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COATING DEVELOPMENT AND PLANT TRIALS FOR POWDER PRIMING OF SMC PANELS

By

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ABSTRACT

Based on the newly discovered powder primer failure mechanism, a joint project was undertaken by GM R&D, Meridian, AOC, and Ashland with the goal of developing powder primer capable class A SMC materials. To that end, more than 40 SMC formulations were prepared and molded into panels for powder primer application readiness. The panels were evaluated for shrinkage, surface profile, moisture absorption, and powder application. Based on these results, four of the SMC formulations were selected for plant trials. The panels molded with the selected SMC materials were sent through the ELPO and powder process of a GM vehicle production plant. Based on the observed results, it was concluded that the selected final four SMC formulations do not show powder primer popping due to air outgassing, and their moisture absorption is low enough to allow powder priming when there is no line stoppage. It was also noted that, in case of an extended line stoppage and subsequent moisture uptake by SMC panels, the conventional conductive coatings cannot slow down moisture outgassing. Therefore, there is a need to develop a new generation of conductive coatings, which can further slow down moisture penetration into the powder primer. Such experimental conductive coating was developed and modified through a series of iterations till a final formulation was arrived at. The modified version shows excellent adhesion to all substrates and passes all adhesion tests.

INTRODUCTION

The use of powder primers on SMC body panels has become a major challenge for the automotive industry. The driving force is that using powder primers in place of liquid primers reduces unwanted paint emissions and overspray waste. The downside is that powder primers are not compatible with the current high moisture absorbing plastics in general [1,2], and with SMC materials in particular[3,4]. The body panels molded with SMC show paint popping in the bake oven of the powder primer, resulting in an unacceptable surface finish.

In a previous study [5], a variety of SMC materials and conductive primers/sealers were evaluated for their ability to produce a pop free surface. In that work, among other factors, the effects of molding pressure and the panel moisture content on the degree of popping were studied. The experimental results showed that popping increased with the increase in moisture content and with the decrease in molding pressure. The extent of popping, however, varied with the type of SMC and the conductive primer. It was found that none of the SMC materials or conductive primers were able to eliminate the pops completely at high moisture levels. More importantly, it was concluded that moisture is not the only cause of the popping and that there are other factors that contribute.

In a subsequent study [6], a systematic research effort was carried out to identify the factors that contribute to powder primer popping. Several potential variables that could affect popping, such as volatiles in the substrate, thermal conductivity of the substrate, static charges, and powder bake profile, were studied. The experiments showed that the type and functionality of the low profile additive (LPA) had the most impact on the popping issue. More specifically, the micro void formation of the low profile additive that eliminates SMC shrinkage, and enables a smooth surface finish, also causes primer popping. Based on the experimental results, it was concluded that the air permeation into these micro voids was the reason behind the popping of the moisture free SMC substrates. This understanding of the failure mechanism, paves the way for developing low moisture absorbing SMC materials that do not show air outgassing.

Based on the above understanding of powder primer failure mechanism, a joint project was undertaken by GM R&D, Meridian Automotive Systems, AOC, and Ashland Specialty Chemical Company with the goal of developing powder primer capable class A SMC materials. This report captures our progress to this day and documents the approach and the experimental results.

MATERIALS AND PROCEDURES

Materials:

Part I. Material Development

In this segment of the study we used two types of SMC: Type A as shown in Tables 1 and 2, and Type B as shown in Tables 3 and 4. In the first part of this study, one conventional conductive coating (BP9471), and one experimental conductive coating (493S), both from Redspot Paints and Varnishes Co., Inc, were used to enable powder priming of the panels. In these experiments, a commercially available powder primer from PPG, PCV Envirocron 70104, was used to coat the panels.

Part II. Process Validation

In this phase of the project, we used the second generation of Type A and B SMC materials as shown in Table 5. In these experiments, two conventional conductive primers UAE2560C and P35AM758 from Redspot Paints and Varnishes Co., Inc. and BASF Corp. respectively were used. UAE 2560C is a 2-component conductive sealer, whereas, P35AM758 also known as Dynaseal, is a UV/Thermal dual cure, two-component conductive sealer. After conductive coating application, all panels were powder primed with PUA 1177/HG, a commercially available powder primer from Seibert. PUA 1177/HG is a polyurethane based powder and is being used by GM in some of the vehicle production plants

Procedures:

Part I. Material Development

The procedures for molding, cleaning, and conditioning of the SMC panels are described in detail in a previous report [5].

Moisture Absorption:

Two panels were used for each type of SMC. The panels were first prepared and dried per procedure described in the previous report [5]. The panels' dry initial weight was first recorded, and then they were exposed to 90% RH at 40°C for seven days. The weight of the panels was recorded at specific time intervals during the seven days. The moisture content (weight %) at time t, was then calculated by

$$\frac{\text{Final weight of panel} - \text{Initial weight of panel}}{\text{Initial weight of panel}} * 100$$

Shrinkage Measurement:

In order to calculate the shrinkage of the panels, the 305 mm by 457 mm flat plaque molding tool, used at Owens Corning Automotive in Novi, Michigan, was measured at room temperature with a hand held digital caliper at six different points: three measurements across the width (center and 25 mm inside of each corner), and three measurements across the length (center and 25 mm inside of each corner). The target thickness for all molded panels was 2.50 mm, therefore, these reference measurements were at 2.50 mm above the bottom of the tool so as to reflect the maximum dimensions of the molded panel (due to draft angle at the tool edges). These six points were measured six times each and then averaged to yield each reference measurement.

The shrinkage or expansion percentage for each formulation type was based on two panels, six measurements on each, at the same points as on the molding tool. The shrinkage or expansion at each point on the molded panel was calculated by: panel measurement minus the reference measurement, divided by the reference measurement, and then multiplied by 100 to yield a percentage. The overall percentage for each formulation type is an average of all measurements---- a negative result indicates shrinkage and a positive result indicates expansion. All molded panels were measured for shrinkage at room temperature and at least twenty-four hours after molding.

Surface Profile Evaluation:

The appearance of uncoated panels was visually evaluated and ranked on an arbitrary scale for long term waviness and surface haze. Surface profile ranking ranged from 1 for high waviness (poor) to 5 for low waviness (good). A group of five researchers familiar with SMC materials each ranked the uncoated materials by direct comparison. A light box with equally spaced horizontal and vertical lines was employed to view the distortion of the lines in the projected light box image on the parts. The final rankings reflected the average of the five individual readings. Haziness or the ability of the part to reflect the light box image was graded as low, medium, or high.

Powder coating and popping:

Dry Panels:

Panels were first prepared and dried per the procedure described in a separate report [5]. They were then coated with conventional conductive primer at PPG in Flint, MI. These panels were again dried for 24 hours at 110°C, and were then sealed in Ludlow moisture barrier bags and transported to PPG in Flint, MI for powder spray application. Powder was then sprayed on the dry panels at ambient conditions (20°C/55%RH).

Wet Panels:

Panels were first prepared and dried (24 hours at 110°C) per the procedure described earlier [5]. They were then coated with the experimental coating at PPG in Flint, MI. These panels were brought back to the R&D Center in Warren, MI. They were then dried for 24 hours at 110°C followed by an exposure to 90%RH at 40°C for 48 hours. These panels were then sealed in Ludlow moisture barrier bags and transported to PPG in Flint, MI for powder spray on the same day.

After powder application, the panels were inspected for popping/foaming by the naked eye and with a microscope. The finish of the panels was rated as unacceptable with severe defects (red color), unacceptable with minor defects (yellow color) and acceptable with no defects (green color). To help differentiate between materials with a red or severe popping ranking these panels were further ranked on the following scale: Red-1 has popping on over 80% of the panel surface with the popping so extreme in frequency as to cause a leathery texture to the surface, Red-2 has the above extreme popping in small isolated areas, Red-3 has popping over more than 80% of the surface without the extreme leathery effect while Red-4 has popping on less than 80% of the surface (Figure 1).

Part II. Process Validation

Molding:

In order to evaluate the new SMC formulations we needed to identify a vehicle body panel that had the right overall dimensions, surface profile, and edge finish. To that end the Hummer H2 tool for fenders was used to mold the selected materials. The compounded SMC materials (24 inch wide) were cut to charge sizes similar to production materials and were molded under similar conditions (150 ∞C, 7 MPa), and using similar charge layout. Also no in-mold coating was applied on these panels similar to production parts. The molded panels, each weighing 2.5 kg, were then de-flashed and prepared for receiving the conductive coatings described earlier. The panels were then shipped to the GM assembly plant for powder primer application.

Lab validation

For lab validation, the procedures for all tests except for the humidity exposure before powder application were similar to the procedures used in part I of this study described above. For powder priming experiments, the panels were exposed to 65%RH at 30°C for four days instead of 90%RH at 40°C. This change was made to reflect the plant environment more realistically. The procedures used in the plant trial are as follows:

Plant validation

Figure 2 shows a typical paint process from ELPO to topcoats. Although SMC parts do not benefit from the Phosphate and ELPO operation, they have to endure these treatments along with the rest of the vehicle. To that end, SMC parts were evaluated in two different scenarios that a vehicle body will typically see at the automotive paint shop. First a straight through scenario when the line does not stop and the parts go through the entire paint process uninterrupted. In the second scenario, the paint line stops before the weekend shutdown. In this case, the parts that go through ELPO process are stored in the strip area during the shutdown period. These parts then absorb the moisture which may later cause popping during the powder bake.

Straight Through Run:

Twenty fenders were assembled on two different mules (Twelve horizontal on one mule and eight vertical on another mule). Figure 3 shows the picture of one of the molded fenders, while Figure 4 shows the layout of the mule. The mule with panels assembled vertically went through the entire paint process shown in Figure 2 uninterrupted with basecoat and clear-coat applied manually with hand held cup gun by plant personnel. The other mule went through only the ELPO and powder application, again with no interruption; however, they received no basecoat or clear-coat application. It took about two hours for the mules to reach to the powder primer booth after they came out of the ELPO oven.

The panels were then inspected for popping by the naked eye, and the finish was rated using the same procedure described earlier.

Weekend Shutdown Run:

Twelve fenders were assembled on a mule horizontally. The mule was then sent through the ELPO process. After it came out of the ELPO, the mule was removed from the paint line and was stored in the strip area for four days, which included the weekend. The plant climate control system was off over the weekend as the plant was not running. The ambient temperature humidity data was recorded by a Dickson TP120 Data Logger during this period. The mule went through the normal powder application process when the line resumed after the shutdown. The mule was removed from the line after the powder bake and did not go through the basecoat and clear-coat applications. The panels were then inspected visually for popping, and the surface finish was rated as before.

Panel cleaning Procedures:

Two different pre-cleaning methods were used to clean the SMC surface prior to the application of the conductive primer. A brief description of each test method is given below:

Method 1:

Panels were first hand washed with a Henkel 3292 solution at 2.0% concentration, followed by rinsing with a Henkel PolyPrep 400 solution at 0.5% concentration. They were rinsed with tap water and dried in an electric oven for 15 minutes at 285°F. The panels were then cooled for 10 minutes prior to application of conductive primer.

Method 2:

Panels were wiped with isopropyl alcohol (IPA) using a cotton cloth. They were then dried for 7-10 minutes at room temperature prior to the conductive primer application.

RESULTS AND DISCUSSION

Material Development

Type A Materials: Phase I

Fifteen formulations as shown in Table 1 were evaluated in this part of the project. Formulation B is a typical Class A SMC used on automotive body panel applications. This formulation is used as a control and is expected to demonstrate typical powder prime performance. Previous work in the field has suggested that composite morphology plays a key role in powder prime performance [5]. These experiments focused on methods to change this morphology in a variety of ways. Formulations C, D, F, H, K, and L represent modifications to the chemistry and structure of the low profile additive package. Formulations E, G, and I represent structural changes to the unsaturated resin component while formulation J combines a resin and low profile additive modification. Formulations A and M explore changes to the viscosity profile of the composite and formulation R6 looks at the effect of filler. Formulation N provides an electrically conductive composite that does not require a conductive coating prior to the electro statically applied powder prime.

Moisture Absorption

An absorption chart, shown in Figure 5 depicts moisture content (weight %) plotted against time (hours). As seen, with the exception of R6, the moisture absorption for most formulations was in the range of 0.32% - 0.54% in the first 48 hours and 0.47% - 0.65% after seven days of exposure. R6, which had a lower density than the rest, had the highest and fastest absorption of all. It absorbed approximately 0.85% after first 48 hours and 1.35% after seven days of exposure. Formulation J and H absorbed the least amount of moisture. In the first 48 hours they absorbed approximately 0.32% and 0.35% moisture respectively. Formulations M, G, and E absorbed slightly more moisture---- approximately 0.4% in the same time period.

Powder coating and popping

To study the powder popping, the experiments were run in two sets: dry and wet. Dry runs simulates the straight through scenario in the plant while the wet runs simulate the weekend/shutdown scenario when the parts are stored in the strip area and are allowed to absorb moisture. All materials, except “N”, were coated with conductive primers. Formulation “N” contained carbon fibers which made the panels conductive and eliminated the need for an additional conductive layer. For the dry run, conventional conductive coating was used, whereas, the experimental coating was used for the wet runs.

The results are shown in Table 6. In the dry state, as seen in the chart, only formulation H, J and M had an acceptable appearance, while formulation G & I showed minor popping. All other formulations showed severe popping in the dry state. When exposed to moisture, all panels showed popping. The extent of popping varied with the substrate and the failure ranking is shown in the Table 6. As seen, formulation J showed the least amount of popping (dry - green, wet - yellow) followed by formulation H (dry - green, wet - red 1) and M (dry - green, wet - red 2). There was no significant difference among the other materials. Based on these findings two formulations, were selected to become the base for the phase II of the development.

Type A Materials: Phase II

Using the above two formulations, five variations were developed as shown in Table 2. Based on the results of phase 1, optimization experiments resulted in further refinements of the unsaturated resin and low profile additive materials. Formulations 91A, B, and C utilize the same resin component but contain modifications to the low profile additives. Formulations 91D and E represent modifications of both the resin and low profile additive components.

Moisture Absorption

Figure 6 shows an absorption chart of moisture content (weight %) in the panels plotted against time (hours). As seen, 91E showed the least amount of moisture absorption, while 91A showed the highest. 91E absorbed 0.2% in the first 48 hours and 0.29% in seven days of exposure. In the same time period, 91A absorbed 0.29% and 0.36% respectively. 91B and 91D showed similar behavior of moisture absorption. Thus, the SMC formulations in the order of increasing moisture absorption are: 91E, 91C, 91B, 91D and 91A.

Shrinkage and Surface Profile

Table 7 shows the amount of shrinkage and the surface profile ratings for each material. All formulations show expansion in the range of 0.025%-0.068%. Formulation 91D showed the highest expansion (0.068%) followed closely by 91A (0.067%) and 91B (0.064%). Formulation 91C showed the least amount of expansion (0.025%).

Based on the visual observations, 91B showed the best surface appearance with least long term waviness and was rated as 4. On the same scale, 91C had the poorest appearance and was rated as 2. It should be noted that even though 91E appeared to have less waviness, the haziness of this material was very high and could have affected our ratings for the waviness.

Powder coating and popping

The results of powder coating of the panels are shown in Table 7. None of the five formulations showed popping in the dry state. Among the panels exposed to moisture, formulation 91B and 91C did not show any popping, however, 91C showed a very high haziness. Also, 91D and 91E showed minor popping and 91A showed severe popping. Based on these findings two formulations (91B and 91D) were selected to be used for plant trials.

Type B Materials: Phase I

In this group of materials, also, fifteen formulations as shown in Table 3 were evaluated. This group of formulations was developed after a prescreening set of experiments. A range of Resins, Low Profile Blends, Additives and formulation adjustments were made. The goal of this grouping was to bracket the different types of Resins, Low Profiles Blends and Additives to gain knowledge on how the constituents and formulations impact testing results. Different ranges of filler & Additives were included in this matrix.

Moisture Absorption

An absorption chart, shown in Figure 7 depicts moisture content (weight %) plotted against time (hours). As seen, with exception of 2733, the moisture absorption for most formulations was in the range of 0.21% - 0.33% in the first 48 hours, and 0.32% - 0.41% after seven days of exposure. Formulation 2733 had the highest and fastest absorption of all. It absorbed 0.42% moisture after the first 48 hours and 0.46% after seven days of exposure. Formulation 2721, 2725 and 2729 absorbed the least amount of moisture---- in the first 48 hours they absorbed approximately 0.21-0.23% moisture. Formulation 2724, 2726 and 2729 absorbed slightly more moisture approximately 0.25% in the same time period.

Shrinkage and Surface Profile

Table 8 shows the amount of shrinkage and the surface profile ratings for each material. All formulations show expansion in the range of 0.015%-0.049%. Formulation 2719 showed the highest expansion (0.049%) followed closely by 2727 (0.067%), 2723 (0.042%) and 2724 (0.042%). Formulation 2725 showed the least amount of expansion (0.015%).

Based on the visual observations, 2719 showed the best surface appearance with least long term waviness and was rated as 5. 2723 and 2729 also had low waviness and were rated as 3.5-4. On the same scale, 2721, 2722, 2727, 2728 and 2730 had poor appearance and were rated as 1.5- 2. Formulations 2723, 2726, 2727 and 2730 showed low levels of haziness, whereas, formulations 2725, 2729 and 2732 showed high levels of haziness.

Powder coating and popping

The results are shown in Table 8. With the exception of 2733, none of the panels showed popping in the dry state. Also, except for 2727 having minor popping, similar results were observed in the wet run as the panels were powder primed after the exposure to moisture. Only formulation 2733 showed popping in both dry and wet runs. Based on these findings two formulations, i.e., 2719 and 2724 were selected to become the base for the phase II of the development.

Type B Materials: Phase II

Once again, using the above two formulations as the baseline, a series of different components combinations were evaluated, out of which, five variations were selected as shown in Table 4.

Moisture Absorption

Figure 8 shows an absorption chart of moisture content (weight %) in the panels plotted against time (hours). As seen, 2747 showed the least amount of moisture absorption, while 2750 showed the highest. The panels made with 2747 absorbed 0.27% in the first 48 hours and 0.36% in seven days of exposure. In the same time period, 2750 absorbed 0.29% and 0.4% respectively. Note that the difference between moisture absorption of these five substrates is very narrow and all of them show similar rate of moisture absorption. SMC formulations in the order of increasing moisture absorption were: 2747, 2719, 2748, 2749 and 2750.

Shrinkage and Surface Profile

Table 9 shows the amount of shrinkage and the surface profile ratings for each material. All formulations showed expansion in the range of 0.027%-0.038%. Formulations 2748 and 2750 showed the highest expansion (0.038%) followed closely by 2719 (0.033%). Formulation 2747 showed the least amount of expansion (0.027%).

Based on the visual observations, 2750 showed the best surface appearance with the least long term waviness, and was rated as 2.5. On the same scale, 2747 and 2749 had the highest waviness and were rated as 1. Haziness rankings showed no significant differences among these materials.

Powder coating and popping

The results of powder coating experiments are shown in Table 9. None of the five formulations showed popping in the dry state. Also, among the panels exposed to moisture, formulations 2719 and 2749 did not show any popping, while the others showed minor popping. Based on these findings two formulations, i.e., 2719 and 2749 were selected to be used for plant trial.

Plant trials

The selected two SMC formulations from each group along with two different conventional conductive primers, as shown in Table 5, were used in the plant trials. Please note that 113A in Table 5 is the same as 91B, and 113B is the same as 91D---- the names were changed to be consistent with the manufacturer's log book. Using the tools for Hummer H2 fenders, experimental panels were made with the selected SMC materials, and were conductive coated at Meridian Automotive Systems per the procedure described in the earlier sections. Some of the fenders were then cut to 12x18 inch test samples for laboratory validation, and the rest of the fenders were used in the plant trials.

ELPO tests

Before conducting plant trials one has to ensure that the experimental fenders will not have any negative impact to on the plant operations. To that end, 4x12 inch test samples from the fenders were cut and sent to DuPont Lab in Mount Clemens, Michigan, to test the compatibility of conductive coated panels to the ELPO. The tests were performed per TM08B4A and the panels were rated per procedure described in Table 10, and the results are shown in Table 11. As seen, all panels passed the test with appearance rating of 9 as well as crater rating of 9 or higher. These results thus indicate that the SMC parts when dipped into the ELPO bath in the plant will not contaminate the bath and will survive the ELPO process with no defects on the surface.

Powder coating and popping

Also to ensure compatibility with the plant powder, experiments were conducted using the plant powder and the results are shown in Table 12. This table also shows the corresponding percent of moisture content in the panels. None of the four formulations showed popping in the dry state. However, as expected, all panels when exposed to moisture showed severe popping, because the applied conductive coatings were of conventional type.

Moisture Absorption

Moisture absorption behavior of these materials was tested again to insure consistency of the compounding and molding processes. Figure 9 shows an absorption chart of moisture content (weight %) in the panels plotted against time (hours). As seen, 113 B showed the least amount of moisture absorption, while 2749 showed the highest. 113 B absorbed 0.23% in first 48 hours and 0.33% in seven days of exposure. In the same time period, 2749 absorbed 0.26% and 0.38% respectively. Note that the difference between moisture absorption of these four substrates is very narrow and all of them show similar rate of moisture absorption. The type of conductive primer did not have any effect on the moisture absorption profile of the same substrate. SMC formulations in the order of increasing moisture absorption are: 113 B, 113 A, 2719, and 2749.

In a typical automotive plant, the SMC parts will likely go through one of the following two scenarios during normal paint operations.

1. Straight through run (ELPO to clear-coat) when there is no line stoppage.
2. Weekend/shutdown period when the parts that have already seen ELPO bake, are stored in the strip area. These parts then absorb moisture during the shutdown period and when the line resumes, they will go through the rest of the paint process without any preheating.

Therefore in our plant trials, the SMC parts were evaluated for both of the above scenarios, and the results are shown in Table 13. None of the panels in the straight through run showed popping. As was mentioned earlier, in the straight through run, it took about two hours for the mule to reach the powder booth after it came out of the ELPO bake oven. So it was concluded that the low moisture SMC materials do not show popping due to air outgassing. Also, it was concluded that, these SMC materials even when coated with conventional conductive coatings can withstand two hours of ambient exposure before powder application and would not show popping.

The same combinations of SMC and conventional conductive primers, however, were not able to prevent popping when the parts were exposed to ambient environment in the strip area for four days [See Table 13]. Based on the weight gain of two 12x18 SMC panels of the same material that were stored in the strip area along with the fenders, it was estimated that the parts absorbed 0.13-0.16% moisture during this period, slightly less compared to 0.18%-0.21% in the lab tests at 65%RH/30°C. All the panels irrespective of type of conductive primers used, showed severe popping, confirming the observations made in the lab tests. Thus, it was concluded that the low moisture SMC materials coated with the conventional conductive primers are not resilient enough to prevent powder popping when exposed to long term moisture conditions.

Coating Modification

Three different versions of EXP COATING -1, including the original formulation and two modified versions, EXP COATING -2 and EXP COATING-3, were evaluated in this study. The EXP COATING -2 coating was modified by the addition of another solvent, while EXP COATING-3 was modified with a proprietary additive to improve the coating adhesion. Seven low moisture SMC substrates from the suppliers were selected for this study and designated as SMC-B-2 through SMC-B8. SMC-B-1, which is being used on Corvette body panels, was used as the control GM approved substrate. The test panels were first cleaned using Method 1, described above. Conductive primer was then applied per recommended procedure. The panels were evaluated for 1mm cross hatch tape adhesion, before and after humidity exposure. The tests were run in a duplicate set. Table 7 shows the results. It can be seen that the original EXP COATING -1 coating, as well as the modified version EXP COATING -2, did not show good adhesion to any of the substrates. On the other hand, the modified version EXP COATING-3 showed excellent adhesion to all substrates and met GM's requirement of a minimum 95% paint retention after 240 hours of humidity exposure. Only one of the two panels of SMC-B-6 and SMC-B-2 showed acceptable adhesion to the original EXP COATING -1 coating. In general, SMC-B-5 and SMC-B-6 materials showed relatively better adhesion to all coatings. These results were in line with the observations made in earlier experiments. It should be noted that there was a large variation in the adhesion ratings within a set of each substrates. For example, one of the SMC-B-2 panels passed the test with 98% paint retention while the other panel showed extremely poor adhesion with a 0 rating. To verify that the surface preparation method that we used had no effect on the results, we repeated the experiments with the EXP COATING -1 original and the EXP COATING-3 coating, and used Method 2 (IPA wipe) for cleaning the surface prior to the conductive primer application. The results are shown in Table 15. The results were similar to our earlier conclusions, but showed slightly more severe failure in the case of EXP COATING -1 adhesion to SMC-B-7, SMC-B-4 and SMC-B-2. The modified version, EXP COATING-3, however, again showed excellent adhesion to all substrates. Based on these results, we chose the EXP COATING-3 coating for further evaluation.

In summary, in order to eliminate the powder popping, one must use the combination of both low moisture absorbing SMC and a conductive primer such as the experimental coating we used in our work. In the next phase of this project, the potential benefit of using such coatings will be explored.

CONCLUSIONS

1. More than 40 SMC formulations were prepared and molded into panels for powder primer application readiness. The panels were evaluated for shrinkage, surface profile, moisture absorption, and powder application. Based on these results, four of the SMC formulations were selected for plant trials.

2. In the first plant trial, twenty panels on two mules were sent through the ELPO and powder process and all panels accepted the powder without popping. The time elapse between the ELPO oven and the start of powder was about 2 hours.

3. In the second plant trial, twelve panels on one mule were run through the ELPO, and then sent to the strip area and stored. They were then sent through the powder primer application. The time elapse between the ELPO oven and the start of the powder was about 96 hours. All panels showed popping out of the oven.

4. It was concluded that the selected final four SMC formulations do not show powder primer popping due to air outgassing, and their moisture absorption is low enough to allow powder priming when there is no line stoppage.

5. It was also noted that conventional conductive coatings cannot slow down moisture outgassing, and there is a need to develop a new generation of conductive coatings that can slow down moisture penetration into the powder primer.

6. The coating formulation was modified through a series of iterations and the final formulation shows excellent adhesion to all substrates and passes all adhesion tests.

SUMMARY AND FUTURE WORK

More than 40 SMC formulations were prepared and molded into panels for powder primer application readiness. It was concluded that the selected final four SMC formulations do not show powder primer popping due to air outgassing, and their moisture absorption is low enough to allow powder priming when there is no line stoppage. The future work will be focused on improving the surface profile of these SMC formulations along with the development of more favorable conductive coating. The final formulations will be validated on a production paint line.

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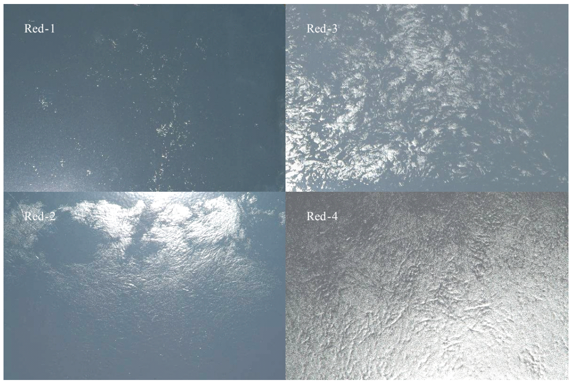

Figure 1. Ranking of severe popping on powder coated SMC panels.

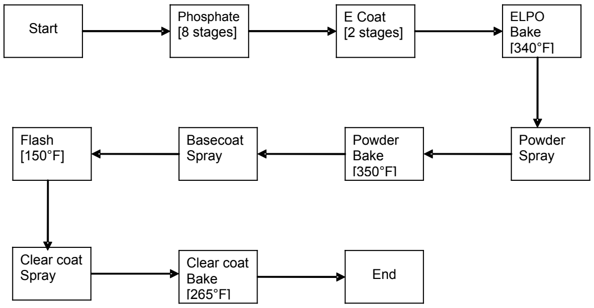

Figure 2. A typical automotive paint process using the powder primer system.

Figure 3. A molded fender made with experimental SMC.

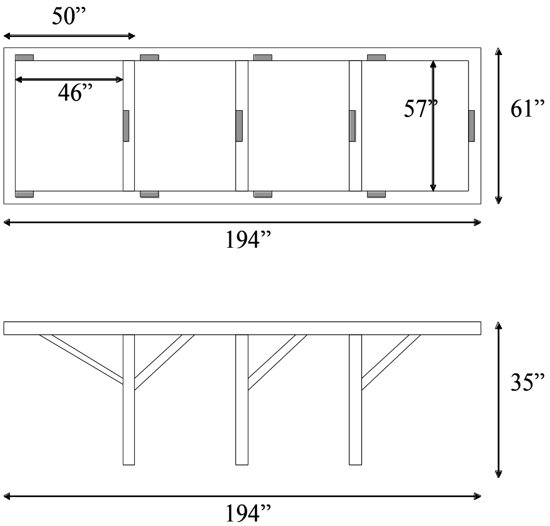

Figure 4. An schematic representation of the mule used to carry SMC fenders during the paint trial.

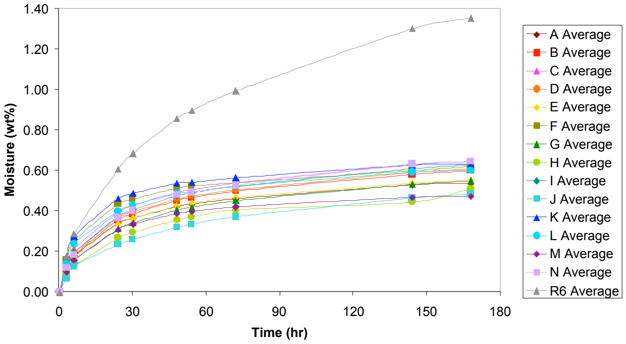

Figure 5. Moisture absorption charts of Type A SMC materials from phase I at 90%RH/40°C

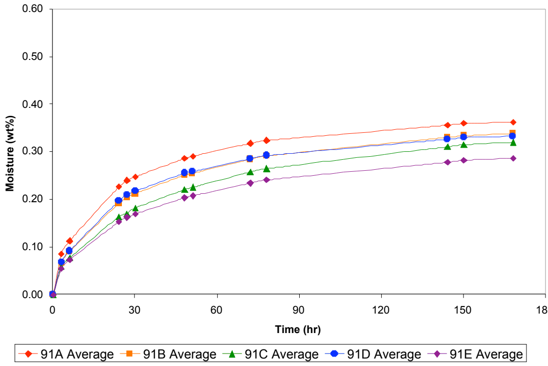

Figure 6. Moisture absorption charts of Type A SMC materials from phase II at 90%RH/40°C

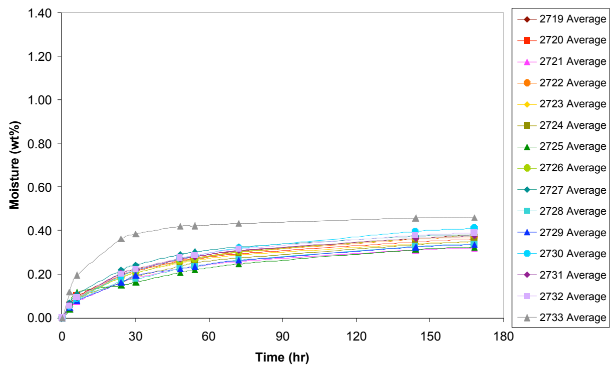

Figure 7. Moisture absorption charts of Type B SMC materials from Phase I at 90%RH/40°C

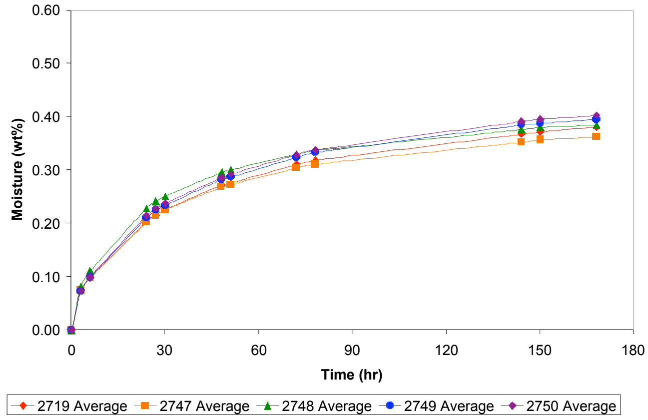

Figure 8. Moisture absorption charts of Type B SMC materials from phase II at 90%RH/40°C

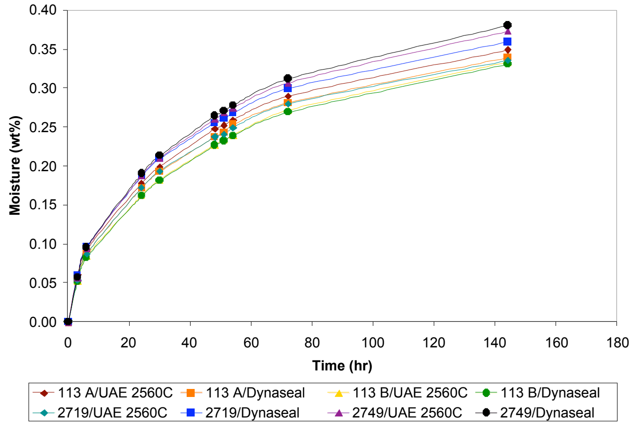

Figure 9. Moisture absorption charts of fenders at 90%RH/40°C

Material Identification	**Material Description**
A	Viscosity Modification 1
B	Typical Class A SMC (Control)
C	LPA Modification 1
D	LPA Modification 2
E	Resin Modification 1
F	LPA Modification 3
G	Resin Modification 2
H	LPA Modification 4
I	Resin Modification 3
J	Resin Modification 3 and LPA Modification 4
K	LPA Modification 5
L	LPA Modification 6
M	Viscosity Modification 2
N	Coating Performance Additive
R6	Filler Modification

Table 1. SMC materials description for Type A materials: phase I

Material Identification	**Material Description**
91A	Resin Type A LPA Type A
91B	Resin Type A LPA Type B
91C	Resin Type A LPA Type C
91D	Resin Type B LPA Type D
91E	Resin Type C LPA Type E

Table 2. SMC materials description for Type A materials: phase II

Material Identification	**Material Description**
2719	Resin 1, Low Profile Blend 1
2720	Resin 1, Low Profile Blend 1, Additive 1
2721	Resin 1, Low Profile Blend 1, Additive 2
2722	Resin 1, Low Profile Blend 1, Additive 3
2723	Resin 1, Low Profile Blend 2 , Additive 1
2724	Resin 1, Low Profile Blend 3, Additive 1
2725	Resin 1, Low Profile Blend 4
2726	Resin 2, Low Profile Blend 1
2727	Resin 1, Low Profile Blend 4, Additive 1
2728	Resin 1, Low Profile Blend 5, Additive 1
2729	Resin 1, Low Profile Blend 1, Additive 4
2730	Resin 2, Low Profile Blend 1, Additive 5
2731	Resin 1, Low Profile Blend 1, Additives 1 & 3
2732	Resin 1, Low Profile Blend 1, Additive 5
2733	Control SMC

Table 3. SMC materials description for Type B materials: phase I

Material Identification	**Material Description**
2719	Resin 1, Low Profile Blend 1
2747	Resin 1, Low Profile Blend 2, Formulation Adjustments
2748	Resin 1, Low Profile Blend 6, Formulation Adjustments
2749	Resin 2, Low Profile Blend 7, Formulation Adjustments
2750	Resin 2, Low Profile Blend 6, Formulation Adjustments

Table 4. SMC materials description for Type B materials: phase II

Material Identification	**Material Description**
113 A	Resin Type I LPA Type I
113 B	Resin Type I LPA Type II
2719	Resin 1, Low Profile Blend 1
2749	Resin 2, Low Profile Blend 7, Formulation Adjustments

Table 5. SMC materials used in part II: Process Validation

SMC	**Popping**	
	Dry	**Wet**
A	4	4
B	3	4
C	3	4
D	4	4
E	1	4
F	3	3
G	🟨	2
H	🟩	1
I	🟨	4
J	🟩	🟨
K	1	3
L	3	4
M	🟩	2
N	1	4
N (No CC)	4	4
R6	4	4

Failure ranking 1 to 4 (4 worst)

Table 6. Powder popping on Type A SMC materials in phase I: Material Development

SMC	Popping		Shrinkage (Expansion)		Surface Profile	Haze
	Dry	Wet	Average	Std Dev.		
91A	🟩	🟥	0.067	0.005	2.5	High
91B	🟩	🟩	0.064	0.006	4	Med
91C	🟩	🟩	0.025	0.007	2	High
91D	🟩	🟨	0.068	0.008	3	Med
91E	🟩	🟨	0.034	0.007	3.5	Very High

Failure ranking 1 to 4 (4 worst)

Surface Profile (Long Term Waviness): 1 - high waviness (poor), 5 - low waviness (good)

Table 7. Powder popping on Type A SMC materials in phase II: Material Development

SMC	Popping		Shrinkage (Expansion)		Surface Profile	Haze
	Dry	Wet	Average	Std Dev.		
2719	🟩	🟩	0.049	0.004	5	Med
2720	🟩	🟩	0.043	0.005	2.5	Med
2721	🟩	🟩	0.027	0.009	1.5	Med
2722	🟩	🟩	0.029	0.007	2	Med
2723	🟩	🟩	0.042	0.006	4	Low
2724	🟩	🟩	0.042	0.007	2.5	Med
2725	🟩	🟩	0.015	0.01	2.5	High
2726	🟩	🟩	0.038	0.016	3	Low
2727	🟩	🟨	0.048	0.008	2	Low
2728	🟩	🟩	0.033	0.007	2	Med
2729	🟩	🟩	0.028	0.009	3.5	Very High
2730	🟩	🟩	0.022	0.008	2	Low
2731	🟩	🟩	0.033	0.007	3	Med
2732	🟩	🟩	0.038	0.007	2.5	High
2733	🟥	🟥	---	---	---	None

Surface Profile (Long Term Waviness): 1 – high waviness (poor), 5 - low waviness (good)

Table 8. Powder popping on Type B SMC materials in phase I: Material Development

SMC	Popping		Shrinkage (Expansion)		Surface Profile	Haze
	Dry	Wet	Average	Std Dev.		
2719	🟩	🟩	0.033	0.004	2	Med
2747	🟩	🟨	0.027	0.013	1	Med
2748	🟩	🟨	0.038	0.006	1.5	Med
2749	🟩	🟩	0.028	0.003	1	Low
2750	🟩	🟨	0.038	0.005	2.5	Low

Failure ranking 1 to 4 (4 worst)

Surface Profile (Long Term Waviness): 1 - high waviness (poor), 5 - low waviness (good)

Table 9. Powder popping on Type B SMC materials in phase II: Material Development

Number of Craters	Crater Rating	Pass/Fail
0	10	Pass
1 - 2	9	Pass
3 - 5	8	Pass
6 - 10	7	Pass
19 - 34	6	Fail
35 - 66	5	Fail
67 - 130	4	Fail
131 - 258	3	Fail
259 - 514	2	Fail
> 514	1	Fail

Table 10. Soak and crater rating for E-coat compatibility test per TM0884A

SMC Material	Conductive Primer	Appearance	Crater Rating	Pass/Fail
2719	UAE 2560C	9	10-0 craters	Pass
	Dynaseal	9	10-0 craters	Pass
2749	UAE 2560C	9	9-1 crater	Pass
	Dynaseal	9	9-1 crater	Pass
113-A	UAE 2560C	9	9-1 crater	Pass
	Dynaseal	9	10-0 craters	Pass
113-B	UAE 2560C	9	9-1 crater	Pass
	Dynaseal	9	10-0 craters	Pass

Table 11. Crater rating for SMC materials tested for E-coat compatibility per TM0884A

Conductive Primer	Substrate	Dry (Straight through)	4-days @30°C/65%RH
Dynaseal	2719	0	0.194
	2749	0	0.206
	113-A	0	0.193
	113-B	0	0.192
UAE 2560	2719	0	0.185
	2749	0	0.208
	113-A	0	0.186
	113-B	0	0.177

Table 12. Powder popping on SMC in part II: Lab Validation

Conductive Primer	Substrate	Straight Through	4-days in the strip area
Dynaseal	2719	🟩	🟥
	2749	🟩	🟥
	113-A	🟩	🟥
	113-B	🟩	🟥
UAE 2560	2719	🟩	🟥
	2749	🟩	🟥
	113-A	🟩	🟥
	113-B	🟩	🟥

Table 13. Powder popping on SMC in part II: Validation at the plant trial

Substrate	EXP COATING -1			EXP COATING -2			EXP COATING-3		
	Initial	96 hrs	240 hrs	Initial	96 hrs	240 hrs	Initial	96 hrs	240 hrs
SMC-B-7	100	0	50	100	0	0	100	99	98
SMC-B-7	100	25	97	100	0	0	100	99	99
SMC-B-8	100	0	0	100	0	0	100	99	98
SMC-B-8	100	0	0	100	0	0	100	99	98
SMC-B-3	100	0	0	100	0	0	100	99	99
SMC-B-3	100	0	0	100	0	0	100	99	98
SMC-B-4	100	0	95	100	0	0	99	99	98
SMC-B-4	100	10	80	100	0	0	100	99	99
SMC-B-5	100	97	90	100	95	20	100	99	99
SMC-B-5	100	50	50	99	75	50	99	99	99
SMC-B-6	100	90	98	100	60	90	99	99	98
SMC-B-6	100	99	99	100	99	90	99	95	99
SMC-B-1	100	0	90	100	25	0	98	97	98
SMC-B-1	100	0	0	100	0	0	99	98	98
SMC-B-2	100	25	0	100	0	0	100	99	95
SMC-B-2	100	98	98	100	0	20	100	99	99

Table 14. Adhesion test results of SMC substrates coated with different versions of EXP COATING -1 coating: Pre-cleaning Method 1

Substrate	EXP COATING -1			EXP COATING-3		
	Initial	96 hrs	240 hrs	Initial	96 hrs	240 hrs
SMC-B-7	100	0	0	99	99	98
SMC-B-8	100	0	0	99	98	99
SMC-B-3	100	0	0	99	100	99
SMC-B-4	100	0	0	100	99	99
SMC-B-5	100	50	50	100	98	99
SMC-B-6	100	75	75	99	99	99
SMC-B-1	100	25	0	99	99	95
SMC-B-2	99	0	0	99	100	99

Table 15. Adhesion test results) of SMC substrates coated with different versions of EXP COATING -1 coating: Pre-cleaning Method 2

Hamid Kia, Lab Group Manager at GM R&D, received his PhD from Cambridge University and is the author of more than 30 published papers and has over 10 patents in his name. In 1993 He brought together a team of experts and with their help published the book of SMC Science and Technology.