NATIONAL BUREAU OF STANDARDS REPORT

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PROGRESS REPORT

April 1 through June 30, 1966

Development of Methods of Test
For Quality Control of Porcelain Enamels

by

M. D. Burdick and M. A. Rushmer

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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SUMMARY

A spot test for estimating the acid resistance of porcelain enamels within the low gloss or mat range has been developed and is described in detail. The agreement of this grading procedure for mat enamels is compared with the citric acid spot test for glossy and semi-glossy surfaces by means of the boiling acid solubility test which is applicable to all porcelain enamels regardless of gloss.

The procurement of a series of Nature-Tone enamels on both steel and aluminum for exposure testing is nearing completion. Laboratory measurements on all specimens received are given. Early installation of these specimens is anticipated.

A detailed report of the six month's results of the Porcelain Enamel Institute's Aluminum Council Weathering program has been submitted to the sponsoring group.
A majority of the one-year results for the same program are now available and will be similarly reported. A preliminary analysis of the aluminum enamel weathering results after one year, shows a remarkably good correlation between color retention and the boiling acid solubility.

I. A SPOT TEST FOR MAT PORCELAIN ENAMELS

INTRODUCTION

The citric acid spot test has served for many years as a rapid indicator of the acid resistance of porcelain enamels. It is considered an accelerated test of quality for appliance enamels that may be exposed to acid conditions and for architectural enamels which are exposed to weathering action. The spot test is an important part of specifications for porcelain enamels applied to both steel and aluminum.

A current trend in architectural porcelain enamels is toward mat surfaces and away from the more glossy surfaces that have characterized this material in the past. One of the desirable features of a mat enamel surface is the absence of distinct highlights and reflections.

The Specification for Architectural Porcelain Enamel on Steel for Exterior Use (PEI: S-100 (65)) requires a citric acid spot test to determine whether the product has the desired degree of acid resistance. A part of the rating process involves the use of a blurring highlight test and a wet-rubbing test to the acid treated spot to determine compliance with the specification requirement. The occurrence of an initially blurred and indistinct highlight on untreated areas of enamels of low gloss makes the blurring highlight test extremely difficult to interpret.

The above specification mentions as a "supplementary consideration" a determination of the acid resistance of porcelain enamels by the boiling acid test given in ASTM C-283. This test is not a part of the specification but is suggested as an aid to those specifying architectural porcelain enamel.

Two courses of action might be suggested to overcome the difficult interpretation of The ACID RESISTANCE REQUIREMENT of the current specification for architectural porcelain enamel.

(1) Utilize the boiling acid test as the specification requirement, or

(2) Develop a spot test for estimating the degree of acid resistance of porcelain enamels in the low gloss range.

Some work has been done toward the development of such a spot test for mat enamels.

RESULTS AND DISCUSSION.

The citric acid spot test consists of a 15 minute exposure of a small specimen area to a fairly concentrated acid. The grading of the acid resistance of the enamel is achieved by estimating the extent or degree of acid etching if any. The acid concentration and exposure time are such that non-acid resistant enamels are deeply etched, while acid resisting grades are etched only slightly or not visibly attacked.

A spot test was sought, in the present work, which would use simply the appearance or non-appearance of visible attack as the sole criterion for failing or passing the test. This may be contrasted with an estimation of the degree of etching when visible attack occurred in the citric acid spot test. For this reason it was not unreasonable to explore more dilute acid concentrations and/or shorter exposure times.

Exploratory surveys with single acids, with both concentration and exposure time as variables, failed to give much promise for distinguishing enamels of acceptable from those of not acceptable acid solubility.

The work of previous investigators on glass and porcelain enamels suggested passivation of the enamel surface as a pretreatment.

Weyl[1/] stated that the sodium ion can be replaced in a surface layer of glass by other ions without materially changing the atomic pattern. The alkali in glass compares with surface-active ingredients in water. These are said to migrate to the surface because they lower the surface free energy of the system. Because of the tendency of the system to keep its surface energy at a minimum, the structure and composition of the surface layer will be different from the interior. In an earlier paper Williams and Weyl[2/] described various methods of removing alkali from the surface of glass and found that such treatments (as acid leaching) greatly increased the chemical resistivity. Andrews and Bennett[3/] described a method for improving the acid resistance of enamels by leaching them in acid and then refiring to restore the gloss. Harrison, Richmond, and Crandall[4/] demonstrated the passivation effect of 10 percent acetic acid and of 2 percent butyric acid. Citric acid spot tests made on virgin enamels before and after 10 percent acetic acid treatment showed an increased chemical resistance or passivation which resulted in many titania opacified enamels increasing in apparent acid resistance from grade B to AA and others from B to A.

It was thought that, for the purpose of a spot test for mat enamels, an acid pretreatment might cause the chemical resistivity of the surface layer of all enamels to approach the resistivity of the basic interior glass. In this way, a spot test, acting on the extreme surface layer, might reflect, in a real way, the chemical resistivity of the underlying glass.

Experiments on a selection of mat enamels covering a wide range of acid solubility (determined by the boiling acid test, ASTM C-283,) see table 1, showed a varying response to a 0.1 percent citric acid treatment for a three minute exposure time. All except one enamel showed a visible attack to this acid concentration. Number 101, which showed no visible spot had an acid solubility of 14 milligrams per square inch, while all of the enamels including those with better acid solubility resistance were visibly spotted by this treatment. When the 0.1 percent citric acid treatment was preceded by an acetic acid leaching a good separation was obtained at an acid solubility rating of about 14 milligrams per square inch. An attempt was made to effect a separation at about 12 milligrams per square inch by increasing the citric acid concentration. The best separation in this series was obtained with a citric acid concentration of 0.6 percent for a 3 minute exposure time. The criterion of the test was the presence or absence of a visible attack with 0.6 percent citric acid for three minutes, applied in the area pretreated with 10 percent acetic acid for 5 minutes.

The testing and grading procedure which was developed is described below:

A Spot Test for Porcelain Enamels with Mat Finish

Reagents Required: Acetic acid, 10 percent by weight,
Citric acid, 0.6 percrnt by weight,
Trisodium phosphate

Equipment Required: A device to limit the coverage of 10 milliliters of acetic acid to a round area of a flat specimen about 1.5 inch in diameter; 1-inch watch glasses; dropper bottle.

Procedure: (1) Clean specimen with a cellulose sponge moistened with a one percent solution of trisodium phosphate. Rinse with tap water and then with distilled water. Dry by blotting with a clean towel. (2) Apply 10 milliliters of 10 percent acetic acid to a specimen spot about 1.5 inches in diameter for five minutes. (3) Rinse with tap water and dry specimen by blotting as above. (4) Apply 6 to 8 drops of 0.6 percent by weight citric acid, within the area pretreated with acetic acid and cover with a 1-inch watch glass. Continue the citric acid treatment for 3 minutes. Flush with tap water and dry as above.

Rating of Treated Areas: Four grades of acid resistance may be recognized:

Porcelain enamels which show no visible spot with either acetic or citric acids shall be graded I.

Enamels which show no spot with acetic acid but do show a citric acid spot shall be graded Ib.

Enamels which show an acetic acid spot but are not spotted by citric acid shall be graded II.

Enamels which show both acetic and citric acid spots shall be graded III.

Grade	Degree of Acid Resistance
I	Best *
Ib	Better *
II	Good *
III	Non-acid resistant **

* Recommended for architectural applications.
** Not recommended for architectural applications.

A schematic representation of the grading system for mat enamels is shown in Figure 1 and may be compared with the grading system of the citric acid spot test shown in Figure 2.

The test was applied to a larger group of mat enamels from the current Naturetone series and reserve specimens of mat enamels from the NBS-PEI weathering test. The results are given in Table 2. It can be seen that the mat enamel rating system places in Grade I some enamels whose acid solubility is as high as 3.9 mg/in^2 and Grade II includes some compositions with acid solubilities as low as 0.7 mg/in^2. A very similar overlap is seen to exist with the citric acid spot test on glossy enamels as shown in Table 3.

The results of the proposed spot test for mat enamels may be compared with the familiar citric acid spot test by reference to Table 3 and Figure 3. From these data one may conclude that the spot test for mat enamels provides as good a separation between acceptable and not acceptable mat enamels as does the citric acid spot test for glossy enamels. The correlation of these two spot tests with acid solubility is quite similar.

FUTURE WORK

This proposed test for mat enamels was described here to elicit comment and results from other groups who may try the method. In order to obtain a better judgement of the usefulness of this test method it is planned to tabulate and analyse the results obtained from other users. It would be most helpful if results of both the spot test for mat enamels and the boiling acid solubility test on companion specimens were submitted.

II. Weathering Tests of Porcelain Enamels

The Porcelain Enamel Institute Research Associateship is currently involved with four long-time weathering tests and some confusion has resulted about the identification of these test programs. Therefore, these test programs will be referred to by the year in which exposure was initiated.

The first test, initiated in 1939, consisted solely of porcelain enamels on steel exposed at Lakeland, Florida; St. Louis, Missouri; Atlantic City, New Jersey; and Washington, D.C. Reports on this test have been published after one,[5/] seven,[6/] and fifteen[7/] years' exposure. The test terminated after 15 years at all sites except Washington. A final inspection of the enamels exposed at Washington is planned after 30 years' exposure.

A second test was initiated in 1956 and included many new types of enamels, 80 on steel and 14 on aluminum, developed after World War II. The enamels in this test were exposed at Los Angeles, California; Wahington, D.C.; Dallas, Texas; New Orleans, Louisiana; Pittsburgh, Pennsylvania, and two sites at Kure Beach, North Carolina. Reports on this test program have been published after one,[8/] three,[9/] and seven years' exposure.[10/] The next inspection is planned after fifteen years exposure.

Because the limited number of enamels on aluminum included in the 1956 test were selected fairly early in the development of this product a further evaluation of the weathering resistance of currently produced porcelain enamels on aluminum was initiated in 1965.

The enamels in this test are exposed at Montreal, Canada; Washington, D.C; New York City, New York; Kure Beach, North Carolina and Los Angeles, California. The one-year inspection of the enamels exposed at Montreal and New York City was completed during this report period.

A new Weathering test of Nature-Tone or mat enamels on steel is scheduled to begin in 1966. Many of the enamels to be included in this test have been received at the National Bureau of Standards and laboratory tests on these enamels have been completed.

A. 1966 Test of Nature-Tone Enamels on Steel

Six specimens of each of twenty-five colors are to be exposed at each of three sites: Kure Beach, North Carolina - 80 feet from the ocean; Miami, Florida - near Biscayne Bay; and Gaithersburg, Maryland - the new location of the National Bureau of Standards, about 20 miles northwest of Washington. During the last report period, 16 of the 25 enamels had been received and 11 of these had been subjected to cleaning and laboratory tests. Eight of the remaining enamels were received during this report period.

B. 1965 Test of Porcelain Enamels on Aluminum

The one-year inspection of the enamels in the exposure test authorized by the Aluminum Council of PEI in 1964 is nearing completion. The storage enamels and those exposed at Washington underwent their one-year inspection during the preceding report period. During this report period, the specimens at New York City, and Montreal were inspected and those exposed at Kure Beach were removed from the exposure racks.

INSPECTION PROCEDURE

1. Cleaning of Specimens

Previous exposure tests [7,10] have indicated the need to scour the specimens after exposure at one or more of the sites before meaningful gloss and color measurements could be made. These scouring treatments usually tended to increase the gloss readings of the scoured enamels making comparisons with unscoured enamels exposed at the other sites invalid. Therefore, it was decided to scour all the specimens in the 1965 and 1966 exposure test both before and after exposure. The cleaning procedure adopted was to 1) scour 30 strokes with a sponge that had been moistened with a solution containing one weight percent trisodium phosphate and sprinkled with calcium carbonate, 2) rinse with tap water, 3) rinse with distilled water and 4) rinse with alcohol.

2. Gloss and Color

The 45° specular gloss of the specimens was measured at four orientations near the center of the specimen. The gloss is reported as the percentage of initial gloss retained after exposure.

The change in color was measured with a color difference meter. One of the three storage specimens of each enamel was, in turn, measured against NBS color standards to determine whether the enamels have changed color during cleaning and storage. The color change after exposure is reported as color retention which is 100 minus the color change in NBS units.

RESULTS

A. 1966 Test of Nature-Tone Enamels on Steel

1. Specimens Received

At the end of this report period, 24 of the 25 Nature-Tone enamels had been received and subjected to cleaning and laboratory tests.

2. Cleaning and Thickness Measurements

All specimens received were subjected to the above cleaning process. After cleaning, the coating thickness was determined with a magnetic thickness gage for 12 of the 48 specimens of each enamel. The average thickness of each enamel is given in Table 5.

3. Continuity of Coating

Since the Nature-Tone enamels in a previous exposure test exhibited quite poor coverage, it seemed desirable to determine the usefulness of the continuity of coating test, now under study, in eliminating specimens with poor coverage. Therefore, three of the six specimens to be exposed at each site consisted of specimens which had no areas of poor coverage as indicated by the high voltage probing method. A voltage of 2kVdc was selected as the optimumtest voltage. This selection was based on the best separation between specimens which did and did not rust in a preliminary weathering exposure of Nature-Tone enamels which were approximately eight mils thick. However, when the enamels were received, it was noted that many of the enamels were thicker than the earlier nature-tone enamels. This increased thickness indicated that the test voltage should be increased to 2.5 kV to insure a voltage sufficient to jump a possible 10 (or 12) mil air gap. Another modification of the test voltage was made when it was realized that there were too few specimens of some enamels to get the required number of specimens (9) needed for exposure. In these cases the voltage was decreased to 1.5 kV and sometimes to 1 kV to get the required nine specimens.

The improved correlation sought between tested and untested specimens may be somewhat masked since seven of the enamels showed no defects when probed at 2.5 kV to get nine specimens with continuous coatings and an additional three enamels had only one defective specimen each. This indicates that tested and untested specimens of these enamels (tabulated as "good" in table 5) could be expected to show no difference with respect to rusting tendency in weathering. In contrast to these "good" enamels, four of the enamels had to be probed at test voltages as low as 1.0 to 1.5 kV in order to get the requisite number of specimens to pass. These enamels are designated as "poor" in table 5. It is possible that these test voltages are low enough to pass all specimens regardless of whether there are defects present or not.

Eliminating both the "good" and "poor" enamels leaves 10 or 11 "medium" enamels which may give the desired correlation. The "percentage passed" column in Table 5 indicates that the "medium" enamels had between 26 and 82 percent of the enamels passing the high-voltage probe. This indicates that all three of the untested specimens at any site would be unlikely to rust at the same time interval. Indeed, it is possible on the basis of random selection, that the untested specimens could be as good as the tested ones with respect to coverage.

4. Acid Resistance

The boiling acid solubility and the acid spot test ratings were determined for triplicate specimens of each enamel. These results are given in Table 5.

5. Gloss and Color

The initial gloss and color measurements were made as previously described. The initial gloss values are reported in Table 5.

6. Edge and Back Coverage

Since the enamel coverage on the edges of the specimens was light, the edges were coated with two coats of paint; one zinc chromate primer and one black exterior paint. This was done to prevent rust from forming on the edges and covering the surface of the enamel with a thin rust film.

It was also noted by Moore and Harrison[6/] that poor back coverage on a specimen that is exposed to moisture will eventually lead to spalling of the enamel from the front surface. This would cause corrosion of the base metal to be noticable on the front surface. Since this test was designed, in part, to determine whether the high-voltage test was satisfactory for weeding out enamels with poor coverage, it was decided that the pin marks on the back of the specimens should be coated with a coat of paint to minimize the possibility of rust occurring on the front surface due to the poor coverage on the back.

B. 1965 Test of Porcelain Enamels on Aluminum

1. Cleaning of Specimens

The specimens exposed at New York City and Montreal were covered with a fairly heavy dirt film which was satisfactorily removed by the cleaning procedure outlined above. The ease with which the New York City specimens were cleaned was surprising since these same specimens were extremely difficult to clean following six months' exposure. This increased cleanability was probably due, at least in part, to the increased rainfall during the past six months.

2. Gloss and Color

The gloss and color were measured as previously described. These data have been reduced to percentage gloss retained and color retention and are reported in Table 6. There are several low and medium gloss enamels that have increased in gloss between six months and one years' exposure. This increase in gloss was not noted for either the storage or the Washington enamels after one year's exposure. It therefore seems unlikely that the increase in gloss was caused by the routine scouring treatment included in the cleaning procedure. However, the dirt on the specimens exposed at Montreal and New York may have been more abrasive than the calcium carbonate used in cleaning. This could cause the enamels in the lower gloss ranges to increase in gloss as noted in the work done before selecting a cleaning procedure.

3. Comparison of Exposure Sites

A two-sided sign test [11/] was performed on the gloss and color data for the enamels exposed at Montreal, New York City, and Washington to determine whether there were significant differences in the weathering of enamels exposed at these sites.

The color data indicated that Montreal caused less change in the enamels than did either New York City or Washington. New York City and Washington caused nearly equal changes in the enamels.

The gloss data, however, indicated that no two sites produced the same changes in the enamels. Washington caused the most change followed by Montreal and New York City.

These discrepencies in the ranking by gloss and color are probably attributed to the polishing effect of the dirt on the specimens exposed at Montreal and New York City.

4. Correlation of Color Retention with Acid Solubility

A definite relationship exists between the acid solubility and the color retention of the enamels exposed for one year at Washington, Montreal, and New York City. This relationship is illustrated in Figure 4. The red enamels were omitted from this figure since they failed the 15-second nitric acid spot test and therefore would not normally be used in architectural installations. Pearson's correlation coefficients,[12/] of - 0.92, - 0.94 and - 0.90 for Montreal, New York City and Washington respectively confirm a good correlation between acid solubility and color retention.

5. Nature-Tone Enamels on Aluminum

Eight nature-tone enamels on aluminum are to be added to the program after the one-year inspection. Seven of these enamels have been received. Six of these enamels were cut into exposure specimens at the fabricator's plant, while the seventh enamel is still in the original 3 x 5 foot sheet. This enamel will be cut into exposure specimens after the final enamel is received, since this one may also need to be cut. The acid resistance, both boiling acid solubility and acid spot test ratings, were determined for the six enamels that were received in specimen form and the values for these enamels are reported in Table 7, together with the initial gloss, color and thickness of the enamels to be exposed.

PLANS FOR NEXT REPORT PERIOD

A. 1966 Test of Nature-Tone Enamels on Steel

The final nature-tone enamel should be received during the next report period. This enamel will be cleaned and tested as previously described. All the enamels will then be exposed at KureBeach, North Carolina - 80 feet from the ocean; Miami, Florida - near Biscayne Bay; and Gaithersburg, Maryland - the new location of the National Bureau of Standards about 20 miles northwest of Washington.

The first inspection is scheduled after six months' exposure.

B. 1965 Test of Porcelain Enamels on Aluminum

The enamels exposed for one year at Kure Beach and Los Angeles should be inspected and a complete on-year report written for the Aluminum Council.

The one remaining Nature-Tone emanel on aluminum should be received and the enamels should be returned to the exposure racks.

III. CONTINUITY OF COATING

INTRODUCTION

Work towards the development of a continuity of coating test for porcelain enamels has been proceeding intermittently between other projects for the past year and a half. During this time many test methods were reviewed and the high-voltage discharge test appeared to offer the best possibilities for being developed into a test for continuity of coating because it located large bubbles, blisters, and metallic contamination as well as pinholes and cracks that are open to the substrate.

Many storage specimens of enamels included in PEI-NBS exposure tests (initiated in 1956 and 1965) have been probed to determine if duplicate specimens of enamels that rusted in service would be punctured with a lower voltage than the enamels that did not rust. These probings indicated a definite separation between the rusted and unrusted specimens occurred at 2.5 kV for the enamels in the earlier test and 2.0 kV for the enamels in the later test. It was also noted that the earlier enamels were approximately 10 mils thick while the later ones were only 8 mils. The difference in separation voltage for the enamels in these tests was therefore attributed to the difference in the thickness of the enamels.

Some manufacturers of porcelain enamels were then asked to submit samples having "good" and "bad" continuity in thinner direct-on coatings so the effect of thickness could be determined.

RESULTS

Specimens of a white cover coat enamel and a laundry basket enamel having "good" and "bad" continuity of coating were received from the manufacturers. These enamels ranged in thickness from three to five mils.

When these enamels were probed there was no difference in the test voltage required to puncture the "good" and "bad" white enamels but a separation was found for the laundry basket enamels (see Table 8). However, the "good" laundry basket enamel was more than a mil thicker than the "bad" one and it was not certain whether the separation was caused by differences in continuity of coating or just to the increased thickness of enamel. Therefore, the enamels were subjected to the electrolytic cell test which was described in a previous report. This test, which is capable of locating only those portions of enamel having pinholes or cracks open to the substrate, indicated a difference between the "good" and "bad" laundry enamels but not between the white cover coat enamels. This confirms the results found with the high-voltage tester.

PLANS FOR NEXT REPORT PERIOD

Although this data indicates that the test voltage for a separation between good and bad enamels decreasesas the coating thickness decreases, it is not known what fraction of the voltage, if any, is needed to puncture the enamel and what part is needed to ionize, or breakdown, the air between the probe and substrate. Therefore, it has been decided to re-probe all the specimens tested so far that have had high-voltage discharges occurring on them. These specimens would be similar to future untested specimens but they would eliminate the fraction of the voltage, if any, that is used to puncture a very thin layer of enamel existing either over or under a discontinuity since this enamel layer would have been removed by previous probing.

If these probings give the desired results, then this method of purposely puncturing an enamel and then re-probing it to determine the voltage necessary to ionize the air between the probe and the base metal could be used to calibrate high-voltage instruments used in other laboratories regardless of whether they are ac or dc instruments.

IV. CLEANABILITY

No detailed progress toward a cleanability test procedure is included in this report. The fluorometer was returned to the supplier for the replacement of two components and was not available for use during a major portion of the report period.

Table 1. Spotting Tests on Various Porcelain Enamels With a Mat Finish.

Enamel No.	Acid Solubility mg/in^2	0.1 % Citric for 3 minutes on untreated area	HAc[1/]; 5 minutes followed by 0.1 % Citric for 3 minutes	HAc[1/]; 5 minutes followed by 0.6 % Citric for 3 minutes	HAc[1/]; 5 minutes followed by 1.0 % Citric for 3 minutes
109	0.7	vis	nv	nv	nv
105	1.6	vis			
107	1.8	vis (F)	nv	nv	nv
5 (R8)	2.4	vis (F)	nv	nv	nv
6	6.9	vis (F)	nv	nv	vis (F)
104	7.4	vis (M)	nv	nv	nv
106	7.8	vis	nv	nv	vis (VF)
7	8.4	vis	nv	nv	nv
RA-3	14.1	vis	nv	nv	nv
101	14.4	nv	nv	nv	nv
SA-2	14.6	vis (S)	nv	vis (F)	vis (M)
PA-4	36.2	vis (F)	vis (F)	vis (M)	vis (S)
PA-2	56.9	vis (S)	vis (F)	vis (M)	vis (M)

1/ HAc represents Acetic Acid, 10 percent by weight

F represents faint spot
M represents medium spot
S represents strong spot
vis represents visible spot
nv represents no visible attack

Table 2. Acid Resistance Grading Using A Spot Test For Mat Enamels

GRADE I			GRADE II			GRADE III		
Enamel No.	Acid Solubility mg/in^2	Spot Test Rating 1/	Enamel No.	Acid Solubility mg/in^2	Spot Test Rating 1/	Enamel No.	Acid Solubility mg/in^2	Spot Test Rating 1/
109	0.7	A	9	0.7	A	R-2	12.0	B
110	0.8	AA	116	0.9	A	SA-2	14.6	C
112	0.9	A	111	1.0	A	PA-4	36.2	C
115	0.9	A	114	1.0	A	PA-2	56.9	C
113	1.0	A	105	1.6	A	PA-1	42.4	D
108	1.2	A	5	2.4	A			
107	1.8	A	1	2.6	A			
8	3.9	A	4	2.8	A			
			3	3.0	A			
			6	6.9	B			
			104	7.4	B			
			106	7.8	A			
			103	8.3	A			
			7	8.4	B			
			102	9.5	B			
			RA-3	14.1	B			
			101	14.4	B			
Average Solubility	1.4			5.5			32.4	

1/ Rating by the Citric Acid Spot Test (ASTM C 282) assumed that these enamels passed the blurring highlight test. See Figure 2.

Table 3 A Comparison of Acid Resistance Grading Tests.

CITRIC ACID SPOT TEST
Glossy Enamels on Steel in the Current Weathering Test
(Summarized from Table 4)

Spot Test Rating	Acid Solubility mg/in^2	
	Average	Range
AA	1.5	0.5 to 4
A	2.4	0.9 to 7
B	11.8	7 to 19
C	14.6	1.2 to 42
D	33.9	19 to 64

SPOT TEST FOR MAT ENAMELS
Naturetone Enamels and Mat Enamels from the
Current Weathering Test

Mat Rating	Acid Solubility mg/in^2	
	Average	Range
I	1.4	0.7 to 4
II	5.5	0.7 to 14
III	32.4	12 to 57

Table 4. The Relation Between Citric Acid Spot Test Rating and Boiling Acid Solubility. 49 Glossy Enamels on Steel From the Current Weathering Test a/

Citric Acid Spot Test Rating

AA		A				B		C		D	
Enamel No. and Acid Solubility, mg/in²		Enamel No. and Acid Solubility, mg/in²				Enamel No. and Acid Solubility, mg/in²		Enamel No. and Acid Solubility, mg/in²		Enamel No. and Acid Solubility, mg/in²	
A-1	1.0	B-3	7.0	H-2	1.7	B-1	13.4	C-1	280 b/	C-3	536 b/
A-2	1.1	D-2	1.4	H-3	0.9	B-2	18.6	C-2	433 b/	C-4	376 b/
A-3	1.4	F-2	4.4	H-4	2.1	B-4	8.2	D-1	4.7	E-3	20.1
A-4	0.6	G-1	1.5	L-1	1.9	F-3	6.8	E-1	1.2	E-4	22.3
D-3	3.4	G-3	2.7	L-2	2.2			E-2	3.2	K-2	19.2
D-4	4.0	G-4	1.9	L-3	3.2			F-1	7.1	K-3	43.8
G-2	0.9	GA-1	1.7	M-1	2.7			F-4	5.5	K-4	63.9
H-1	0.5	GA-2	1.3	M-2	2.6			FA-4	5.1	N-2	34.3
L-4	0.8	GA-3	2.1	M-3	1.9			K-1	20.9		
		GA-4	2.1	M-4	2.5			N-1	21.1		
								N-3	36.1		
								N-4	41.5		
Avg.	1.5		2.4				11.8		14.6		33.9
Range	0.5 to 4		0.9 to 7				6.8 to 18.6		1.2 to 41.5		19 to 63.9

a/ Data from "Weather Resistance of Porcelain Enamels", M.A. Rushmer and M.D. Burdick, National Bureau of Standards, Building Science Series No. 4.

b/ Omitted from average and range

Table 5. Summary of Data for Nature-Tone Enamels on Steel

Enamel	45° Specular Gloss	Acid Spot Rating	Acid Solubility (mg/in^2)	Thickness (mils)	kV	Percentage passed	Estimated Coverage
104	17.4	B	7.4	9.2	2.0	100	Good
108	19.2	A	1.2	9.4	2.5	90	Good
109	16.6	A	0.7	9.2	2.5	100	Good
110	20.7	AA	0.8	9.0	2.0	100	Good
111	18.5	A	1.0	10.8	2.5	90	Good
112	13.5	A	0.9	10.7	2.0	100	Good
113	10.1	A	1.0	10.8	2.5	100	Good
115	99.3	A	0.9	10.6	2.5	90	Good
6	2/2	B	8.4	9.1	2.0	100	Good
7	3.4	B	6.9	9.4	2.5	100	Good
102	13.5	B	9.5	8.0	2.0	56	Medium
106	27.3	A	7.8	9.1	2.0	35	Medium
114	15.0	A	1.0	8.8	2.0	65	Medium
116	16.8	A	0.9	9.9	2.5	53	Medium
1	24.4	A	2.6	9.0	2.0	33	Medium
3	20.5	A	3.0	9.6	2.5*	26	Medium
4	11.3	A	2.8	8.8	2.0	82	Medium
117(R-8)	20.7	A	2.4	8.7	2.0	60	Medium
119(8)	27.7	A	3.9	9.4	2.5	56	Medium
120(9)	21.2	A	0.7	9.2	2.0	64	Medium
118	---------------not yet received---------------------------------------						
101	13.8	B	14.4	8.8	1.5	43	Poor
103	13.3	A	8.3	7.5	1.5	25	Poor
105	14.9	A	1.6	9.6	1.0	25	Poor
107	14.4	A	1.8	9.9	1.5	35	Poor

*All of the 4-7/16 in. sq. specimens passed at 2.5 kV, but voltage was lowered to 1.5 kV for the 4 x 6 in. specimens.

Table 6. Summary of Data for Porcelain Enamels on Aluminum Exposed for One Year at New York City and Montreal.

Enamel	New York City Gloss 6 mo.	New York City Gloss 1 yr.	New York City Color 6 mo.	New York City Color 1 yr.	Montreal Gloss 6 mo.	Montreal Gloss 1 yr.	Montreal Color 6 mo.	Montreal Color 1 yr.	Visual Color	Acid Solubility mg/in^2
AA-A	98.3	96.5	99.4	99.3	93.8	90.4	99.5	99.6	White	5.5
AA-B	94.5	93.5	99.7	99.4	98.6	93.2	99.4	99.4	White	5.9
AA-C	92.3	89.6	99.2	99.0	92.0	87.6	98.9	99.0	White	5.0
AA-D	101.1	97.8	97.9	97.4	100.0	93.1	97.8	97.8	White	12.7
AB-A	95.9	94.2	98.1	97.8	83.9	85.7	98.7	98.5	White	7.2
AB-C	83.9	84.4	99.2	99.0	82.7	82.7	99.4	99.4	White	4.9
AB-D	100.5	112.1	98.3	98.4	80.0	95.9	98.9	98.9	White	7.9
AC-A	96.3	93.1	99.3	99.3	98.6	93.1	98.6	99.3	White	6.4
AC-B	103.4	98.4	101.3	97.1	99.0	97.1	99.0	98.4	White	11.3
AC-C	99.0	96.8	98.7	98.4	98;3	94.1	98.9	98.9	White	9.9
AD-A	100.9	99.9	99.2	99.2	90.3	91.1	99.5	99.3	White	6.2
AD-B	97.4	94.5	99.1	99.2	90.5	88.2	99.5	99.5	White	6.7
AD-C	105.3	106.4	98.1	97.9	88.6	94.5	99.1	98.9	White	7.1
AD-D	104.7	114.6	98.1	96.7	87.7	100.3	98.8	99.1	White	12.4
AE-A	82.1	80.3	99.8	99.1	82.1	80.2	99.8	99.9	Black	6.5
AE-B	84.6	83.7	99.6	99.4	88.8	85.1	99.5	99.0	Black	10.1
AE-C	86.7	83.7	99.6	99.6	91.9	87.9	99.5	100.0	Black	12.1
AE-D	83.3	79.9	98.9	98.2	87.4	83.0	99.7	98.4	Black	15.5
AF-A	82.1	82.1	98.5	97.7	90.4	84.3	99.3	98.4	Black	14.2
AF-B	88.3	93.5	99.4	98.4	95.6	95.3	99.4	99.7	Black	9.0
AF-C	84.4	83.3	99.3	98.1	88.2	85.4	99.8	99.4	Black	10.1
AG-B	76.2	100.4	98.4	98.5	81.3	100.5	98.9	98.5	Black	12.5
AG-C	35.9	101.0	98.3	98.1	31.8	97.0	99.5	99.5	Black	7.5
AH-A	118.3	121.3	97.6	97.1	97.8	103.6	97.5	97.4	Red	8.1
AH-B	81.7	75.6	96.6	95.1	75.4	75.7	95.2	95.2	Red	8.8
AH-C	75.5	75.6	91.5	90.7	77.3	73.6	92.8	91.8	Red	6.5
AH-D	79.0	77.0	95.2	90.8	82.8	77.6	89.7	88.1	Red	10.5
AO-A	80.2	78.5	99.7	99.0	83.8	81.4	99.3	99.3	Dk. Green	19.9
AO-B	83.0	83.1	99.7	99.3	83.4	83.1	99.7	99.5	Dk. Green	10.1
AO-D	81.0	79.1	99.4	98.6	87.8	84.9	99.4	99.0	Dk. Green	17.0
AP-A	102.3	104.9	99.4	99.5	92.1	94.8	99.5	99.3	Lt. Green	12.3
AP-B	86.3	94.6	99.6	99.4	78.6	82.8	99.6	99.4	Lt. Green	6.4
AP-C	85.8	98.9	99.6	99.7	76.4	83.9	99.5	99.6	Lt. Green	6.2
AP-D	95.4	100.8	99.5	99.3	91.7	94.7	99.3	99.3	Lt. Green	10.0
AR-A	54.2	138.4	99.3	99.3	62.4	106.5	99.3	99.7	Lt. Green	4.4
AR-B	0.0	110.9	98.8	98.7	4.4	73.6	99.7	99.7	Lt. Green	5.5
AR-C	0.0	84.6	98.8	98.6	0.0	69.6	99.7	99.6	Lt. Green	8.1
AS-A	91.7	88.3	99.4	99.3	91.2	89.7	99.5	99.4	Gray	13.4
AS-B	85.0	84.5	99.2	99.4	83.0	82.3	99.4	99.3	Gray	7.4
AS-C	90.4	89.9	99.6	99.5	91.7	89.1	99.8	99.6	Gray	5.4
AT-A	80.4	94.1	98.9	98.8	68.3	83.1	99.1	99.1	Blue	6.2
AT-B	91.5	95.6	98.6	98.8	91.0	90.9	99.3	99.1	Blue	7.0
AT-C	83.3	83.0	99.7	99.1	80.9	79.9	99.3	99.4	Blue	6.1
AU-A	88.3	90.7	99.7	99.8	81.2	83.4	99.8	99.7	Brown	5.3
AU-B	98.0	108.1	99.5	99.4	79.9	89.7	99.8	99.6	Brown	7.5
AU-C	95.1	98.0	99.6	99.6	91.5	93.5	99.8	99.8	Brown	7.6
AW-A	86.2	85.1	99.5	99.5	85.7	83.5	99.6	99.6	Yellow	7.8
AW-B	95.6	94.3	99.3	99.2	94.2	92.7	99.2	99.3	Yellow	8.7
AW-C	91.4	85.4	99.4	99.1	90.3	86.3	99.4	99.4	Yellow	18.6
AZ-A	103.4	99.2	99.9	99.0	102.4	98.0	99.1	99.2	White	9.5
AZ-B	90.9	64.1	99.2	98.9	93.9	89.2	99.3	99.0	White	5.2
Average	85.7	93.2	98.8	98.4	81.7	88.3	98.9	98.8		

Table 7. Summary of Initial Data for Nature-Tone Enamels on Aluminum

Enamel	Visual Color	45° Specular Gloss	Thickness mils	Acid Solubility mg/in^2	Acid Spot Test
AM-1	Brown ----------Not Yet Received--------------------				
AM-2	Light Brown	19.5	2.3	10.0	A
AM-3	Blue	10.5	2.6	13.0	A
AM-4	Light Blue	7.6	2.1	9.3	A
AM-5	Green	17.4	2.7	13.6	A
AM-6	Light Green	16.5	3.1	8.0	A
AM-7	Gray	11.2	2.1	11.7	B
AM-8	Light Gray -----Not Yet Cut Into Exposure Specimens---				

Table 8. Comparison of Continuity of Coating Methods for "Good" and "Bad" Direct-on Enamels

Type of Enamel	Cover Coat White		Laundry Basket	
Manufacturer's Estimate of the Enamel's Continuity	Good	Bad	Good	Bad
Results of Electrolytic Cell Test	Pass	Pass	Pass	Fail
Voltage Required for Discharge to Occur	1.5 kV	1.5 kV	1.0 kV	0.5 kV
Thickness of Enamel - mils	5.3	5.0	4.7	3.5

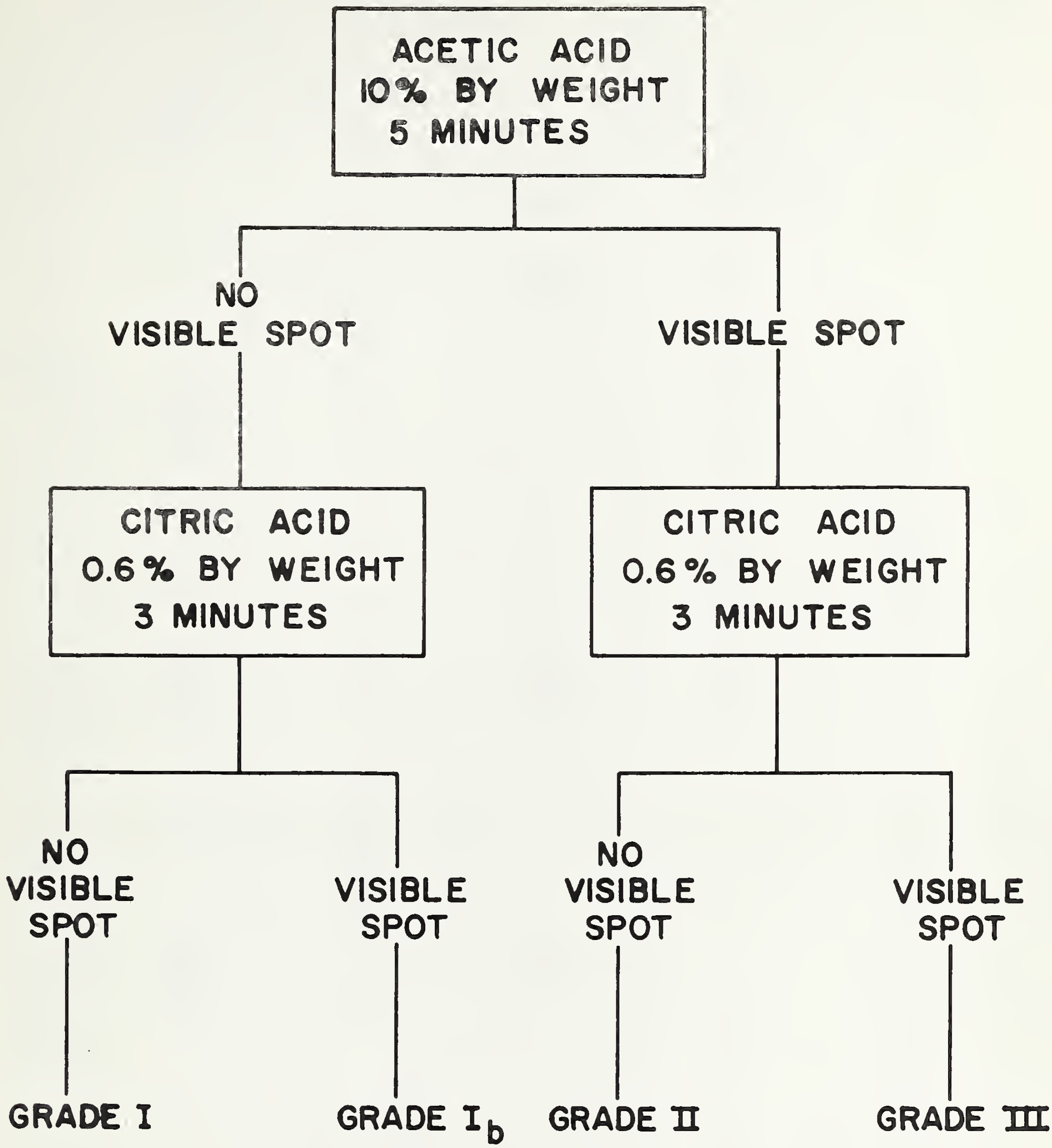

FIG. 1. The Rating System Used in the Spot Test for Mat Enamels.

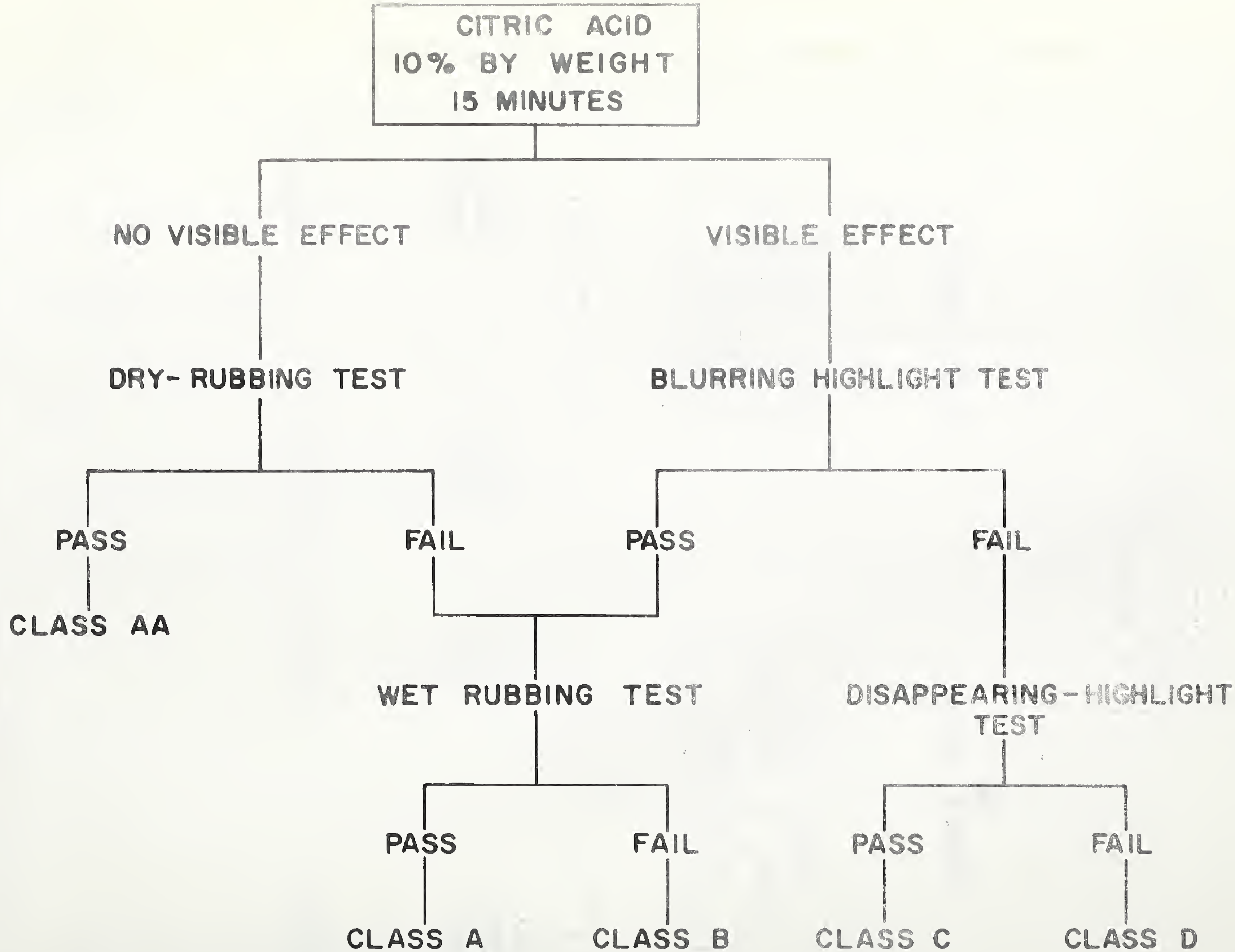

FIG. 2. The Citric Acid Spot Test Rating System.

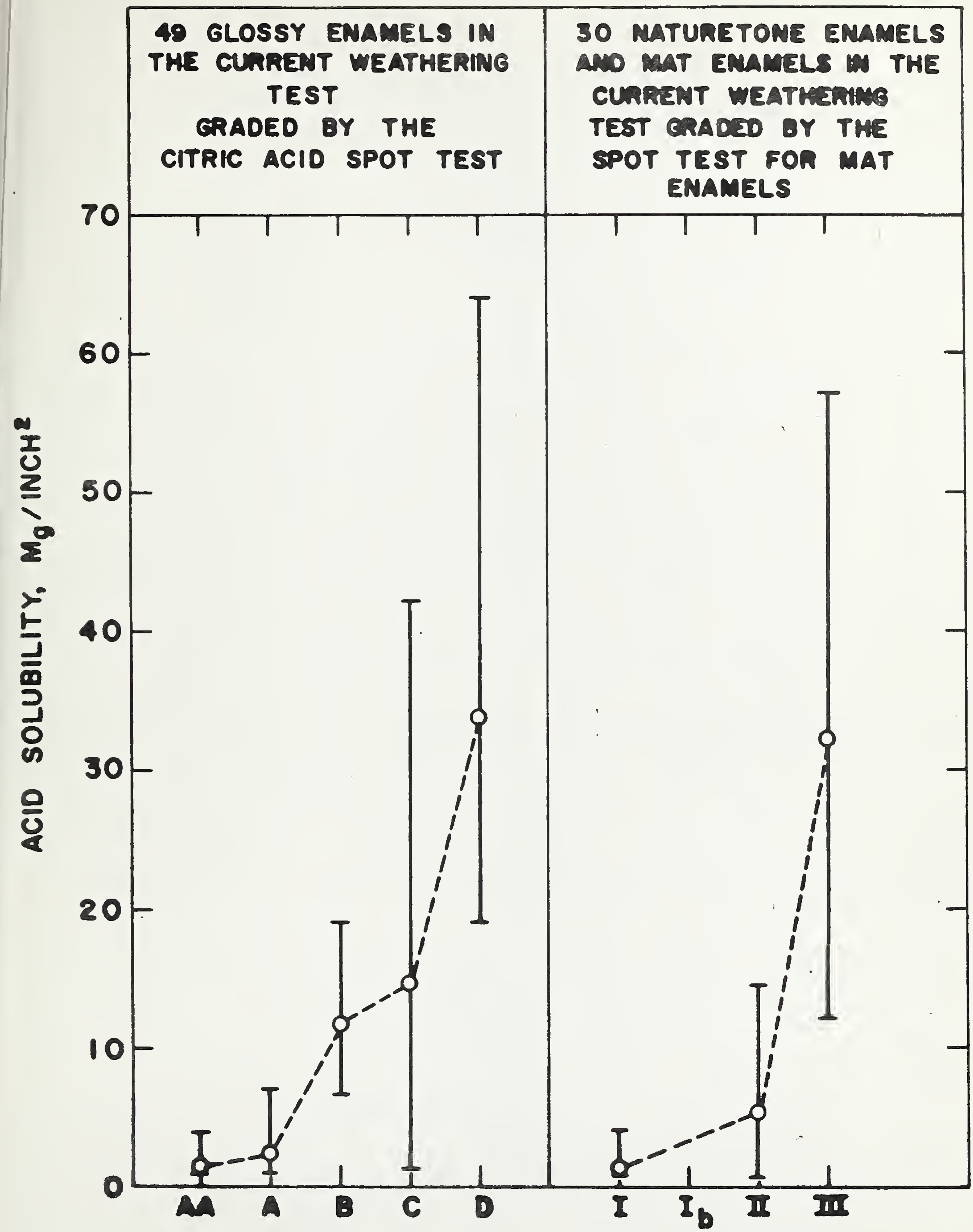

FIG. 3. A COMPARISON OF ACID RESISTANCE GRADING

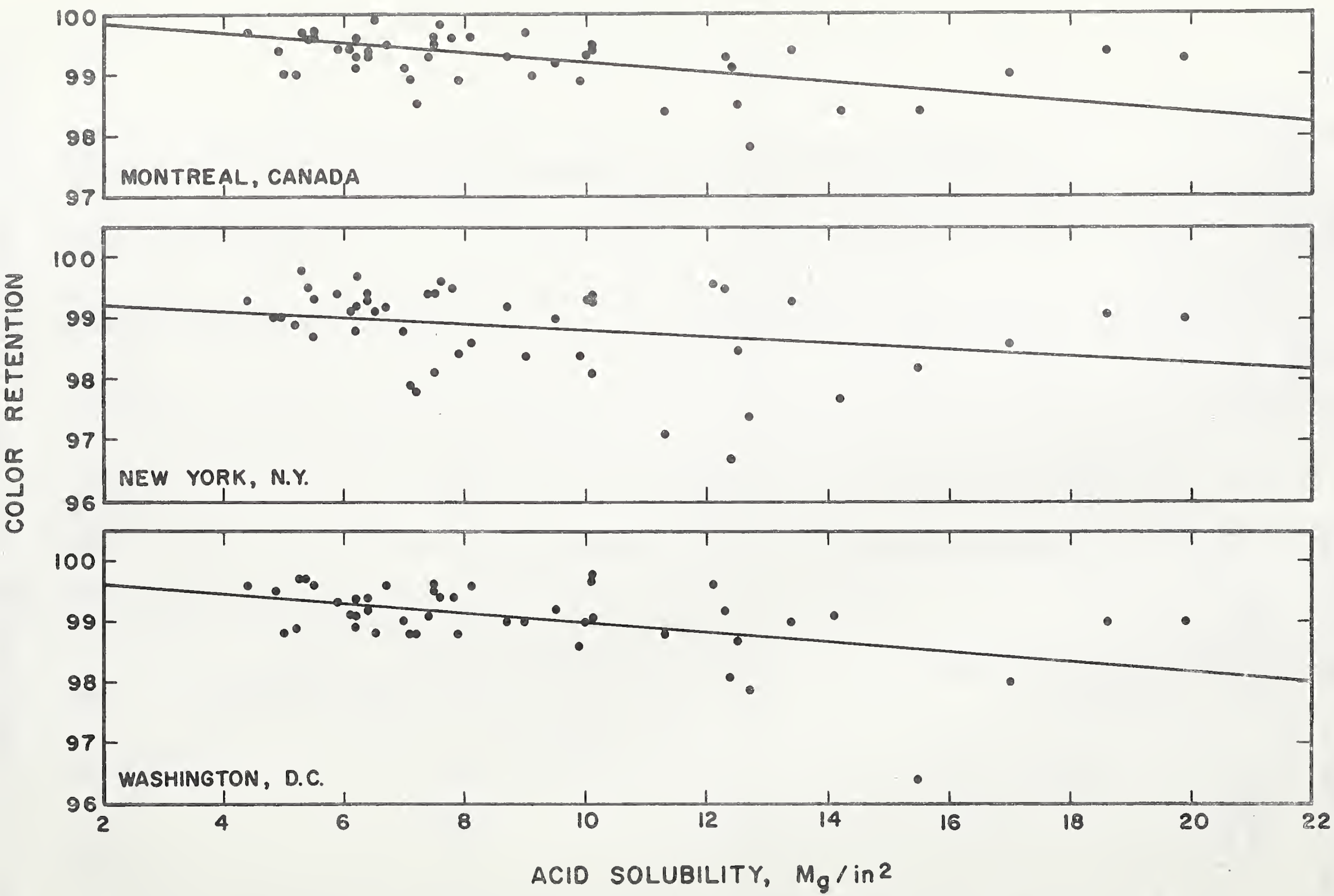

Fig. 4. Correlation of the Color Retention of Porcelain Enamels on Aluminum and their Boiling Acid Solubility.

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