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Foreword

Comments by the Technical Forum Chairman

I want you to know what a real pleasure it has been for me to have the opportunity to serve as chairman of this year's PEI Technical Forum. I have been aided by a host of individuals to whom I express my appreciation for all their hard work and creative efforts. Certainly, they have contributed mightily to this 56th in the long series of technical meetings serving the porcelain enameling industry that started on the campus of the Ohio State University in 1937. Until 1989, the annual event alternated each fall between Ohio State and the University of Illinois.

To my Vice Chairman, Dave Thomas, I particularly want to say, "Thank you," for all that he has done to ensure the success of this year's meeting. Also, I am most grateful to all the members of our very productive committee who decided upon the meeting's format, selected the topics to be covered, and then went out and lined up the fine group of authors who prepared and presented the papers. Of course, the most essential ingredient—the speakers and panelists who really were this year's Technical Forum—deserve our fullest thanks and appreciation. Also, we are all grateful for the support of the supplier companies that has booths at the Suppliers' Mart this year and, as exhibitors, sponsored the reception for all of the registrants on two evenings of our meeting.

The papers and panel sessions from this year's meeting make up the contents of these proceedings. We hope that you agree that they are worthy additions to the earlier volumes that continue to be useful reference documents for our industry.

Rusty Rarey, LTV Steel Co.
Chairman, 1994 Technical Forum Committee
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Chip Resistance of Two-Coat/One-Fire Porcelain Enamels as Determined by Torsion Testing

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An investigation was conducted of the variables that affect the torsion resistance of two-coat/one-fire powder systems. The effects of firing conditions, base coat application, cover coat application, and warp are discussed.

Introduction

Chippage of porcelain enamels is a problem that occurs throughout the porcelain enamel industry. It causes rejects at inspection stations, returns from assembly, and complaints from customers. There are several tests that can be utilized to evaluate chip resistance. Impact testing and torsion testing are the most widely used methods. Torsion testing was selected for this study based on positive results in developing systems to reduce chippage at customers' plants. The objective of this study was to correlate the effects of firing temperature, firing time, cover coat refire thickness, base coat thickness, and warpage on the chip resistance of two-coat/one-fire porcelain enamel powder systems.

Experimental Procedures

The angles used for torsion testing were made from 20-gauge cleaned-only decarburized steel. The sample plates were 2 x 12 in. and were bent lengthwise at a 90° angle. Torsion testing was performed according to ASTM test C409-79\(^1\) except that the specimens were not coated on both sides with the

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base coat. The C409-79 test procedure states that the first enamel coat should cover both the front and back sides of the plate; however, this procedure was written for two-coat/two-fire wet systems. It was felt that the "electrostatic wrap" of base coat powder on the back of the steel would duplicate production operations better than using a full application of base coat. The torsion test apparatus is shown in Fig. 1. One end of the sample is held fixed while the other end rotates at a constant 100°/min. This twisting action causes torsion tension in the enamel. The degree of twisting required to produce failure on the radius indicates the torsion resistance of the enamel. A higher torsion failure corresponds to a more chip-resistant enamel.

A typical range industry base coat and a typical range industry cover coat were selected to study the effects that firing temperature, firing time, base coat thickness, and cover coat refire thickness have on chip resistance. Base coat and cover coat thicknesses were determined by the application weights of the enamels. Photomicrographs of cross sections of the enameled plates confirmed that enamel thicknesses were correct.

Two additional range cover coats were used to study the effect that warp has on the chip resistance. Warps of the cover coats were determined by spraying 36 g/ft² of a wet ground coat on the front (convex side) and 30 g/ft² of a wet ground coat on the back of 4 x 12-in. cleaned-only decarburized 20-gauge panels. The panels were then fired at 1550°F for 3.5 min and were allowed to partially cool before they were removed from the furnace. Using an Ames dial, the initial warp of each panel was determined. The cover coat was then applied at 40 g/ft² on the face side of the panel. All the powder that electrostatically wrapped on the back side of the panel was removed. A 1-in.-wide strip of powder was removed from the center of each panel in the 12-in. direction. This 1-in. strip stops the panel from warping along the diagonal. The panels were fired at 1510°F for 3.5 min. The samples were allowed to partially cool before removing them from the furnace. After the panels cooled to room temperature, they were re-read on the Ames dial. This read-

Fig. 1. Torsion tester.
ing minus the previous Ames reading gives the warpage of the system, which then must also be corrected for slight variations in application weights or steel thickness.

Results

A constant base coat thickness of 1.0 mil and a constant cover coat thickness of 4.0 mil were used in determining the effect that firing time and firing temperature have on torsion resistance. The plot of firing temperature vs torsion failure (Fig. 2) shows a steady increase in torsion failure (decrease in chippage) as the firing temperature is increased from 1430° to 1590°F. It should be noted that each data point plotted for each variable vs chip resistance is an average of 15 different test samples.

Figure 3 illustrates the effect of firing time vs torsion failure. There is a very gradual increase in the torsion failure as the firing time is increased from 2.5 to 4.5 min. There is a large increase in the torsion failure at a 5.5-min fire. However, under typical porcelain enamel range plant firing conditions (i.e., less than a 4.5-min fire), there is not a significant difference between the results.

Test specimens that were originally coated with 1.0 mil of base coat and 4.0 mil of cover coat and that were fired at 1510°F for 3.5 min were used to determine the effect of refire application on torsion failure. A second cover coat application was applied to the sample specimens and then they were re-

Fig. 2. Firing temperature vs torsion failure.
fired at 1510°F for 3.5 min. Figure 4 shows there is only a small decrease in the torsion failure of the enamel at low refire applications. However, there is a large decrease in the torsion failure above 8.0 mil of total cover coat application (4.0 mil refire application). It is important to recognize the fact that enamels do not apply evenly to parts and that it is typical for edges to have a thicker film build than flat areas. One should check the enamel build on the edges of parts as well as the flat areas, and care should be taken to control the enamel thickness as much as possible.

The effect of base coat application vs torsion failure (Fig. 5) shows that there is an optimum range of base coat thickness needed in order to achieve chip resistance. Photomicrographs were utilized to determine the thickness of base coat on the test specimen. At low base coat applications (0.5 mil), there is not enough base coat to provide adherence of the porcelain system to the steel. It is theorized that at high base coat thicknesses, the overall increase in thickness of the two-coat/one-fire system causes the torsion failure to decrease. Fortunately, the recommended range (0.8–1.5 mil) of base coat application needed to provide black speck resistance and adherence will also provide the best chip resistance.

The results of warp vs torsion failure (Fig. 6) show that there is not a direct correlation. The mid-warp system had the lowest torsion failure, whereas the high-warp system had the highest torsion failure (most chip resistant). These results verify the findings of Lochridge and Miller. They also found that torsion results do not correlate directly with warpage results.
Fig. 4. Refire application vs torsion failure.

Fig. 5. Cover coat refire application vs torsion failure.