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1964 Exposure Test of Porcelain Enamels on Aluminum Three Year Inspection

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Contents

1964 Exposure Test of Porcelain Enamels on Aluminum—Three Year Inspection

Margaret A. Baker *

An exposure test of porcelain enamels on aluminum was initiated by the National Bureau of Standards and the Porcelain Enamel Institute in 1964. The enamels were returned from the exposure sites to the laboratory at NBS to be measured for changes in gloss and color after exposures of six months, one year, and three years. Changes were found to be greatest at Kure Beach and least at Montreal and Los Angeles, with moderate changes occurring at Washington and New York.

Although the boiling citric acid test is used as an acceptance test for these enamels, the correlation with color change, particularly at Kure Beach, was not as good as expected. A cupric chloride test was developed which shows an improvement in this correlation.

Key words: Color; gloss; porcelain enamel on aluminum; weather resistance.

1. Introduction

The application of porcelain enamels to aluminum is a relatively recent development in the field of porcelain enameling. A few of the early porcelain enamels on aluminum included in an exposure test initiated in 1956 [1] [1] indicated that accelerated tests used with confidence for porcelain enamels on steel were not reliable indicators of the weatherability of the new, lower firing porcelain enamels on aluminum. Therefore the Aluminum Council of the Porcelain Enamel Institute agreed to sponsor, with the National Bureau of Standards, an exposure test consisting solely of porcelain enamels on aluminum. Nine colors used in porcelain enamels on aluminum and enamels varying in initial gloss and thickness were tested.

The enamels in this test are exposed at Kure Beach, North Carolina; New York, New York; Washington, D.C.; Los Angeles, California; and Montreal, Canada. They were inspected after exposures of six months, one year, and three years and were returned to the exposure racks for further exposure. This report is a summary of the results of these three inspections. The next inspection is tentatively scheduled after five years of exposure.

2. Materials and Procedures

2.1. Enamels

Sixteen enamel systems were included in this test. These enamel systems were represented by nine colors, three gloss ranges, and both one- and two-coat enamels as indicated in table 1.

The enamels in this test were coded for identification. Each enamel system can be identified by the first two code letters. The first letter is always A and indicates an enamel on aluminum. This letter may seem redundant but it is included because the manufacturers recognize their enamels by the three letter code. The second letter indicates the enamel system—color, number of coats, and gloss range—while the third letter indicates the different fabricators for each system. The differences between the enamel systems are apparent (see table 1) for all systems except AA and AZ, which were planned to have significantly different thicknesses. However, this difference was not attained during manufacture.

When variations in milling and firing of the enamels by the different fabricators are taken into account, there are, in effect, 51 different enamels included in this test.

2.2. Test Specimens

Each enamel was sprayed onto a 3 × 5-ft sheet of 0.064-in 6061 aluminum alloy. After the enamel was fired the sheet was cut with a band saw into a seventy-eight $4\frac{7}{16}$-in-square and nine 4 × 6-in exposure specimens. This was done to obtain more uniform specimens than could be obtained by spraying and firing small individual metal blanks. Also, the specimens thus obtained would more closely simulate actual production enamels than small individually prepared specimens.

2.3. Exposure Sites

Three of the $4\frac{7}{16}$-in-square specimens of each enamel were exposed on the roofs of Federal Government Buildings in New York, N.Y.; Los Angeles, California; and Washington, D.C.; as well as on the roof of the Stores Department Building in Montreal, Canada. Three of the 4 × 6-in specimens of each enamel

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[1] Figures in brackets indicate the literature references at the end of this paper.

were exposed at a ground site of the International Nickel Company's Corrosion Laboratory at Kure Beach, North Carolina, 80 feet from the ocean. In addition to the exposed specimens, three specimens of each enamel were stored for reference purposes. The remaining specimens of each enamel were kept for use in laboratory tests and for the development of new test methods.

2.4. Cleaning of Specimens

The enamel surface was cleaned before being measured for gloss and color. The cleaning treatment consisted of (1) scouring 30 strokes with a sponge that had been dampened with a 1 percent solution of trisodium phosphate and sprinkled with calcium carbonate, (2) rinsing with tap water, (3) rinsing with

TABLE 1. *Initial data for porcelain enamels on aluminum*

Enamel	Specified properties			Measured properties			
	Visual color	Nominal gloss	Number of coats	45° [a] Specular gloss	Thickness [b]	Boiling [c] acid solubility	Acid [d] spot test ratings
					mils	*mg/in²*	
AA–A	White	High	Two	70.1	4.5	5.5	A
AA–B				74.2	4.3	5.9	A
AA–C				71.5	3.4	5.0	AA
AA–D				71.9	6.5	12.7	AA
AB–A	White	Medium	Two	56.8	4.0	7.2	B
AB–C				55.6	4.0	4.9	A
AB–D				28.9	6.2	7.9	A
AC–A	White	High	One	74.5	3.5	6.4	A
AC–B				71.8	2.8	11.3	AA
AC–C				70.5	3.3	9.9	AA
AD–A	White	Medium	One	55.0	2.8	6.2	AA
AD–B				68.3	4.3	6.7	B
AD–C				42.4	3.2	7.1	B
AD–D				34.9	2.7	12.4	A
AE–A	Black	High	One	75.6	2.4	6.5	A
AE–B				78.0	1.6	10.1	A
AE–C				78.1	2.0	12.1	A
AE–D				75.0	3.4	15.5	B
AF–A	Black	Medium	One	78.4	1.5	14.2	B
AF–B				58.5	2.7	9.0	B
AF–C				76.8	3.1	10.1	C
AG–B	Black	Low	One	26.0	3.0	12.5	B
AG–C				12.6	2.0	7.5	A
AH–A	Red	High	One	46.9	2.8	7.4	A
AH–B				85.3	3.1	8.8	B
AH–C				85.6	3.1	6.5	B
AH–D				82.0	1.9	10.5	B
AO–A	Dark green	High	One	78.8	3.2	19.9	A
AO–B				79.8	1.6	10.1	A
AO–D				78.3	2.1	17.0	A
AP–A	Light green	Medium	Two	42.4	6.4	12.3	B
AP–B				38.5	4.1	6.4	A
AP–C				30.2	4.0	6.2	A
AP–D				45.3	6.4	10.0	A
AR–A	Light green	Low	Two	9.6	3.2	4.4	A
AR–B				7.3	2.7	5.5	A
AR–C				5.7	4.3	8.1	A
AS–A	Grey	Medium	Two	64.9	5.0	13.4	A
AS–B				61.6	5.5	7.4	AA
AS–C				62.2	3.9	5.4	A
AT–A	Blue	Medium	Two	32.9	4.4	6.2	A
AT–B				54.8	3.6	7.0	A
AT–C				62.4	2.9	6.1	AA
AU–A	Brown	Medium	Two	50.0	7.2	5.3	A
AU–B				35.4	6.4	7.5	A
AU–C				46.6	4.4	7.6	A
AW–A	Yellow	Medium	Two	62.4	5.8	7.8	A
AW–B				63.1	4.1	8.7	A
AW–C				80.9	5.0	18.6	A
AZ–A	White	High	Two	72.0	4.2	9.5	A
AZ–B				71.2	2.7	5.2	A

[a] The 45° specular gloss was measured in accordance with ASTM designation C–346.
[b] The thickness was measured in accordance with ASTM designation E–376.
[c] The boiling acid solubilities were determined in accordance with ASTM designation C–283.
[d] The acid spot test ratings were determined in accordance with ASTM designation C–282.

distilled water, and (4) rinsing with alcohol. Before adopting this cleaning procedure, representative specimens of low, medium, and high gloss enamels were scoured with calcium carbonate for 650 strokes. No change in gloss was noted on the high gloss enamels while an increase of about 5 percent was noted after 350 strokes on both the medium and low gloss enamels. The gloss increased by about 15 percent after 650 strokes. The increase caused by the scouring may be the result of a smoother surface which reflects light better than the original surface. Since the increase was only 5 percent after 350 strokes (enough for 10 inspections) it was thought that this treatment would not significantly affect the exposure test results. The scouring treatment produced no noticeable color change.

2.5. Acid Resistance

The acid resistance of porcelain enamels on aluminum is measured by either the boiling acid solubility test [2] or by the citric acid spot test [3]. The enamels are rated by the boiling acid solubility test on the basis of weight loss per unit area; the enamels with the best acid resistance have the lowest weight loss. In the citric acid spot test the enamels are divided into five categories: AA, A, B, C, or D, with respectively decreasing acid resistance. Both the boiling acid solubility and citric acid spot test ratings for the enamels included in this test are presented in table 1.

2.6. Thickness

The enamel thickness was measured at four locations on each specimen with an eddy current thickness gage [4]. The average thickness for each enamel is presented in table 1.

2.7. Gloss and Color

The 45-degree specular gloss of the enamels was measured [5] at four orientations near the center of the specimen before and after exposure. The average initial gloss for each enamel is given in table 1. The gloss after exposure is reported as the percentage gloss retained.

The color is measured before and after exposure with a color difference meter [6]. One of the three average storage specimens of each enamel was selected as the color standard to obtain the maximum efficiency possible with this type of instrument. The color change was calculated [7] from the color values and is reported as color retention which is 100 minus the color change in NBS units.

3. Results and Discussion

3.1. Visual Observation of Enamels

a. Amount of Soil Retained

A visual examination revealed that enamels exposed at New York City had the most dirt adhering to them while those exposed at Los Angeles, Washington, Montreal, and Kure Beach had respectively cleaner surfaces. The dirt deposits were readily removed from the enamels exposed at all sites except New York by the cleaning procedure outlined in section 2.4. The enamels exposed at New York required vigorous scouring with a sponge that was sprinkled with calcium carbonate to remove the dirt film.

b. Spalling

After the specimens were cleaned it was observed that "fishscale" type spalling occurred on some enamels exposed at all sites. In no case was the spalled area large enough to constitute failure [8].

c. Visual Evaluation of Color and Gloss

The enamels exposed at Washington, New York, Montreal, and Los Angeles appeared to have good color and gloss retention with the exception of the red enamels, which appeared lighter than the unexposed enamels. Many of the enamels exposed at Kure Beach had obviously undergone substantial color changes. The reds, blacks, dark greens, and blues lightened considerably. The red, dark green, and blue enamel surfaces had the appearance of light particles surrounded by a darker colored matrix, while the black enamel surfaces appeared uniformly lightened. Many of the white enamels exposed at Kure Beach appeared to be yellowing. The weathering of some of the enamels exposed at Kure Beach had progressed to a point where changes in the gloss were readily apparent and the surfaces appeared chalky.

3.2. Instrumental Determinations of Color and Gloss

The average color- and percentage gloss-retention values obtained from the six-months', one-year's and three-years' inspections of these enamels are presented in tables 2 and 3. The data in figures 1 and 2 indicate that gloss does not change as uniformly with exposure time as color. The nonuniformity is probably caused by the exceptionally large percentage changes which result from small gloss changes for the low gloss enamels. For example, a change of one gloss unit will produce a 17 percent change in the gloss retained for low gloss enamel, AR-C, but only a 1 percent change for high gloss enamel, AO-A. The increase in percentage gloss retained for many of the low gloss enamels after three years' exposure (see table 3) may be caused by a smoothing of the surface by the weather.

An increase in the gloss-rentention values of many low and medium gloss enamels exposed at New York City was also observed. These increases are attributed more to the severe scouring treatment necessary to

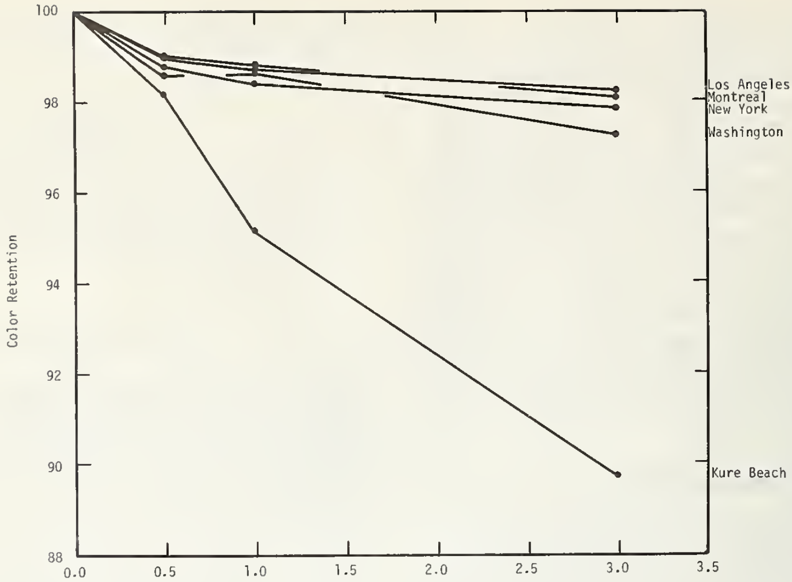

FIGURE 1. *The effect of exposure time at the five weathering sites on the color retention of porcelain enamel on aluminum.*

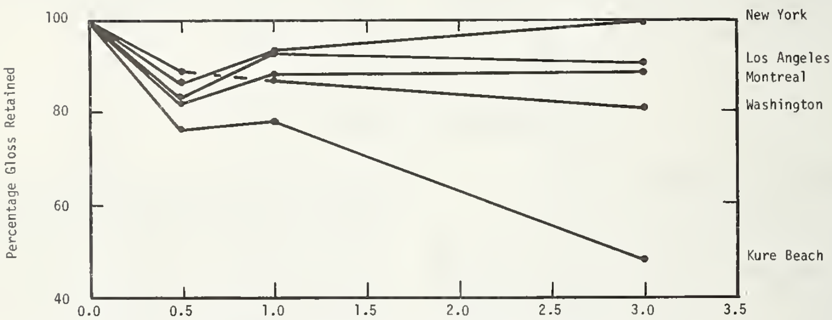

FIGURE 2. *The effect of exposure time at the five weathering sites on the gloss retention of porcelain enamel on aluminum.*

clean these specimens than to the action of the weather.

Since the percentage gloss-retention values were more variable than the color-retention values, the remainder of this report will be based primarily on color retention.

3.3. Comparison of Exposure Sites

The color-retention data were subjected to a two-sided sign test [9] to determine if the exposure conditions at the various sites caused significant differences in the color retention of the enamels. The exposure sites were divided into three categories on the basis of the observed results of the sign test. Kure Beach was in a category by itself and caused the greatest color change in the enamels. New York and Washington were grouped together and caused less severe color changes than Kure Beach but more severe than the sites in the third category, Montreal and Los Angeles.

3.4. Effect of Different Colors

The average color retentions for the nine enamel colors are presented in table 4 and figure 3. It can be seen that large color changes occurred for the red enamels exposed at all sites. This was expected since all the red enamels included in this test failed the nitric acid test for color retention [10] and would not be recommended for outdoor exposures.

Large color changes also occurred on the black, dark green, grey, and blue enamels exposed at Kure Beach. These changes were not predicted by any of the current tests for porcelain enamels on aluminum.

3.5. Effect of Initial Gloss

The enamels included in this test program were produced in three gloss ranges; low, having an initial 45-degree specular gloss of 35 or less; medium, between 36 and 69; and high, 70 or over. The average color-retention data (top section of table 5) indicate

TABLE 2. *Percentage gloss-retained data for the enamels exposed for three years in the 1964 exposure test of porcelain enamel on aluminum*

Enamel	Average percentage of initial gloss retained for enamels exposed at:[a]														
	Kure Beach			New York			Washington			Los Angeles			Montreal		
	6-Mo.	1-Yr.	3-Yr.	6-Mo.	1-Yr.	3-Yr.	6-Mo.	1-Yr.	3-Yr.	6-Mo.	1-Yr.	3-Yr.	6-Mo.	1-Yr.	3-Yr.
AA–A	85.5	95.2	46.9	98.3	96.5	96.3	93.2	91.6	96.9	95.6	97.8	94.1	93.8	90.4	92.6
AA–B	94.0	87.5	98.9	94.5	93.5	90.8	92.7	91.5	94.3	103.0	100.9	95.1	98.6	93.2	90.3
AA–C	90.7	107.4	94.6	92.3	89.6	90.6	90.7	90.8	102.1	96.0	96.8	90.9	92.0	87.6	90.8
AA–D	76.0	33.0	7.8	101.1	97.8	97.4	94.6	92.5	25.0	101.0	100.4	93.5	100.0	93.1	69.3
AB–A	81.2	88.4	42.6	95.9	94.2	102.5	82.8	80.9	75.3	84.5	88.3	84.8	83.9	95.7	81.5
AB–C	79.6	86.4	63.6	83.9	84.4	86.7	81.0	33.6	79.7	83.6	87.9	84.6	82.7	82.7	82.3
AB–D	75.3	80.2	25.8	100.5	112.1	118.6	93.3	92.0	94.2	79.6	98.1	99.1	80.0	95.9	100.8
AC–A	90.2	90.7	80.0	96.3	93.1	85.3	93.0	91.8	94.8	102.6	101.0	95.5	98.6	93.1	91.5
AC–B	85.8	37.3	8.2	103.4	98.4	95.9	92.8	90.2	49.7	102.1	101.3	98.7	101.3	97.1	87.0
AC–C	90.6	65.3	14.1	99.0	96.8	99.4	93.7	92.1	91.7	98.2	98.1	95.0	98.3	94.1	93.1
AD–A	87.6	96.9	43.4	100.9	99.9	101.9	91.7	91.1	94.9	90.3	95.7	94.6	90.3	91.1	92.3
AD–B	89.0	93.8	94.1	97.4	94.5	95.0	89.8	88.9	87.0	92.4	94.9	92.4	90.5	88.2	88.8
AD–C	82.8	91.3	27.6	105.3	106.4	116.3	90.9	90.3	92.2	87.5	95.4	94.7	88.6	94.5	95.5
AD–D	87.5	58.0	19.7	104.7	114.6	118.6	98.0	96.5	41.1	88.6	103.1	104.8	87.7	100.3	91.6
AE–A	76.4	68.4	49.7	82.1	80.3	80.8	81.3	80.5	78.8	80.5	80.5	78.5	82.1	80.2	80.3
AE–B	65.1	55.8	16.7	84.6	83.7	82.7	86.5	82.9	78.9	87.9	86.6	81.9	88.8	95.1	80.7
AE–C	72.6	68.2	36.4	86.7	83.7	83.8	89.4	85.6	80.8	91.1	89.9	84.7	91.9	85.1	83.0
AE–D	71.1	37.8	8.2	83.3	79.9	80.2	82.2	78.4	76.3	85.5	83.2	78.9	87.4	83.0	78.3
AF–A	65.6	67.9	23.5	82.1	82.1	98.0	85.7	80.0	76.3	85.7	84.3	81.9	90.4	84.3	79.5
AF–B	69.7	58.5	16.2	88.3	95.3	81.7	84.5	91.7	89.6	96.1	96.5	94.3	95.6	95.3	94.6
AF–C	72.2	76.8	42.0	84.4	83.3	79.7	84.5	82.6	77.2	87.5	86.6	81.4	88.2	85.4	81.2
AG–B	82.0	83.7	39.6	76.2	100.4	108.1	100.5	97.8	93.4	79.5	103.1	103.3	98.9	100.5	104.6
AG–C	46.9	112.8	78.4	35.9	101.0	127.2	105.7	100.8	85.3	33.2	103.8	109.8	31.8	97.0	107.5
AH–A	90.8	79.3	51.6	118.3	121.3	103.8	95.8	96.6	97.1	103.7	113.2	111.7	97.8	103.6	103.8
AH–B	64.3	44.8	8.5	81.7	75.6	76.8	72.3	70.0	65.4	76.8	77.6	73.3	75.4	75.7	71.5
AH–C	73.9	59.2	43.6	79.0	75.6	77.1	70.8	68.5	67.8	77.6	77.4	70.8	77.3	93.6	70.4
AH–D	59.7	37.8	6.5	79.0	77.0	77.6	74.7	70.6	64.5	83.2	81.8	75.2	82.8	77.6	66.5
AO–A	76.6	60.9	35.4	80.2	78.5	81.6	82.1	79.3	78.4	83.3	83.3	79.0	83.8	81.4	80.6
AO–B	72.5	67.0	34.3	83.0	83.1	80.4	84.0	82.7	76.4	84.6	86.0	81.3	83.4	83.1	80.0
AO–D	74.1	50.8	15.2	81.0	79.1	73.2	83.8	80.7	77.7	87.0	84.2	79.1	87.8	84.9	81.2
AP–A	82.2	80.4	16.3	102.3	104.9	113.0	95.5	93.4	84.1	90.2	97.4	95.2	92.1	98.3	95.0
AP–B	75.5	87.1	78.6	86.3	94.6	109.8	82.9	81.9	80.0	77.0	89.6	86.2	78.6	82.8	85.5
AP–C	73.9	84.1	84.3	85.8	98.9	116.6	85.7	83.9	82.7	72.5	91.3	88.2	85.7	83.9	90.0
AP–D	87.5	88.9	42.7	95.4	100.8	111.3	93.9	93.4	92.7	88.0	95.2	93.4	91.7	94.7	96.7
AR–A	47.0	128.2	109.4	54.2	138.4	174.5	111.8	104.8	95.7	25.5	122.2	128.8	62.4	106.5	118.1
AR–B	0.0	96.1	60.7	0.0	110.9	157.0	82.5	74.7	59.7	0.0	81.7	101.7	4.4	73.6	97.4
AR–C	0.0	105.9	70.0	0.0	84.6	117.0	85.7	81.6	58.2	0.0	81.6	109.0	0.0	69.6	105.3
AS–A	78.2	59.5	22.2	91.7	88.3	93.9	90.2	93.0	75.4	92.1	93.0	88.6	91.2	89.7	87.3
AS–B	83.7	86.4	33.6	85.0	84.5	92.6	83.0	82.3	81.3	82.5	84.6	82.8	83.0	82.3	81.9
AS–C	92.5	97.7	80.7	90.4	89.9	96.5	91.8	92.2	93.1	93.3	95.5	91.5	91.7	89.1	90.6
AT–A	75.2	93.8	82.2	80.4	94.1	116.0	83.8	83.2	72.9	71.4	91.0	87.3	68.3	83.1	87.4
AT–B	79.8	93.4	38.0	91.5	95.6	107.3	93.8	94.1	97.2	90.9	95.5	92.8	91.5	90.9	94.9
AT–C	81.5	82.0	32.4	83.3	83.0	89.5	78.8	79.2	76.2	82.0	84.0	80.8	80.9	79.9	77.5
AU–A	89.1	89.8	99.1	88.3	90.7	104.0	84.3	84.9	84.4	87.7	92.5	86.3	81.2	83.4	85.5
AU–B	75.7	93.4	70.1	98.0	108.1	121.5	92.4	91.8	86.4	80.3	94.9	94.6	79.9	89.7	94.2
AU–C	87.4	94.7	72.3	95.1	98.0	106.1	94.5	93.9	92.9	91.4	97.9	95.9	91.5	93.5	95.3
AW–A	81.4	80.1	98.0	86.2	85.1	87.8	82.7	81.5	77.9	85.3	85.8	83.2	85.7	83.5	81.7
AW–B	78.8	79.2	27.9	95.6	94.3	95.0	93.3	92.4	93.3	93.7	95.2	93.0	94.2	92.7	92.4
AW–C	72.1	47.6	17.7	91.4	85.4	86.4	84.6	81.4	66.3	91.7	90.3	85.8	90.3	86.3	74.7
AZ–A	100.9	50.1	9.5	103.4	99.2	102.2	93.5	91.5	84.2	104.1	102.1	99.9	102.4	98.0	94.5
AZ–B	94.2	110.7	102.2	90.9	64.1	91.7	90.6	91.2	101.7	99.1	98.0	90.8	93.9	89.2	88.5
Average	75.8	77.9	47.5	85.7	93.2	99.6	88.8	86.7	80.7	82.9	92.9	91.0	81.7	88.3	88.5

[a] Computed from three speciamens at each site.

no difference between the low and medium gloss enamels at any site but the high gloss enamels have lower color retentions at all sites. When the enamels were separated into individual colors, it was found that only the white, black, and light green enamels were produced in more than one gloss range. Study of the gloss-retained values for these colors (bottom of table 5) indicated no consistent correlation between color retention and initial gloss.

3.6. Effect of Coating Thickness

The average color retention for the one- and two-coat enamels (top part of table 6) indicates a difference in these systems. However, since the enamel colors weather differently, the only valid comparison is between white enamels, the only color produced in both one- and two-coat forms. This comparison is given in the lower part of table 6. Although the

TABLE 3. *Color-retention data for enamels exposed for three years in the 1964 exposure test of porcelain enamels on aluminum*

Enamel	Average color retention [a] for enamels exposed at:[b]														
	Kure Beach			New York			Washington			Los Angeles			Montreal		
	6-Mo.	1-Yr.	3-Yr.	6-Mo.	1-Yr.	3-Yr.	6-Mo.	1-Yr.	3-Yr.	6-Mo.	1-Yr.	3-Yr.	6-Mo.	1-Yr.	3-Yr.
AA–A	99.4	98.1	96.4	99.4	99.3	99.1	99.5	99.6	99.4	99.5	99.3	99.3	99.5	99.6	99.5
AA–B	99.3	98.7	96.4	99.7	99.4	98.9	99.5	99.3	99.2	99.3	99.0	99.3	99.4	99.4	99.3
AA–C	99.0	97.0	95.1	99.2	99.0	98.8	98.8	98.8	98.5	99.0	98.5	98.8	98.9	99.0	98.9
AA–D	98.3	97.0	96.4	97.9	97.4	95.8	97.8	97.9	97.2	98.2	98.8	97.6	97.8	97.8	96.2
AB–A	98.8	97.8	94.8	98.1	97.8	97.0	98.8	98.8	98.6	98.7	98.6	97.8	98.7	98.5	97.8
AB–C	99.6	99.1	99.2	99.2	99.0	98.7	99.5	99.5	99.5	99.4	99.3	99.3	99.4	99.4	99.2
AB–D	98.5	97.6	95.8	98.3	98.4	97.9	98.9	98.8	98.5	98.4	99.1	97.5	98.9	98.9	97.2
AC–A	99.4	98.7	96.5	99.3	99.3	99.0	99.3	99.2	99.1	99.1	98.7	99.0	98.6	99.3	99.2
AC–B	98.7	98.1	97.6	99.0	97.1	97.1	99.1	98.8	98.4	98.6	99.2	98.2	99.0	98.4	97.9
AC–C	98.3	96.9	95.1	98.7	98.4	98.3	98.6	98.6	98.7	98.9	98.8	98.2	98.9	98.9	98.0
AD–A	98.9	98.6	96.6	99.2	99.2	98.4	99.4	99.4	99.1	99.4	99.3	99.4	99.5	99.3	99.1
AD–B	99.4	98.3	95.1	99.1	99.2	99.0	99.6	99.6	99.6	99.4	99.3	99.4	99.5	99.5	99.2
AD–C	98.1	96.9	91.9	98.1	97.9	97.4	99.0	98.8	98.0	98.5	98.4	97.6	99.1	98.9	95.5
AD–D	98.1	97.3	96.0	98.1	96.7	96.6	96.9	98.1	97.4	98.4	98.9	99.0	98.8	99.1	98.1
AE–A	99.1	94.3	79.0	99.8	99.1	99.5	98.6	98.8	97.9	99.8	97.2	99.1	99.8	99.9	99.6
AE–B	98.6	89.1	73.4	99.6	99.4	99.6	99.8	99.8	98.7	99.7	99.1	99.4	99.5	99.0	99.0
AE–C	98.9	92.9	82.0	99.6	99.6	98.4	99.6	99.6	98.8	99.4	99.2	98.8	99.5	99.0	99.4
AE–D	98.6	76.6	50.3	98.9	98.2	96.4	98.0	96.4	94.3	99.4	97.2	99.0	99.7	98.4	98.1
AF–A	98.4	88.8	61.0	98.5	97.7	98.3	99.2	99.1	97.5	99.6	97.9	98.6	99.3	98.4	98.2
AF–B	99.1	88.7	84.7	99.4	98.4	95.3	98.8	99.0	96.9	99.3	99.4	99.4	99.4	99.7	99.4
AF–C	98.4	93.1	84.6	99.3	98.1	94.1	98.8	99.1	94.0	99.6	98.3	98.6	99.8	99.4	99.1
AG–B	97.6	88.2	81.7	98.4	98.5	97.0	98.6	98.7	97.2	99.3	98.1	98.0	98.9	98.5	98.9
AG–C	98.2	97.1	83.8	98.3	98.1	98.4	99.4	99.5	98.1	99.4	99.0	98.7	99.5	99.5	99.1
AH–A	97.5	93.5	85.9	97.6	97.1	95.7	98.1	97.6	96.9	97.4	96.9	95.3	97.5	97.4	95.5
AH–B	93.0	83.1	63.0	96.6	95.1	92.9	94.6	94.0	89.6	95.5	94.4	93.9	95.2	95.2	93.5
AH–C	90.1	86.3	71.0	91.5	90.7	90.1	91.9	91.5	73.4	91.9	91.4	92.7	92.8	91.8	90.1
AH–D	83.6	70.2	61.2	95.2	90.8	86.3	88.9	87.2	82.5	91.0	88.4	85.8	89.7	88.1	80.8
AO–A	95.4	91.7	83.0	99.7	99.0	99.0	99.1	99.0	97.6	99.9	99.2	98.3	99.3	99.0	99.2
AO–B	99.5	97.3	87.2	99.7	99.3	99.1	99.5	99.7	98.9	99.8	99.4	99.5	99.7	99.3	99.5
AO–D	97.8	92.0	80.9	99.4	98.6	97.6	98.5	98.0	95.8	98.9	98.6	96.6	99.4	99.0	98.2
AP–A	98.7	95.2	88.4	99.4	99.5	99.5	99.4	99.2	98.1	99.3	99.3	98.9	99.5	99.3	98.8
AP–B	99.4	98.7	96.3	99.6	99.4	99.5	99.4	99.4	99.2	99.6	99.6	99.4	99.6	99.4	99.1
AP–C	99.5	98.9	97.5	99.6	99.7	99.5	99.0	99.1	99.0	99.2	99.6	99.2	99.5	99.6	98.9
AP–D	99.1	97.1	91.7	99.5	99.3	99.2	99.0	99.0	98.8	99.2	99.3	98.8	99.3	99.3	98.7
AR–A	99.6	99.6	99.0	99.3	99.3	98.8	99.5	99.4	99.4	99.6	99.6	99.4	99.6	99.7	99.5
AR–B	99.4	98.8	95.9	98.8	98.7	97.9	99.6	98.7	97.9	99.6	99.6	99.6	99.7	99.7	99.3
AR–C	99.4	98.3	94.8	98.8	98.6	98.1	99.6	99.6	96.2	99.5	99.4	99.3	99.7	99.6	99.3
AS–A	98.7	96.2	91.2	99.4	99.3	99.5	99.4	99.0	97.0	99.5	99.6	98.8	99.5	99.4	98.7
AS–B	98.9	97.3	88.7	99.2	99.4	98.8	99.3	99.1	98.1	99.3	99.3	98.8	99.4	99.3	98.7
AS–C	99.8	99.6	96.2	99.6	99.5	99.7	99.6	99.7	99.3	99.8	99.6	99.6	99.8	99.6	99.6
AT–A	99.0	97.4	90.6	98.9	98.8	98.0	98.9	98.9	98.2	99.1	99.3	98.6	99.1	99.1	98.8
AT–B	98.6	94.9	87.9	98.6	98.8	98.2	98.9	99.0	98.1	97.9	97.8	98.2	99.3	99.1	98.6
AT–C	98.7	96.2	86.2	99.7	99.1	98.7	97.1	99.1	98.4	99.0	98.9	98.3	99.3	99.4	99.3
AU–A	99.3	99.4	98.1	99.7	99.8	98.0	99.7	99.7	99.4	99.7	99.7	99.6	99.8	99.7	99.6
AU–B	99.2	99.4	97.6	99.5	99.4	99.1	99.6	99.6	99.0	99.8	99.7	99.5	99.8	99.6	99.4
AU–C	99.8	99.6	97.8	99.6	99.6	99.6	99.5	99.4	99.3	99.8	99.8	99.6	99.8	99.8	99.2
AW–A	99.2	98.7	95.3	99.5	99.5	99.0	99.4	99.4	98.7	99.6	99.5	98.9	99.6	99.6	99.2
AW–B	99.3	97.3	93.9	99.3	99.2	98.8	99.2	99.0	98.8	99.3	99.3	98.8	99.2	99.3	99.2
AW–C	98.9	95.9	92.6	99.4	99.0	98.6	99.4	99.0	96.4	99.4	99.5	98.6	99.4	99.4	97.8
AZ–A	97.7	98.9	98.0	99.2	99.0	98.5	99.3	99.2	99.0	98.9	99.1	99.0	99.1	99.2	98.2
AZ–B	99.1	97.8	95.3	99.2	98.9	98.9	99.0	98.9	98.8	98.8	98.8	99.0	99.3	99.0	99.0
Average	98.2	95.1	88.7	98.8	98.4	97.8	98.6	98.6	97.2	98.9	98.7	98.2	98.9	98.8	98.1

[a] Color Retention is 100 minus the color change in NBS units.
[b] Computed from three specimens at each site.

TABLE 4. *Color Retention for the various colors of porcelain enamels on aluminum after three years' exposure*

Enamel color	Average color retention [a] for the enamels exposed at:				
	Kure Beach	Washington	New York	Montreal	Los Angeles
Red	70.3	85.6	91.3	90.0	91.9
Black	75.6	97.0	97.2	99.0	98.8
Dark green	83.7	97.4	98.6	99.0	98.1
Blue	88.2	98.2	98.3	98.9	98.4
Grey	88.7	98.1	99.3	99.0	99.1
Yellow	93.9	98.0	98.8	98.7	98.8
White	96.0	98.7	98.1	98.3	98.5
Light green	94.8	98.4	98.9	99.1	99.2
Browu	97.8	99.2	98.9	99.4	99.6

[a] Color retention is 100 minus the color change in NBS units.

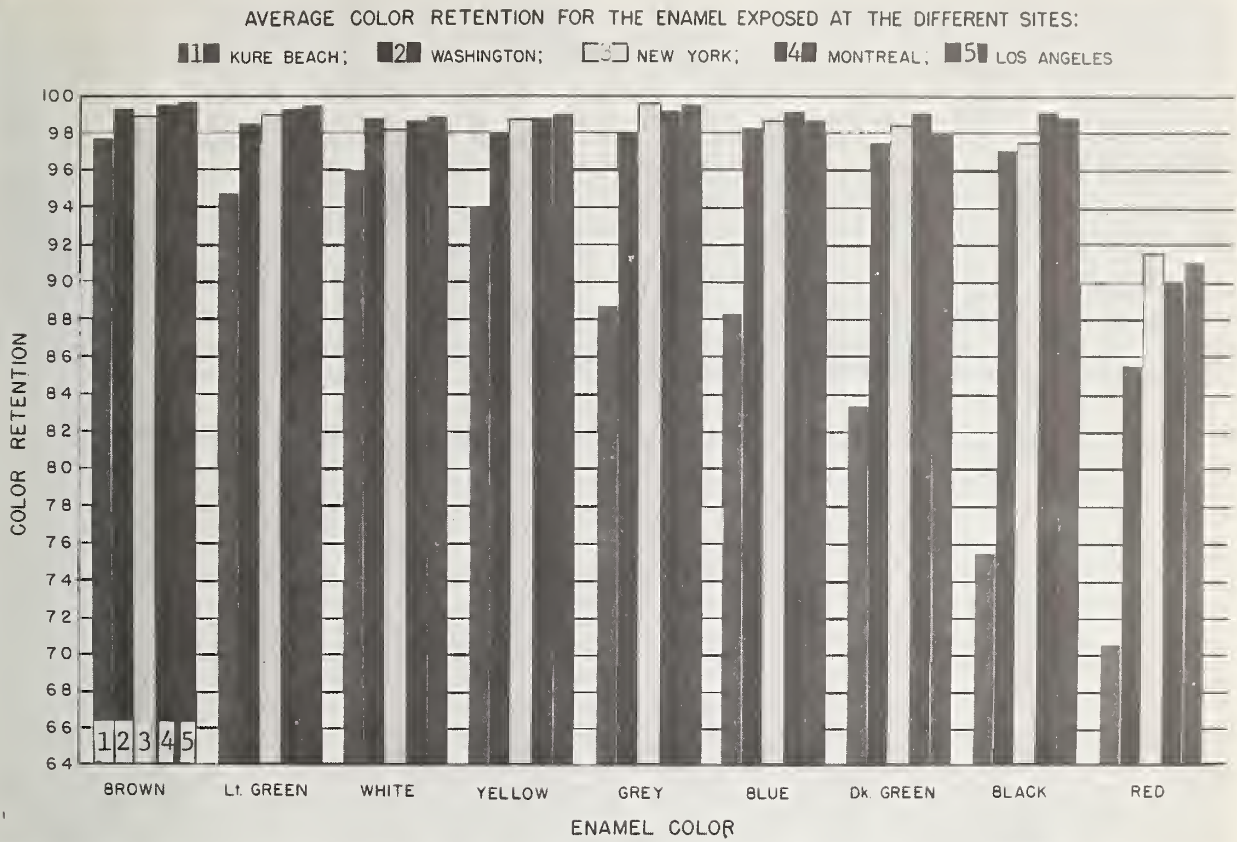

FIGURE 3. *Comparison of the color retention of the nine different colors included in this test program.*

TABLE 5. *Effect of initial gloss on the color retention of porcelain enamels on aluminum*

Initial gloss	Average color retention [a] for the enamels exposed at:				
	Kure Beach	Washington	New York	Montreal	Los Angeles
	All Enamels				
Low	92.8	97.8	98.0	98.8	98.8
Medium	92.9	98.5	98.5	98.7	98.8
High	83.4	95.6	97.0	97.2	97.6
	Colors produced in more than one gloss range				
	White				
Low	95.9	98.0	97.3	97.7	97.7
Medium	95.5	99.0	98.1	98.2	98.2
High	96.3	98.7	98.3	98.5	98.7
	Black				
Low	82.8	97.7	97.7	99.0	98.4
Medium	84.7	96.9	95.8	99.4	99.4
High	71.7	96.9	97.7	99.1	98.9
	Light green				
Low	96.6	97.8	98.3	99.5	99.4
Medium	93.5	98.8	99.4	99.1	98.5

[a] Color retention is 100 minus the color change in NBS units.

Table 6. *Effect of one and two coats on the color retention of porcelain enamels on aluminum*

Number of coats	Average color retention [a] for the enamels exposed at:				
	Kure Beach	Washington	New York	Montreal	Los Angeles
	All Enamels				
One	81.8	95.6	96.7	97.1	97.5
Two	94.5	98.5	98.6	98.8	98.9
	White Enamels Only				
One	96.4	98.2	98.7	98.6	98.4
Two	95.5	98.0	98.6	98.1	98.1

[a] Color retention is 100 minus the color change in NBS units.

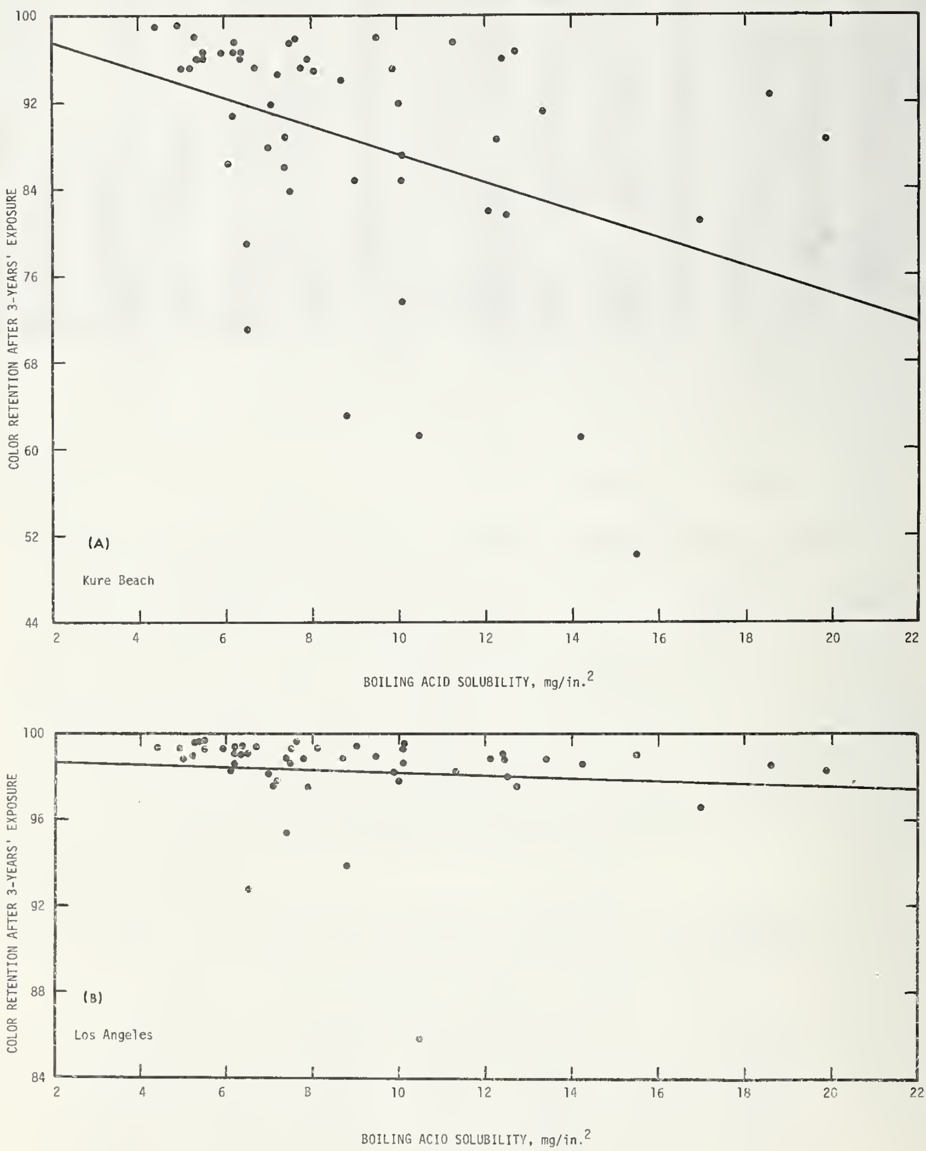

Figure 4. *Correlation between boiling acid solubility test and color retention for the enamels exposed at (a) Kure Beach, (b) Los Angeles.*

differences in color retention of the one- and two-coat systems are small, less than one NBS unit at all sites, they may prove significant after longer exposure times. The one-coat enamels had consistently higher color retentions than the two-coat enamels.

3.7. Correlation with Accelerated Tests

The correlation between color retention and the boiling acid solubility test is illustrated for Kure Beach and Los Angeles in figure 4. It can be seen that at the mild site, Los Angeles, the color retention remains high regardless of the boiling acid solubility, while at the severe site, Kure Beach, the color retention may be as low as 70 or as high as 98 for approximately the same value of boiling acid solubility.

The relatively poor correlation between color retention and boiling acid solubility led to the development of another test which could be useful in predicting the color retentions of these enamels. The new test uses the same apparatus as the boiling acid solubility test but the reagents and time of treatment were changed. Fifty ml of 12.5 percent aqueous cupric chloride solution are substituted for 150 ml of 6 percent citric acid. The specimen surface is exposed to boiling cupric chloride solution for one hour. The treated area is then rinsed with 10 ml of a 1 percent solution of oxalic acid to remove any green copper stains that may have accumulated. The specimen is removed from the apparatus, washed with a mild detergent solution, rinsed with tap water, distilled

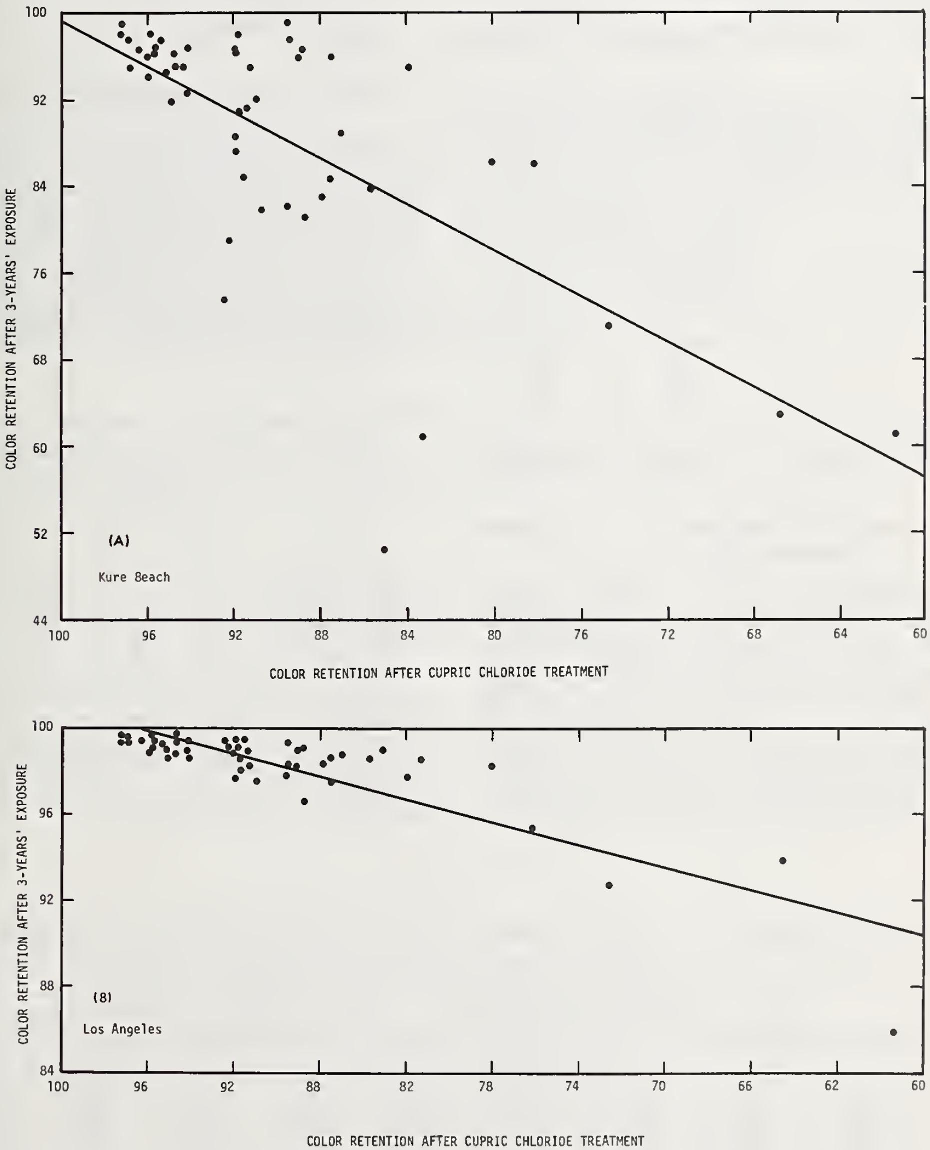

FIGURE 5. *Correlation between boiling cupric chloride treatment and color retention for the enamels exposed at (a) Kure Beach, (b) Los Angeles.*

water, and alcohol, and allowed to dry in a near vertical position. After the specimens are dry the color difference between the tested and untested portions of the specimens is determined and is used as a measure of the specimens' weather resistance. These values are plotted as a function of the color-retention values after three years' exposure in figure 5. The correlation is improved over that obtained for the boiling acid solubility as indicated by the smaller residual standard deviations (see table 7) for the fits of the least squares lines. Although the correlation between the color retention and the results of the boiling cupric chloride test is better than that with the boiling acid solubility test, it is felt that longer exposure times are necessary before any recommendations for specification changes are made. This increased exposure time is necessary because the color retention after three years' exposure of the enamels that passed the boiling acid solubility test is adequate (more than 94) at all sites except Kure Beach.

TABLE 7. *Comparison of the residual standard deviations [a] for the least squares fits for boiling acid solubility and cupric chloride tests versus color retention of exposed enamels*

Exposure site	Residual standard deviation of fit	
	Boiling acid solubility	Cupric chloride
Kure Beach	10.24	8.14
Washington	4.39	3.11
New York	2.45	1.48
Montreal	3.00	1.85
Los Angeles	2.23	1.20

[a] These residual standard deviations were computed by a subroutine called "Ortho", Walsh, P., Ortho, Commun. Assoc. Computing Mach. 5 511–13 (1962).

3.8. Correlation with Enamels in a Previous Exposure Test

Kure Beach, Washington, and Los Angeles are three sites common to both the current test and a test initiated in 1956 [11]. The average color-retention data for the enamels exposed at these sites in both tests are included in table 8. These data indicate that the enamels in the current test are as durable as the early porcelain enamels on aluminum at all sites, and at the milder sites, Washington and Los Angeles, are as good as the acid resistant enamels on steel. Since it was shown (sec. 2.4) that the initial color has a marked effect on the color retention, only the white, yellow, and green enamels on aluminum were used in this comparison.

TABLE 8. *Comparison of the color retention of the enamels in this test with those in an earlier test*

Exposure test	Type of enamel	Average color retention [a] for enamels exposed at:		
		Kure Beach	Washington	Los Angeles
1956 [b]	Acid resistant, on steel	97.9	98.2	98.4
1956 [b]	On aluminum, (green, white, and yellow)	93.3	97.1	97.1
1964	On aluminum, (green, white, and yellow)	94.0	98.4	98.7

[a] Color retention is 100 minus the color change in NBS units.
[b] Data taken from Reference 11.

3.9. Nature-Tone Enamels on Aluminum

Seven nature-tone or mat enamels on aluminum were added to the test program after the one-year inspection. The initial gloss, color, and thickness of these enamels are presented in table 9 while the color-retention and percentage gloss-retained data for these enamels are presented in table 10. These data indicate good gloss and color retention for most enamels at all sites. One enamel, AM-7, spalled enough to constitute failure at all sites.

TABLE 9. *Initial data for nature-tone enamels on aluminum*

Enamel	Color	45-deg [a] Specular gloss	Thickness [b]	Boiling [c] acid solubility	Acid [d] spot test
			mils	*mg/in²*	
AM–2	Lt. brown	19.5	2.3	10.0	A
AM–3	Blue	10.5	2.6	13.0	A
AM–4	Lt. blue	7.6	2.1	9.3	A
AM–5	Green	17.4	2.7	13.6	A
AM–6	Lt. green	16.5	3.1	8.0	A
AM–7	Gray	11.2	2.1	11.7	B
AM–8	Lt. gray	45.3	2.0	15.7	B

[a] The 45-deg specular gloss was measured in accordance with ASTM designation C–346.
[b] The thickness was measured in accordance with ASTM designation E–376.
[c] The boiling acid solubility was determined in accordance with ASTM designation C–283.
[d] The acid spot test ratings were determined in accordance witb ASTM designation C–282.

TABLE 10. *Gloss and color retention of nature-tone enamels on aluminum after two years' exposure*

Enamel	Average color retention [a] for enamels exposed at:					Average percentage gloss retained for enamels exposed at:				
	Kure Beach	Washington	New York	Montreal	Los Angeles	Kure Beach	Washington	New York	Montreal	Los Angeles
AM–2	92.9	97.1	98.9	97.5	98.8	76.8	91.5	119.2	87.3	85.7
AM–3	92.5	95.1	99.3	98.1	98.8	74.0	88.8	103.0	95.2	92.9
AM–4	95.2	98.9	99.3	99.2	99.1	79.9	82.4	108.3	105.6	103.0
AM–5	96.2	99.0	99.7	98.3	99.6	88.0	92.5	113.1	95.1	95.1
AM–6	96.4	98.9	99.5	99.7	98.9	77.3	89.9	110.7	91.4	85.2
AM–7	91.3	98.2	99.4	99.3	98.7	76.6	77.3	155.3	88.9	87.7
AM–8	93.9	97.8	98.7	97.7	98.6	65.0	93.0	84.9	84.9	82.2

[a] Color retention is 100 minus the color change in NBS units.

4. Summary

The 3-year inspection of the enamels included in the 1964 Exposure Test of Porcelain Enamels on Aluminum indicated that:

1. The color retention of all colors except reds was good at all sites except Kure Beach.
2. There was no significant spalling on any of the enamels originally included in this test. One nature-tone enamel added to the test after one year's exposure did spall.
3. The atmosphere at Kure Beach was extremely aggressive on many of the enamels included in this test.
4. There were no significant effects attributable either to initial gloss or coating thickness.
5. The correlation between color retention and boiling acid solubility was poor.
6. The results of the boiling cupric chloride test correlated better with color retention than did those of the boiling acid solubility test.

5. References

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