color buffing" to remove the slight tarnish that had developed in storage. All specimens were carefully inspected before plating, and those with visible surface defects were rejected.

Before plating the specimens, they were subjected to appropriate cleaning and dipping operations. In general, the specimens were subjected to the following cycle of operations: (1) removal of grease with organic solvents, (2) cathodic cleaning in an alkaline solution, (3) rinsing in water, (4) dipping in acid, and (5) rinsing in water. If the first plating was to be done in a cyanide copper solution, the rinsed specimens were dipped into a solution containing 30 g/liter (4 oz/gal) of sodium cyanide and again rinsed. The conditions used in these operations are given below.

(a) USE OF ORGANIC SOLVENTS

The 1936 specimens were merely dipped into carbon tetrachloride. The 1938 specimens were cleaned in a vapor degreaser with stabilized trichloroethylene.

(b) CATHODIC CLEANING

The solutions and conditions for cleaning each basis metal are listed in table 2. A small amount, about 0.1 g/liter, or 0.01 oz/gal, of liquid soap was added to each cleaning solution to reduce the formation of spray.

TABLE 2.—Cathodic cleaning of metals

Basis metal	Solution composition								Temperature	Current density		Time	
	Na ₂ CO ₃		Na ₃ PO ₄		Na ₂ SiO ₃		NaOH						
	g/liter	oz/gal	g/liter	oz/gal	g/liter	oz/gal	g/liter	oz/gal	°C	°F	amp/dm ²	amp/ft ²	sec
Steel and iron.....	30	4	30	4	-----	-----	4	0.5	90	195	5	50	60
Copper and brass..	15	2	15	2	8	1	4	.5	90	195	2	20	120
Zinc alloys.....	23	3	23	3	-----	-----	-----	-----	90	195	2.5	25	30
Buffed nickel.....	15	2	15	2	-----	-----	4	.5	75	170	3.5	35	15

(c) DIPS

(1) *Steel and iron*.—Each metal was dipped into the acid designated in table 3 for a period sufficiently long to produce a slight visible etching. After pickling the cast-iron specimens they were scrubbed with pumice and water to remove any loose graphite.

Sets 102 and 182 were pickled cathodically in 2 *N* sulfuric acid (7.5 fl oz/gal) at 50° C (120° F) for 2 minutes at 2 amp/dm² (19 amp/ft²). Lead anodes were used.

(2) *Copper and brass*.—In general, the copper and brass specimens were cleaned in the solution designated in table 2, rinsed, dipped into 1 *N* hydrochloric acid (13 fl oz/gal) at room temperature, and rinsed again.

⁵ P. W. C. Strausser, Monthly Rev. Am. Electroplaters' Soc. 23, No. 10, 23 (1936).

TABLE 3.—*Pickling of steel and iron*

Basis metal	Composition of solution				Temperature		Time
	Sulfuric acid		Hydrochloric acid				
	H ₂ SO ₄	Com. acid 95%; sp gr 1.84	HCl	Com. acid 32%; sp gr 1.16			
	<i>g/liter</i>	<i>fl oz/gal</i>	<i>g/liter</i>	<i>fl oz/gal</i>	<i>°C</i>	<i>°F</i>	<i>sec</i>
Cold-rolled steel I.....	98	7			50	120	120
Cold-rolled steel II.....	98	7			50	120	15
Spring steel III.....			73	25	25	75	15
Gray cast iron IV.....	98	7			50	120	10
Malleable cast iron V.....	98	7			50	120	8

Instead of being dipped into hydrochloric acid, two sets (C 3 and B 43) were etched anodically in ammonium citrate.⁶ The ammonium citrate solution was prepared by neutralizing 50 g of citric acid with ammonium hydroxide, adding 20 g of citric acid, and diluting to 1 liter. Etching was conducted at room temperature for 1 minute, with an anodic current density of 1 amp/dm² (9 amp/ft²).

On sets B 6, B 45, B 54, and B 55, anodic etching was conducted at room temperature in *N* sulfuric acid (3.5 fl oz/gal) for 2 seconds at 1 amp/dm² (9 amp/ft²). Even this short treatment sometimes left a dark film on the surface, which was removed by swabbing with water.

One set of brass (B 59A) was dipped for 2 seconds into a "bright dip" of the following composition:

Bright dip	ml/liter	fl oz/gal
Sulfuric acid, H ₂ SO ₄ (sp gr 1.84).....	530	68
Nitric acid, HNO ₃ (sp gr 1.42).....	160	20
Hydrochloric acid, HCl (sp gr 1.19).....	8	.1
Water, H ₂ O.....	320	40

Even this short dip etched the surface so much that the nickel deposits, after buffing, were not as bright as the regular buffed-nickel coatings.

The nickel-brass specimens were prepared like the brass except that, after the alkaline cleaning, they were scrubbed with pumice and water. When chromium was to be deposited directly on the nickel-brass, the metal was dipped into 2 *N* sulfuric acid (7 fl oz/gal) instead of into hydrochloric acid.

(3) *Zinc and zinc-base die-castings*.—After cleaning and rinsing the 1936 specimens, they were dipped into 0.5 *N* hydrochloric acid (6 fl oz/gal) until effervescence just started over the entire surface. For rolled zinc, this required about 2 seconds; for die-casting XXI, 3 seconds; and for XXIII, 5 seconds.

The 1938 specimens of XXI and XXIII alloys were dipped for 25 seconds into 0.7 *N* sulfuric acid (2.5 fl oz/gal).

⁶ A. W. Hothersall, *The adhesion of electrodeposited nickel to brass*, J. Electrodepositors' Tech. Soc. 7, 115 (1932).

3. CONDITIONS USED IN PLATING

The plating baths and operating conditions are listed in tables 4 to 7. The specimens were held in racks so designed that, except near the edges, the thickness of each deposit was uniform within ± 5 percent, as determined by microscopic and magnetic measurements. As this distribution is more uniform than that generally attainable in commercial plating, the results of the exposure tests apply approximately to the *minimum* and not the average thicknesses of plating on commercial articles.

(a) NICKEL PLATING

The conditions used for the "standard" and "high sulfate" nickel baths are listed in table 4.

TABLE 4.—*Compositions and operating conditions of nickel baths*
COMPOSITION

	"Standard" nickel bath				"High-sulfate" nickel bath			
	N	M	g/liter	oz/gal	N	M	g/liter	oz/gal
Nickel sulfate, $\text{NiSO}_4 \cdot 7\text{H}_2\text{O}$	1.4	-----	200	27	0.5	-----	75	10
Nickel chloride, $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$.....	.4	-----	45	6	-----	-----	-----	-----
Ammonium chloride, NH_4Cl	-----	-----	-----	-----	1.25	-----	15	2
Sodium sulfate, Na_2SO_4	-----	-----	-----	-----	1.5	-----	110	15
Boric acid, H_3BO_3	-----	0.5	30	4	-----	0.25	15	2

OPERATING CONDITIONS

Type of operation	pH	Temperature		Current density		pH	Temperature		Current density	
		$^{\circ}\text{C}$	$^{\circ}\text{F}$	amp/ dm^2	amp/ ft^2		$^{\circ}\text{C}$	$^{\circ}\text{F}$	amp/ dm^2	amp/ ft^2
Standard.....	5.3	35	95	2	19	5.5	22	72	1.3	12
With air agitation.....	5.3	50	122	4	37	5.5	-----	-----	-----	-----
With low pH.....	2.5	60	140	4	37	5.5	-----	-----	-----	-----
Over Cu deposit.....	5.3	40	104	4	37	5.5	-----	-----	-----	-----
Over high-sulfate Ni.....	5.3	40	104	5	48	5.5	-----	-----	-----	-----
Strike (45 seconds).....	5.3	-----	-----	-----	-----	5.5	22	72	4.5	42

In 1938, specimens were plated at the National Bureau of Standards from four proprietary "bright nickel" baths. The compositions of the baths were undisclosed, but the plating was done under the supervision of representatives of the companies that supplied the baths. The specimens from the four baths were mixed and were exposed and inspected without identification. The results for bright nickel therefore represent a composite of the four types used.

In 1938 several sets of zinc-base die-castings were plated in proprietary bright nickel baths in three commercial plating plants. The specimens from the three plants were mixed, exposed, and inspected without identification.

(b) COPPER PLATING

The acid copper bath and the two cyanide copper baths are described in tables 5 and 6.

TABLE 5.—*Composition and operating conditions of acid copper-plating bath*

Composition					Temperature		Current density	
	N	g/liter	oz/gal	ft oz/gal	$^{\circ}\text{C}$	$^{\circ}\text{F}$	amp/ dm^2	amp/ ft^2
Copper sulfate, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	2	250	33	-----	35	95	2.5	23
Sulfuric acid, H_2SO_4	1.5	75	10	5.7	35	95	2.5	23

TABLE 6.—Composition and operating conditions of cyanide copper-plating baths
COMPOSITION

	"Standard" cyanide (used in 1936)			"Rochelle salt" (used in 1938)		
	N	g/liter	oz/gal	N	g/liter	oz/gal
Copper cyanide, CuCN.....	0.25	23	3	0.33	30	4
Total sodium cyanide, NaCN.....	.65	34	4.5	.75	38	5
Free sodium cyanide, NaCN.....	.15	7.5	1	.09	4.5	.6
Sodium carbonate, Na ₂ CO ₃.....	.30	15	2	.60	30	4
Rochelle salt, NaKC ₄ H ₄ O ₆ ·4H ₂ O.....				.32	45	6

OPERATING CONDITIONS

pH (glass electrode, uncorrected).....		11.5
Temperature.....	50	65
	122	149
Current density.....	1.5	3
	14	28

(c) CHROMIUM PLATING

The conditions used in chromium plating are listed in table 7.

TABLE 7.—Composition and operating conditions of chromium-plating bath

COMPOSITION

	M	N	g/liter	avdp oz/gal	fl oz/gal
Chromic acid, CrO ₃	2.5		250	33	
Sulfuric acid, H ₂ SO ₄		0.05	2.5	.33	0.19

OPERATING CONDITIONS

Type of operation	Temperature		Current density	
	°C	°F	amp/dm ²	amp/ft ²
On brass or nickel.....	45	113	16	150
Directly on zinc, "warm".....	45	113	18	170
Directly on zinc, "cold".....	30	86	10	93

4. BUFFING

All of the plain nickel coatings and about half of the bright nickel coatings were "colored" on "loose buff" cloth wheels with commercial buffing compounds. A few of the copper coatings (indicated in the tables) were also buffed. The direct chromium coatings were "colored" on a sewed buff and were finished on a loose buff. The loss in weight by buffing (usually 5 to 10 percent of the coating) was determined in trial runs, and was taken into account, so that the buffed deposits had the specified thicknesses (within ± 5 percent).

5. SCHEDULE OF DEPOSITS

The compositions and thicknesses of the deposits are listed in tables 8, 9, and 10. The specimens comprising those sets with no letter following the serial designation number were plated and exposed in 1936, and those with such a letter were plated and exposed in 1938. Many of the latter sets duplicated earlier ones. In these tables and throughout the text, the term "standard," as applied to a bath or deposit, merely designates a basis for comparison and is not an evidence of superiority.

TABLE 8.—Plated coatings on steel and iron

Set	Basis metal	Coating				Variations	
		Composition	Thickness				
			Ni	Cu	Ni		Cr
S 1	Cold-rolled steel I.	Ni	<i>in.</i> 0.001	<i>in.</i>	<i>in.</i>	Standard Ni.	
S 101	} do	Ni, Cr	.001		0.00002	Standard Ni, Cr.	
S 101A		do					
S 102		do	.001		.00002	Cathode pickle.	
S 106		do	.002		.00002	Thickness of Ni.	
S 109A	do	Cu(Cy), Ni, Cr		0.0005	0.0005	Cu layer.	
S 109B	do	do		.0005	.0005	Bright Ni.	
S 113	do	Ni, Cu(Ac), Ni, Cr	.0002	.0003	.0005	Acid-Cu layer.	
S 114	do	Ni, Cu(Cy), Ni, Cr	.0002	.0003	.0005	Cyanide-Cu layer.	
S 116	do	Ni, Cu(Ac), Ni, Cr	.0004	.0006	.001	Acid-Cu thickness.	
S 171	do	Ni, Cu(Cy), Ni, Cr	.0002	.0005	.0003	Final Ni thin.	
S 172	do	Ni, Cr	.001			Thickness of Cr.	
S 173	do	do	.001			Do.	
S 174	do	do	.002			Do.	
S 175	do	do	.001			.00002	
S 181	} Cold-rolled steel II.	do	.001			.00002	
S 181A		do					
S 182		do	.001			.00002	
S 189A		do	Cu(Cy), Ni, Cr		.0005	.0005	Cathode pickle.
S 189B	do	do		.0005	.0005	Cu layer.	
S 191	Spring steel III.	Ni, Cr	.001			.00002	
S 192	do	Ni, Cu(Cy), Ni, Cr	.0002	.0003	.0005	.00002	
I 1	Gray cast iron IV.	Cu ^a (Cy), Ni, Cr		.00005	.002	.00002	
I 2	do	do. ^a		.001	.001	.00002	
I 3	Malleable cast iron V.	do. ^a		.00005	.002	.00002	
I 4	do	do. ^a		.001	.001	.00002	
						Thick Cu.	

^a These copper coatings were buffed.

TABLE 9.—Plated Coatings on Copper and Brass

Set	Basis metal	Coating				Variations
		Composition	Thickness			
			Cu	Ni	Cr	
C 1-----	Copper, VI-----	Ni, Cr-----	<i>in.</i>	<i>in.</i>	<i>in.</i>	Standard.
C 2-----	do-----	do-----		0.0002	0.00002	Thickness of Ni.
C 3-----	do-----	do-----		.0005	.00002	Citrate anodic etch.
C 4-----	do-----	Cr ^a -----			.0002	Direct Cr.
B 1-----	Cast high-brass VII-----	Ni, Cr-----		.0002	.00002	Standard.
B 2-----	do-----	do-----		.0001	.00002	Thickness of Ni.
B 3-----	do-----	do-----		.0005	.00002	Do.
B 4-----	do-----	do-----		.0002	.00001	Thickness of Cr.
B 5-----	do-----	Cu(Cy), Ni, Cr-----	0.00005	.0002	.00002	Cu flash.
B 6-----	do-----	Ni, Cr-----		.0002	.00002	H ₂ SO ₄ anodic etch.
B 7-----	do-----	Cr ^a -----			.0002	Direct Cr.
B 11-----	Cast low brass VIII-----	Ni, Cr-----		.0002	.00002	Standard.
B 13-----	do-----	Cu(Cy), Ni, Cr-----	.00005	.0002	.00002	Cu flash.
B 14-----	do-----	Cr ^a -----			.0002	Direct Cr.
B 21-----	Extruded brass IX-----	Ni, Cr-----		.0002	.00002	Standard.
B 23-----	do-----	Cu(Cy), Ni, Cr-----	.00005	.0002	.00002	Cu flash.
B 24-----	do-----	Cr ^a -----			.0002	Direct Cr.
B 31-----	} Rolled high-brass X-----	Ni, Cr-----		.0002	.00002	Standard.
B 31A-----		do-----				
B 31B-----		do-----		.0002	.00002	Bright Ni.
B 31C-----		do-----		.0002	.00002	No organic degreaser.
B 32-----	} do-----	do-----		.0001	.00002	Thickness of Ni.
B 32A-----		do-----				
B 33-----		do-----		.0002	.00003	Thickness of Cr.
B 33A-----		do-----				
B 34-----	} do-----	do-----		.0005	.00002	Thickness of Ni.
B 34A-----		do-----				

^a These Cr layers were buffed.

TABLE 9.—Plated Coatings on Copper and Brass—Continued

Set	Basis metal	Coating			Variations		
		Composition	Thickness				
			Cu	Ni		Cr	
			<i>in.</i>	<i>in.</i>	<i>in.</i>		
B 34B	Rolled high-brass X	Ni, Cr		0.0005	0.0002	Bright Ni.	
B 35		do		.0002	.00001	Thickness of Cr.	
B 35A		do					
B 36		do	do		.0003	.00002	Thickness of Ni.
B 36A	Rolled high brass X	do		.0002	.00005	Thickness of Cr.	
B 37		do					
B 37A		do					
B 38		do	Ni		.0002		No chromium.
B 38A	do	Cr			.00003	Direct Cr, thin.	
B 39		do	Cu(Cy), Ni, Cr	0.00005	.0002	.00002	Cyanide-Cu flash.
B 40		do	Cu(Ac), Ni, Cr	.00005	.0002	.00002	Acid-Cu flash.
B 41		do	Ni, Cr		.0002	.00002	Nickel, not buffed.
B 42	do	do		.0002	.00002	Citrate anodic etch.	
B 43	do	Cr ^a			.0002	Direct Cr, thick.	
B 44	do	Ni, Cr		.0002	.00002	H ₂ SO ₄ anodic etch.	
B 45	do	do		.0002	.00002	Low pH Ni.	
B 46	do	do		.00005	.00002	Thickness of Ni.	
B 47		do		.0002	.00002	Air-agitated Ni bath.	
B 47A		do		.0002	.00002	Standard.	
B 48		do	Cr ^a		.0002	.00002	Direct Cr.
B 51	Rolled low brass XI	Ni, Cr		.0002	.00002	H ₂ SO ₄ anodic etch.	
B 53		do		.0002	.00002	H ₂ SO ₄ anodic etch; low pH, Ni	
B 54		do	do		.0002	.00002	Thickness of Ni.
B 55		do	do		.001	.00002	Do.
B 56A	Rolled high brass X	do		.0002	.00005	Thickness of Cr.	
B 57A		do		.0002	.00002	Brass bright-dipped.	
B 8A		do					
B 59A		do					
N 1	Rolled Ni brass XII	Cr ^a		.0002	.00002	Direct Cr.	
N 2		Cr		.0001	.00001	Thickness of Cr.	
N 3		do		.00005	.00005	Do.	
N 4		do	Ni, Cr		.0001	.0001	Thickness of Ni, Cr.
N 5	do	do		.0002	.00002	Standard.	
N 11	Cast Ni brass XIII	Cr ^a		.0002	.0002	Direct Cr.	
N 12		do. ^a		.0001	.00001	Thickness of Cr.	
N 13		do.		.00005	.00005	Do.	
N 14		do.	Cu(Cy), Ni, Cr	.00005	.0002	.00002	Copper flash.
N 15	do	Ni, Cr		.0002	.00002	Standard.	

^a These chromium layers were buffed.

TABLE 10.—Plated coatings on zinc and zinc-base die castings

H, high sulfate nickel bath; S, standard nickel bath

Set	Basis metal	Coatings			Variations	
		Composition	Thickness			
			Cu	Ni		Cr
			<i>in.</i>	<i>in.</i>	<i>in.</i>	
Z 1	Rolled zinc XIV	Ni(HS), Cr		0.0005	0.00002	Standard.
Z 2	do	do		.0003	.00002	Thickness of Ni.
Z 3	do	do		.0005	.00003	Thickness of Cr.
Z 4	do	do		.0005	.00001	Do.
Z 5	do	Ni(HS), Ni(S), Cr		{.0002 .0003}	.00002	Duplex Ni.
Z 6	do	Cu(Cy), Ni(S), Cr	0.0002	.0003	.00002	Cu layer.
Z 11	Zinc alloy XXI	Ni(HS), Cr		.0005	.00002	Standard.
Z 12	do	Ni(HS), Ni(S), Cr		{.0002 .0003}	.00002	Duplex Ni.
Z 13	do	do		{.0002 .0003}	.00002	Thickness of Ni.
Z 14	do	Cu(Cy), Ni(S), Cr	.0002	.0003	.00002	Cu layer.
Z 15	do	do	.0001	.00009	.00002	Thickness of Cu, Ni.
Z 16	do	Cr ^a		.0001	.0001	Direct Cr, cold.
Z 17	do	Ni(HS), Cr		.001	.00002	Thickness of Ni.
Z 19	Zinc alloy XXIII	Ni(HS)		.0005		Standard Ni.
Z 20	do	do		.0003		Thickness of Ni.

^a These Cr and Cu layers were buffed.

TABLE 10.—Plated coatings on zinc and zinc-base die castings—Continued

Set	Basis metal	Coatings			Variations		
		Composition	Thickness				
			Cu	Ni		Cr	
			<i>in.</i>	<i>in.</i>	<i>in.</i>		
Z 22	Zincalloy XXIII	Ni(HS), Cr	0.0005	0.0002		Standard Ni, Cr.	
Z 22A							
Z 24		do	.0003	.0002		Thickness of Ni.	
Z 24A							
Z 25		do	.0005	.0001		Thickness of Cr.	
Z 26		do	.0005	.0003		Do.	
Z 31		do	Cr ^a	.0001		Direct Cr.	
Z 33		do	do ^a	.0001		Direct Cr, cold.	
Z 35		do	Ni(HS), Ni(S), Cr	.0002	.0002		Standard duplex Ni.
Z 35A				.0003			
Z 36	do	do	.0002	.0001		Thickness of Cr.	
Z 37	do	do	.0003	.0002		Thickness of Ni.	
Z 37A			.0002				
Z 38	do	do	.0008	.0002		Do.	
Z 38A			.0002				
Z 40	do	Cu(Cy), Ni(S), Cr	0.0002	.0003	.0002	Standard Cu, Ni, Cr.	
Z 40A							.0018
Z 41	do	do	.0004	.0006	.0002	Thickness of Cu, Ni.	
Z 41A							
Z 42	do	Cu ^a (Cy), Ni(S), Cr	.0005	.0015	.00002	Do.	
Z 42A	do	Cu(Cy), Ni(S), Cr	.0003	.0002	.00002	Ratio Cu/Ni.	
Z 43	do	Ni(HS), Cu(Cy), Ni	.0003	.0002	.0002	Intermediate Cu layer.	
Z 45	do	(S), Cr		.0005			
Z 47	do	Ni(HS), Cr		.001	.0002	Thickness of Ni.	
Z 48	do	do		.0002	.0002	Do.	
Z 48A							
Z 49	do	Cu ^a (Cy), Ni(S), Cr	.0005	.00075	.00002	Thickness of Cu, Ni.	
Z 50	do	Cu ^a (Cy), Cr	.0005		.00032	No Ni.	
Z 51A	do	Ni(HS), Cr		.00075	.0002	Thickness of Ni.	
Z 52A	do	Ni(HS), Ni(S), Cr		.0003	.0002	Standard duplex Ni.	
Z 53A	do	Cu(Cy), Ni(S), Cr	.00025	.0005			
Z 53B	do	Cu(Cy), Ni(B), Cr	.00025	.0005	.0002	Standard Cu, Ni.	
Z 53E,G,H	do	do	.00025	.0005	.0002	Bright Ni.	
						Bright Ni in commercial plants.	
Z 54A	do	Cu(Cy), Ni(S), Cr	.00025	.0005	.00001	Thickness of Cr.	
Z 55A	do	do	.00025	.0005	.00003	Do.	
Z 56A	do	do	.00025	.0005	.00005	Do.	
Z 61A	Zincalloy XXI	do	.00025	.0005	.00002	Different Zn alloy.	
Z 61B		Cu(Cy), Ni(B), Cr	.00025	.0005	.00002	Bright Ni.	
Z 61E,G,H		do	do	.00025	.0005	.00002	Bright Ni in commercial plants.

^a These Cr and Cu layers were buffed.

III. ATMOSPHERIC EXPOSURE TESTS

1. CONDITIONS OF EXPOSURE

Five specimens of each set were exposed in each of six locations: Key West, Fla.; New York, N. Y.; Pittsburgh, Pa.; Sandy Hook, N. J.; State College, Pa.; and Washington, D. C. The racks were located as described in NBS Research Paper RP712, page 336, except that in Pittsburgh in 1938 the new specimens were exposed on the roof of a Bureau of Mines' Building. Although the atmosphere there is somewhat less contaminated than at the former location on Brunot's Island, it still represents a severe industrial exposure. The racks and mounting were the same as in the previous exposure tests (Research Papers RP712 and RP867).

2. METHOD OF INSPECTION AND RATING

In the previous exposure tests, each inspector assigned to each specimen a numerical rating from 0 to 5, based upon the percentage of the surface that was rusted. In the tests here described, this scale was applied to coatings on nonferrous metals, taking into account *all* evidences of failure, such as light or dark stains, blisters, cracks, and peeling, to each of which equal weight was given.

The ratings of the steel specimens exposed in 1936 were based upon rust only and were therefore directly comparable with those reported in previous papers. In order to make the ratings of coatings on steel also comparable with those on the nonferrous metals, in the 1938 exposures the steel specimens were rated separately for (a) rust and (b) all defects including rust. The results obtained by the two methods of rating were nearly alike, which indicates that in 1938 the rusting was the predominating cause of failure. In some of the earlier tests on steel, when a greater variety of coatings was included, considerable blistering and peeling were observed, which were reported but were not taken into account in the numerical ratings and scores.

The scores were obtained by multiplying the average rating during each inspection period by the number of weeks in that period. The "total scores" were then converted to "percentage scores"; that is, to the percentage of a perfect score for the total period of exposure involved. In this system the results in different locations are directly comparable, even though the periods of exposure may not be identical. The relation of these numerical values is given in table 11, which shows that this scale is not a linear, but a roughly logarithmic function of the proportion of the surface that is corroded.

TABLE 11.—*System used for rating of the specimens*

Proportion of surface with rust or other defects		Rating	Corre- sponding score	Proportion of surface with rust or other defects		Rating	Corre- sponding score
Range	Average			Range	Average		
%	%		%	%	%		%
0.....	.....	5	100	10 to 20.....	15	2	40
0 to 5.....	2.5	4	80	20 to 50.....	35	1	20
5 to 10.....	7.5	3	60	50 to 100.....	75	0	0

During the last series of exposures, E. M. Baker⁷ suggested that, in addition to the numerical ratings, each inspector should indicate whether, in his opinion, the specimens were still "satisfactory" as judged from the standpoint of a user. Such a system might permit a decision as to how long a certain coating would give good service under the prevailing conditions. In effect, it gives each inspector an opportunity to weight the different types of failure according to his opinion, instead of giving equal weight to all kinds of failure.

It was possible to apply this supplemental rating at only two inspection periods, and after many of the specimens had obviously failed. Therefore the data obtained are not valid evidence of the

⁷ University of Michigan. Private communication.

possible value of the method if it had been applied throughout the exposures. Most inspectors reported as "unsatisfactory" those specimens with a rating of 3 or less. In a few cases, specimens with a rating of 4, but with a single conspicuous defect, were also reported as "unsatisfactory." These few observations indicate that the numerical system of rating yields a good measure of quality, although it may not record minor differences. In any similar future tests, Baker's plan may well be given a more thorough trial as a supplement to the numerical ratings.

Exposure tests of plated coatings in one or more locations cannot be expected to yield absolute figures for the protective value of various coatings in service, as service conditions may involve various factors that are either not present, or are not present in the same degree in the exposure tests. The exposure data are useful chiefly for indicating the relative value of various coatings, and especially their order of merit.

In interpreting the data it is necessary to estimate their reproducibility; that is, the magnitude of differences that are likely to be significant. Analysis of the thousands of ratings made by different inspectors at different locations and at various periods indicates that the five specimens of each set were very uniform in behavior. It was very unusual for one specimen to differ by more than one point from the others of that set, that is, to influence the average by more than about 0.2 point. The ratings of any one of three or more inspectors for a set seldom differed from their average by more than one point. The averages were probably reliable to 0.5 point, which is 10 percent on the scale. In a series of inspections, any tendency for one person or group to mark high or low would not affect the relative scores of the sets at that location, although it might influence the comparative values at different locations. From all considerations, it is believed that the final percentage scores are consistent within ± 10 percent. Therefore no major conclusions have been based on differences of less than 10 percent from the average, although consistent smaller differences may be valid evidence of trends in the results.

In tables 12 to 24 are recorded the percentage scores of each set in each location and the average for each set in the six locations. For groups of comparable coatings, for example those with the same thickness but differing in the basis metal or method of application, the average scores have also been computed. Each score that differs by more than 10 percent from the average of comparable scores is marked with an "a". The average deviation from the mean value for each group is indicated after each mean, for example 54 ± 5 percent. The fact that most of these average deviations are less than 10 percent shows that the effects of many of the variables studied were less than the reproducibility of the observations.

3. USE OF COLOR PHOTOGRAPHY

Although the numerical system of rating yields very useful comparisons of the coatings, it does not furnish a permanent objective record of their appearance at any given inspection. In an effort to

obtain such a record, color photographs were made of many of the specimens in the different locations.⁸ The results showed that although color photographs are much more informative than black and white pictures, they do not record the same appearance that is seen by the eye. It was especially difficult to obtain authentic pictures of mirror surfaces, which reflected the sky or other surrounding surfaces. The results to date may be considered as purely exploratory, but they are sufficiently promising to warrant a thorough study in any future tests, including means of securing more uniform illumination.

4. EFFECT OF CLEANING THE EXPOSED SPECIMENS

The scores listed in the tables are based on the appearance of the specimens during continuous exposure, with no treatment except light brushing to remove loose dust. Especially in New York and Pittsburgh, sufficient dust and soot adhered to the specimens to prevent accurate estimates of the extent of corrosion or tarnish. In some locations the corrosion products spread over the surface and gave misleading results.

To determine the true condition of the surfaces, one specimen of each set was cleaned with water and fine tripoli after 1 year's exposure. In the four severe exposure sites (Key West, New York, Pittsburgh, and Sandy Hook), the cleaning improved the ratings on iron and steel by about one point, for example from a rating of 2 to a rating of 3, on copper and brass by about two points (somewhat more on nickel-brass), and on zinc by about one point. These results show that on exposure the plated brass is less deeply corroded than is the steel or zinc. Within a few months the cleaned specimens had about the same ratings as those not cleaned. The cleaning should therefore be considered merely as an aid to inspection and not as a preventive of failure. At best, it is difficult to apply any cleaning procedure uniformly, especially by different persons in various locations and at different seasons, and hence cleaning was not included in the regular inspections.

5. EFFECT OF A GREASE FILM APPLIED TO THE COATINGS

The widespread and generally beneficial use of a grease or wax film on plated parts of automobiles might lead one to consider such a treatment as a panacea for defective plating. To throw light on this question, one or two specimens of each set were given a thin film of petrolatum by brushing the surface with a 2-percent solution of petrolatum in mineral spirits. (Prior to use, both materials were tested by standard methods and found to cause no tarnishing of copper.) As the resultant thin grease film (about 0.000005 in.) tended to hold dust, the surface was wiped with a dry cloth prior to each inspection, and a new film of grease was applied after the inspection.

The results showed that, in general, the ratings of the greased specimens were about one to two points higher than those of the ungreased, that is, 10 to 20 percent less of the surface had failed.

⁸ C. A. Vincent-Daviss and W. Blum, *The use of color photography for recording the results of exposure tests*, Monthly Rev. Am. Electroplaters' Soc. 24, 818 (1937).

The sets were usually in the same order; that is, specimens with inferior coatings (for example, with no nickel under the chromium) failed most rapidly, whether greased or not. However, in a few sets, especially in marine locations, the greased specimens failed more rapidly than those without grease. It is possible that any salt absorbed by the dust on the greased specimens was not as readily removed by rain as the salt on the other specimens.

The petrolatum solution was used because it produced a transparent film of fairly uniform thickness and entered the pores. A suitable wax mixture might have yielded better or more prolonged protection, but it would have been more difficult to apply uniformly.

Although a grease or wax film is generally advantageous, it does not justify the use of thin or porous coatings. Especially in marine locations, it should be frequently removed and renewed.

IV. EFFECTS OF ATMOSPHERIC EXPOSURE

1. EFFECT OF ENVIRONMENT

Of the six locations, State College and Washington may be considered as mild exposures, Key West and Sandy Hook as marine, and New York and Pittsburgh as industrial. In the mild locations only those sets that were very poor elsewhere showed marked failure, but most of the others had scores of 90 percent or more even after 2 years of exposure. In the following tables, data are included for each location. The principal conclusions are based on the average of the six locations, which represents, at least roughly, an average condition of outdoor exposure, such as miscellaneous plated articles might be required to withstand. For certain coatings, or for special purposes, the data for a particular type of exposure may be of more interest than the average of all locations.

2. PROTECTIVE VALUE OF COATINGS

The following conclusions are based principally upon exposures of the 1936 specimens for 2.2 years (except in Pittsburgh, where practically all of the specimens had failed within 1 year), and of the 1938 specimens for 1.3 years.

(a) ON STEEL

The data obtained with coatings on steel are summarized in tables 12 and 13, from which the following conclusions are drawn regarding effects of the specified variables.

(1) *Effect of thickness of nickel (plus copper).*—As only two total thicknesses (0.001 and 0.002 in.) were included, their average results (54 and 77 percent) merely confirm the increase in protective value with thickness of coating that was reported in Research Paper RP712.

TABLE 12.—*Effect of variations in thickness of nickel (plus copper) on steel and iron*

[Unless otherwise noted, Cr=0.00002 in. Tests started in 1933; total time 2.2 years (except for P only 1 year). Based on rust only.]

Set	Basis metal	Variation	T equals total percentage score													
			KW		NY		P		SH		SC		W		General average	
			T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg
(a) 0.001 in. total Cu+Ni																
S 1.....	Cold-rolled I.....	No Cr.....	% 57	% +8	% 38	% 0	% 38	% +11	% 39	% +12	% 72	% +21	% 81	% -6	% 54	% -0
S 101.....	do.....	Standard.....	51	+2	48	+10	18	-9	29	+2	85	-8	84	-3	53	-1
S 102.....	do.....	Cathode pickle.....	43	-6	41	+3	32	+5	34	+7	90	-3	79	-8	53	-1
S 113.....	do.....	Ni, Cu(A), Ni.....	31	-18	31	-7	17	-10	13	-14	98	+5	88	+1	46	-8
S 114.....	do.....	Ni, Cu(CN), Ni.....	45	-4	26	-12	17	-10	18	-9	99	+6	96	+9	50	-4
S 171.....	do.....	Final Ni thin.....	34	-15	26	-12	17	-10	15	-12	94	+1	87	0	46	-8
S 175.....	do.....	Ni-air agitation.....	46	-3	46	+8	35	+8	26	-1	94	+1	82	-5	55	+1
S 181.....	Cold-rolled II.....	Standard.....	70	+21	48	+10	34	+7	45	+18	100	+7	92	+5	65	+11
S 182.....	do.....	Cathode pickle.....	65	+16	46	+8	34	+7	30	+3	100	+7	90	+3	61	+7
S 191.....	Spring steel.....	Standard.....	64	+15	36	-2	42	+15	27	0	94	+1	83	+4	58	+4
S 192.....	do.....	Ni, Cu(CN), Ni.....	35	-14	29	-9	17	-10	18	-9	97	+4	93	+6	48	-6
Average.....			49	±10	38	±7	27	±9	27	±8	93	±6	87	±5	54	±5
£ 172 ^b	Cold-rolled I.....	0.00005 in. of Cr.....	70	-----	61	-----	58	-----	67	-----	96	-----	82	-----	72	-----
S 173 ^b	do.....	.0001 in. of Cr.....	79	-----	67	-----	51	-----	68	-----	89	-----	87	-----	74	-----
(b) 0.002 in. total Cu+Ni																
S 106.....	Cold-rolled I.....	Standard.....	84	+9	75	+22	64	+5	66	-8	100	+1	99	+1	81	+4
S 116.....	do.....	Ni, Cu(A), Ni.....	84	+9	47	-5	44	-15	77	+3	100	+1	99	+1	75	-2
S 174.....	do.....	0.0001 Cr.....	81	+6	69	+16	52	-7	79	+5	100	+1	96	-2	80	+3
I 1.....	Gray cast.....	Cu(flash), Ni.....	77	+2	49	-4	67	+8	75	+1	99	0	98	0	78	+1
I 2.....	do.....	Cu(CN), Ni.....	79	+4	40	-13	62	+3	77	+3	99	0	98	0	76	-1
I 3.....	Malleable.....	Cu(flash), Ni.....	52	-23	53	0	67	+8	73	-1	98	-1	98	0	74	-3
I 4.....	do.....	Cu(CN), Ni.....	70	-5	35	-18	57	-2	72	-2	99	0	99	+1	72	-5
Average.....			75	±8	53	±11	59	±7	74	±3	99	±1	98	±1	77	±3

^a Sets differing by more than 10 percent from average of comparable sets.^b Not included in average.

TABLE 13.—*Comparison of bright and plain nickel on steel*

[Test started in 1938; 1.3 years of exposure. All coatings (except 101A and 181A, which are 0.001 in. Ni, plus 0.00002 in. Cr) have 0.0005 in. Cu, 0.0005 in. Ni, and 0.00002 in. Cr. Based on all defects.]

Set	Steel	Nickel	<i>T</i> equals total percentage scores													
			KW		NY		P		SH		SC		W		General average	
			<i>T</i>	Dev. from avg	<i>T</i>	Dev. from avg	<i>T</i>	Dev. from avg	<i>T</i>	Dev. from avg	<i>T</i>	Dev. from avg	<i>T</i>	Dev. from avg	<i>T</i>	Dev. from avg
S 109A	Reg. I	Plain	% 40	% -20	% 25	% -8	% 24	% -8	% 19	% -8	% 88	% -3	% 80	% +3	% 46	% -8
S 109B	do	Bright, not buffed	64	+4	37	+4	30	-2	42	+15	98	+7	79	+2	60	+6
S 109B	do	Bright, buffed	60	0	37	+4	37	+5	31	+4	89	-2	76	-1	55	+1
S 189A	Spec. II	Plain	47	-13	26	-7	22	-10	21	-6	89	-2	79	+2	48	-6
S 189B	do	Bright, not buffed	57	-3	31	-2	38	+6	34	+7	96	+5	70	-7	54	0
S 189B	do	Bright, buffed	66	+6	34	+1	32	0	27	0	88	-3	76	-1	56	+2
S 101A	Reg. I	Plain	71	+11	44	+11	45	+13	24	-3	83	-8	76	-1	57	+3
S 181A	Spec. II	do	72	+12	32	-1	33	+1	19	-8	96	+5	80	+3	55	+1
Average			60	±9	33	±5	32	±6	27	±6	91	±4	77	±3	54	±3

* Sets differing by more than 10 percent from average of comparable sets.

(2) *Effect of preparation for plating.*—No significant effect on protective value was produced by cathodic pickling (S102 and S182) upon the extent of rust, but observations not included in the tables show that there was more tendency for the formation of small blisters in the coatings on the cathodically pickled steel.

(3) *Effect of method of nickel plating; (a) Air agitation.*—The use of air agitation (S 175) in the nickel bath had no significant effect.

(b) *Bright nickel.*—The proprietary "*bright nickel*" deposits (table 13) yielded, on the average, at least as much protection as plain nickel, but showed slightly more tendency to crack. On all three types of basis metal there was much more variation in the quality of the bright nickel than of the buffed plain nickel coatings. Evidently some of the bright nickel deposits were superior and others were inferior to comparable plain nickel deposits. As the different bright nickel coatings were not identified, only their average performance can be reported. (These and other comparisons of bright nickel in this paper refer only to the coatings from the four solutions used in 1938 for this investigation, in which improvements may since have been made.)

(4) *Effect of a copper layer.*—The data in table 12 indicate that in four sets (S 113, S 114, S 171, and S 192) with a total thickness of 0.001 in., the presence of a copper layer consistently gave scores slightly (7 percent) below the average. This effect was less evident with the 0.002-in. coatings. This result is consistent with those reported in RP712, and indicates that even in relatively thick deposits on steel a copper layer does not have a protective value equal to that of the same thickness of nickel.

(5) *Effect of thickness of chromium.*—The results in table 12 with sets S 172 and S 173 show that a greater thickness of chromium than the customary 0.00002 in. adds materially to the protection against corrosion, as was reported in RP712. Some cracking of these thick chromium coatings occurred, but not nearly so much as with thick chromium coatings over nickel on brass.

(6) *Effect of the basis metal.*—In general (table 12), about the same protection was afforded by a coating 0.002 in. thick on cold-rolled steel, spring steel, gray cast iron, and malleable cast iron.

The data for cold-rolled steels I and II in table 12 show that the latter, which was "full cold-rolled" or "satin finish" steel, was about 10 percent superior to the average (compare S 101 and S 181). In addition, steel II showed somewhat less tendency to blister on the specimens cathodically pickled (S 102 and S 182). However, no such differences in these two steels were observed (table 12) in 16 months' exposure of 1938 specimens (S 101A and S 181A). These few results indicate that variations in a given type or finish of steel may be as significant as variations of type.

(b) ON COPPER AND BRASS

The data in tables 14 to 19 for coatings on copper and brass lead to the following conclusions.

TABLE 14.—*Effect of variations in thickness of nickel (plus copper) on copper, brass, and nickel-brass*

[Scores for all defects. Unless otherwise noted, Cr 0.00002 in. Tests started in 1936; total time 2.2 years]

Set	Basis metal	Nickel thick- ness	Variation	T equals total percentage scores													
				KW		NY		P		SH		SC		W		General	
				T	Dev. from avg.	T	Dev. from avg.	T	Dev. from avg.	T	Dev. from avg.	T	Dev. from avg.	T	Dev. from avg.	T	Dev. from avg.
C 4	Cu	0	Direct Cr:	%	%	%	%	%	%	%	%	%	%	%	%	%	%
B 7	Cast high brass	0	.00002	19	-4	4	-1	12	0	6	-8	30	a-37	32	a-28	17	a-13
B 14	Cast low brass	0	.0002	14	-9	4	-1	12	0	6	-8	76	+9	56	-4	28	-2
B 24	Extruded brass	0	.0002	18	-5	8	+3	12	0	14	0	95	a+28	86	a+26	39	+9
B 44	Rolled high brass	0	.0002	21	-2	4	-1	12	0	11	-3	51	a-16	61	+1	27	-3
B 53	Rolled low brass	0	.0002	22	-1	4	-1	12	0	13	-1	61	-6	45	a-15	26	-4
N 1	Rolled Ni brass	0	.0002	21	-2	4	-1	12	0	10	-4	61	-6	33	a-27	24	-6
N 11	Cast Ni brass	0	.0002	35	a+12	6	+1	12	0	28	a+14	72	+5	76	a+16	38	+8
			.0002	33	+10	4	-1	12	0	26	a+12	91	a+24	88	a+28	42	a+12
			Average	23	±6	5	±1	12	0	14	±6	67	±16	60	±18	30	±7
B 47 ^b	Rolled high brass	0.00005	Thickness of Ni	54	---	15	---	17	---	29	---	89	---	69	---	46	---
B 2	Cast high brass	.00010	do.	43	-10	12	-7	16	-7	13	-9	89	-2	61	-10	39	-8
B 32	Rolled high brass	.00010	do.	63	+10	26	+7	29	+6	31	+9	93	+2	80	+10	54	+7
			Average	53	±7	19	±7	23	±7	22	±9	91	±2	71	±10	47	±8
C 1	Cu	.00020	Standard	56	-1	25	+1	12	-9	34	+5	97	+3	94	+6	53	+1
B 1	Cast high brass	.00020	do.	62	+5	23	-1	12	-9	23	-6	100	+6	79	-9	50	-2
B 6	do.	.00020	Anodic, H ₂ SO ₄	49	-8	33	+9	34	a+13	45	a+16	94	0	83	-5	56	+4
B 11	Cast low brass	.00020	Standard	63	+6	28	+4	38	a+17	27	-2	96	+2	83	-5	56	+4
B 21	Extruded brass	.00020	do.	57	0	28	+4	20	-1	28	-1	94	0	91	+3	53	+1
B 31	Rolled high brass	.00020	do.	68	a+11	18	-6	20	-1	20	-9	92	-2	71	a-17	48	-4
B 43	do.	.00020	Anodic, citrate	53	-4	25	+1	21	0	30	+1	87	-7	95	+7	52	0
B 45	do.	.00020	Anodic, H ₂ SO ₄	57	0	21	-3	16	-5	28	-1	88	-6	91	+3	50	-2
B 46	do.	.00020	Low pH Ni	57	0	21	-3	21	0	22	-7	90	-4	92	+4	51	-1
B 48	do.	.00020	Air-agitated Ni	63	+6	25	+1	24	+3	34	+5	92	-2	94	+6	56	+4
B 51	Rolled low brass	.00020	Standard	53	-4	26	+2	18	-3	32	+3	96	+2	90	+2	53	+1
B 54	do.	.00020	Anodic, H ₂ SO ₄	55	-2	25	+1	12	-9	28	-1	97	+3	94	+6	52	0
B 55	do.	.00020	Anodic, H ₂ SO ₄ ; low pH Ni	55	-2	18	-6	21	0	32	+3	97	+3	95	+7	53	+1

N 5.....	Rolled Ni brass.....	.00020	Standard.....	51	-6	23	-1	18	-3	42	^a +13	96	+2	95	+7	54	+2
N 15.....	Cast Ni brass.....	.00020	do.....	55	-2	22	-2	29	+8	18	-11	89	-5	77	-11	48	-4
			Average.....	57	±4	24	±3	21	±5	29	±6	94	±3	88	±7	52	±2
			Copper flash under nickel:														
B 5.....	Cast high brass.....	.00020	Cyanide Cu.....	46	-10	14	^a -14	12	^a -13	29	-5	92	-3	94	+7	48	-6
B 13.....	Cast low brass.....	.00020	do.....	39	^a -17	29	+1	26	+1	24	-10	100	+5	81	-6	50	-4
B 23.....	Extruded brass.....	.00020	do.....	56	0	22	-6	20	-5	32	-2	88	-7	91	+4	52	-2
B 40.....	Rolled high brass.....	.00020	do.....	74	^a +18	40	^a +12	35	+10	43	+9	94	-1	94	+7	63	+9
B 41.....	do.....	.00020	Acid Cu.....	64	+8	42	^a +14	37	^a +12	40	+6	96	+1	95	+8	62	+8
N 14.....	Cast Ni brass.....	.00020	Cyanide Cu.....	57	+1	21	-7	21	-4	34	0	97	+2	65	^a -22	49	-5
			Average.....	56	±9	28	±9	25	±8	34	±5	95	±3	87	±9	54	±6
B 36 ^b	Rolled high brass.....	.00030	Standard.....	57	-----	24	-----	12	-----	25	-----	93	-----	86	-----	50	-----
C 2.....	Cu.....	.00050	do.....	62	-5	19	-7	12	^a -18	32	-5	100	+2	99	+4	54	-5
C 3.....	do.....	.00050	Anodic, citrate.....	62	-5	19	-7	18	^a -12	31	-6	99	+1	93	-2	54	-5
B 3.....	Cast high brass.....	.00050	Standard.....	66	+1	28	+2	55	^a +25	36	+1	98	0	94	-1	63	+4
B 34.....	Rolled high brass.....	.00050	do.....	78	^a +11	37	^a +11	33	+3	49	^a +12	96	-2	95	0	65	+6
			Average.....	67	±6	26	±7	30	±15	37	±6	98	±1	95	±5	59	±5

^a Sets differing by more than 10 percent from average of comparable sets.^b Not included in average.

TABLE 15.—*Effect of variations in thickness of nickel (plus copper) on copper, brass, and nickel-brass*

[Scores for all defects. Unless otherwise noted, Cr=0.00002 in. Tests started in 1938; total time 1.3 years]

Set	Base metal	Thick- ness of nickel	Variation	<i>T</i> equals total percentage scores													
				KW		NY		P		SH		SC		W		General average	
				<i>T</i>	Dev. from avg	<i>T</i>	Dev. from avg	<i>T</i>	Dev. from avg	<i>T</i>	Dev. from avg	<i>T</i>	Dev. from avg	<i>T</i>	Dev. from avg	<i>T</i>	Dev. from avg
B 47A	Rolled high brass	<i>in.</i> 0.00005	Thickness of Ni	% 39	% 13	% 13	% 9	% 18	% 18	% 85	% 69	% 39	% 39	% 39	% 39	% 39	% 39
B 32A	do	.00010	do	69	15	15	10	36	36	96	81	51	51	51	51	51	51
B 56A	do	.00015	do	58	17	17	9	22	22	88	73	45	45	45	45	45	45
B 31A	Rolled high brass	.00020	Standard	84	+18	23	+3	11	+1	26	-3	100	+6	73	-5	53	+3
B 31C	do	.00020	No degreaser	65	-1	20	0	11	+1	35	+4	99	+5	81	+3	52	+2
B 59A	do	.00020	Bright-dipped	50	-17	16	-4	9	-1	29	0	84	-10	80	+2	45	-5
			Average	66	±12	20	±2	10	±1	29	±2	94	±7	78	±3	50	±3
B 36A	Rolled high brass	.00030	Standard	68	14	14	24	42	42	99	92	92	92	92	92	92	92
B 34A	do	.00050	do	76	27	27	28	34	34	97	94	94	94	94	94	94	94
B 57A	do	.00100	Thickness of Ni	89	58	58	34	66	66	93	92	92	92	92	92	92	92

• Sets differing by more than 10 percent from average of comparable sets.

TABLE 16.—*Effect of variations in thickness of chromium over 0.0002 in. of nickel on brass*

[Tests started in 1936, total time 2.2 years]

Set	Basis metal	Cr thick- ness	Percentage scores						
			KW	NY	P	SH	SC	W	General average
B 38	Rolled high	0 in.	% 35	% 5	% 12	% 15	% 87	% 72	% 38
B 4	Cast high	.000010	48	31	12	30	100	94	53
B 35	Rolled high	.000010	59	20	12	17	88	88	47
Misc	(Table 14)	.000020	57	24	21	29	94	88	52
B 33	Rolled high	.000030	53	20	18	23	91	90	49
B 37	do	.000050	40	10	16	18	59	38	30

TABLE 17.—*Effect of variations in thickness of chromium over 0.0002 in. of nickel on brass*

[Tests started in 1938; total time 1.3 years]

Set	Basis metal	Cr thick- ness	Percentage scores						
			KW	NY	P	SH	SC	W	General average
B 38	Rolled high	0 in.	% 34	% 14	% 9	% 25	% 98	% 62	% 40
B 58A	do	.000005	46	9	9	13	93	87	43
B 35A	do	.000010	69	15	16	28	93	89	52
B 31A	do	.000020	84	23	11	26	100	73	53
B 33A	do	.000030	76	58	31	65	99	73	67
B 37A	do	.000050	36	10	10	12	79	58	34

TABLE 18.—*Effect of variations in thickness of chromium directly on nickel-brass*

[Tests started in 1936; total time 2.2 years]

Set	Basis metal	Cr thick- ness	T equals total percentage scores													
			KW		NY		P		SH		SC		W		General average	
			T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg
N 3	Rolled	in. 0.00005	% 36	% +1	% 8	% +2	% 12	% 12	% 15	% -9	% 52	% -27	% 66	% -9	% 32	% -6
N 13	Cast	.00005	34	-1	6	0	12	24	0	90	+11	74	-1	40	+2	
N 2	Rolled	.00010	41	+6	4	-2	12	25	+1	75	-4	58	-17	36	-2	
N 12	Cast	.00010	32	-3	5	-1	12	24	0	91	+12	85	+10	42	+4	
N 1	Rolled	.00020	35	0	6	0	12	28	+4	72	-7	76	+1	38	0	
N 11	Cast	.00020	33	-2	4	-2	12	26	+2	91	+12	88	+13	42	+4	
	Average		35	±2	6	±1	12	24	±3	79	±12	75	±9	38	±3	

* Sets differing by more than 10 percent from average of comparable sets.

TABLE 19.—Effect of "bright nickel" on brass

[Tests started in 1938, total time 1.3 years. All on rolled high brass. Cr=0.0002 in. thick]

Set	Nickel		Percentage scores						
	Type	Thickness	KW	NY	P	SH	SC	W	General average
B 31A.....	Plain.....	<i>in.</i> 0.0002	% 84	% 23	% 11	% 26	% 100	% 73	% 53
B 31B.....	Bright.....	.0002	85	35	43	50	94	70	63
	Average.....		85	29	27	38	96	72	58
B 34A.....	Plain.....	0.0005	76	27	42	34	97	94	62
B 34B.....	Bright.....	.0005	84	36	48	52	98	84	67
	Average.....		80	32	45	43	98	89	65

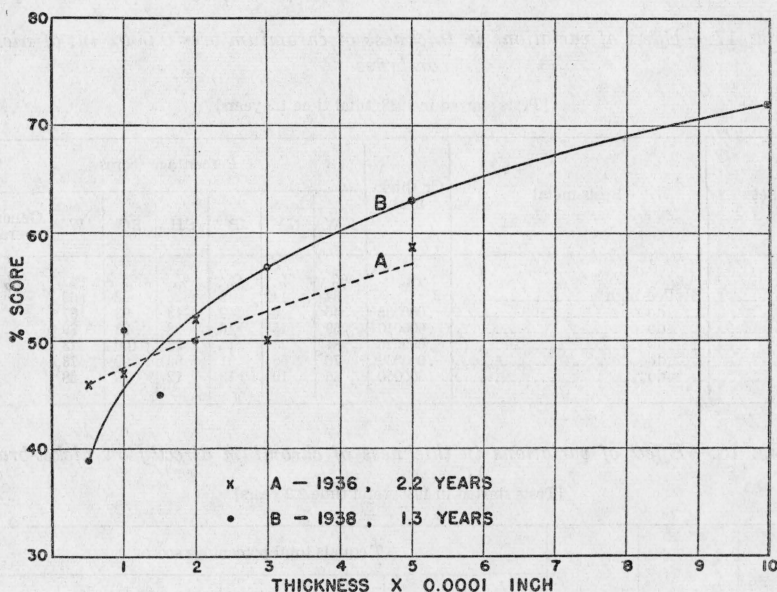


FIGURE 1.—Effect of thickness of nickel on brass upon the percentage scores.

Average of 6 locations. All nickel coatings covered with 0.00002 in. of chromium.

(1) *Effect of thickness of nickel.*—The scores for the first eight sets in table 14 show conclusively that when a relatively thick coating of chromium is applied directly to the copper or brass, with no intervening nickel, very little protection is furnished against corrosion, even in the mild locations. Nickel-brass (N 1 and N 11), which is often plated directly with chromium, behaves only slightly better than the other types of brass. Table 18 shows that the thickness of the chromium applied directly to nickel-brass has little effect.

Tables 14 and 15 show that as little as 0.00005 in. of nickel prior to the customary 0.00002 in. of chromium yields more protection than 0.0002 in. of chromium alone. The score increases as the thickness of nickel is increased but by no means proportionally to the latter. This is illustrated in figure 1 for all sets in the six locations for the 1936 and 1938 tests. (Because the scale is logarithmic, the actual reduction in

corrosion by an increase in thickness is greater than is indicated by the curves.) Although these and similar curves show clearly the general relation between thickness of nickel and protective value, they do not in themselves permit the selection of a certain thickness for a given purpose, which may involve factors other than atmospheric exposure.

(2) *Effect of preparation for plating.*—The data in table 14 show no effects of anodic etching of the brass upon the protective value of the coatings.

(3) *Effect of method of nickel plating*—(a) *Low pH.*—No significant effect was produced by the use of low pH nickel baths.

(b) *Agitation with air.*—No effect was produced by air agitation.

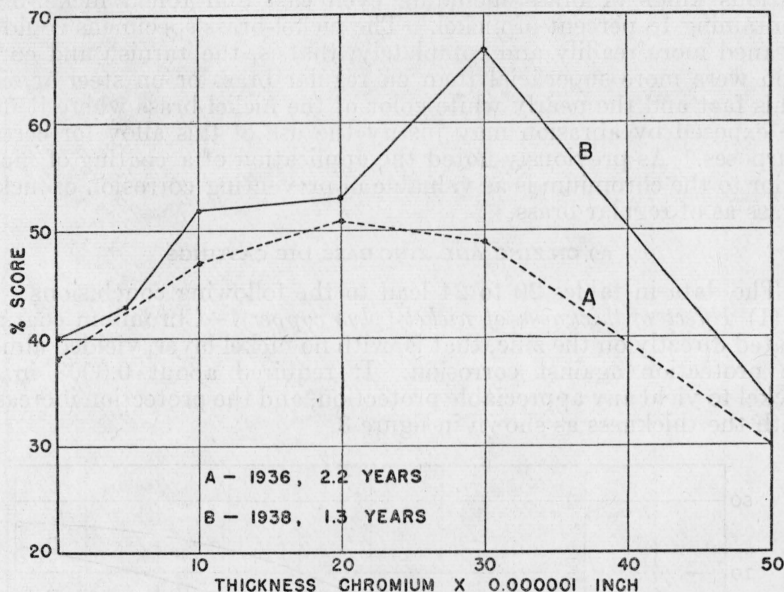


FIGURE 2.—Effect of thickness of chromium over 0.0002 in. of nickel on brass upon the percentage scores.

Average of 6 locations.

(c) *Bright nickel.*—The data in table 19 indicate that the bright nickel gave at least as much protection as plain nickel coatings. There was a tendency for the bright nickel on brass to crack but not so much as with the thicker bright nickel coatings on steel and on zinc.

(4) *Effect of a copper layer (table 14).*—The application of a “flash” (less than 0.00005 in.) of copper to brass prior to nickel plating had no appreciable effect except on rolled high brass, where it produced an improvement of about 10 percent.

(5) *Effect of thickness of chromium.*—The data in tables 16 and 17 and in figure 2 show that as the thickness of chromium plated over 0.0002 in. of nickel on brass is increased, a maximum score is reached, after which there is a decided decrease in protection. The thickest chromium coatings (0.00005 in.) in both series of tests and in all locations showed pronounced cracking, which extended through the nickel and permitted corrosion of the brass.

Although it is not possible to select from these data the optimum thickness of chromium, which is apparently between 0.00001 and 0.00003 in., it is certain that 0.00005 in. of chromium is undesirable over the customary nickel coatings (0.0002 in.) on brass. The absence of severe cracking or corrosion with this thickness of chromium over 0.001 in. of nickel on steel (table 12), or over 0.00075 in. of nickel plus copper on zinc (table 23), may be caused by the fact that the cracking of the chromium could not extend through the greater thicknesses of copper and nickel.

(6) *Effect of the basis metal.*—The data in table 16 show surprisingly little difference in the behavior of similar coatings on copper and various kinds of brass, including even cast and rolled nickel-brass containing 18 percent of nickel. The nickel-brass specimens could be cleaned more readily and completely, that is, the tarnish and corrosion were more superficial than on regular brass or on steel or zinc. This fact and the nearly white color of the nickel-brass where it may be exposed by abrasion may justify the use of this alloy for certain purposes. As previously noted the application of a coating of nickel prior to the chromium is as valuable in preventing corrosion of nickel-brass as of regular brass.

(c) ON ZINC AND ZINC-BASE DIE CASTINGS

The data in tables 20 to 24 lead to the following conclusions:

(1) *Effect of thickness of nickel (plus copper).*—Chromium coatings plated directly on the zinc, that is, with no nickel layer, yielded almost no protection against corrosion. It required about 0.0003 in. of nickel to yield any appreciable protection, and the protection increased with the thickness as shown in figure 3.

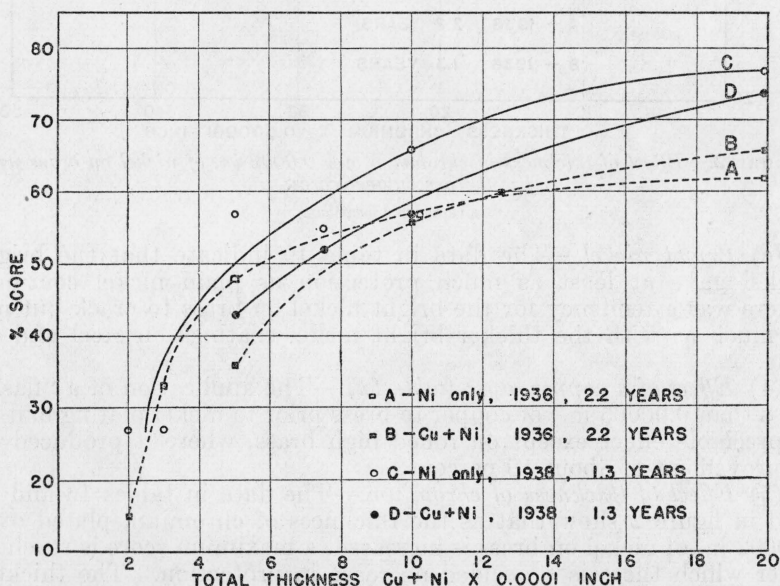


FIGURE 3.—Effect of thickness of nickel, or of nickel plus copper, over zinc-base die-castings upon the percentage scores.

Average of 6 locations. All nickel coatings covered with 0.00002 in. of chromium.

TABLE 20.—*Effect of variations in thickness of nickel (plus copper) on zinc and zinc die castings*

[HS, high sulfate nickel bath; S, standard nickel bath. Scores for all defects. Unless otherwise noted, Cr=0.00002 in. Tests started in 1936; total time 2.2 years]

Set	Basis metal	Thick- ness Ni (+Cu)	Variation	T equals total percentage scores													
				KW		NY		P		SH		SC		W		General aver- age	
				T	Dev. from avg.	T	Dev. from avg.	T	Dev. from avg.	T	Dev. from avg.	T	Dev. from avg.	T	Dev. from avg.	T	Dev. from avg.
Z 16.....	XXI alloy.....	0	<i>Direct Cr.</i>	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Z 31.....	XXIII alloy.....	0	Cold 0.0001.....	13	-1	8	+3	16	-3	8	0	43	a+17	36	a+20	21	+6
Z 33.....	do.....	0	Hot 0.0001.....	14	0	4	-1	20	+1	8	0	6	a-20	4	a-12	9	-6
			Cold 0.0001.....	14	0	4	-1	20	+1	9	+1	30	+4	8	-8	14	-1
			Average.....	14	0	5	±2	19	±2	8	0	26	±14	16	±13	15	±4
Z 48 ^b	XXIII alloy.....	0.00020	HS.....	26		5		12		3		26		16		15	
Z 2.....	Rolled zinc.....	.00030	do.....	57	+10	21	+7	27	+3	24	+8	83	a+27	64	a+21	46	a+13
Z 24.....	XXIII.....	.00030	do.....	37	-10	7	-7	20	-4	7	-9	29	a-27	22	a-21	20	a-13
			Average.....	47	±10	14	±7	24	±4	16	±9	56	±27	43	±21	33	±13
Z 1.....	Rolled zinc.....	0.00050	HS.....	53	-9	31	a+11	32	+9	41	a+17	91	0	73	+4	54	+6
Z 5.....	do.....	.00050	Duplex HS, S.....	67	+5	24	+4	16	-7	32	+8	93	+2	78	+9	52	+4
Z 11.....	XXI.....	.00050	HS.....	66	+4	27	+7	33	+10	29	+5	91	0	84	a+15	55	+7
Z 12.....	do.....	.00050	Duplex HS, S.....	57	-5	12	-8	16	-7	11	a-13	97	+6	76	+7	45	-3
Z 22.....	XXIII.....	.00050	HS.....	61	-1	14	-6	20	-3	16	-8	87	-4	55	a-14	42	-6
Z 35.....	do.....	.00050	Duplex HS, S.....	69	+7	12	-8	20	-3	13	a-11	87	-4	47	a-22	41	-7
			Average.....	62	±5	20	±7	23	±7	24	±10	91	±3	69	±12	48	±6
Z 6.....	Rolled zinc.....	0.00050	Cu, Ni(S).....	62	a+19	19	+6	24	+7	20	+5	72	-8	63	a+13	43	+7
Z 14.....	XXI.....	.00050	do.....	41	-2	11	-2	16	-1	14	-1	83	+3	56	+6	37	+1
Z 40.....	XXIII.....	.00050	do.....	34	-9	11	-2	16	-1	13	-2	83	+3	40	-10	33	-3
Z 43.....	do.....	.00050	do.....	35	-8	9	-4	12	-5	11	-4	80	0	39	a-11	31	-5
			Average.....	43	±10	13	±4	17	±4	15	±3	80	±4	50	±10	36	±4

^a Sets differing by more than 10 percent from average of comparable sets.^b Not included in average.

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TABLE 20.—*Effect of variations in thickness of nickel (plus copper) on zinc and zinc die castings—Continued*

[HS, high sulfate nickel bath; S, standard nickel bath. Scores for all defects. Unless otherwise noted, Cr=0.00002 in. Tests started in 1936; total time 2.2 years]

Set	Basis metal	Thick- ness Ni (+Cu)	Variation	T equals total percentage scores													
				KW		NY		P		SH		SC		W		General aver- age	
				T	Dev. from avg.	T	Dev. from avg.	T	Dev. from avg.	T	Dev. from avg.	T	Dev. from avg.	T	Dev. from avg.	T	Dev. from avg.
Z 13.....	XXI.....	0.00100	Duplex HS, S.....	% 64	% -4	% 30	% +4	% 24	% -9	% 47	% +4	% 90	% -1	% 87	% +3	% 57	% 0
Z 17.....	do.....	.00100	HS.....	76	+8	32	+6	43	+10	48	+5	95	+4	94	+10	65	+8
Z 37.....	XXIII.....	.00100	Duplex HS, S.....	65	-3	22	-4	32	-1	40	-3	92	+1	80	-4	55	-2
Z 47.....	do.....	.00100	HS.....	66	-2	19	-7	32	-1	36	-7	86	-5	74	-10	52	-5
			Average.....	68	±4	26	±5	33	±5	43	±5	91	±3	84	±7	57	±4
Z 15.....	XXI.....	0.00100	Cu, Ni(S).....	62	-4	28	+3	44	+14	45	+4	88	0	87	+1	59	+3
Z 41.....	XXIII.....	.00100	do.....	67	+1	23	-2	20	-10	28	+13	92	+4	86	0	53	-3
Z 45.....	do.....	.00100	Ni(HS), Cu, Ni(S).....	69	+3	24	-1	27	-3	50	+9	84	-4	86	0	57	+1
			Average.....	66	±3	25	±2	30	±9	41	±9	88	±3	86	0	56	±2
Z 49.....	XXIII.....	0.00125	Cu, Ni(S).....	71	-----	28	-----	36	-----	43	-----	95	-----	87	-----	60	-----
Z 38.....	do.....	.00200	Duplex HS, S.....	73	-----	30	-----	40	-----	60	-----	88	-----	82	-----	62	-----
Z 42.....	do.....	.00200	Cu, Ni(S).....	65	-----	29	-----	59	-----	66	-----	84	-----	91	-----	66	-----

^a Sets differing by more than 10 percent from average of comparable sets.

TABLE 21.—Effect of variations in thickness of nickel (plus copper) on zinc and zinc die castings

[HS, high sulfate nickel bath; S, standard nickel bath. Scores for all defects. Cr=0.00002 in. Tests started in 1933; total time 1.3 years]

Set	Basis metal	Thick- ness Ni (+Cu)	Variation	T equals total percentage scores													
				KW		NY		P		SH		SC		W		General average	
				T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg
		in.		%	%	%	%	%	%	%	%	%	%	%	%	%	%
Z 48A ^a	XXIII	0.00020	HS	37		8		13		13		67		21		27	
Z 24A ^a	do	.00030	HS	36		8		13		10		66		27		27	
Z 22A	do	.00050	do	45		16		21		17		94		63		43	
Z 35A	do	.00050	Duplex HS, S.	59		12		17		17		86		60		42	
			Average	52		14		19		17		90		62		42	
Z 40A ^a	do	.00050	Cu, Ni, (S)	50		16		19		16		88		70		43	
Z 51A	do	.00075	HS	63	-3	21	-1	33	+4	25	-2	98	0	76	-4	53	-1
Z 52A	do	.00075	Duplex Ni, HS, S.	75	+9	23	+1	30	+1	34	+7	100	+2	82	+2	57	+3
Z 53A	do	.00075	Cu, Ni (S)	61	-5	23	+1	28	-1	28	+1	93	-5	79	-1	52	-2
Z 61A	XXI	.00075	do	65	-1	22	0	25	-4	22	-5	99	+1	81	+1	52	-2
			Average	66	±5	22	±1	29	±3	27	±4	98	±2	80	±2	54	±2
Z 37A	XXIII	.00100	Duplex HS, S.	79		31		31		63		98		94		66	
Z 41A	do	.00100	Cu, Ni (S)	66		30		22		36		94		95		57	
Z 38A	do	.00200	Duplex HS, S.	85		53		58		69		98		99		77	
Z 42 A	do	.00200	Cu, Ni (S)	76		54		58		70		96		99		74	

^a Not included in average.

TABLE 22.—*Effect of variations in thickness of chromium over nickel (plus copper) on zinc die castings*

[Tests started in 1936; total time 2.2 years. Total thickness=0.0005 in.]

Set	Basis metal	Coating		T equals total percentage scores													
				KW		NY		P		SH		SC		W		General average	
		Composition	Cr thickness	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg
Z 19	XXIII	Ni, Cr	In.	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Z 4	Rolled Zn	do	0	22	^a -31	6	-7	12	-9	9	-8	39	^a -42	28	^a -31	19	^a -22
Z 25	XXIII	do	0.00001	65	^a +12	13	0	16	-5	16	-1	97	^a +16	76	^a +17	47	+6
Z 26	do	do	.00001	59	+6	9	-4	20	-1	13	-4	92	+11	55	-4	41	0
Z 36	do	Cu, Ni, Cr	.00001	51	-2	13	0	20	-1	11	-6	79	-2	55	-4	38	-3
Misc	(Table 20)	Ni, Cr	.00002	62	+9	20	+7	23	+2	24	+7	91	+10	69	+10	48	+7
Z 3	Rolled Zn	do	.00003	57	+4	20	+7	32	^a +11	34	^a +17	89	+8	77	^a +18	52	^a +11
Z 26	XXIII	do	.00003	55	+2	10	-3	23	+2	12	-5	83	+2	53	-6	39	-2
Average				53	±8	13	±4	21	±4	17	±7	81	±13	59	±13	41	±7

^a Sets differing by more than 10 percent from average of comparable sets.TABLE 23.—*Effect of variations in thickness of chromium over nickel (plus copper) on zinc die castings*

[Tests started in 1938; total time 1.3 years. Total thickness=0.00075 in.]

Set	Basis metal	Coating		T equals total percentage scores													
				KW		NY		P		SH		SC		W		General average	
		Composition	Cr thickness	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg
Z 54A	XXIII	Cu, Ni, Cr	In.	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Z 53A	do	do	0.00001	54	^a -15	18	-3	20	-8	28	-8	100	+3	81	-3	50	-6
Z 55A	do	do	.00002	61	-8	23	+2	28	0	28	-8	93	-4	79	-5	52	-4
Z 55A	do	do	.00003	80	^a +11	23	+2	35	+7	40	+4	99	+2	92	+8	62	+6
Z 56A	do	do	.00005	79	+10	18	-3	27	-1	47	^a +11	94	-3	85	+1	58	+2
Average				69	±8	21	±3	28	±4	36	±8	97	±3	84	±4	56	±5

^a Sets differing by more than 10 percent from average of comparable sets.

TABLE 24.—*Effect of "bright nickel" on zinc die castings*

[Tests started in 1938; total time, 1.3 years. All coatings 0.00025 in. Cu; 0.0005 in. Ni; 0.00002 in. Cr]

Set	Basis metal	Type of nickel	T equals total percentage scores													
			KW		NY		P		SH		SC		W		General average	
			T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg	T	Dev. from avg
Z 53A.....	XXIII	Plain.....	% 61	% -1	% 23	% -3	% 28	% -2	% 28	% -3	% 93	% -2	% 79	% +2	% 52	% -3
Z 53B.....	do.	Bright, not buffed.....	70	+8	39	+13	35	+5	50	+19	94	-1	78	+1	61	+6
Z 53B.....	do.	Bright, buffed.....	66	+4	21	-5	23	-7	25	-6	96	+1	82	+5	52	-3
Z 53E, G, H.....	do.	Bright, commercial plants.....	51	-11	20	-6	22	-8	27	-4	92	-3	73	-4	48	-7
Z 61A.....	XXI	Plain.....	65	+3	22	-4	25	-5	22	-9	99	+4	81	+4	52	-3
Z 61B.....	do.	Bright, not buffed.....	71	+9	32	+6	43	+13	33	+7	98	+3	78	+1	60	+5
Z 61B.....	do.	Bright, buffed.....	65	+3	27	+1	42	+12	26	-5	96	+1	76	-1	55	0
Z 61E, G, H.....	do.	Bright, commercial plants.....	50	-12	24	-2	24	-6	30	-1	90	-5	71	-6	48	-7
Average.....			62	±6	26	±5	30	±7	31	±7	95	±3	77	±3	55	±4

* Sets differing by more than 10 percent from average of comparable sets.

(2) *Effect of method of nickel plating; (a) High-sulfate and duplex coatings.*—It is not possible to deposit satisfactory coatings of nickel directly on zinc from ordinary nickel baths, such as the "standard." Adherent nickel may be deposited from the "high-sulfate" bath and, if desired, an additional thickness may then be applied from the standard bath to form a "duplex" nickel coating. Comparison of deposits produced entirely from the high-sulfate bath with the duplex nickel deposits shows no significant differences. However, the high-sulfate deposits are usually more brittle than the standard nickel. Especially if they are as thick as 0.001 in., coatings from the high-sulfate bath deposited on irregularly shaped articles are more likely to crack in service than the duplex coatings.

(b) *Bright nickel.*—The average proprietary bright nickel deposits (table 24) including those produced in the three commercial plants, were at least as protective as the plain nickel, though there was more cracking of the bright coatings.

(3) *Effect of a copper layer.*—Instead of using an initial layer of high-sulfate nickel on the zinc, most commercial plants now apply an initial layer of copper from some type of cyanide bath, such as the rochelle-salt bath, and follow this with regular nickel or bright nickel. The data in table 20 show that with coatings having a total thickness of 0.0005 in. the copper layer furnished no added protection, that is, the score was about the same as that with only the thickness of nickel that was present (in this case 0.0003 in.). With a total thickness of 0.001 in. or more, the scores were about the same with and without copper; in other words, the copper layer furnished about as much protection as an equal thickness of nickel. It is necessary to have an appreciable thickness of nickel, at least 0.0003 in., over the copper to prevent surface copper stains on exposure. The rating for set Z 50 (not in table 20), which had a layer of copper but no nickel under the chromium, was low in all locations (as might be expected from the behavior of chromium plated directly on sheet copper, table 14).

(4) *Effect of thickness of chromium.*—The data in table 22 show little difference in scores for 0.00001 to 0.00003 in. of chromium over 0.0005 in. of nickel on zinc. Table 23 shows that 0.00005 in. of chromium over 0.00075 in. of copper plus nickel on zinc has no such detrimental effect as was observed with this thickness of chromium over nickel on brass. The absence of severe cracking through to the zinc may be caused by the greater total thickness of coating and also by the greater ductility of the copper layer.

(5) *Effect of the basis metal.*—Table 20 shows that for comparable coatings the rolled zinc was slightly, but consistently, better than the die-castings. There was no appreciable difference in the behavior of the two types of die-castings.

V. COMPARISON OF DIFFERENT BASIS METALS

For certain purposes the choice of both the basis metal and the coating may depend upon the thickness of the coating required to furnish satisfactory protection on the metal selected. The average scores for 1 year's exposure in six locations with nickel and chromium coatings on the three types of basis metal are plotted in figure 4. If

a score of 60 percent, that is an average rating of 3 for the year, is used as the basis of comparison, this degree of protection requires on brass about 0.0002 in. of nickel, on zinc and die-castings about 0.0007 in., and on steel about 0.00085 in. These thicknesses are purely relative, but their order would not be changed if another criterion, such as a score of 70 percent, were employed. These values indicate the relative magnitudes that might be employed in specifications for coatings on the three types of basis metal for about the same service.

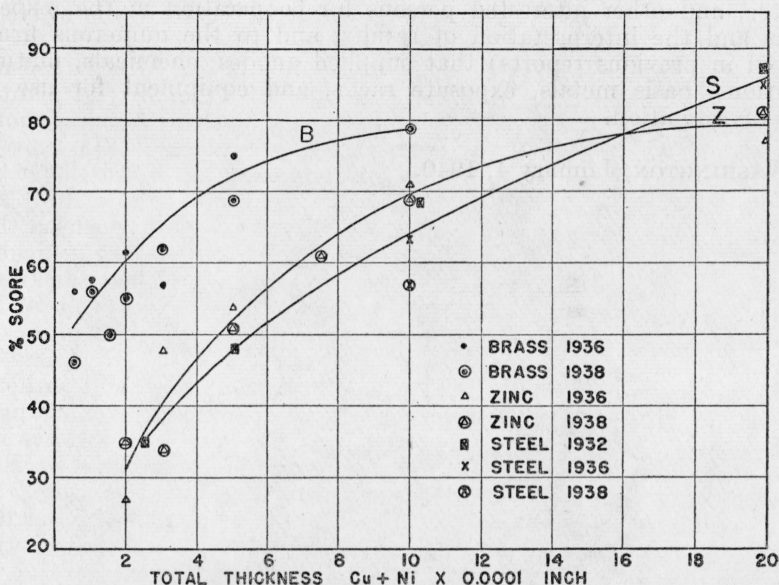


FIGURE 4.—Effect of thickness of nickel (or of nickel plus copper) on percentage scores for 1 year of exposure.

Average of 6 locations. All final nickel coatings covered with 0.00002 in. of chromium.

VI. CONCLUSIONS

1. The most important factor in the protective value of nickel-chromium coatings on steel, brass, or zinc is the thickness of the nickel coatings.

2. On steel or zinc, a layer of copper under the nickel adds little to the protective value of thin coatings. With thick deposits, the protective value of the composite coating approaches, but does not exceed, that of a nickel coating of the same total thickness.

3. Variations in the methods of preparation and of nickel plating, which included the use of four bright nickel solutions supplied in 1938, had no large effects upon the protective value of the coatings.

4. Variations in the thickness of the chromium coating from 0.00001 to 0.00003 in. applied over nickel have very little effect, but if it is 0.00005 in. or more, cracking is likely to occur, especially over nickel coatings on brass.

5. Variations between basis metals of a given group have no large effects. A greater thickness of nickel is required to furnish a given degree of protection on zinc than on brass, and greater on steel than on zinc.

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