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Use of Plastic Replicas in Evaluating Surface Texture of Enamels

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A technique for making ethyl cellulose replicas of enameled and other surfaces is described. Photographic prints of a number of replicas are shown and methods of analyzing the replicas are discussed.

The haze of replicas was used to evaluate 25 enamels abraded in the Standard Porcelain Enamel Institute Surface Abrasion Test. Graphs are shown comparing these ratings with those obtained by the standard method, by visual estimates of the abrasion as seen on the enameled specimens, and by visual estimates of the abrasion as seen in the replicas. The haze of replica method appears to offer advantages for evaluating the amount of abrasion.

I. Introduction

The surface texture of an enamel has an important effect upon the appearance and utility of an enameled article. For most uses, the high gloss usually associated with porcelain enamels is desired from the standpoint of appearance, and the smooth surface is desired for ease in cleaning. For some other uses, however, such as architectural panels, semimat finishes may have an advantage from the standpoint of appearance.

Most enamels, if properly applied and fired, have smooth fire polished surfaces. Surface defects may arise from improper application or firing of the enamel or from other causes. Measurement of surface texture would help to evaluate the surface defects as they occur in the plant, and a simple quantitative method for measuring surface texture of enamels will find wide use not only in the plant but also in the laboratory and field.

Abrasion, etching, and weathering in service tend to roughen the surface of an enamel and destroy its gloss. Laboratory tests for resistance to abrasion and attack by acids or alkalis usually are designed to reproduce under controlled conditions the mechanisms that damage the enamel in service. Quantitative measurements of surface texture should be valuable for evaluating and correlating the results of laboratory tests and performance in service.

II. Methods of Evaluating Surface Texture

An abraded surface usually will differ from a smooth surface in gloss and color, as well as in its tendency to pick up and retain dirt. Roughness caused by abrasive wear can be observed in enameled surfaces by visual inspection. The personal factor may play an important role in visually evaluating surface texture. Therefore, an objective method giving reproducible results is desired.

Way [1] [1] has described a number of mechanical methods for studying the surface finishes of metal, such as the profilograph and surface analyzer. These can be used to measure surface texture and are suitable for some purposes, but the results frequently are not easy to interpret.

Test methods based on optical measurements offer one means of evaluating the surface texture of enamels. Specular gloss measurements have been successfully used to evaluate the change in surface texture (roughening) produced by abrasion [2], etching [3] or weathering [4]. They can also be used to measure the changes in the surface texture of an enamel produced by variations in applications or firing procedures. However, the gloss of a surface is influenced by several other factors besides its texture. Hunter [5] identifies and defines six distinct types of gloss, several of which cannot be measured objectively.

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

829788—49——3

A technique for using plastic replicas of machined metal surfaces to evaluate the surface finish was developed by Herschman [6]. A modification of this technique was applied to enameled surfaces by the present authors, and appears to offer promise as a method for evaluating surface finish (texture).

Allen and Friedberg [7] in a paper published since most of this work was completed, show a number of photomicrographs of ceramic surfaces obtained by replica methods.

III. Plastic Replicas of Enameled Surfaces

1. Procedure for Making Replicas

A solution was prepared by dissolving 1 gram of ethyl cellulose in 100 ml of a solvent composed of 80 parts of toluene to 20 parts of acetone by volume.[2] The general procedure described in a previous Bureau paper [6] was followed in making a replica. This consisted in placing a small amount of solution on a specimen near one edge and pressing a 4- by 4-in. sheet of ethyl cellulose, 0.0075 in. thick on the specimen, over the solution, which was then spread out under the plastic by means of a rubber roller applied to the external surface of the plastic sheet. After drying for a few minutes, the replica was stripped from the specimen and placed in a metal holder to prevent curling.

Replicas prepared in this way were graded by several means, which will be discussed in greater detail in later sections of this paper. These methods include visual examination, with and without magnification, projection of the replicas and examination or measurement of the image produced, and measurements of the haze of the replicas.

[2] Later experiments have shown that a solvent composed of 85 parts of ethyl acetate to 15 parts of 95% ethyl alcohol by volume gives somewhat better duplication but causes severe curling of the replica sheet.

TABLE 1. *Results obtained by five rating methods [1] on 25 Enamels abraded by the Standard PEI Abrasion Treatment*

Enamel No.	Color [2]	Method A			Method B			Method C		Method D		Method E	
		Rating	e [3]	Rank [4]	Rating	e [3]	Rank	Average	Rank	Average	Rank	Percentage	Rank
1	W	83.5	0.9	1	7.7	1.4	1	1.33	1	3.0	1	6.7	5
2	W	78.4	1.2	2	7.8	1.1	2	6.50	4	5.0	5	6.4	3
3	W	74.5	0.8	3	16.8	0.7	22	11.17	12	19.3	20	12.6	19
4	W	74.2	1.4	4	8.1	1.3	3	7.50	7	3.3	2	5.2	1
5	W	69.3	1.5	5	8.6	1.0	5	7.33	6	7.4	7	7.7	7
6	W	69.3	1.1	6	9.2	1.2	7	11.00	11	10.3	9	9.1	10
7	W	68.3	1.5	7	9.2	0.9	6	4.33	2	4.7	4	6.6	4
8	W	67.2	0.5	8	11.6	.7	15	13.00	15	15.6	16	10.1	16
9	W	67.1	.9	9	10.5	2.2	11	12.00	14	11.3	12	9.1	11
10	W	67.0	1.3	10	9.3	0.7	9	11.83	13	7.9	8	7.6	6
11	C	65.8	1.5	11	11.8	.2	16	24.17	25	22.3	22	10.0	15
12	W	65.6	1.2	12	9.4	.6	10	9.00	9	10.4	10	9.3	12
13	W	65.4	1.4	13	9.2	1.4	8	10.67	10	6.9	6	8.2	8
14	W	64.7	1.6	14	12.8	0.8	19	7.17	5	13.1	13	10.2	17
15	W	64.3	0.7	15	10.8	.9	14	7.66	8	13.3	14	10.8	18
16	W	63.8	1.3	16	10.6	1.1	12	5.67	3	10.4	11	8.8	9
17	W	63.3	1.4	17	10.7	0.9	13	16.16	16	13.4	15	9.8	14
18	C	61.9	0.6	18	8.5	1.3	4	22.33	23	3.9	3	6.1	2
19	C	61.8	1.7	19	14.9	1.0	21	17.33	17.5	20.9	21	13.4	21
20	W	60.3	1.4	20	12.2	1.2	17	18.50	20	18.0	19	13.6	22
21	C	58.8	1.0	21	12.2	0.9	18	19.83	21	16.7	17	9.4	13
22	W	56.9	1.4	22	20.1	1.9	23	17.83	19	23.9	25	19.8	23
23	W	56.1	2.0	23	14.5	0.7	20	17.33	17.5	17.3	18	12.7	20
24	W	40.4	1.4	24	24.2	1.5	24	21.67	22	22.9	23	24.7	24
25	W	38.8	2.2	25	26.0	1.6	25	23.67	24	23.7	24	25.2	25

[1] Methods are as follows: A, Standard PEI Surface Abrasion Test; B, haze of replica for same specimens as method A; C, average visual rank as determined by 6 observers on one abraded specimen of each enamel; D, Average visual rank as determined by 7 observers on replicas from same specimens as method C; E, haze of replicas in method D.

[2] W=White; C=colored.

[3] 95%-confidence error.

[4] Inverse rank.

2. Replicas of Abraded Surfaces

(a) Abrasion by Standard PEI Test

Figure 1 illustrates a replica [3] made from an enameled specimen abraded in the standard PEI Test for Resistance of Porcelain Enamels to Surface Abrasion [2]. It can be seen that the pattern consists of several rings, where the abrasion was relatively severe, but confined to circular paths, surrounding an area that is uniformly abraded. In the standard PEI method (method A, table 1) the 45° specular gloss of this central area is measured before and after treatment. The percentage of the original gloss retained after treatment is then taken as the abrasion index of the specimen.

Specimens of 25 types of enamel, representing a wide range of abrasion resistance, were submitted to the Bureau by cooperating members of the PEI for use in a study of the abrasion resistance of enamels. As a part of this study, six specimens of each enamel were tested for abrasion resistance by the standard PEI method (method A).

In order to compare the loss of gloss method with the replica method (method B), surface replicas were made from the abraded specimens, and the haze [4] of these replicas was measured by Federal Specification Test Method No. 3021 [8] (ASTM Method D–672–44T [9]). Figure 2 is a schematic diagram of the haze meter. In making a determination, the lamp rheostat is adjusted until the microammeter reads 100. The specimen is then placed over aperture A, and the total transmission, T, is read on the microammeter. The specimen is then moved to aperture B, and the parallel portion of the light, Tr, transmitted by the sample is read on the microammeter.

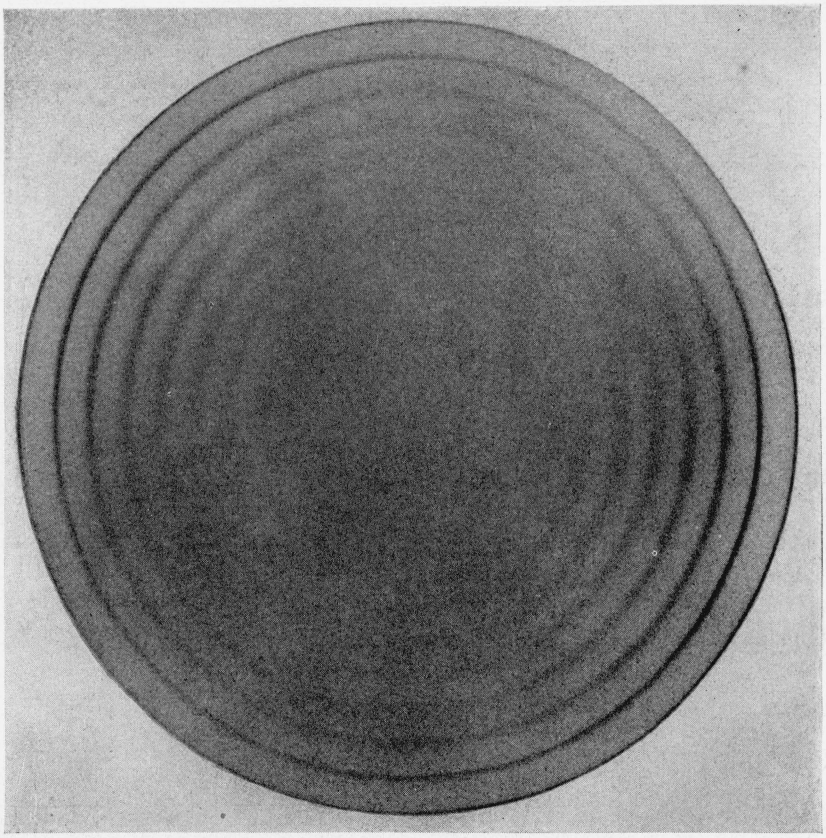

FIGURE 1. *Print from a replica of an enameled specimen abraded in the PEI standard test for resistance of porcelain enamels to surface abrasion.*

[3] Projection of the replicas directly onto photographic paper with only slight magnification produced prints that revealed all of the details that could be seen in the replica. However, these prints were of low contrast. To make engravings for publication, it was necessary to project the replicas onto photographic film, from which prints were made.

[4] Haze is defined as the amount of light diffusely transmitted by a specimen, expressed as a percentage of the total transmission.

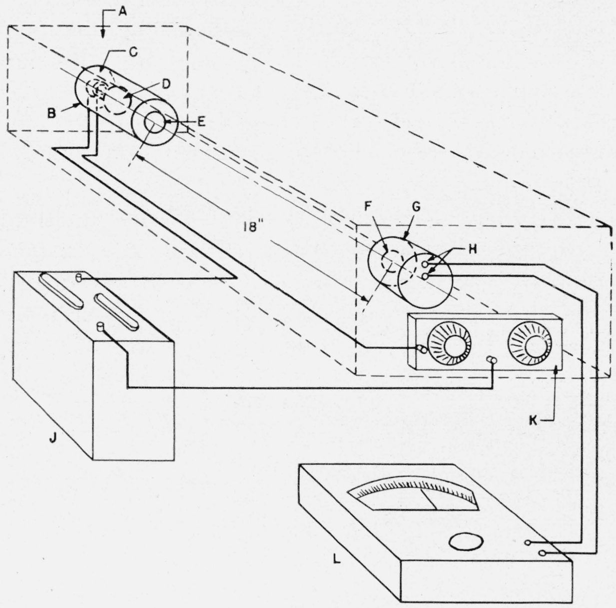

FIGURE 2. *Schematic diagram of the haze meter.*

A, Box (shown in phantom), dull black finish inside; B, cylindrical shield; C, reflector; D, 6-volt lamp; E, aperture B (1-in. diameter); F, aperture A (1-in. diameter); G, photoelectric cell; H, photoelectric cell terminals; J, storage battery 6- or 8-volt source; K, lamp rheostat; L, meter (100-microampere range).

The percentage of haze is then computed from the following formula.

$$\text{Haze}=\frac{T-Tr}{T}\times 100.$$

Figure 3 shows the correlation of the results obtained by the two methods (A and B). In general, the two methods placed the enamels in about the same order, although there were several marked exceptions. The rank coefficient of correlation was 0.70.[5]

Although there was appreciable variation in the original surface texture of the specimens, no replicas were taken before the abrasion tests were made. Replicas were taken, however, from a typical unabraded specimen of each type of enamel. The haze of the abraded specimens was then corrected by subtracting the corresponding haze of unabraded specimen. This correction (averaging about 2.0) did not significantly improve the correlation.

The correlation coefficient indicates fair agreement between methods A and B. The 95-percent-confidence errors [10] for the standard test (A) varied from 0.5 to 2.2 and for the haze reading (B) from 0.2 to 2.2. In general, the statistical errors were slightly lower for the haze values, but not significantly so. If values between which differences are not significant in the light of these errors are assigned the same rank, the rank correlation coefficient would of course be greatly improved.

The two lines shown on each chart are the least squares regression lines, one considering the ordinates alone subject to error, and the other considering the abscissas alone subject to error. The angle between these lines can be taken as a measure of the correlation of the two variables, the smaller the angle, the better the correlation. If α is the acute angle between the lines, the correlation coefficient r may be found from the expression

$$\tan \alpha = 1/2\left(\frac{1}{r}-r\right).$$

If there is perfect correlation, the two lines will coincide and all points will fall on the line, $\alpha=0°$,

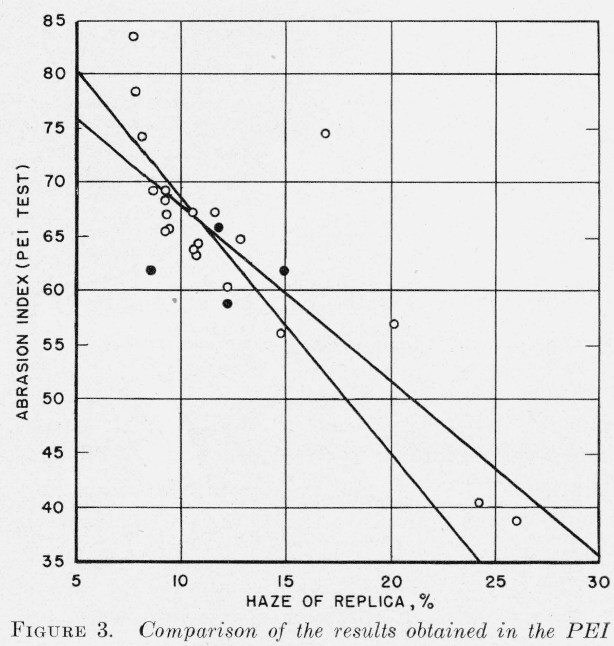

FIGURE 3. *Comparison of the results obtained in the PEI abrasion test with those obtained by haze measurements on replicas taken from the abraded specimens.*

The correlation coefficient is 0.70. ●, Colored; ○, white.

[5] A coefficient of correlation of 1.0 indicates perfect linear relationship, and a coefficient of −1.0 a perfect inverse relationship, in which all points would fall exactly on a straight line. A coefficient of correlation of 0.00 indicates that the relationship is entirely random.

The rank correlation, r, is computed from the formula

$$r=1-\frac{6\Sigma d^2}{N^3-N}$$

in which d=difference in rank of specimen by the two methods, and N=number of specimens.

and $r=1.00$. If $r=0.00$, $\alpha=90°$, and there is no correlation.

There has been considerable discussion in the past as to how well the ratings of abraded specimens by the loss-in-gloss method correlate with the relative appearance of the damaged areas. In an attempt to answer this question, one representative abraded specimen was chosen from the six specimens of each enamel. These 25 abraded specimens were ranked visually by six observers (method C). Each observer was asked to place the specimens in order from least to most damaged. Ratings from 1 to 25 were assigned to the specimens, 1 indicating the least visual damage and 25 the greatest visual damage.

The coefficient of rank correlation between the average visual ratings and the corresponding ratings by the standard test (methods A and C) was 0.69, and between the average visual ratings and haze values (methods B and C) was 0.57. These values indicate that there was fair agreement between the visual estimates and loss-in-gloss ratings determined on the same specimens. There was poorer agreement between visual estimates by observation of the specimens and haze ratings made on replicas from similar specimens (methods B and C).

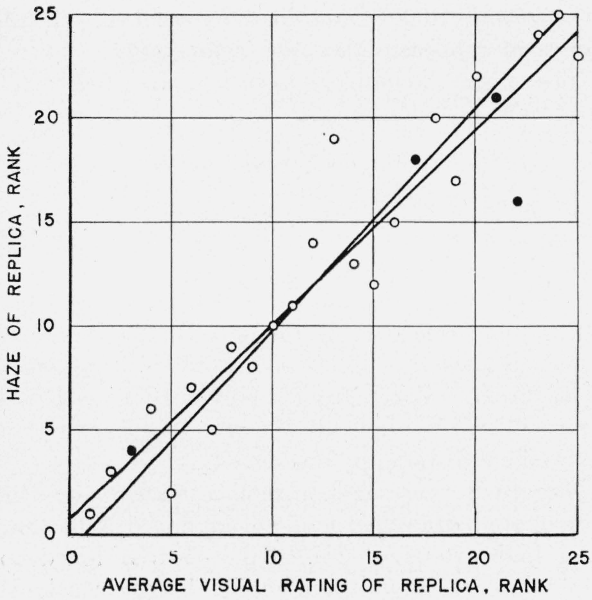

FIGURE 4. *Comparison of the ranks obtained by visual estimates of the amount of damage produced by the abrasion test on 25 enamels, as seen in replicas taken from the specimens, with similar ranks obtained by haze measurements on these replicas.*

The correlation coefficient is 0.94. ●, Colored; ○, white.

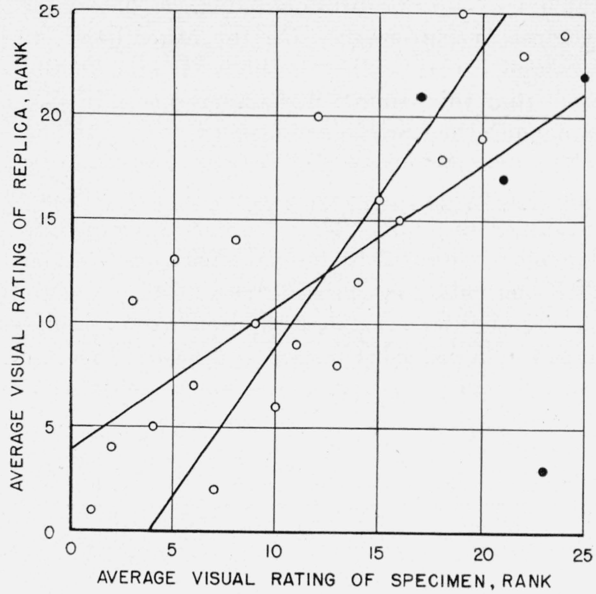

FIGURE 5. *Comparison of the ranks obtained by visual estimates of the amount of damage produced by the abrasion test on 25 enamels, as seen in the specimens, with similar ranks obtained by visual estimates of the amount of damage as seen in replicas taken from the specimens.*

The correlation coefficient is 0.70. Note the one colored enamel in the lower-right corner of the diagram. ●, Colored; ○, white.

Replicas taken from each of the 25 abraded specimens mentioned above were ranked visually by seven observers (method D), by using a procedure similar to that followed in ranking the abraded enameled specimens. In this way the variation in the visual stimulus was limited to the single factor of surface roughness (such factors as color and gloss of the original specimens being eliminated). Figure 4 shows a comparison of these values with the haze values for the same replicas (method E), and indicates that the correlation is much better, the coefficient of rank correlation being 0.94. The data for the various test methods are shown in table 1.

Figure 5 is a comparison of the visual ratings of the specimens with the visual ratings of the replicas (methods C and D). Again the rank correlation is only fair, 0.70.

The point in the lower right corner of figure 5 deserves special consideration. This represents a blue sign enamel, which appeared to have been badly damaged in the abrasion treatment, and which had a low abrasion index, as determined by gloss measurement. On the other hand, the haze and visual replica methods (B and D) indicated that this enamel had undergone only slight damage in the abrasion treatment.

This enamel was found to pass both the wet- and dry-rubbing tests as specified in the PEI acid resistance test [3]. Other enamels, showing little damage when rated by both the haze and standard PEI methods, also passed both tests. Enamels having high haze values and low abrasion indices, however, failed both tests. It appears, therefore, that if roughness of the surface or cleanability are considered of greatest importance, then the replica methods give a better indication of the actual damage suffered by this enamel in the abrasion treatment than is obtained by visual inspection or gloss measurements made on the specimen itself. If appearance of the enamel is considered more important, then the gloss measurement gives a better indication of the damage than does the replica.

In order to obtain a measure of the reproducibility of haze values of different replicas made from the same surface, eight specimens were selected to give a wide range of haze values. Six replicas were made from each of these specimens, and the haze determined. The average, maximum, minimum, and *e* value (95-percent-confidence error) for the haze readings for the six replicas taken from each specimen are shown in table 2. These values indicate that the reproducibility of the haze values is very good, the 95-percent-confidence errors being of approximately the same size regardless of the haze value, and averaging about 0.3 percent haze.

TABLE 2. *Haze values obtained on six replicas taken from each of eight abraded specimens*

Specimen	Haze readings			
	Average	Maximum	Minimum	e [1]
	Percent	*Percent*	*Percent*	*Percent*
A	1.18	1.31	1.09	0.34
B	7.60	7.92	7.03	.32
C	9.32	9.58	9.13	.22
D	10.96	11.13	10.69	.17
E	11.84	12.08	11.42	.29
F	16.88	17.55	16.66	.35
G	26.77	26.08	27.22	.42
H	27.53	28.01	27.07	.37

[1] 95-percent-confidence error [10].

(b) Abrasion by Taber Abraser

There is as yet no standard test that specifies the Taber Abraser as the abrading mechanism on porcelain enamels. However, the wide use of this instrument for abrasion tests of plastics, paints, textiles, and metallic coatings has aroused considerable interest, and some work has been done at the National Bureau of Standards on the application of this test to porcelain enamels.

Federal Specification Method 3021 [8] (visible light transmission and haze of plastics) with minor modifications, is specified in Federal Specification Method 1092 [11] for evaluating surface abrasion (scratching) resistance of plastics. In the latter method, the increase in haze of a plastic specimen produced by 25 revolutions in the Taber Abraser is taken as a measure of the abrasion.

This method was readily adapted for use in evaluating the results of abrasion tests on enamels, except that many more cycles were required for enamels than for comparable abrasion of plastics. Haze measurements were made on replicas taken from a number of specimens before and after abrading. Figure 6 [6] illustrates a replica of a sheet steel enamel that has been abraded for 5,000 revolutions with the Taber Abraser, by using CS–17 wheels and 1,000-grams load on each wheel. A series of replicas, taken at various stages during a test, forms a complete record of the progress of abrasion.

(c) Abrasion and Scratching in Service

Replicas made from articles in service form a convenient means of recording the scratching and abrasion existing at the time the replica is made. A replica can be made from any surface to which a soft-rubber roller can be made to conform, and on which the ethyl cellulose solution can be spread.

Figure 7 is taken from a replica of a steel rule and will serve to indicate the scale of reproduction as well as to show the fine detail.

Figure 8 represents a replica made from the corrugated drainboard of an enameled sink that had had extensive use. There are a few deep scratches which continue across the corrugations, but for the most part, only the tops of the corrugations are abraded. The corrugations were approximately $\frac{1}{10}$ in. deep.

Figure 9 is a replica taken from an enameled table top used daily for at least 10 years. Again

[6] Figures 6 to 18 were produced by the method outlined in footnote 3.

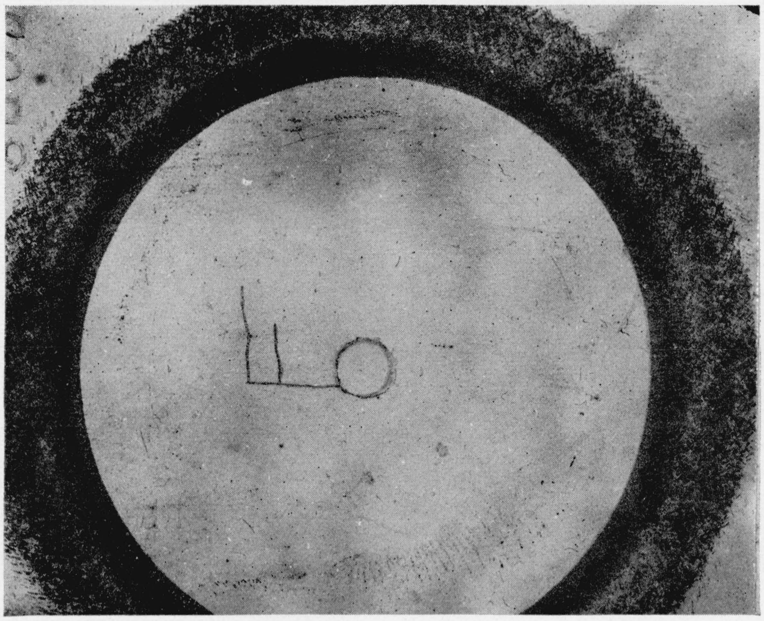

FIGURE 6. *Print made from a replica of a sheet-steel enamel abraded for 5,000 revolutions in the Taber Abraser, using CS–17 wheels with a 1,000-gram load on each wheel.*

The letter F was scratched in the specimen for identification.

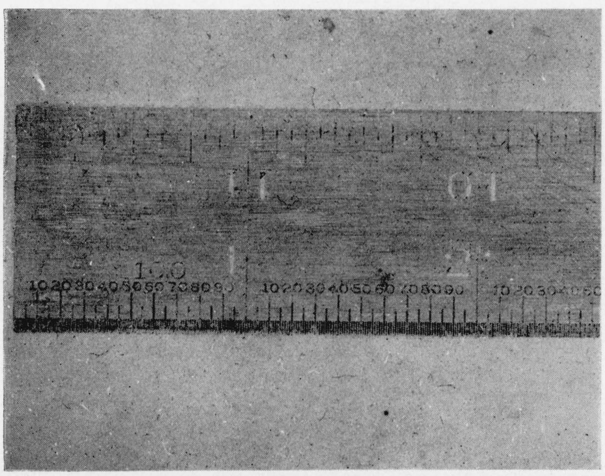

FIGURE 7. *Print made from a replica of a steel rule.*

Note the fine detail brought out by the replica.

there is a concentration of fine scratches, this time in small areas, with a few long scratches. The surface of this enamel exhibited a slight "orange peel" texture, the difference in height between the high and low spots being approximately 0.001 in. The fine scratches appear to be concentrated on the high areas, whereas the low areas show only the deep scratches, as was the case for the corrugated drainboard. The particular area examined was selected as showing the greatest amount of abrasion. The table top had a grained surface, which effectively concealed the damage on casual inspection. The replica brought out clearly the scratches that were apparent only upon close scrutiny of the actual article. The concentration of abrasion in small areas where the tops of high areas have been worn off is more pronounced in figure 10, which illustrates a replica taken from a white table top, which had received extremely hard daily use in a restaurant kitchen for over 20 years. In this case the abrasion was very evident even upon casual inspection.

Figure 11 represents a replica taken from the bottom of an acid-resisting enameled sink after about 1 year of service in a laboratory. This shows scratching, but no general abrasion or etching. Figure 12 illustrates a replica taken from the rim of a nonacid resistant dry-process cast iron bathtub after 20 or more years use. In this case there was so much general etching and abrasion that the original surface of the enamel had been almost completely removed. Even the edges of the scratches have been rounded until they are not readily apparent.

For purpose of comparison, several replicas were taken from common materials other than enamel. Figure 13 is taken from a replica of a china plate after about 10 years of service. Figure

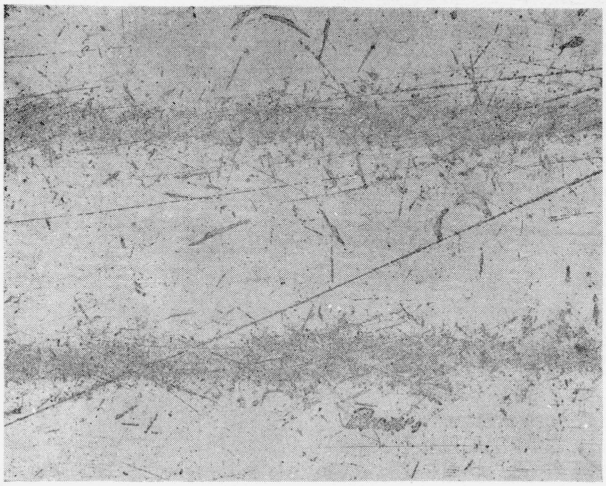

FIGURE 8. *Print from a replica of the currugated drainboard of an enameled cast-iron sink.*

Most of the abrasion has been concentrated on the tops of the corrugations, but a few deep scratches continue across the corrugations.

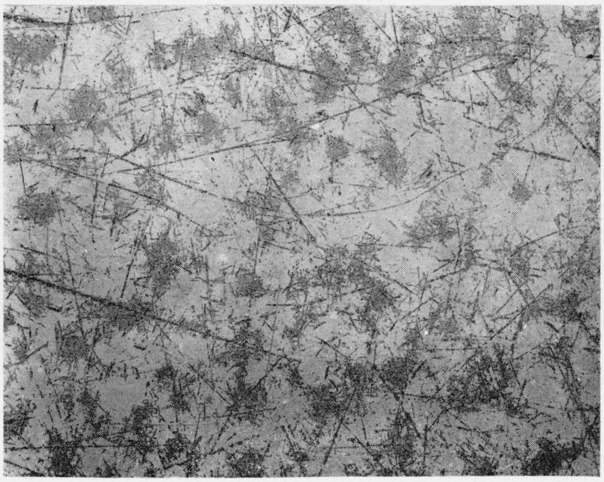

FIGURE 10. *Print from a replica of a second enameled table top.*

The concentration of fine scratches and abrasion on the high areas is even more pronounced than in figure 9.

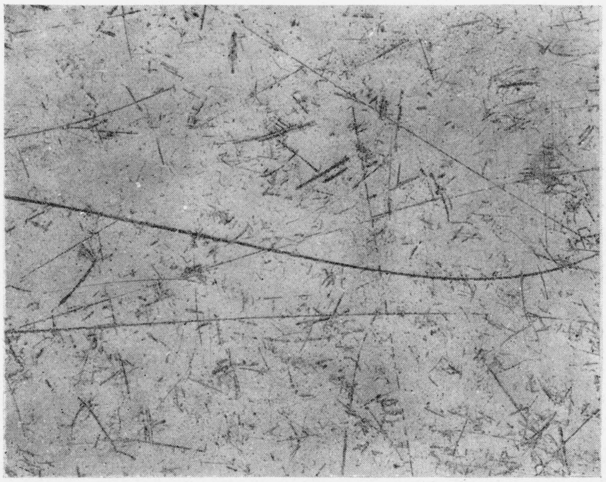

FIGURE 9. *Print from a replica of an enameled table top.*

The surface was slightly orange-peeled, and most of the fine scratches are concentrated on the tops of the hills, although a few deep scratches continue across the hills and valleys.

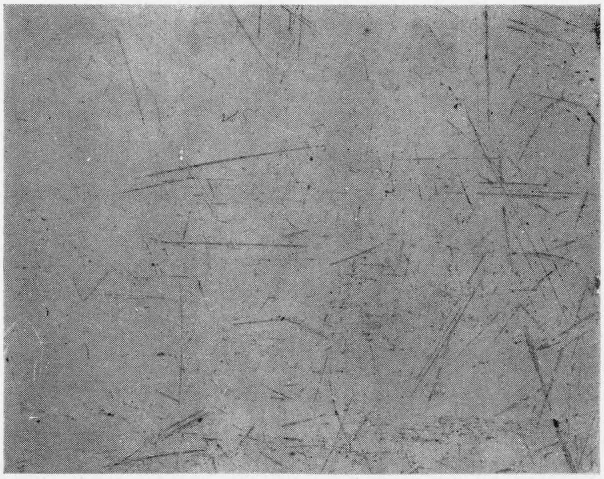

FIGURE 11. *Print from a replica of an acid-resisting cast-iron sink after approximately 1 year of service.*

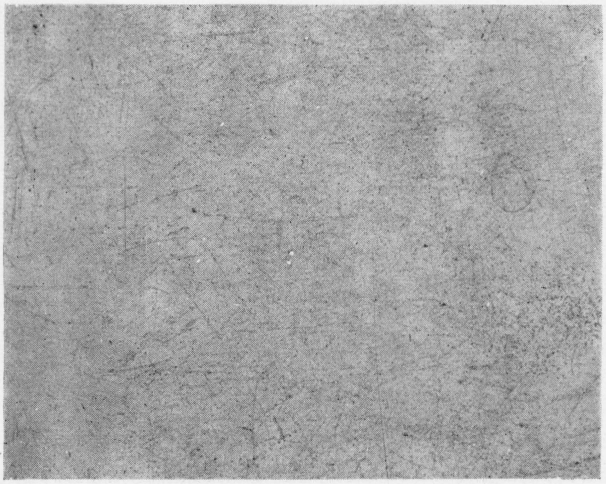

FIGURE 12. *Print from a replica of the rim of a non-acid-resisting dry process cast-iron bathtub after more than 20 years of use.*

Note the etching and abrasion over the entire surface. Even the edges of scratches have been rounded until they are not readily distinguishable.

14 illustrates a replica of a plate from the same set, showing crazing in addition to scratching and abrasion. Figure 15 is taken from a replica of a plate glass shelf used to hold desserts in a cafeteria. The scratches shown in figure 15 have about the same appearance as those occurring in enamel surfaces, but in general the scratches are longer, and there is no segregation of abrasion as was noted in the enamel surface.

3. Replicas of Etched Surfaces

When the surface of an enamel is dissolved, the remaining material is usually roughened. The degree of roughness of the surface, after a specified

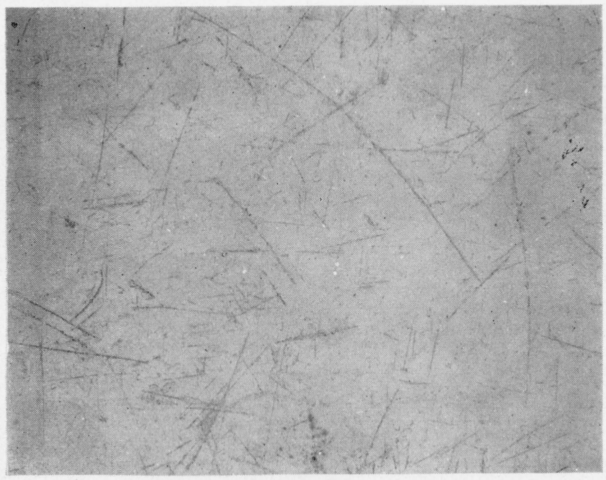

FIGURE 13. *Print from a replica of a china plate after 10 years of service.*

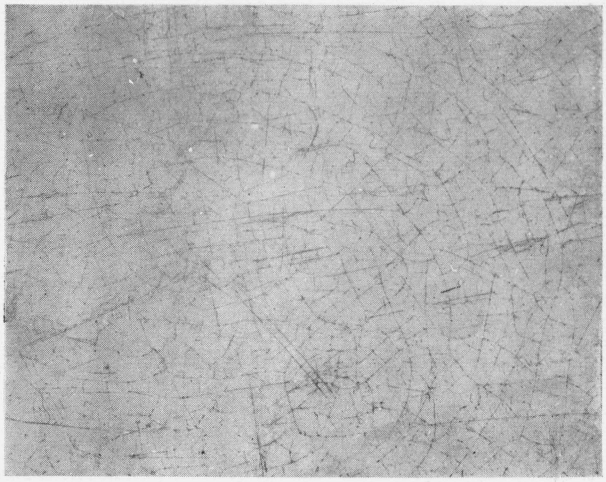

FIGURE 14. *Print from a replica of a second china plate, from the same set as the one shown in figure 13 showing crazing in addition to scratches and abrasion.*

corrosion treatment, has been used as a criterion of the resistance of the enamel to etching. The Porcelain Enamel Institute Standard Test for Acid Resistance [3] separates enamels into five classes, on the basis of the appearance of the treated area, its gloss, and its ability to retain dirt.

Replicas were made of specimens that had been tested for acid resistance by the PEI test. Treated areas of enamels having class AA and class A acid resistance, respectively, were not distinguishable in the replicas. With class B resistance, the treated area could be detected in the replica, but did not have sufficient contrast to reproduce well. Figure 16 represents a replica of a treated specimen having class C acid resistance.

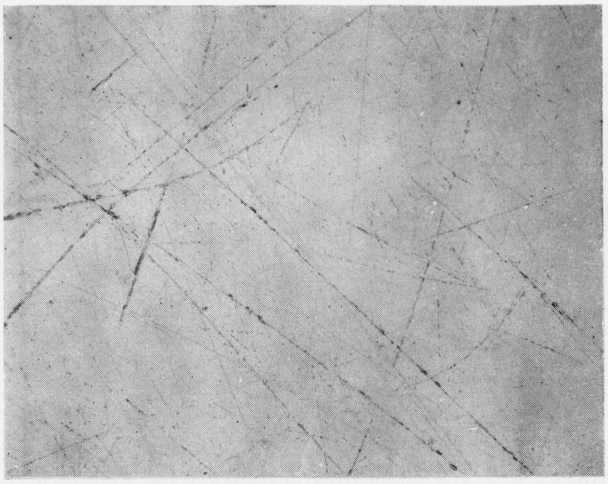

FIGURE 15. *Print from a replica of a plate-glass shelf used to hold desserts in a cafeteria.*

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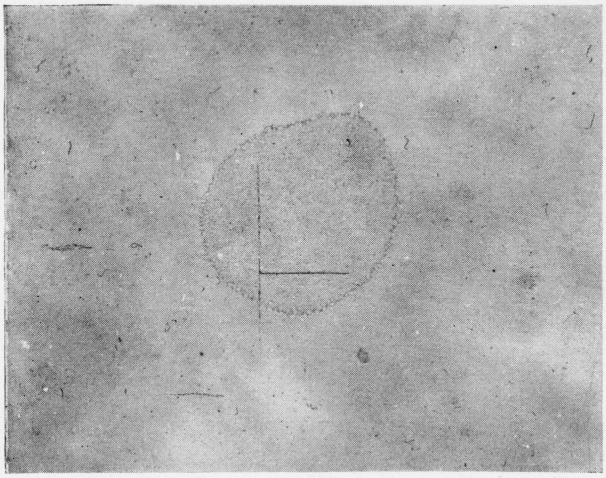

FIGURE 16. *Print from a replica of the tested area of a specimen having class C acid resistance by the PEI test.*

The specimen was scratched before testing.

A replica will readily reveal etching of mat or semimat surfaces, which may be difficult to see in the actual surface. Figure 17 illustrates a replica of a mat enamel that has been tested for acid resistance. The PEI acid resistance test is not adapted to rating mat enamels, hence no rating was assigned to this specimen.

Weathering produces numerous changes in an enameled surface, as previously described by Harrison and Moore [4]. Figure 18 is a replica of a weathered enamel. In this case an enamel of poor weather resistance (left exposed in upper left and lower right) had been coated with dust coats of two acid resistant clear enamels (upper right and lower left) prior to exposure to the weather. The different degrees of attack by weathering can easily be seen.

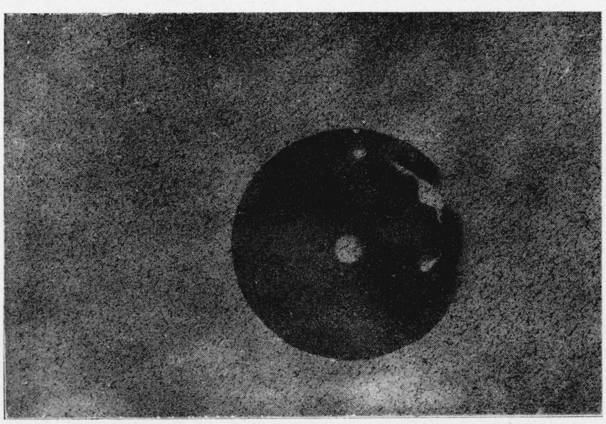

FIGURE 17. *Print made from a replica of the tested area of a specimen of mat enamel tested for acid resistance by the PEI test.*

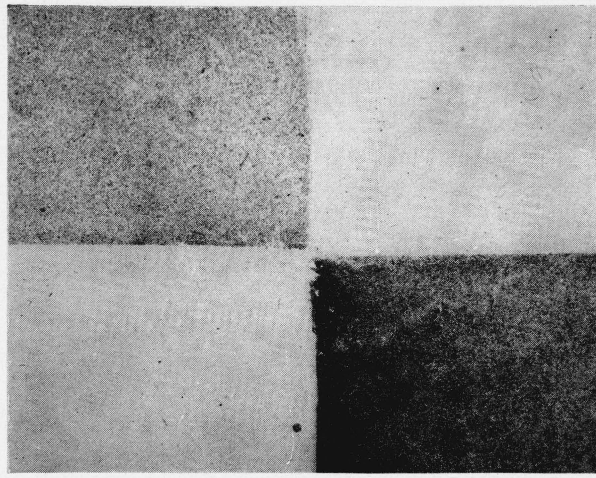

FIGURE 18. *Print made from a replica of a specimen exposed to weathering for 6 years.*

An enamel of poor weather resistance, upper left and lower right, was coated with dust coats of two clear acid-resistant enamels (upper right and lower left), prior to exposure to the weather.

IV. Evaluating Replicas

Several techniques have been used in evaluating surface texture as revealed by replicas. Herschmann [6] used an optical method for machined metal surfaces, in which a replica was moved across a small diaphragm at right angles to the direction of machining, and the light transmitted by the replica fell on a photoelectric cell. The variation in the amount of light transmitted was measured by means of an alternating current voltmeter, which indicated the response of the photoelectric cell. This method worked very well for grading the surface finish of machined surfaces, in which the surface markings are parallel. It was not suitable for use on abraded or etched surfaces where the roughness had random orientation and was nearly uniform over appreciable areas.

Haze measurements, as described in section III, give promise for rating replicas of specimens abraded in the PEI test and with the Taber Abraser. Haze measurements were also made on etched surfaces and those which had been abraded in service.

Replicas can be visually examined, at actual or magnified sizes, by either transmitted or reflected light. Schaefer [12] has found that the use of dye in the solution increases the contrast in the replica and helps to bring out details that might otherwise be missed. Hardy and Plitt [13], also Williams and Wykoff [14] have described shadowing techniques, in which metal is evaporated onto the film at an oblique angle. This serves to bring out fine detail and relief. By the use of this procedure, direct enlargement prints can be made from the replica that give the appearance of an opaque object with the surface lighted by oblique illumination.

Replicas can be projected, and the size of the projected image can be measured directly to determine the size of scratches or area of attack. They also lend themselves readily to the production of direct photographic prints by projection without the use of negatives. At small magnifications, such prints lack contrast, but at greater magnifications this difficulty is overcome.

V. Summary and Discussion

A study was conducted to ascertain the usefulness of plastic replicas of enameled or other surfaces as a means of evaluating surface texture of such surfaces. These replicas lend themselves readily to examination by either transmitted or reflected light, or they may be projected for examination of the enlarged image. Photographic prints can be made directly from the replicas, with or without enlargement.

The replica technique offers a convenient method for studying surface texture. It should find application wherever small-scale surface roughness is evaluated. It can be used to classify enameled surfaces as mat, semimat, or glossy, or to evaluate the degree of roughness developed in application of the enamel. The use of haze measurements of replicas offers a promising method for objectively evaluating surface texture and changes in surface texture resulting from a variety of treatments, including abrasion and etching. This evaluation may be more closely related to the amount of roughening than to the change in appearance. The apparent relative resistance of different enamels to abrasion depends to a considerable extent upon the procedures employed in abrading them. Even when the specimens in a group are all abraded by one procedure but graded by several methods, the relative ratings will vary with the method of grading.

In abrading or etching the surface of a typical enamel, the surface is roughened, the gloss is reduced and, in the case of dark colored enamels, the reflectance and color may undergo large changes. Also, the tendency of the surface to pick up and retain dirt is increased. These properties may be considered the major ones for most uses, although other properties of the enamel are affected. The relative importance of these effects will depend upon the characteristics that are considered paramount in any given service.

The PEI standard surface abrasion test is based on the measurement of the loss in 45° specular gloss of the specimens produced by a standard surface abrasion treatment. The correlation coefficient of 0.69 indicates that the loss-in-gloss measurements show only fair agreement with visual estimates of the damage to the enamel. This might be expected because specular gloss is only one of several factors making up the visual stimulus.

By the use of replicas, the variation in visual stimulus from specimen to specimen can be limited to the single factor of surface roughness and hence may provide a better criterion of the mechanical effect of abrasion than does the appearance of the specimens themselves. Evaluations of the surface replicas by visual means and by haze measurements agree well with each other (fig. 4), but are in no better agreement with visual ranking of the specimens themselves than are gloss measurements. It remains to be determined whether or not the mechanical roughening detected by the replicas is to be preferred over deterioration of appearance as a criterion of abrasion resistance.

The replica technique should lend itself readily to field inspections of enameled articles. Replicas made in the field can be examined by the investigator at his convenience or sent to a central laboratory for study. A series of replicas of the same area of a test item, made before installation and after successive periods of service, will enable the investigator to follow the progressive breakdown of the surface. These replicas can later be compared with those from specimens treated in the laboratory to determine whether the laboratory test produces the type of damage observed in the field.

VI. References

[1] S. Way, Description and observation of metal surfaces, Proceedings, Special Summer Conference on Friction and Surface Finish, p. 44 (Massachusetts Institute of Technology, 1940).

[2] Test for resistance of porcelain enamels to surface abrasion (Porcelain Enamel Institute, Inc., 1942).

[3] Test for acid resistance of porcelain enamels, Part I, flatware (Porcelain Enamel Institute, Inc., 1940).

[4] W. N. Harrison and D. G. Moore, Weather resistance of porcelain-enameled iron structural units, J. Research NBS **28,** 735 (1942) RP1476.

[5] R. S. Hunter, Methods of determining gloss, J. Research NBS **18,** 19 (1937) RP958.

[6] H. K. Herschman, Evaluation of the finish of a metal surface by a replica method, J. Research NBS **34,** 25 (1945) RP1625.

[7] A. W. Allen and A. L. Friedberg, Application of replica techniques to the study of ceramic surfaces with the optical microscope, J. Am. Ceramic Soc. **21,** [3], 83 (1948).

[8] Plastics, organic; general specification, test methods, Federal Specification L–P–406a, p. 33 (1944).

[9] ASTM Standards, p. 1653 (Am. Soc. Testing Materials, 1944).

[10] ASTM Manual on presentation of data, p. 40 to 44 (Am. Soc. Testing Materials, 1943).

[11] Plastics, organic; general specification, test methods, Federal Specification L–P–406a, p. 18 (1944).

[12] V. S. Schaefer, Surface replicas containing dye for use in the light microscope, Metal Progress **44,** 72 (1943).

[13] J. I. Hardy and T. M. Plitt, An improved method for revealing the surface structure of fur fibers, U. S. Dept. of Interior Wildlife Circular **7** (1940).

[14] R. C. Williams and R. W. G. Wyckoff, Applications of metallic shadow-casting to microscopy, J. Applied Phys. **17,** 123 (1946); **15,** 712 (1944).

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