PLANT TRIALS FOR POWDER PRIMING OF SMC

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Abstract

Based on the information generated at GM R&D Center, six SMC formulations were developed and produced by SMC suppliers and subsequently molded into automotive body panels for powder primer application readiness tests. The panels were evaluated in the lab for shrinkage, moisture absorption, adhesion to the conductive coating, and powder application. Based on the results, all six formulations were approved for plant trials. The trials took place in Shreveport and Lordstown assembly plants. It was noted that the use of infrared heating to bake the powder is detrimental to SMC as it causes rapid heating of SMC substrate, resulting in a high flux of moisture in a short period of time. It was also learned that the experimental conductive coating improves the powder prime capability of SMC and allows powder priming after an extended exposure to the plant environment.

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 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.

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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, paved 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, Continental Structural Plastics, AOC, and Ashland Specialty Chemical Company 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 [7]. The panels molded with the selected SMC materials were sent through the ELPO and powder process of a GM vehicle assembly plant in Oklahoma City [7]. The time elapse between the ELPO oven and the start of powder was about two hours in one trial, and about 96 hours in another trial. 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 the case of an extended line stoppage and subsequent moisture uptake by SMC panels, the conventional conductive coatings cannot slow down moisture outgassing. Therefore, there was a need to develop a new generation of conductive coatings, which could further slow down moisture penetration into the powder primer.

Redspot Paints and Varnishes Co. developed one such coating (493S) that in combination with selected non-degassing, low moisture absorbing SMC materials could deliver panels that can be powder primed without defects [8]. This report discusses the results from the evaluation of the low moisture SMC panels coated with 493S in the lab, as well as in the GM assembly plants in Shreveport and in Lordstown.

Materials and Procedures

Materials

Six experimental low moisture SMC materials from three different suppliers were tested. The list is shown in Table 1 and Table 2. AOC-1, AOC-2 and AOC-3 are made by AOC and molded by Meridian Automotive Systems. Ashland-A and Ashland-B are made by Ashland and molded by Meridian Automotive Systems. AOC-2 and Ashland-B are the standard low moisture formulations that have been evaluated in the previous trial in Oklahoma City while AOC-1, AOC-2 and Ashland-A are modified versions to lower moisture absorption and to improve the surface quality. BD 860 is an experimental, low moisture SMC made and molded by Continental Structural Plastics (CSP).

Table 1. List of SMC materials used in the Shreveport plant trial

ID*	Description	Supplier	Product Code
AOC-1	Experimental low moisture cosmetic SMC	AOC / Meridian Automotive Systems	8843
AOC-2	Experimental low moisture cosmetic SMC	AOC / Meridian Automotive Systems	8607, 9286 (SLI 365)
Ashland-B	Experimental low moisture cosmetic SMC	Ashland Specialty Chemical Co. / Meridian Automotive Systems	7126-3
BD 860	Experimental low moisture cosmetic SMC	Continental Structural Plastics	BD 860

*ID used in this report

Table 2. List of SMC materials used in the Lordstown plant trial

ID*	Description	Supplier	Product Code
AOC-2	Experimental low moisture cosmetic SMC	AOC / Meridian Automotive Systems	8607, 9286 (SLI 365)
AOC-3	Experimental low moisture cosmetic SMC	AOC / Meridian Automotive Systems	9287
Ashland-A	Experimental low moisture cosmetic SMC	Ashland Specialty Chemical Co. / Meridian Automotive Systems	7126
Ashland-B	Experimental low moisture cosmetic SMC	Ashland Specialty Chemical Co. / Meridian Automotive Systems	7126-3
BD 860	Experimental low moisture cosmetic SMC	Continental Structural Plastics	BD 860

*ID used in this report

n this study, we used the 493S conductive coating to enable powder priming of the panels. 493S is an experimental 2K conductive coating developed by Redspot Paints and Varnishes Co., Inc. A high strength adhesive was used to bond inner and outer body panels where applicable. Meridian used PLIOGRIP® 5000A/5020B epoxy adhesive made by Ashland while CSP used Lord 380/383 adhesive for this purpose. A commercially available powder primer from PPG, PCV Envirocron 70104, was used to coat the panels for lab tests. This primer is a polyester epoxy hybrid that is used by GM at the Lordstown plant on compact cars such as Chevrolet Cobalt and Pontiac G5. PUA 1177/HG, a commercially available powder primer from Seibert is a polyurethane based powder and is being used by GM in Shreveport assembly plants on vehicles such as Chevrolet Colorado, GMC Canyon and Hummer H3.

Procedures

Part I. Lab Tests

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

<u>*Moisture Absorption*</u> – 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 dry initial weight of the panels was first recorded, and then they were exposed to 90% RH at 40°C for seven days. The weight of the panels was subsequently recorded at specific time intervals during the moisture exposure. The moisture content (weight %) at time t, was then calculated by

$$\left(\frac{\text{Weight of the panel (g) at time, t - Initial weight of the panel (g)}}{\text{Initial weight of the panel (g)}}\right) * 100$$

<u>*Shrinkage Measurement*</u> – 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 (taking into account the 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.

<u>*Tape Adhesion Test (GM 9071P)*</u> –This standard procedure specifies the test method to be used for evaluating the adhesion properties of painted metal or plastic before and after environmental testing. Since the test panels were coated with the conductive primer only, which was less than 50 microns thick, the 1-mm cross hatch tape test (Method A) was used to test the panels. These tests were performed 72 hours after curing, as well as after different intervals of humidity exposure at 38^{o}C and 100% condensing relative humidity per GM 4465P. In order to pass the test a minimum of 95% of the paint must remain in the tested area.

<u>*Dime Scrape Test (GM 9506P)*</u> – This test is used to evaluate paint adhesion to rigid plastic substrates and to determine the brittleness of the paint film. Like the tape adhesion test, this test was performed 72 hours after curing, as well as after different intervals of humidity exposure. A “fair” or better rating on the GM 9506P scale is required to pass the test.

Powder Coating and Popping

Dry Panels

Panels were first prepared and dried per the procedure described in our previous 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 for powder spray application. Powder was then sprayed on the dry panels at ambient conditions (20°C and 55%RH).

Wet Panels

SMC 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. Afterwards, the panels were brought back to the R&D Center and were dried for 24 hours at 110°C followed by an exposure to 90%RH at 40°C for 48 hours. They were then sealed in Ludlow moisture barrier bags and transported to PPG for powder spray on the same day.

After powder application, the panels were inspected for popping/foaming with 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).

Part II. Plant Trials

Molding

In order to evaluate the new SMC formulations in the assembly plants we needed to identify a vehicle body panel that had the right overall dimensions, surface profile, and edge finish. To that end the tools for hoods were used to mold the selected materials for the Shreveport trial. Meridian used a Cadillac 295 tool while CSP used a Corvette C6 tool to mold the hoods. Figure 1 shows the picture of a C6 hood. The inner panels for these hoods were also made with the same material. 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), using similar charge layout. The molded panels were then de-flashed and the inner and outer panels were bonded together using high strength adhesive. The bonded parts were then prepared for receiving the conductive coatings described earlier. They were then shipped to the GM assembly plant for powder primer application. For the paint trial in Lordstown assembly plant, smaller parts were needed as there was no dedicated mule available for the E-coat process, and the parts had to be tied in place inside the body frame of a small car. Therefore, Meridian used a Corvette Decklid tool while CSP used a Corvette Quarter Panel tool to make the parts. Figure 2 shows the pictures of these parts. The decklid inner panels were made of the same material as the outer panels. The quarter panel did not have any inner panel.

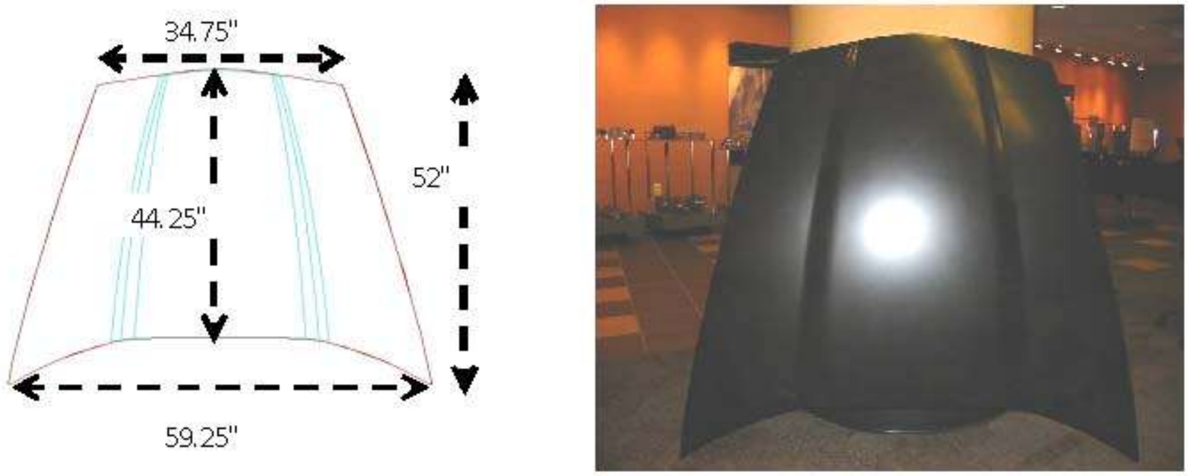

Figure 1. A molded Corvette C6 hood made with experimental SMC.

Figure 2. A molded Corvette C6 quarter panel and a decklid made with experimental SMC

Plant Validation

<u>Shreveport</u> – Figure 3 shows a typical paint process from ELPO to topcoat in the Shreveport assembly plant. Although SMC parts do not benefit from the phosphate and E-coat operations, 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, in which the line does not stop and the parts go through the entire paint process uninterrupted. In the second scenario, the paint line stops for an extended shutdown period. In this case, the parts that go through the ELPO process are stored in the strip area during the shutdown period. These parts then absorb moisture, which can later cause popping during the powder bake.

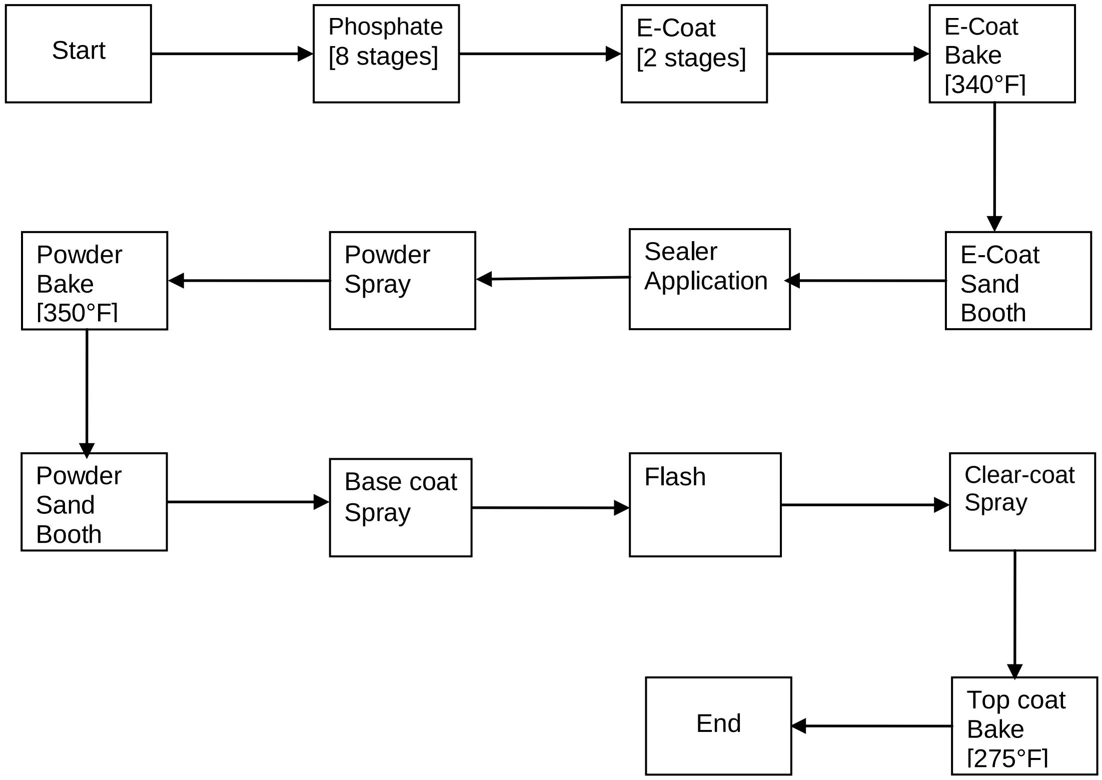

Figure 3. A typical automotive paint process using the powder primer system.

<u>*Straight Through Run*</u> **–** Eight hoods were assembled horizontally on two different ELPO mules. Figure 1 shows the picture of one of the molded hoods, while Figure 4 shows the pictures of the mules used. Both mules went through the ELPO process. After they came out of the ELPO, the mules were removed from the paint line and the hoods were then transferred to the powder mule (see Figure 5). Subsequently they went through the powder application and the bake process with no interruption.

The total time elapse between the end of the E-coat oven and the powder prime booth was about 2 hours. The panels were then inspected for popping by the naked eye, and the finish was rated using the same procedure described earlier. The parts were then mounted on individual vehicle mules for the top coat processing. (Figure 5).

Figure 4. Mule used to carry SMC hoods through E-coat process at Shreveport paint shop.

Figure 5. Mules used to carry SMC hoods through powder and top-coat application process at Shreveport paint shop.

Extended Shutdown Run – Eight hoods were assembled horizontally on two different ELPO mules. The mules were then sent through the ELPO process. After they came out of the ELPO, the mules were removed from the paint line and the hoods were returned to the storage rack for storage in the strip area for ten weeks, which included the two week summer shutdown. The plant climate control system was off over the weekends and the summer shutdown period as the plant was not running. The ambient temperature humidity data was recorded by a Dickson TP120 Data Logger during this period. The mules went through the normal powder application process when the line resumed after the shutdown. The detailed powder spray parameters are discussed in earlier section. 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.

Lordstown

The paint process at Lordstown is almost similar to the one in Shreveport as shown in Figure 3 with few changes. Lordstown uses color key/specific powder primer and no IR heating was used during the powder bake, and the black wall radiant ovens were the only heat source. As in the previous trial in Shreveport, SMC parts were evaluated in two different scenarios discussed below:

Straight Through Run – Four Decklids and a quarter panel were tied in place inside three different vehicles. Figure 2 shows the picture of the molded parts, while Figure 6 shows the picture of the mule vehicle. All parts went through the ELPO process. After they came out of the ELPO, the parts were removed from the vehicles. They were then transferred to the mule vehicles used for powder application (see Figure 6). The parts were mounted on the vehicles in the hood and rear deck positions and sent through the powder application and bake process with no interruption.

Figure 6. Test panels assembled on carrier vehicles for powder process at Lordstown paint shop.

Due to the limited availability of mule vehicles for the powder application, two of the decklids (AOC-3 and Ashland-B) were positioned inside the vehicle and the powder was applied manually. The total time elapse between the end of the E-coat oven and the powder prime booth was about two hours. The panels were then inspected for popping by the naked eye, and the finish was rated using the same procedure described earlier.

Extended Shutdown Run – Four decklids and a quarter panel were tied securely inside three different vehicles. The vehicles were then sent through the ELPO process. After they came out of the ELPO, the parts were removed from the vehicles. They were then transferred to the storage area where they would absorb moisture for two weeks. The ambient temperature humidity data was recorded by a Dickson TP120 Data Logger during this period. After two weeks the parts were mounted on two mule vehicles. On the first vehicle, the decklids were attached in the hood and roof position while the quarter panel was attached in the rear deck position. On the second vehicle, both decklids were attached in the hood and the rear deck positions. All parts, except the one attached to the roof, went through the normal powder application process. The panel attached to the roof was powder coated manually. The parts were removed from the line after the powder bake and did not go through the basecoat and clear-coat applications. They were then inspected visually for popping, and the surface finish was rated as before.

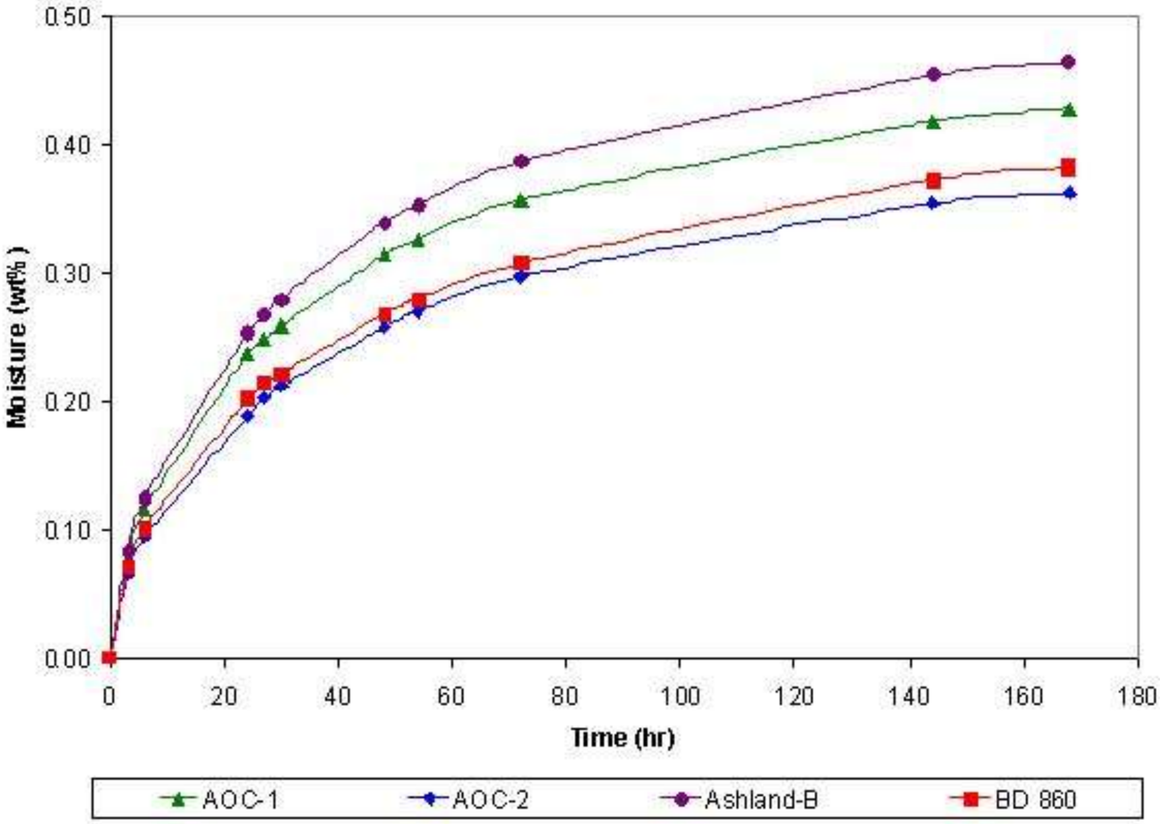

Figure 7. Moisture absorption chart of experimental SMC materials at 90%RH/40 °C

Results and Discussion

Part I: Lab Tests

Four formulations as shown in Table 1 were evaluated in this study. All four formulations were experimental formulations developed by suppliers based on our previous work [7]. The performance of these materials in many key areas was assessed in the lab prior to the plant trials. This included moisture absorption, shrinkage, adhesion to the conductive coating, and powder prime capability.

Moisture Absorption

Figure 7 shows a moisture absorption chart based on weight % change in the panels with time. As it can be seen, AOC-2 showed the least amount of moisture absorption, while Ashland-B showed the highest. AOC-2 absorbed 0.26% in the first 48 hours and 0.36% in seven days of exposure. In the same time periods, Ashland-B absorbed 0.34% and 0.47% respectively. The SMC formulations in the order of increasing moisture absorption are: AOC-2, BD 860, AOC-1, and Ashland-B.

Shrinkage

Table 3 shows the amount of shrinkage for each material. All formulations show expansion in the range of 0.036%-0.053% with the exception of BD 860 which showed shrinkage of -0.005%. Ashland-B formulation showed the highest expansion (0.053%) followed closely by AOC-2 (0.046%). Formulation AOC-1 showed the least amount of expansion (0.036%).

Table 3. Shrinkage

SMC	Average shrinkage/expansion (%)	Std. Dev.
AOC-1	0.036	0.008
AOC-2	0.046	0.01
Ashland-B	0.053	0.005
BD 860	-0.005	0.016

Adhesion of the conductive coating to the substrate:

The panels were evaluated for 1mm cross hatch tape adhesion per GM 9071P (Method A) and the dime scrape test per 9506P, before and after, 96 hours and 240 hours, of humidity exposure per GM4465P. Table 4 shows the results. All test panels passed the 1mm cross hatch adhesion tests and dime scrape tests even after 240 hours of exposure to humidity.

Table 4. Adhesion

SMC	1mm cross hatch adhesion			Dime Scrape Test		
	Initial	96 hrs	240 hrs	Initial	96 hrs	240 hrs
AOC-1						
AOC-2						
Ashland-B						
BD 860						

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 shutdown scenario when the parts are stored in the strip area and are allowed to absorb moisture. All materials were coated with the 493S conductive primer.

Table 5. Powder popping on SMC in part I: Lab Validation

SMC	Dry	Wet
AOC-1		0.297
AOC-2		0.266
Ashland-B		0.316
BD 860		0.243

The results are shown in Table 5. This table also shows the corresponding percent of moisture content in the panels. As expected, none of the four formulations showed popping in the dry state. Also, among the panels exposed to moisture, none showed any popping. It should be noted that in our previous study, the same SMC substrates in combination with conventional coatings, showed popping when powder coated after the same humidity exposure duration [7-8]. These latest results show the improvement in the powder prime capability of SMC due to the new experimental coating (493S). In combination with this coating, the experimental SMC materials thus are resilient enough to withstand at least 48 hours of exposure to high humidity environment (90%RH/40°C).

Part II-a: Shreveport Plant Trials

The selected four SMC formulations (Table 1) coated with the experimental conductive coating, 493S, were used in the plant trials. As mentioned earlier, both inner and outer panels were made with the selected SMC materials and were bonded and conductive coated at the source.

ELPO and Phosphate Compatibility Tests

The Global Paint and Polymer Center and the assembly plants require that any new substrate expected to be painted in the plant is evaluated for E-coat and phosphate compatibility to ensure that they will not have any negative impact on the plant operations. To that end, 4x12 inch test samples were bonded and coated with the 493S conductive primer and sent to Henkel Laboratories in Madison Heights, Michigan, and to ACT Bodycote test labs in Hillsdale, Michigan, to be tested for compatibility with the phosphate and E-coat systems. The phosphate compatibility tests were performed per an internal test method developed by the supplier. In this test the panels were processed through a laboratory simulation of General Motors Shreveport metal pretreatment system. After processing the panels through the metal pretreatment system, no visual changes were observed in the operating baths or on the panels. However, the physical weight of all the panels increased slightly (by 0.03% avg.) after the processing possibly due to water absorption by the substrate.

Table 6. Crater rating for E-coat compatibility test per Ford FLTM BV 119-01 (12/00)

# of Craters on 4”x9” surface	Crater Rating	# of Craters on 4”x9” surface	Crater Rating
0	10	13 - 15	5
1 - 3	9	16 - 18	4
4 - 6	8	19 - 21	3
7 - 9	7	*22 - 24*	*2*
10 - 12	6	*> 25*	*1*

The E-coat compatibility tests were performed per Ford FLTM BV 119-01 and BI 120-01 specifications. In procedure A, the test material was attached to the substrate while in the procedure B, the bath was contaminated with SMC (5 grams/gallon). The panels were rated per the rating scale shown in Table 6. Table 7 and Table 8 show the results of these tests. As seen, all panels passed the tests with crater rating of 9. There was no visual change on the test panels and the appearance was the same as the control. 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.

Table 7. Crater rating for SMC materials tested for E-coat compatibility per Ford FLTM BV 119-01 (12/00): Procedure A (Test material attached to the substrate)

SMC Material	Panel	Crater Rating	Visual Appearance
AOC-1	Initial Control	9	Control
	Test Panel	9	Same as control
	Final Control	9	Same as control
AOC-2	Initial Control	9	Control
	Test Panel	9	Same as control
	Final Control	9	Same as control
Ashland-B	Initial Control	9	Control
	Test Panel	9	Same as control
	Final Control	9	Same as control
BD 860	Initial Control	9	Control
	Test Panel	9	Same as control
	Final Control	9	Same as control

Table 8. Crater rating for SMC materials tested for E-coat compatibility per Ford FLTM BV 119-01 (12/00): Procedure B (Bath Contamination 5 grams per gallon)

SMC Material	Panel	Crater Rating	Visual Appearance
AOC-1	Initial Control	9	Control
	Test Panel	9	Same as control
AOC-2	Initial Control	9	Control
	Test Panel	9	Same as control
Ashland-B	Initial Control	9	Control
	Test Panel	9	Same as control
BD 860	Initial Control	9	Control
	Test Panel	9	Same as control

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. Extended 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. The test period for the later scenario was about ten weeks of which two weeks were the actual plant shutdown period. The climate control system in the plant was ON all the time except the shutdown period. Figure 8 shows the temperature and humidity data in the strip area during the test period except the two weeks prior to the powder application. As seen, during the shutdown period, humidity in the plant went as high as 92%RH while the average temperature remained above 80°F. After the shutdown however, the average humidity was 65-70 %RH.

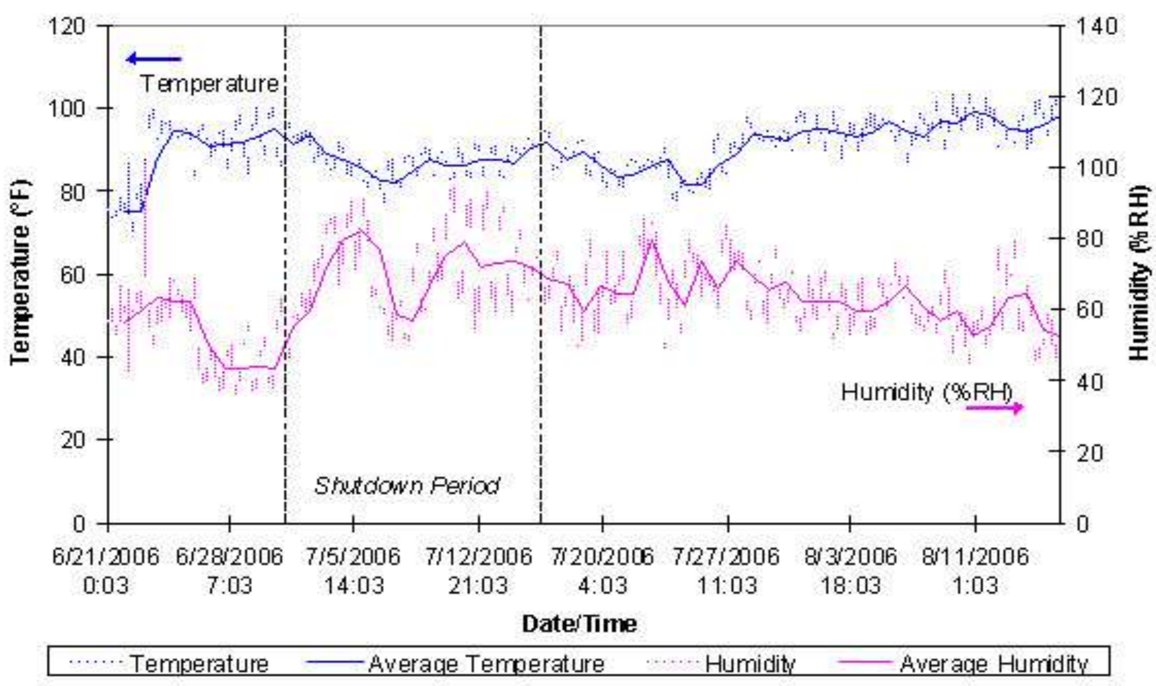

Figure 8. Humidity and temperature data at Shreveport Plant during the test period

Table 9 shows the popping results for SMC panels after the powder primer was applied. 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. It was concluded that the low moisture SMC materials can be powder primed with no ill effects when there is no line stoppage. This confirmed the test results from the Oklahoma City Plant trial [7].

Table 9. Powder popping on SMC in part II-a: Shreveport plant trial

SMC	Straight Through Run	Extended Shutdown Run
AOC - 1		
AOC - 2		
Ashland-B		
BD 860		

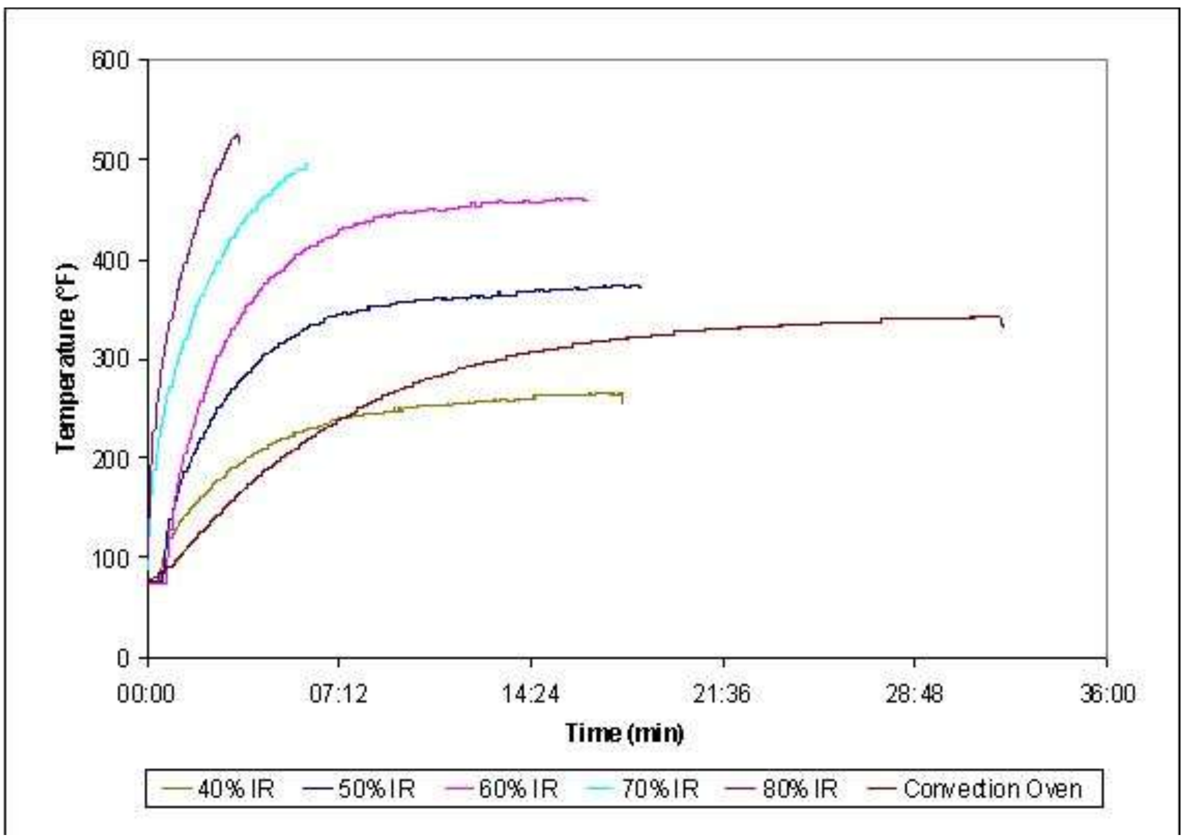

Figure 9. Effect of IR intensity on the heating of SMC panel

The same combinations of SMC and experimental conductive primer, however, were not able to prevent popping when the parts were exposed to ambient environment in the strip area for more than ten weeks [See Table 9]. Based on the weight gain of the two 12"x18" SMC panels of the same material that were stored in the strip area along with the hoods, it was estimated that the parts absorbed 0.15-0.18% moisture during this period. Yet, all the panels showed severe popping with a leathery look, contradicting the results from the lab tests. Closer observation on the backside of the hoods revealed that there was no popping in the powder overspray on the back side of the parts. The only difference between the powder coating on the front and back side of the hoods was the exposure to IR lamps during the bake. This led to the conclusion that the infrared heating used in the plant to bake powder was detrimental to SMC. Use of IR lamps even for few minutes in the beginning of powder bake can cause SMC to heat at a very fast rate. The rate at which SMC is heated depends on the intensity of the lamps and the distance of the part from the lamps. Figure 9 shows the effect of IR intensity on the heating rate of the SMC panel kept at a constant distance. As shown, faster heating would definitely cause a rapid loss of moisture into the powder layer in a very short period of time causing popping defects with a leathery look. In the lab tests no IR lamps were used, and hence, no popping was observed. Thus, it was concluded that the IR lamp exposure during the powder bake is detrimental to SMC with moisture. It should be noted that because of this sever heating rate, it was not possible to evaluate the resiliency of the SMC coated with 493S to prevent powder popping when exposed to long term moisture conditions. Therefore, in order to evaluate the ability of the low moisture SMC coated with 493S to prevent powder popping, we decided to conduct another plant trial in the Lordstown assembly plant, which does not use IR lamps to bake the powder.

Part II-b: Lordstown Plant Trials

The selected five SMC formulations, shown in Table 2 were evaluated again at the Lordstown assembly plant in Ohio. Meridian Automotive Systems used the tool for Corvette C6 Decklid while Continental Structural Plastics used the tool for Corvette C6 quarter panel to make the parts. Inner panels for the decklids were made of the same material as the outer panels while the quarter panel did not have any inner panel. The conductive coating was then applied at the molder's plant per the procedure described in the earlier sections.

As before, the parts were tested at ACT Bodycote test labs in Hillsdale, Michigan for their compatibility with E-coat system in the plant. The results are shown in Table 10 and Table 11. All panels passed the test with appearance the same as the control and the crater rating of 9.

As in the previous trial in Shreveport, the parts were evaluated for both straight through and extended shutdown scenario. The test period for the later scenario was about two weeks. The climate control system in the plant was running at all times as there was no actual plant shutdown planned during this period. The humidity and temperature data in the plant during these two weeks is shown in Figure 10. The average humidity and temperature in the paint shop during the test period was about 60%RH and 70°F respectively. The results are shown in Table 12.

Table 10. Crater rating for SMC materials tested for E-coat compatibility per Ford FLTM BV 119-01 (12/00): Procedure A (Test material attached to the substrate)

SMC Material	Panel	Crater Rating	Visual Appearance
AOC-2	Initial Control	9	Control
	Test Panel	9	Same as control
	Final Control	9	Same as control
AOC-3	Initial Control	9	Control
	Test Panel	9	Same as control
	Final Control	9	Same as control
Ashland-A	Initial Control	9	Control
	Test Panel	9	Same as control
	Final Control	9	Same as control
Ashland-B	Initial Control	9	Control
	Test Panel	9	Same as control
	Final Control	9	Same as control
BD 860	Initial Control	9	Control
	Test Panel	9	Same as control
	Final Control	9	Same as control

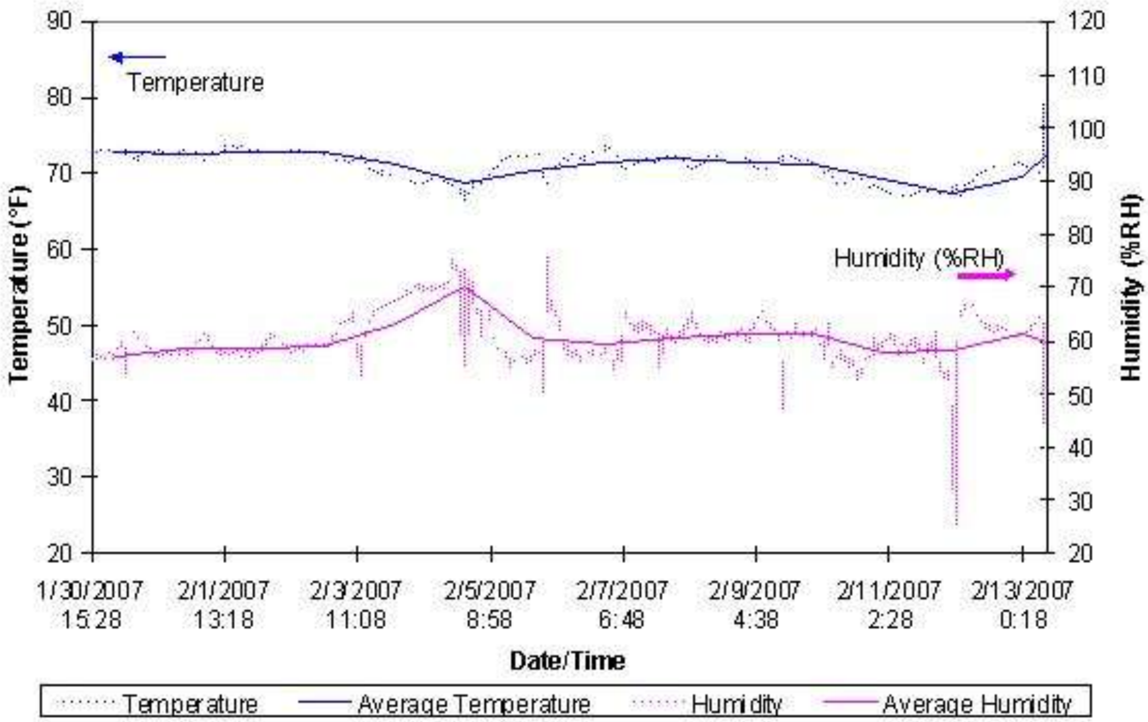

Table 11. Crater rating for SMC materials tested for E-coat compatibility per Ford FLTM BV 119-01 (12/00): Procedure B (Bath Contamination 5 grams per gallon)

SMC Material	Panel	Crater Rating	Visual Appearance
AOC-2	Initial Control	9	Control
	Test Panel	9	Same as control
AOC-3	Initial Control	9	Control
	Test Panel	9	Same as control
Ashland-A	Initial Control	9	Control
	Test Panel	9	Same as control
Ashland-B	Initial Control	9	Control
	Test Panel	9	Same as control
BD 860	Initial Control	9	Control
	Test Panel	9	Same as control

Table 12. Powder popping on SMC in part II-b: Lordstown plant trial

SMC	**Straight Through Run**	**Extended Shutdown Run**
AOC - 2		
AOC - 3		
Ashland-A		*
Ashland-B		*
BD 860		*

* Minor popping along parts of the edges

All panels went through the powder prime process successfully. None of the panels in the straight through run showed popping, once again confirming the results from previous trials. In the extended line stoppage run, among the parts that were stored in the plant for two weeks prior to the powder application, AOC-2 and AOC-3 did not show popping. The rest of the panels Ashland-A, Ashland-B and BD 860 showed very minor popping along the edges of the parts. Ashland panels had sporadic tiny popping in the middle portion too. None of these panels showed leathery look. In fact the defects were so tiny that the subsequent layers of paint i.e. base-coat and clear-coats were able to hide them. Microscopic analysis of the cross-sections of these parts revealed that the powder thickness was much higher than the target thickness (up to 125 microns instead of 65-75 microns). The temperature and humidity during this period varied between 66°F-74°F and 55%RH-75%RH respectively. Based on the weight measurements of the test panels that were kept next to the test parts, it was estimated that the moisture absorption by test parts was in the range of 0.15% -0.18% by wt. Thus the results confirmed our conclusion from the previous trial in Shreveport that an exposure to IR in the beginning of powder bake is detrimental to SMC. It was concluded from these results that the experimental low moisture SMC materials in combination with newly developed conductive coating can be powder primed with no popping in an assembly plant that do not use IR, even after two weeks of ambient exposure to the plant environment.

Conclusions

1. In the first plant trial in Shreveport assembly plant, eight hoods 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 two hours.

2. In the second plant trial in Shreveport assembly plant, eight hoods on two mules 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 ten weeks. All panels showed popping out of the oven.

3. In the first plant trial in Lordstown assembly plant, four decklids and a quarter panel 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 two hours.

4. In the second plant trial in Lordstown assembly plant, four decklids and a quarter panel were run through the ELPO, and then sent to the storage 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 two weeks. Two decklids accepted the powder without popping while the rest showed a very minor popping along the edges of the parts. The popping was minor enough to be covered by the subsequent paint layers.

5. It was concluded that the selected 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.

6. It was noted that the use of infrared heating to bake the powder is detrimental to SMC as it causes rapid heating of SMC substrate, possibly releasing large quantity of moisture in short period of time.

7. It was also concluded that the experimental conductive coating improves the powder prime capability of SMC and allows powder priming after at least two weeks of exposure to the plant environment, provided no infrared heating is used in the bake oven.

Open Questions

Although the plant trials have been very successful, there are still many issues to be resolved. We need to establish a better understanding of how the heating rate affects the popping issue as a function of moisture content. To that end, one has to map out how the moisture content changes for different SMC formulations as exposed to plant environment for different length of time. Also, one has to define the heating rate as affected by the oven temperature, the temperature ramp, the location of the part on the vehicle, and the line speed. In other words, the next step should be part specific and designed to establish a working window for each SMC formulation.

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References

1. Cleveland, M., Rao, N., Migda, F, and Hulway J. Low Paint Emissions and Low Vehicle Mass: Conflicting Challenges?, International Coatings for Plastics Symposium, June 4-6, 2001, Troy, MI., USA

2. Marsh, G.,“Manipulating Matrices”, Reinforced Plastics, July/August 2003 Page 22-27

3. Jacob, A. ,“Stopping The Pops-The Final Challenge for SMC” Reinforced Plastics, Nov. 2002 Page 38-41

4. Abrams L. M., Castro J.M., “Powder Coating of Sheet Molding Compound (SMC) Body Panels”, Polymer Composites, Oct. 2001, Vol. 22 No. 5, Page 702-709

5. Kia, H.G., Mitchell, H.A., Wathen, T.J., Shah, B. and Berger, C.R.. Powder Priming of SMC, Part I: Assessment of the Current Technologies, Journal of Composite Materials, vol. 22, 2005.

6. Kia, H.G., Mitchell, H.A., Wathen, T.J., Shah, B. and Berger, C.R.. Powder Priming of SMC, Part II: Failure mechanism, Journal of Composite Materials, vol. 22:, 2005.

7. Kia, H.G., Wathen, T.J., Shah, B., Robbins, J., Kleese, E., and Seats, R. “New Developments in Powder Priming of SMC”, JEC Annual Meeting Proceedings, Paris, France, March 28-30, 2006, Automotive Section, Number 5.

8. Kia, H.G., Wathen, T.J., Shah, B., and Berger, C.R. “Development of Conductive Coating for Powder Priming of SMC”, American Composites Manufacturers Association Annual Meeting Proceedings, October 18-20, 2006.