NATIONAL BUREAU OF STANDARDS REPORT

9462

PROGRESS REPORT

1964 EXPOSURE TEST OF PORCELAIN ENAMELS ON ALUMINUM

One-Year Report

by

Margaret A. Rushmer

November 30, 1966

Porcelain Enamel Institute Research Associateship

National Bureau of Standards

Washington, D. C.

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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421.04-12-4212270

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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] 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. With this knowledge 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. The new test was to incorporate enamels employing the nine basic color oxides used in porcelain enamels on aluminum. This test was also designed to evaluate the effect of varying both the initial gloss and thickness.

The enamels in this test have been exposed for one year at Kure Beach, North Carolina; New York, New York; Washington, D. C.; Los Angeles, California; and Montreal, Canada. This report is a summary of the findings of the one-year inspection and is the second in a series of reports to the sponsors of this

program, the first being a summary of the six-months' inspection. The first published report is tentatively planned after the three-year inspection.

MATERIALS AND PROCEDURES

1. Enamels

Sixteen enamel systems were included in this test. These enamel systems are represented by nine colors, three gloss ranges and both one- and two-coat enamels as indicated in Table 1. The initial 45° specular gloss values and the thicknesses of the enamels as well as their acid solubilities and acid spot test ratings are also reported in Table 1.

The enamels in this test have been coded for easy identification. Each enamel system can be identified by the first two code letters, while different fabricators for each enamel system are indicated by the third code letter. The differences between the enamel systems are readily apparent (see Table 1) for all systems except AA and AZ. These systems were planned to be two-coat enamels having significantly different thicknesses. However, this difference did not materialize during manufacture of the specimens.

If small 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. Test Specimens

Each enamel was applied to a 3 X 5 foot sheet of 0.064 inch 6061 aluminum alloy. After the enamel was fired the sheet was cut, with a band saw, into seventy-eight 4-7/16 inch^2 and nine 4 X 6 inch exposure specimens. This was done to produce more uniform specimens than could be obtained by hand spraying and firing small individual metal blanks.

3. Exposure Sites

Three of the 4-7/16 inch square specimens of each enamel were exposed on the roofs of Federal Government Buildings in New York, New York, Los Angeles, California; and Washington, D.C.; as well as the roof of the Stores Department Building in Montreal, Canada. Three of the 4 X 6 inch specimens of each enamel 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 designated as "storage" enamels. These enamels were set aside in a dry, dark place and allowed to age indoors. The remaining 69 specimens of each enamel were kept for use in laboratory tests and for the development of new test methods, as needed.

4. Cleaning of Specimens

A standard cleaning process was selected to remove all dirt, fingerprints, etc. from the enamel surface before it was measured for gloss and color. The cleaning treatment consisted of 1) scouring 30 strokes with a sponge that had been dampened with a one percent, by weight, solution of tri-

sodium phosphate and sprinkled with calcium carbonate, 2) rinsing with tap water, 3) rinsing with distilled water, and 4) rinsing with alcohol.

5. Gloss and Color

The 45° specular gloss of the enamels was measured at four orientations near the center of the specimens both before and after exposure. The gloss is reported as the percentage gloss retained after exposure.

The color change of the enamels was measured with a color difference meter. One of the three storage specimens was used as the standard in measuring the color difference. This was done to obtain maximum efficiency with this type of instrument. The storage specimens were, in turn, measured against calibrated NBS color standards to determine whether the enamels changed color during storage. The color change is reported as color retention, which is 100 minus the color difference in NBS units.

RESULTS

1. Appearance and Cleaning of Specimens

When the specimens were returned to the laboratory at the National Bureau of Standards for their one-year inspection; those exposed at Kure Beach appeared clean while those exposed at Washington, Montreal, New York and Los Angeles had increasingly heavier dirt films on them. These dirt films were easily removed from all specimens by the cleaning procedure outlined above.

This was somewhat unexpected since the specimens exposed for six months at New York required a severe scouring treatment to remove the adherent dirt film. The ease with which the dirt film was removed between six-months' and one-year's exposure is probably due, at least in part, to the increased rainfall during this time.

2. Gloss and Color

The gloss and color of each enameled specimen after one-year's exposure was measured as described above. The average percentage gloss retained and color retention for the three specimens of each enamel exposed at each site as well as the storage enamels are given in Table 2.

Since small changes in color are more noticable than large changes in gloss, the data in the remainder of this report will be presented primarily on the basis of color retention. The percentage gloss retained will be presented as supplementary information.

3. Comparison of Exposure Sites

The average values for color retention and percentage gloss retained for all enamels exposed at each site are given in Table 3. A two-sided sign test [2/] performed on the data in Table 2 indicated that the gloss and color were not effected by the weather in the same manner. Thus when the color data were analyzed, the enamels exposed at Kure Beach underwent significantly more color change than those exposed at any other site.

The enamels exposed at New York, Washington, and Los Angeles showed significantly less color change than those exposed at Kure Beach but were not different from each other while the enamels exposed at Montreal showed a significantly smaller color change than those exposed at all the other sites. This is illustrated in Figure 1.

When the gloss data were treated in a similar fashion, different results were obtained. These data indicated that the atmospheric conditions at Kure Beach, Washington, and Montreal caused the most change in an enamel's gloss while the atmospheric conditions at New York and Los Angeles, respectively, caused significantly less change in the enamel's gloss. This is also illustrated in Figure 1.

With this apparent difference in the degradation of gloss and color of the enamels exposed at the different sites, it is important to recall that changes in color are more noticable than changes in gloss. Therefore the color change, or retention, will be emphasized in this report.

4. Correlation of Color Retention with Boiling Acid Solubility

The relationship between color retention and boiling acid solubility for all the enamels, except the reds, exposed at all sites is illustrated in Figure 2. (The red enamels were omitted because they failed the 15-second nitric acid spot test [3] and would not normally be used for outdoor exposure.) It can be noted that the effect of boiling acid solubility on color retention is greatest at the most aggressive site, Kure Beach. At this site, which as an extremely corrosive atmosphere,

only those enamels with very low acid solubilities should be used.

In an effort to stress the improvement in quality that could be effected if the boiling acid solubility limits were reduced from 20 to 10 mg/in^2, two sets of data will be given in most of the following tables; one set will include all the enamels in the test while the other will include only those enamels with boiling acid solubilities under 10 mg/in^2.

3. Comparison of Enamel Colors

The average color retention and percentage gloss retained for the nine different colors included in this test are presented in Table 4. It is evident from observation of this table that some of the enamel colors, light green and brown, have excellent color retention even at the most aggressive site, Kure Beach, while another color, red, had poor color retention at all exposure sites. The relatively poor color retention of the red enamels is not a cause for too much concern since it could have been predicted by the 15-second nitric acid spot test which is included in the specification for architectural porcelain enamels on aluminum.[3/] Because these enamels had poor color retention, and because the poor color retention could be predicted, the values for the red enamels will be omitted from many of the following tables.

The low color retention of the black and dark green enamels exposed at the most aggressive site, Kure Beach, was unexpected. These values were greatly improved (see Table 5) when only those enamels having boiling acid solubilities under

10 mg/in^2 were considered. This again suggests that enamels with lower boiling acid solubilities should be used, whenever possible, to insure good color stability.

6. Comparison of One- and Two-Coat Enamel Systems

The average color retention and percentage gloss retained for the one- and two-coat enamel systems are presented in Table 6. These data indicate that the color retention of the two-coat systems is slightly better than for the one-coat systems. This may be due to better weather resistance of the two-coat enamels or it could be due to the inherent differences in the colors that were produced in one-and two-coat enamels. For example; the one-coat enamels were primarily dark colors while the two-coat enamels were primarily pastel colors. Indeed, the only completely valid comparison of these coating systems would be to compare the white enamels that were produced in both one- and two- coat systems. This comparison follows:

No. of Coats	Kure Beach	New York	Wash-ington	Los Angeles	Mont-real
One	97.7	98.3	98.9	98.9	99.1
Two	98.1	98.7	99.0	98.9	99.0

Thus it can be seen that when the same enamel color is compared in both one- and two-coat systems, it is extremely difficult to say, at this time, that one coating system is better than the other.

7. Comparison of Enamels in Different Gloss Ranges

The average color retention and percentage gloss retained for the enamels included in the three gloss ranges is given in Table 7. When all enamels are considered, there are only

slight differences in the average color retention of the enamels included in these three gloss ranges with the exception of the high-gloss enamels exposed at Kure Beach. When only the enamels with boiling acid solubilities under 10 mg/in^2 are considered, the differences in color retention are minimized and it could be said that the initial gloss of the enamel does not have any bearing on its color retention after one-year's exposure.

Observation of the gloss data in Table 7 indicates that the low gloss enamels have the highest gloss retained values followed by the medium and high gloss enamels. This would be acceptable if the low and medium gloss enamels did not increase in the percentage gloss retained between six-month's and one-year's exposure. This increase in gloss could be explained in several ways: 1) the enamel is being selectively erroded either by the weather or by the scouring action during the removal of the adherent dirt film. This selective removal of enamel might result in a more nearly plane surface which would tend to increase the 45° specular gloss, 2) invisible films could be forming on the surface of the specimens which would produce a doubly reflecting surface that would tend to increase the gloss, or 3) the gloss meter may not be sensitive enough to accurately measure changes in low gloss enamels. At this time it is impossible to say which one of these mechanisms, if any, is responsible for the increase in gloss noted for these specimens. These specimens will be carefully monitored in future inspections to see if this unexpected trend continues.

This increase in gloss of the low and medium gloss enamels, uncoubtedly had some effect in producing the non-correlation of the site-severity ratings (section 3 of results).

8. Spall Resistance

A "fish-scale" type of spalling was observed on several of the 153 specimens exposed at each site. This spalling was noted on 8 specimens exposed at Kure Beach, 17 at New York, 1 at Washington, and 22 at both Los Angeles and Montreal. These areas of spalling, while plainly visible on close examination probably would not be objectionable on the side of a building or a sign. In no case was there 1/8 inch of bare metal visible but in some cases the bare metal and the fractured enamel would measure more than 1/8 inch. Since this spalling is still confined to small areas, it is not thought to be a serious defect at this time.

9. Effect of Exposure Time on Color Retention

The effect of exposure time on the average color retention of all the enamels included in this test is illustrated in Figure 3. Here it can be seen that the color change is the greatest during the first six months' exposure and then the rate of color change decreases for the enamels exposed at all sites except Kure Beach where the color continues to change at a rapid rate.

10. Comparison of Enamels in this Test with Those in Previous Exposure Tests

The average color retention and percentage gloss retained for the acid-resistant enamels on steel and the enamels on aluminum included in the 1956 test as well as the enamels on

aluminum included in this test are presented in Table 8. It can be seen that the enamels on aluminum exposed at Washington and Los Angeles in this test have better color retention than those included in the 1956 test and they have color retentions as good as the acid resistant enamels on steel included in the 1956 test. When considering only the non-red enamels having acid solubilities under 10 mg/in^2 the enamels in this test exposed at these sites have slightly better color retention than the acid-resistant enamels on steel included in the 1956 test.

This, however, does not hold true for the enamels exposed at Kure Beach. When all of the enamels in the 1964 test are considered, their color retention is somewhat poorer than either the enamels on aluminum or the acid-resistant enamels on steel in the 1956 test. When considering only the non-red enamels with boiling acid solubilities under 10 mg/in^2, the color retention of the enamels on aluminum included in the 1964 test is better than the enamels on aluminum included in the 1956 test but it is somewhat lower than the acid-resistant enamels on steel exposed at this same site in the 1956 test. This again supports the statement that only the very best enamels, having low boiling acid solubilites, should be used for coastal installations.

SUMMARY

After one-year's exposure at Kure Beach, North Carolina; New York, New York; Washington, D.C.; Los Angeles, California: and Montreal, Canada the changes in gloss, color and general surface conditions of triplicate specimens of 51 porcelain

enamels on aluminum were determined. A summary of the more important findings follows.

1. All specimens were easily cleaned.
2. The enamels exposed at Kure Beach retained less color than those at any other site, while the enamels exposed at Montreal retained the most color. The enamels exposed at New York, Washington and Los Angeles were intermediate between these two extremes and did not differ significantly from each other.
3. The color retention correlated well with the boiling acid solubility.
4. For the best weatherability, consideration should be given to limiting the boiling acid solubility to 10 mg/in^2.
5. The red enamels were the only ones having boiling acid solubilities under 10 mg/in^2 that showed large color changes.
6. There were no appreciable differences between the color retention of enamels produced with one or two coats of enamel or among enamels having low, medium, or high initial gloss.
7. There was no extensive spalling noted at this time.
8. The enamels in this test with boiling acid solubilities under 10 mg/in^2 had better color retention than the enamels on aluminum included in the 1956 test.

Table 1. Summary of Initial Data for Porcelain Enamels on Aluminum

Enamel	Visual Color	Nominal Gloss	45° Specular Gloss	Number of Coats	Thickness mils	Acid Solubility mg/in^2	Acid Spot Test Ratings
AA-A	White	High	70.1	Two	4.5	5.5	A
AA-B	White	High	74.2	Two	4.3	5.9	A
AA-C	White	High	71.5	Two	3.44	5.0	AA
AA-D	White	High	71.9	Two	6.5	12.7	AA
AB-A	White	Medium	56.8	Two	4.0	7.2	B
AB-C	White	Medium	55.6	Two	4.0	4.9	A
AB-D	White	Medium	28.9	Two	6.2	7.9	A
AC-A	White	High	74.5	One	3.5	6.4	A
AC-B	White	High	71.8	One	2.8	11.3	AA
AC-C	White	High	70.5	One	3.3	9.9	AA
AD-A	White	Medium	55.0	One	2.8	6.2	AA
AD-B	White	Medium	68.3	One	4.3	6.7	B
AD-C	White	Medium	42.4	One	3.2	7.1	B
AD-D	White	Medium	34.9	One	2.7	12.4	A
AE-A	Black	High	75.6	One	2.4	6.5	A
AE-B	Black	High	78.0	One	1.6	10.1	A
AE-C	Black	High	78.1	One	2.0	12.1	A
AE-D	Black	High	75.0	One	3.4	15.5	B
AF-A	Black	Medium	78.4	One	1.5	14.2	B
AF-B	Black	Medium	58.5	One	2.7	9.0	B
AF-C	Black	Medium	76.8	One	3.1	10.1	C
AG-B	Black	Low	26.0	One	3.0	12.5	B
AG-C	Black	Low	12.6	One	2.0	7.5	A
AH-A	Red	High	46.9	One	2.8	7.4	A
AH-B	Red	High	85.3	One	3.1	8.8	B
AH-C	Red	High	85.6	One	3.1	6.5	B
AH-D	Red	High	82.0	One	1.9	10.5	B
AO-A	Dark Green	High	78.8	One	3.2	19.9	A
AO-B	Dark Green	High	79.8	One	1.6	10.1	A
AO-D	Dark Green	High	78.3	One	2.1	17.0	A
AP-A	Light Green	Medium	42.4	Two	6.4	12.3	B
AP-B	Light Green	Medium	38.5	Two	4.1	6.4	A
AP-C	Light Green	Medium	30.2	Two	4.0	6.2	A
AP-D	Light Green	Medium	45.3	Two	6.4	10.0	A
AR-A	Light Green	Low	9.6	Two	3.2	4.4	A
AR-B	Light Green	Low	7.3	Two	2.7	5.5	A
AR-C	Light Green	Low	5.7	Two	4.3	8.1	A
AS-A	Gray	Medium	64.9	Two	5.0	13.4	A
AS-B	Gray	Medium	61.6	Two	5.5	7.4	AA
AS-C	Gray	Medium	62.2	Two	3.9	5.4	A
AT-A	Blue	Medium	32.9	Two	4.4	6.2	A
AT-B	Blue	Medium	54.8	Two	3.6	7.0	A
AT-C	Blue	Medium	62.4	Two	2.9	6.1	AA
AU-A	Brown	Medium	50.0	Two	7.2	5.3	A
AU-B	Brown	Medium	35.4	Two	6.4	7.5	A
AU-C	Brown	Medium	46.6	Two	4.4	7.6	A
AW-A	Yellow	Medium	62.4	Two	5.8	7.8	A
AW-B	Yellow	Medium	63.1	Two	4.1	8.7	A
AW-C	Yellow	Medium	80.9	Two	5.0	18.6	A
AZ-A	White	High	72.0	Two	4.2	9.5	A
AZ-B	White	High	71.2	Two	2.7	5.2	A

Table 2. Summary of One Year's Exposure Data for Porcelain Enamels on Aluminum

Enamel	Kure Beach Gloss	Kure Beach Color	New York Gloss	New York Color	Washington Gloss	Washington Color	Los Angeles Gloss	Los Angeles Color	Montreal Gloss	Montreal Color	Storage Gloss	Storage Color	Visual Color
AA-A	95.2	98.1	96.5	99.3	91.6	99.6	97.8	99.3	90.4	99.6	98.2	99.9	White
AA-B	87.5	98.7	93.5	99.4	91.5	99.3	100.9	99.0	93.2	99.4	98.4	99.8	White
AA-C	107.4	97.6	89.6	99.0	90.8	98.8	96.8	98.5	87.6	99.0	98.7	99.8	White
AA-D	33.0	97.0	97.8	97.4	92.5	97.9	100.4	98.3	93.1	97.8	98.7	99.7	White
AE-A	[illegible]	97.3	94.2	97.3	80.9	98.3	86.3	98.6	85.7	98.5	96.7	99.9	White
AE-C	86.4	99.1	84.4	99.0	83.6	99.5	87.9	99.3	82.7	99.4	96.9	99.8	White
AE-D	80.2	97.6	112.1	98.4	92.6	98.6	98.1	99.1	95.9	98.9	97.1	99.9	White
AC-A	90.7	98.7	93.1	99.3	91.8	99.2	101.0	98.7	93.1	99.3	98.8	99.7	White
AC-B	37.3	98.1	98.4	97.1	90.2	98.8	101.3	99.2	97.1	98.4	98.8	99.7	White
AC-C	85.3	96.9	96.8	98.4	92.1	98.6	98.1	98.8	94.1	98.9	99.5	99.8	White
AD-A	96.9	98.6	99.9	99.2	91.1	99.4	95.7	99.3	91.1	99.3	98.5	99.8	White
AD-B	93.8	98.3	94.5	99.2	88.9	99.6	94.9	99.3	88.2	99.5	99.2	99.9	White
AD-C	91.3	96.9	106.4	97.9	90.3	98.8	95.4	98.4	94.5	98.9	98.0	99.9	White
AD-D	58.0	97.3	114.6	96.7	96.5	98.1	103.1	98.9	100.3	99.1	98.8	99.9	White
AE-A	68.4	94.3	80.3	99.1	80.5	98.8	80.5	97.2	80.2	99.9	96.5	99.7	Black
AE-B	55.8	89.1	83.7	99.4	82.9	99.8	86.6	99.1	85.1	99.0	97.7	99.7	Black
AE-C	68.2	92.9	83.7	99.0	85.0	99.0	89.9	99.2	85.1	99.0	97.7	99.7	Black
AE-D	37.8	76.6	79.9	96.2	76.4	96.4	83.2	97.2	83.0	96.4	97.1	99.6	Black
AE-A	87.9	96.[illegible]	[illegible]2.1	97.7	90.6	99.1	34.3	97.9	84.3	98.4	98.1	99.9	Black
AE-B	85.5	[illegible].7	95.3	98.4	91.7	99.0	96.5	99.4	95.3	99.7	98.1	99.9	Black
AE-C	78.6	95.1	83.3	98.1	82.6	99.1	86.6	98.3	85.4	99.4	97.9	99.7	Black
AG-B	83.7	88.2	100.4	98.5	97.8	98.7	103.1	98.1	100.5	98.5	96.8	99.7	Black
AG-C	112.8	97.1	101.0	98.1	100.8	99.5	103.8	99.0	97.0	99.5	92.3	99.6	Black
AH-A	79.3	93.5	121.3	97.1	96.6	97.6	113.2	96.9	103.6	97.4	100.1	99.4	Red
AH-B	44.8	83.1	75.6	95.1	70.0	94.0	77.6	94.4	75.7	95.2	99.6	99.7	Red
AH-C	59.2	86.3	75.6	90.7	68.5	91.5	77.4	91.4	93.6	91.8	99.7	99.7	Red
AH-D	37.8	70.2	77.0	90.8	70.6	87.2	81.8	88.4	77.6	88.1	98.9	99.6	Red
AO-A	60.9	91.7	78.5	99.0	79.3	99.0	83.3	99.2	81.4	99.3	98.8	99.9	Dark Green
AO-B	67.0	97.3	83.1	99.3	82.7	99.7	86.0	99.4	83.1	99.5	98.3	99.6	Dark Green
AO-D	50.8	92.0	79.1	98.6	80.7	98.0	84.2	98.6	84.9	99.0	97.3	99.8	Dark Green
AP-A	80.4	95.2	104.9	99.5	93.4	99.2	97.4	99.3	94.8	99.3	98.3	99.8	Light Green
AP-B	67.1	96.7	94.6	99.4	81.9	99.4	89.6	99.6	82.6	99.4	98.0	99.8	Light Green
AP-C	84.1	96.9	98.9	99.7	83.9	99.1	91.3	99.6	83.9	99.6	97.5	99.8	Light Green
AP-D	86.9	97.1	100.6	99.3	93.4	99.0	95.2	99.3	94.7	99.3	97.8	99.9	Light Green
AR-A	120.2	99.6	130.4	99.3	104.6	99.4	122.2	99.6	106.5	99.7	90.6	99.7	Light Green
AR-B	96.1	98.[illegible]	110.9	9[illegible].7	74.7	99.6	91.7	99.6	73.6	99.7	91.4	99.7	Light Green
AR-C	105.9	98.3	84.6	98.6	75.6	99.6	81.6	99.4	69.6	99.6	89.9	99.8	Light Green
AS-A	59.5	96.2	88.3	99.3	86.4	99.0	93.0	99.6	89.7	99.4	97.7	99.8	Gray
AS-B	86.4	97.3	84.5	99.4	82.3	99.1	84.6	99.3	82.3	99.3	98.9	99.6	Gray
AS-C	97.7	99.6	89.9	99.5	92.2	99.7	95.5	99.6	89.1	99.6	98.9	99.6	Gray
AT-A	93.8	97.4	94.1	98.8	83.2	98.9	91.0	99.3	83.1	99.1	98.8	99.9	Blue
AT-B	93.4	94.9	95.6	98.8	94.1	99.0	95.5	97.8	90.9	99.1	98.8	99.9	Blue
AT-C	82.0	96.2	83.0	99.1	79.2	99.1	84.0	98.9	79.9	99.4	98.2	99.7	Blue
AU-A	89.8	99.4	90.7	99.8	84.9	99.7	92.5	99.7	83.4	99.7	98.7	99.6	Brown
AU-B	93.4	99.4	108.1	99.4	91.8	99.6	94.9	99.7	89.7	99.6	97.6	99.6	Brown
AU-C	94.7	99.6	98.0	99.6	93.9	99.4	97.9	99.8	93.5	99.8	98.2	99.6	Brown
AW-A	80.1	98.7	85.1	99.5	81.5	99.4	85.8	99.5	83.5	99.6	98.2	99.9	Yellow
AW-B	79.2	97.3	94.3	99.2	92.4	99.0	95.2	99.3	92.7	99.3	98.1	99.7	Yellow
AW-C	47.6	95.9	85.4	99.1	81.4	99.0	90.3	99.5	86.3	99.4	99.0	99.8	Yellow
AZ-A	50.1	98.9	99.2	99.0	91.5	99.2	102.1	99.1	98.0	99.2	100.2	99.8	White
AZ-B	110.7	97.8	64.1	98.9	91.2	98.9	98.0	98.8	89.2	99.0	99.7	99.6	White
Average	77.9	95.1	93.2	98.4	86.7	98.6	92.9	98.7	88.3	98.8	97.8	99.7	

Table 3. Average Percentage Gloss Retained and Color Retention of Porcelain Enameled Aluminum at the Different Exposure Sites

Exposure Site	Color Retention	Percentage Gloss Retained
Kure Beach-80	95.1	77.9
New York	98.4	93.2
Washington	98.6	96.7
Los Angeles	98.7	92.9
Montreal	98.8	98.3
Storage	99.7	97.8

Table 4. Average Color Retention and Percentage Gloss Retained for the Different Colors of Porcelain Enameled Aluminum after One Year's Exposure.

ALL ENAMELS

Color Retention

Enamel Color	Kure Beach	New York	Washington	Los Angeles	Montreal	Storage	Average of Exposed Enamels
Red	83.3	93.4	92.6	92.8	93.1	99.6	91.0
Black	89.9	98.6	98.9	98.4	99.2	99.7	97.0
Dk. Green	93.7	99.8	98.9	99.1	99.3	99.8	98.0
Blue	96.2	98.9	99.0	98.9	99.0	99.8	98.7
White	97.9	98.5	99.0	98.9	99.0	99.8	98.9
Yellow	97.3	99.3	99.1	99.4	99.4	99.8	98.9
Gray	97.7	99.4	99.3	99.5	99.4	99.7	99.1
Lt. Green	98.1	99.2	99.3	99.5	99.5	99.8	99.1
Brown	99.5	99.6	99.6	99.7	99.7	99.6	99.6

Percentage Gloss Retained

Enamel Color	Kure Beach	New York	Washington	Los Angeles	Montreal	Storage	Average of Exposed Enamels
Red	55.3	87.3	76.4	87.5	82.6	99.6	77.8
Black	70.0	87.5	86.7	90.5	89.9	96.9	84.9
Dk. Green	59.6	80.2	85.0	84.5	83.1	98.1	78.4
Blue	89.7	90.9	85.5	90.2	84.6	98.6	88.2
White	79.5	95.9	90.3	97.5	92.1	98.6	91.1
Yellow	69.0	88.3	85.0	90.4	87.5	98.4	84.0
Gray	81.3	87.6	87.0	91.0	87.0	98.5	86.8
Lt. Green	95.8	104.7	89.7	94.1	86.6	94.8	94.2
Brown	92.6	93.8	90.2	95.1	88.9	98.2	92.1

Table 5. Average Color Retention and Percentage Gloss Retained for the Different Colors of Porcelain Enameled Aluminum after One Year's Exposure.

ENAMELS WITH BOILING ACID SOLUBILITIES UNDER 10 MG/IN^2

Color Retention

Enamel Color	Kure Beach	New York	Washington	Los Angeles	Montreal	Storage	Average of Exposed Enamels
Red	87.6	94.3	94.4	94.2	94.8	99.8	93.1
Black	93.4	98.5	99.1	98.5	99.7	99.7	97.4
Dk. Green	----	----	----	----	----	----	----
Blue	96.2	98.9	99.0	98.7	99.2	99.8	98.4
White	98.0	98.9	99.1	98.9	99.2	99.8	98.8
Yellow	98.0	99.4	99.2	99.4	99.5	99.8	99.1
Gray	98.5	99.5	99.4	99.5	99.5	99.6	99.3
Lt. Green	98.9	99.1	99.4	99.6	99.6	99.8	99.3
Brown	99.5	99.6	99.6	99.7	99.7	99.6	99.6

Percentage Gloss Retained

Enamel Color	Kure Beach	New York	Washington	Los Angeles	Montreal	Storage	Average of Exposed Enamels
Red	61.1	90.8	78.3	89.4	91.0	99.8	82.1
Black	79.9	92.2	91.0	93.6	90.8	95.6	89.5
Dk. Green	----	----	----	----	----	----	----
Blue	89.7	90.9	85.5	90.2	84.6	98.6	88.2
White	87.9	94.2	96.5	96.5	91.1	98.6	93.2
Yellow	79.7	89.7	87.0	90.5	88.1	98.2	87.0
Gray	92.1	87.2	84.4	88.8	86.0	98.3	87.7
Lt. Green	100.3	105.5	84.2	93.3	83.3	93.5	93.3
Brown	92.6	93.8	90.2	95.1	88.9	98.2	92.1

Table 6. Average Color Retention and Percentage Gloss Retained for One and Two Coat Systems of Porcelain Enameld Aluminum after One Year's Exposure.

ALL ENAMELS

Color Retention

Number of Coats	Kure Beach	New York	Washington	Los Angeles	Montreal	Storage	Average of Exposed Enamels
One*	93.3	98.5	98.9	98.7	99.2	99.8	97.7
Two	97.9	99.1	99.2	99.2	99.3	99.8	98.9

Percentage Gloss Retained

Number of Coats	Kure Beach	New York	Washington	Los Angeles	Montreal	Storage	Average of Exposed Enamels
One*	68.2	95.1	87.5	92.5	89.7	99.7	86.6
Two	86.0	91.2	87.7	93.9	88.1	99.8	89.4

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ENAMELS WITH BOILING ACID SOLUBILITIES UNDER 10 MG/IN^2

Color Retention

Number of Coats	Kure Beach	New York	Washington	Los Angeles	Montreal	Storage	Average of Exposed Enamels
One*	96.1	98.7	99.1	98.7	99.4	99.8	98.4
Two	98.2	99.1	99.3	99.2	99.4	99.8	99.0

Percentage Gloss Retained

Number of Coats	Kure Beach	New York	Washington	Los Angeles	Montreal	Storage	Average of Exposed Enamels
One*	77.9	91.6	88.2	92.7	89.4	97.8	88.0
Two	91.2	95.0	87.4	93.6	87.3	97.4	90.9

*The red enamels were omitted when the average values for the one coat systems were calculated because they failed the 15-second nitric acid test and would not be recommended for architectural purposes.

Table 7. Average Color Retention and Percentage Gloss Retained for the Different Gloss Ranges of Porcelain Enameled Aluminum Exposed for One Year.

ALL ENAMELS

Color Retention

Gloss Range	Kure Beach	New York	Washington	Los Angeles	Montreal	Storage	Average of Exposed Enamels
Low	97.0	98.5	99.1	99.2	98.5	99.8	98.5
Medium*	97.5	99.1	99.2	99.2	99.1	99.8	98.8
High*	93.9	98.7	98.9	98.7	99.4	99.8	97.7

Percentage Gloss Retained

Gloss Range	Kure Beach	New York	Washington	Los Angeles	Montreal	Storage	Average of Exposed Enamels
Low	93.6	106.1	90.0	97.3	90.0	99.7	95.4
Medium*	85.7	94.2	88.0	92.6	88.7	98.3	89.8
High*	67.3	82.2	86.1	92.2	88.3	98.4	83.2

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ENAMELS WITH BOILING ACID SOLUBILITIES UNDER 10 MG/IN^2

Color Retention

Gloss Range	Kure Beach	New York	Washington	Los Angeles	Montreal	Storage	Average of Exposed Enamels
Low	98.2	98.8	99.3	99.4	99.4	99.8	99.0
Medium*	97.5	99.1	99.3	99.2	99.4	99.8	98.9
High*	97.6	99.1	99.1	98.7	99.3	99.8	98.8

Percentage Gloss Retained

Gloss Range	Kure Beach	New York	Washington	Los Angeles	Montreal	Storage	Average of Exposed Enamels
Low	92.5	105.7	87.9	95.7	87.1	94.0	93.8
Medium*	87.4	93.7	87.5	92.1	87.8	98.3	89.7
High*	75.9	89.1	90.1	96.9	90.7	98.8	88.5

*The red enamels were omitted when the average values for the medium and high gloss enamels were calculated because they failed the 15-second nitric acid test and would not be recommended for architectural purposes.

Table 8. Comparison of the Color Retention and Percentage Gloss Retained for the Enamels in the 1956 and 1964 Exposure Tests

Enamels	Color Retention			Percentage Gloss Retained		
	Kure Beach	Wash-ington	Los Angeles	Kure Beach	Wash-ington	Los Angeles
Acid-Resisting Steel, 1956 Test	98.9	98.8	98.6	81.1	83.4	90.0
Aluminum, 1956 Test	96.7	98.2	98.3	75.7	72.8	76.5
Aluminum, 1964 Test All Enamels	95.1	98.6	98.7	77.9	86.7	92.9
Aluminum, 1964 Test Enamels with Boiling Acid Solubilities under 10 mg/in^2	97.7	99.2	99.1	89.5	88.3	94.2

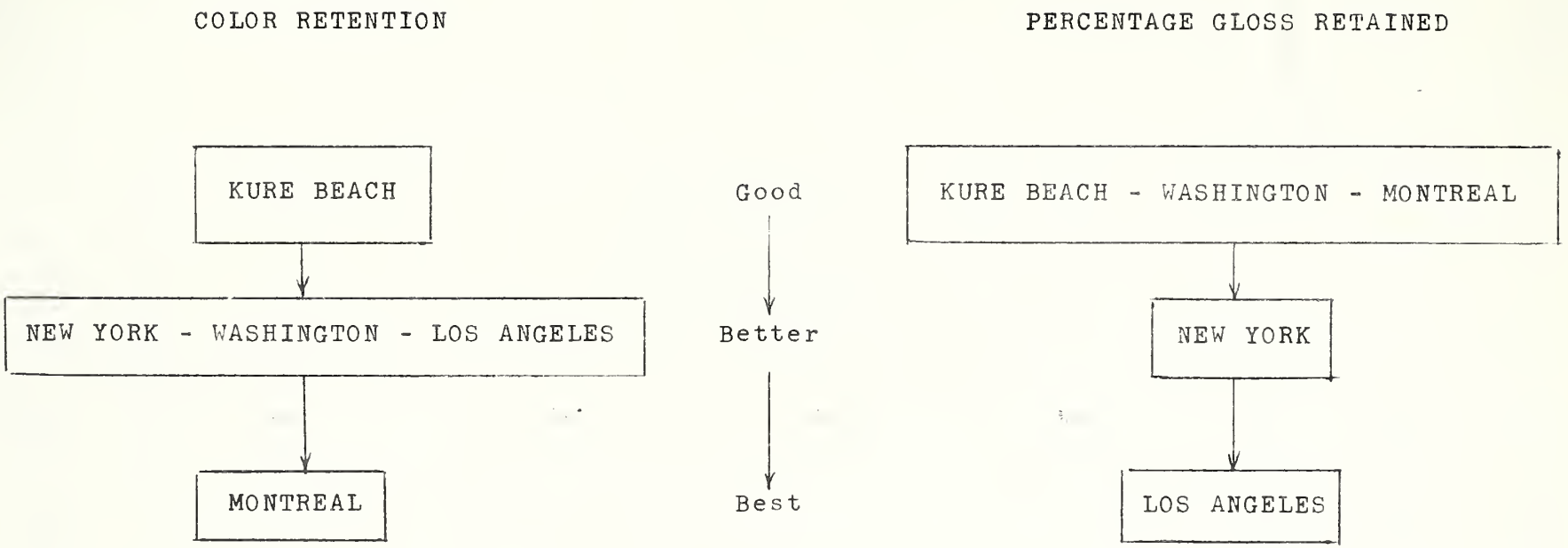

Figure 1. Graphical Representation of the Relative Effects of the Exposure Sites on the Gloss and Color Retention of Exposed Porcelain Enameled Aluminum Specimens.

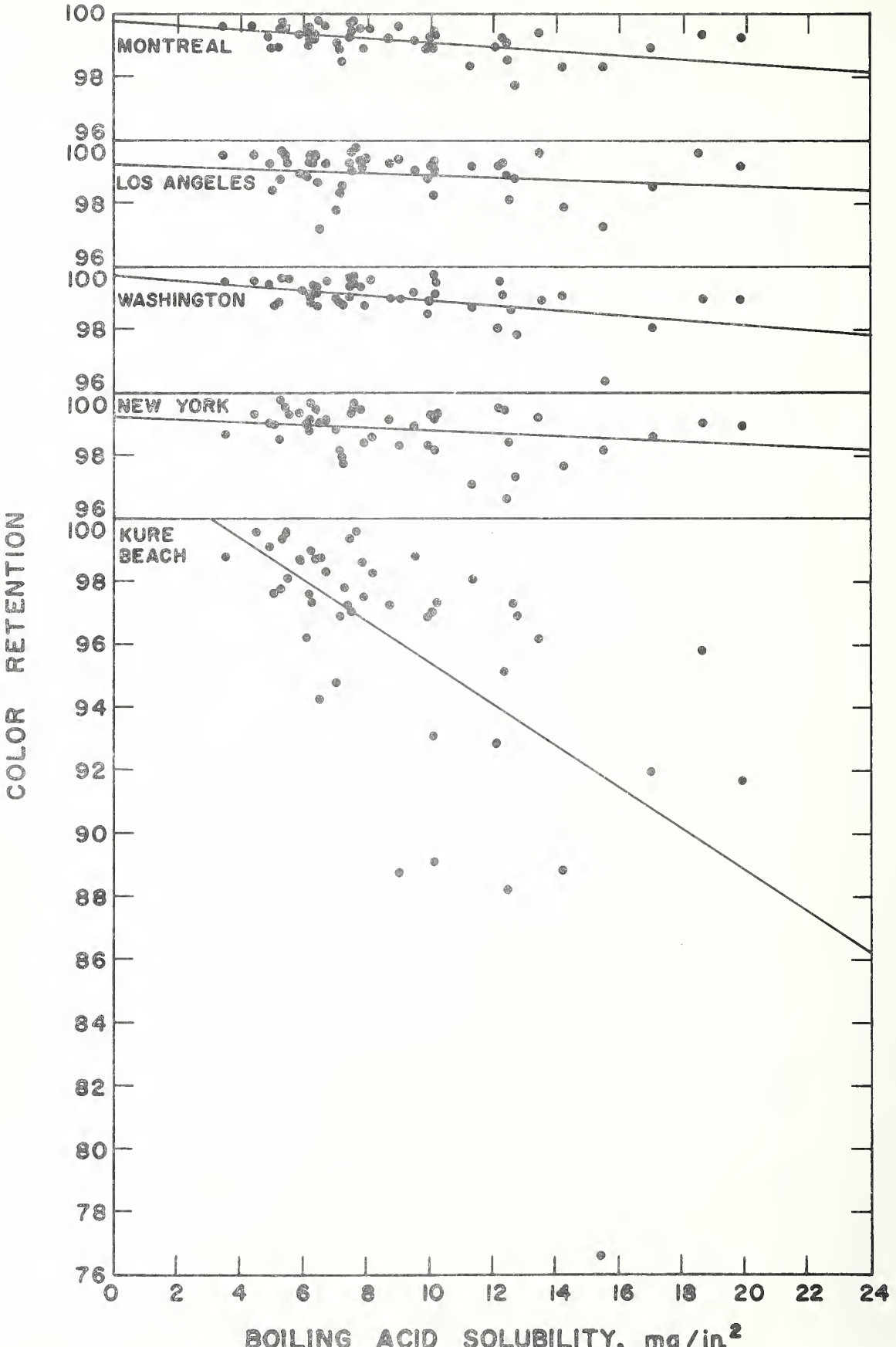

Figure 2. Correlation of the Color Retention of Porcelain Enamels on Aluminum with their Boiling Acid Solubility.

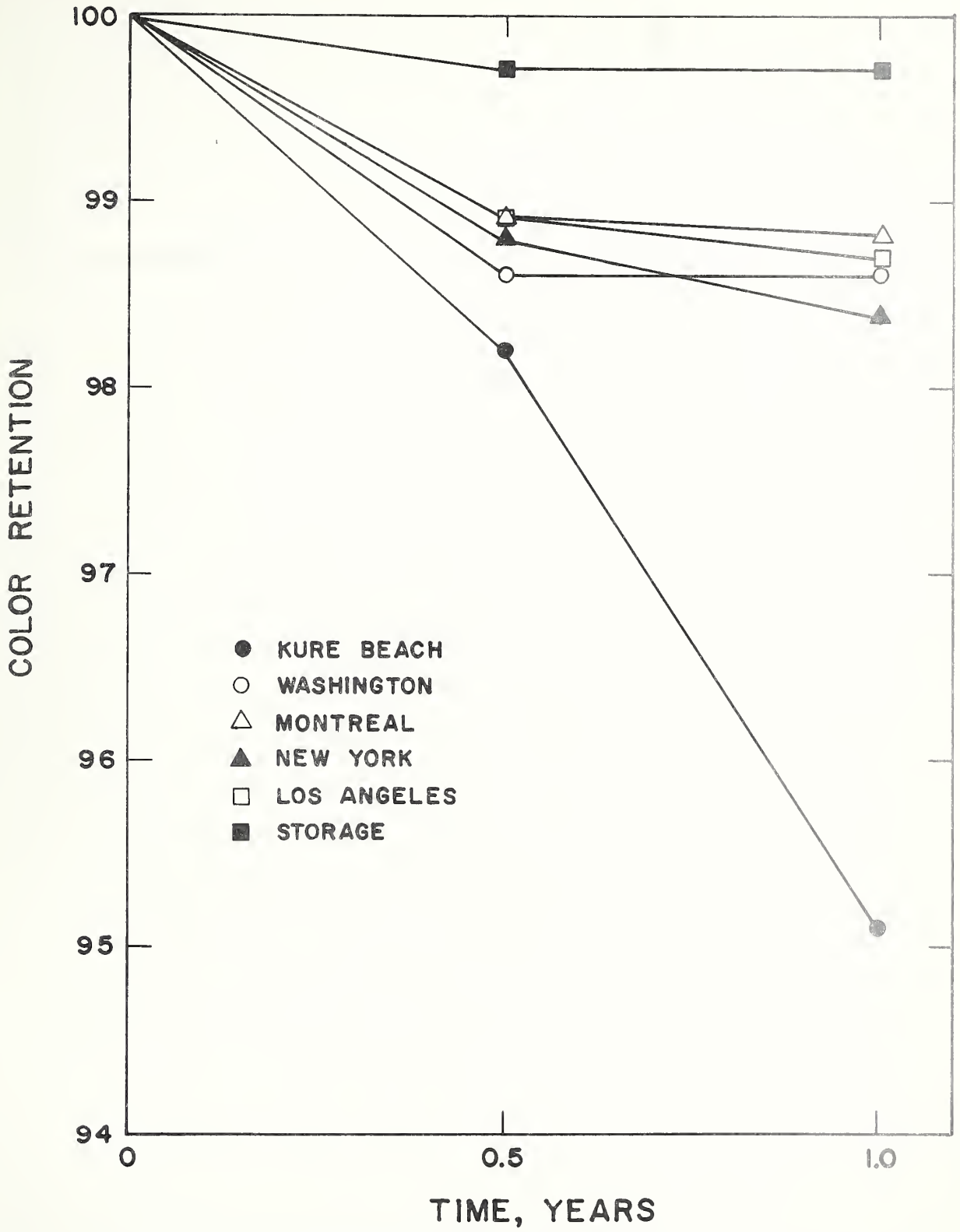

Figure 3. The Effect of Exposure Time on the Color Retention of Porcelain Enameled Aluminum.


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