ALTERNATIVE METHODS TO ENABLE THE POWDER PRIMING OF SMC

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Abstract

Our previous work has shown that the newly developed SMC systems are powder primer ready in straight through operations. However, after an extended stoppage in the operation such as July shutdown, the success of the powder application depends on the severity of temperature ramp in the oven. To overcome this issue, in this work, an alternative short term preheating is proposed after any long term humidity exposure in the plant. It was observed that using the newly developed experimental low moisture SMC/conductive coating systems, only four minutes of preheating in the oven at 180°C, or three minutes of IR exposure was sufficient to enable powder priming in a plant simulation without popping. The preheating approach also allowed the use of conventional conductive coating on the experimental low moisture SMC without compromising its powder capability. Similarly, using this method, it was possible to powder prime conventional SMC in combination with the experimental conductive coating with no popping. However, the preheating method could not benefit the combination of conventional-SMC/conventional-conductive-coating.

Introduction

The use of powder primers on SMC body panels has become a major challenge for the automotive industry. The benefits of powder primers are well known, but the downside is that powder primers are not compatible with the current high moisture absorbing plastics in general [1, 2], and SMC in particular [3-5]. The body panels molded with SMC show paint popping in the bake oven of the powder primer, resulting in an unacceptable surface finish.

Based on the work done in our previous studies, it was concluded that a combination of an experimental low moisture SMC and an experimental conductive coating, 493S, was required in order to powder prime SMC with no popping [6-8]. The advantage of using this combination was that no modification in the paint process was needed to powder prime the parts at GM assembly plants. However, the plant trials showed that the new materials are not robust and are very sensitive to the powder bake temperature profile and the amount of moisture absorbed [8]. To overcome the inflexibility of the narrow range of materials and process parameters that can be used in production, an alternate method of powder priming SMC is proposed which involves heating the top surface of SMC panels prior to powder application. Although this modified method requires some deviation from the standard procedure used in GM assembly plants, it ensures that the process is very robust and opens the door for some commercially available materials to be used in the powder prime application. The modifications can be made in the assembly line by installing heating devices such as a bank of infrared lamps between the E-coat booth and the powder booth. It should be noted that this pre-powder heating is required only after the extended shutdown period when the SMC panels have a high moisture content. The experimental low moisture SMC, if run straight through with no line stoppage, does not show any popping [5-8]. Therefore, the suggested modification in the process applies only to parts that have high amounts of moisture due to storage in the strip area.

The main objective of this study was to investigate the effectiveness of the new process to produce a pop free surface after the powder application. The process parameters such as heating conditions and subsequent cooling time were optimized for different SMC formulations. The new process was also tested for its robustness to changes in key variables such as the amount of moisture and the powder bake temperature profile.

Materials and Procedures

Materials

Both commercially available SMC and experimental low moisture SMC panels were tested. The list is shown in Table 1. SMC-1 is a commercially available class A SMC based on toughened class A polyester resin and is made by Continental Structural Plastics. It is currently being used by GM in Cadillac XLR and Chevrolet Corvette C6 hoods. SMC-2 is an unsaturated polyester based commercially available SMC made by Meridian Automotive Systems. It is currently being used in Corvette C6 decklids and Hummer H2 fenders. SMC-3 is an experimental low moisture SMC developed by Meridian Automotive Systems in collaboration with AOC. It is one of the experimental low moisture SMC formultations currently being tested.

Table 1: *List of materials.*

Product Code	Description	Supplier
SMC Formulations		
SMC-1	**Polyester based toughened class A SMC**	**Continental Structural Plastics**
SMC-2	**Polyester based toughened class A SMC**	**Meridian Automotive Systems**
SMC-3	**Experimental low moisture SMC**	**Meridian Automotive Systems**
Conductive Coatings		
CC-1	**1K coating**	**Redspot Paints and Varnishes Co. Inc**
493S	**Experimental 2K coating**	**Redspot Paints and Varnishes Co. Inc**
Powder Primer		
PCV Envirocron 70114	**Polyester epoxy hybrid powder**	**PPG Industries**

Two different conductive coatings, CC-1 and 493S, were used to enable powder priming of the panels. Both conductive coatings are made by Redspot Paints and Varnishes Co., Inc. CC-1 is a conventional 1K conductive coating while 493S is an experimental 2K conductive coating. A commercially available powder primer from PPG, PCV Envirocron 70104, was also used to prime the panels. This primer is a polyester epoxy hybrid that is used by GM at the Lordstown plant on compact cars such as the Chevrolet Cobalt and Pontiac G5.

Procedures

The procedures for molding, cleaning, and conditioning of the SMC panels have been described in detail in a previous report [4], and are not repeated here.

Powder Priming and Popping

Panels were first prepared and dried (24 hours at 110°C) per the procedures described earlier [4]. They were then coated with either the commercial or the experimental conductive 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 unless otherwise specified. These panels were then sealed in Ludlow moisture barrier bags and transported to PPG for powder spray on the same day. Prior to the powder application, the panels were heated for a specified time using one of the following two methods.

Heating Method I: Forced Air Convection Batch Ovens

In this method the panels were heated in batch ovens preset to specified temperatures for specified durations. The temperature profile in the oven was recorded. The panels were then cooled for about ten minutes, unless otherwise specified, before being powder coated. A handheld infrared thermometer was used to ensure that the surface temperature of the SMC, at the time of powder application, was below 30°C.

Heating Method II: Infrared Lamps

In this method, the panels were heated under a bank of infrared lamps for the specified duration. Three different locations under the lamp were used for this testing. The temperature profile of the SMC panel at each location was recorded. The details of the lamps are as followed:

- Number of lamps in a row; 3
- Number of rows: 6
- Lamp Length: 27 inches
- Voltage used: 460V
- Distance between the part and the lamp: 15 inches

The panels were then cooled for about ten minutes unless otherwise specified before being powder coated. The powder was then baked in a large industrial batch oven with a gradual ramp up of temperature, unless otherwise specified. In some experiments, in addition to the convection heat, infrared lamps (15%) were used in the first fifteen minutes of the bake. In experiments involving SMC-3 panels coated with 493S, the powder was baked in a small batch oven preset at 180°C with no ramp. Figure 1 shows the SMC temperature profile for all three bake conditions.

After powder application, the panels were inspected for popping/foaming with the naked eye and with a microscope. The finish of the panels was rated as severe defects (red color), major defects (orange color), moderate defects (yellow color), minor defects (lime color) and no defects (green color). Only green colored panels were qualified as production ready.

🟥 **Severe popping**	🟧	🟨	🟩	🟩 **No Popping**

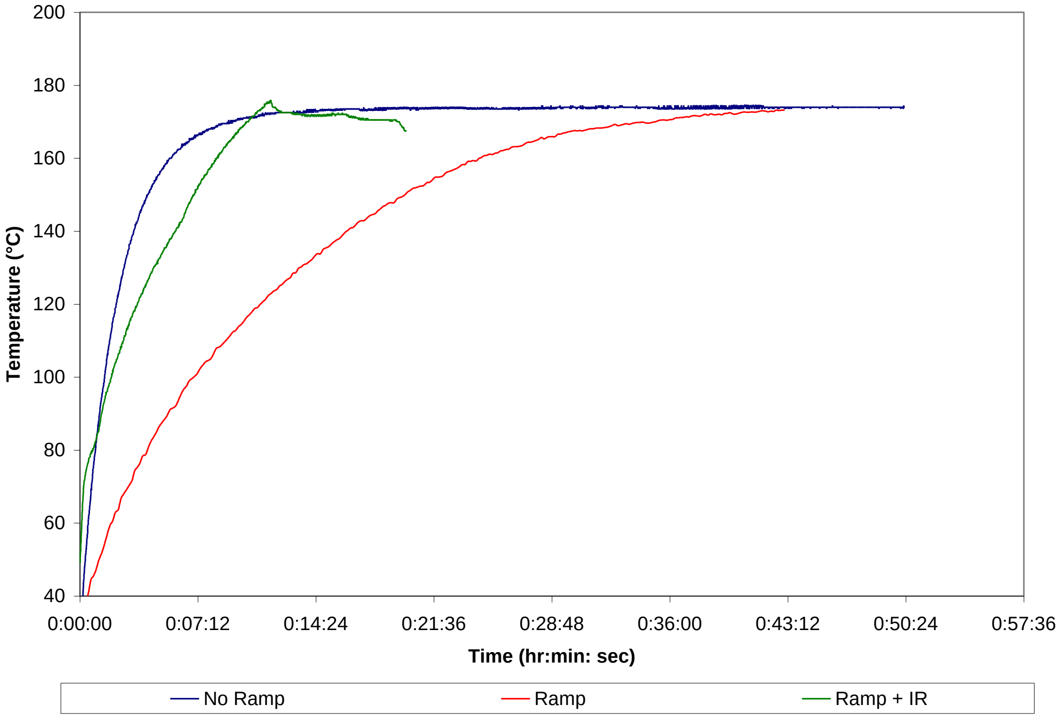


Figure 1: *Powder bake temperature profiles used in the study.*

Results and Discussion

Six different SMC/primer combinations, as shown in Table 1, were evaluated in this study. They were comprised of two commercial and one experimental low moisture SMC's coated with either a commercially available conductive coating, CC-1, or with an experimental conductive coating, 493S. Of the six systems tested, the experimental low moisture SMC coated with the experimental conductive coating, SMC-3/493S, was studied in a separate experiment with a faster powder bake temperature profile as it does not show popping when baked under the slower heating rate used in this study. Two different heating methods were tested to heat the SMC panel prior to the powder application. First, the minimum temperature and the exposure time to yield a pop free surface were determined. Then, after heat treatment at these conditions, it was determined whether panels can be stored at ambient conditions for a reasonable amount of time without causing any popping when powder coated. Once the heating conditions were optimized for each SMC, the effects of key variables such as the amount of moisture and the powder bake temperature profile were also studied. The results of these studies are presented in the following paragraphs.

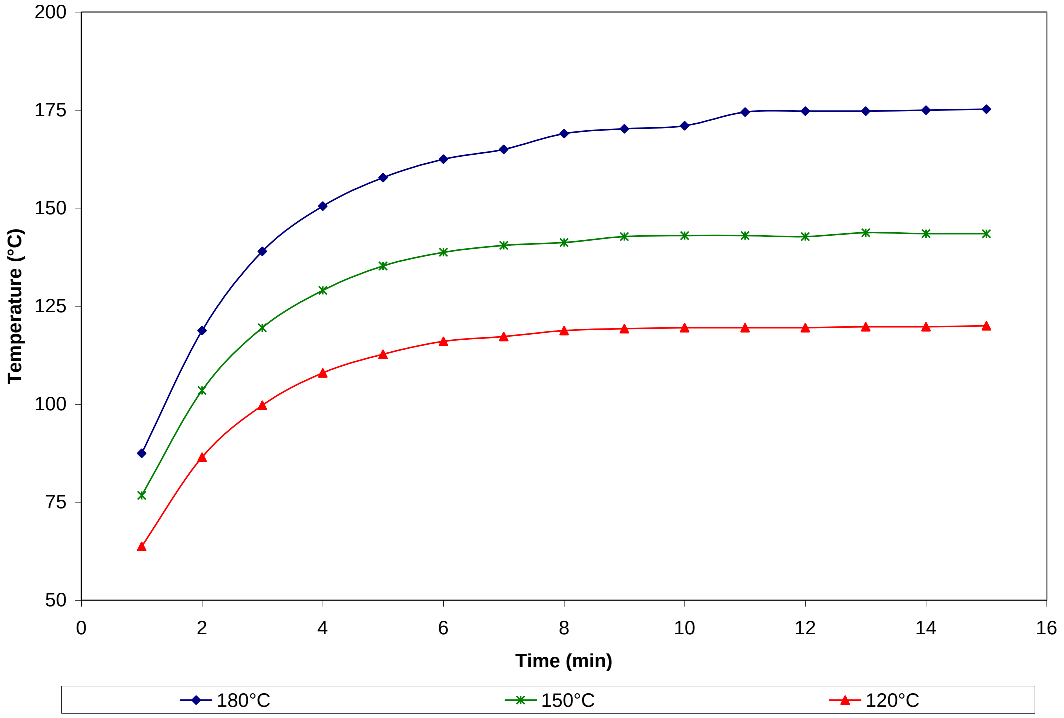
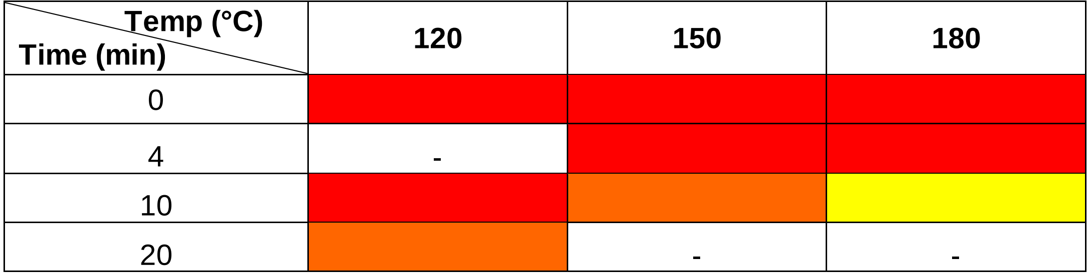


Figure 2: *Temperature profile in the forced air convection batch ovens set at different temperatures.*

Heating Method I: Forced Air Convection Batch Oven

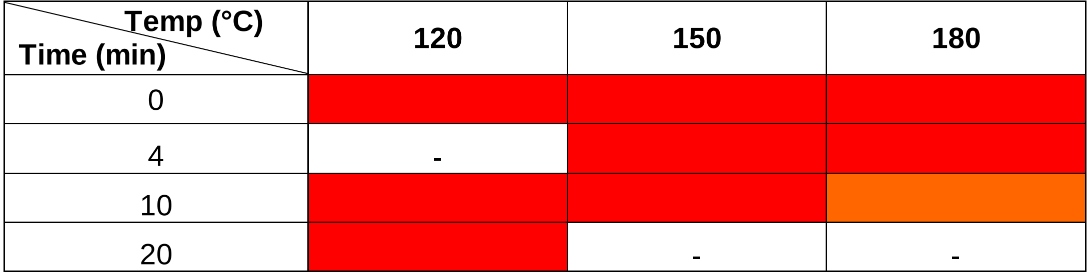
The panels were washed, dried and conditioned per the procedures described in earlier sections. All panels were subjected to a 90%RH/40°C environment for 48 hours. Prior to the powder application, the panels were heated in the batch ovens for a specified time and temperature, ranging from 120°C to 180°C for up to twenty minutes. The temperature profiles in the batch ovens used in this experiment are shown in Figure 2. The panels were then cooled for about ten minutes unless otherwise specified before being powder coated. No powder melt was observed upon the application of the powder indicating that the surface temperature was below the melting point of the powder. Tables 2a-2e show the heating conditions and the powder popping results for each SMC system. All panels showed improved results with a reduced amount of popping after heating prior to the powder application compared to the control panels with no prior heat exposure. The amount of popping decreased with the increase in the heating temperature and the heating time. Commercial SMC's such as SMC-1 and SMC-2 coated with commercial conductive coating, CC-1 showed reduced popping after heating [Table 2a and 2b], however, none were acceptable. All other SMC systems, including the commercial SMC coated with 493S, showed more promising results and were successfully powder primed after heating. The minimum temperature and heating time required to eliminate popping varied among the different SMC systems tested. For instance, only ten minutes of heating at 180°C was sufficient to eliminate the powder popping in SMC-2/493S SMC, while SMC-1/493S needed thirteen minutes to achieve the same quality. SMC-3/CC-1 needed the least heating time, only six minutes at 180°C eliminated the popping. At lower temperatures, SMC-2 and SMC-3 needed longer heating times; twenty minutes at 120°C and ten minutes at 150°C. However, the same heating exposure for SMC-1 was not sufficient to prevent popping.

Table 2a: *Powder popping on SMC-2/CC-1 SMC heated in the convection oven prior to powder application.*



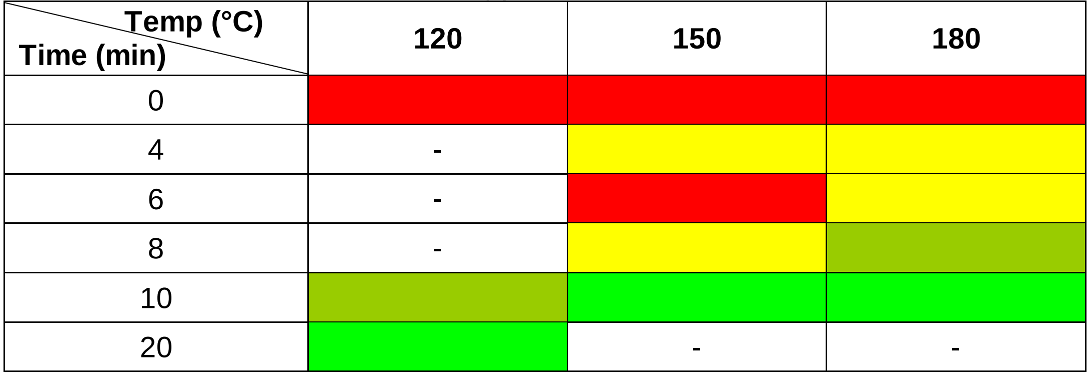
Temp (°C) **Time (min)**	**120**	**150**	**180**
0	🟥	🟥	🟥
4	-	🟥	🟥
10	🟥	🟧	🟨
20	🟧	-	-

Table 2b: *Powder popping on SMC-1/CC-1 SMC heated in the convection oven prior to powder application.*



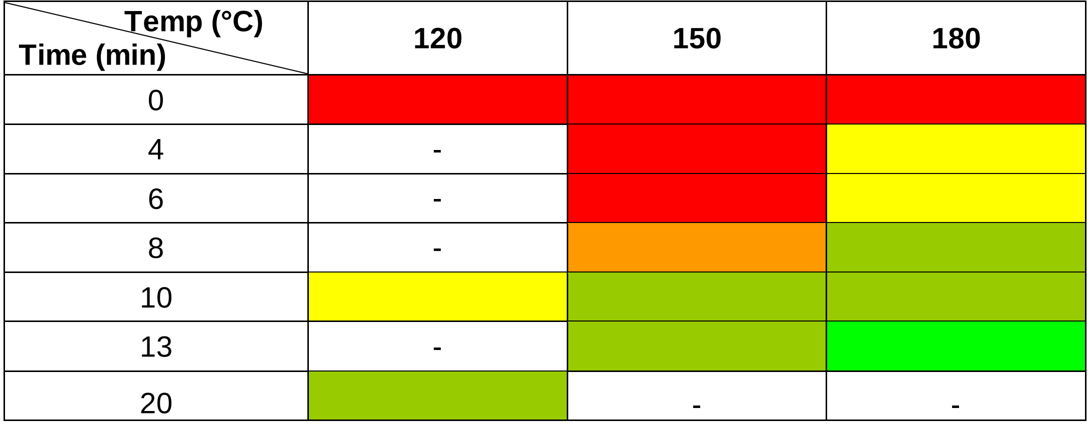
Temp (°C) **Time (min)**	**120**	**150**	**180**
0	🟥	🟥	🟥
4	-	🟥	🟥
10	🟥	🟥	🟧
20	🟥	-	-

Table 2c*: Powder popping on SMC-2/493S SMC heated in the convection oven prior to powder application*.



Temp (°C) **Time (min)**	**120**	**150**	**180**
0	🟥	🟥	🟥
4	-	🟨	🟨
6	-	🟥	🟨
8	-	🟨	🟩
10	🟩	🟩	🟩
20	🟩	-	-

Table 2d: *Powder popping on SMC-1/493S SMC heated in the convection oven prior to powder application.*



Temp (°C) **Time (min)**	**120**	**150**	**180**
0	🟥	🟥	🟥
4	-	🟥	🟨
6	-	🟥	🟨
8	-	🟧	🟩
10	🟨	🟩	🟩
13	-	🟩	🟩
20	🟩	-	-

Table 2e: *Powder popping on SMC-3/CC-1 SMC heated in the convection oven prior to powder application.*

Temp (°C) Time (min)	120	150	180
0	🟥	🟥	🟥
4	-	🟨	🟨
6	-	🟨	🟩
8	-	🟨	🟩
10	🟩	🟩	🟩
20	🟩	-	-

Figure 3 shows the typical moisture desorption profile of experimental low moisture SMC at 180°C. For instance, it can be seen that after 10 minutes of exposure to the 180°C oven, at least 50% of the original moisture is still retained. Thus, it is fair to conclude that the SMC would have a significant amount of moisture left in it at the time of powder application in the above mentioned experiments. It is interesting that this moisture, however, did not cause any popping on the powdered SMC panels. This indicates that the moisture close to the surface is the root cause for popping and not the total moisture content. Moisture from the core of the panel probably takes a long time to travel to the surface and hence does not contribute to the powder popping issue.

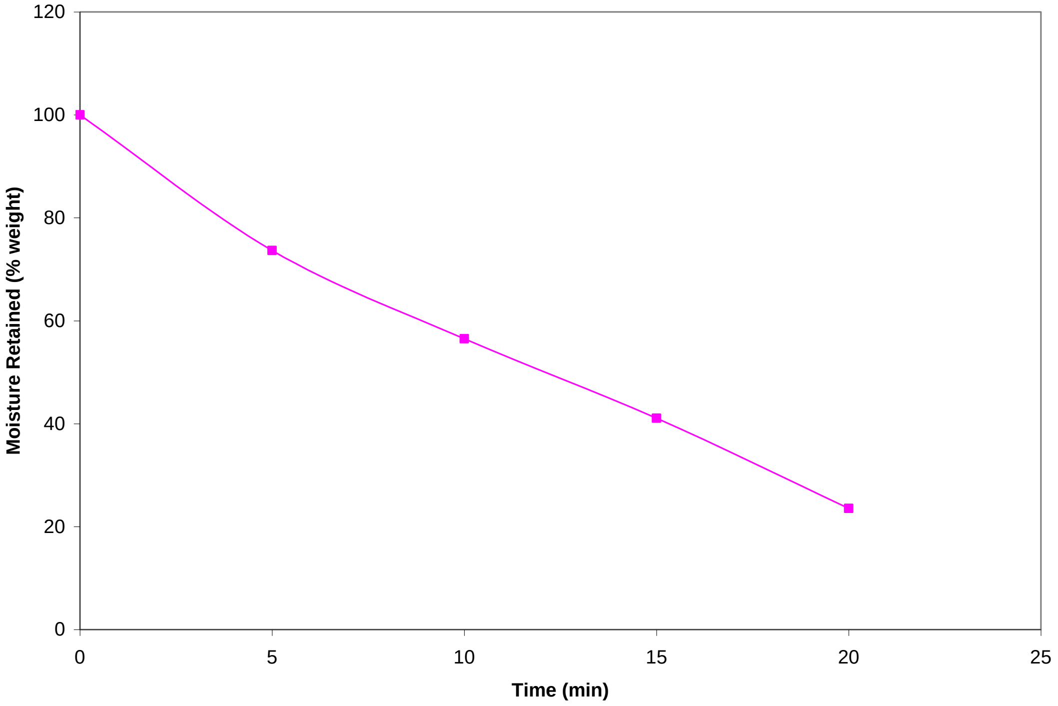


Figure 3: *Moisture desorption chart for typical experimental low moisture SMC in an oven preheated to 180°C.*

Another set of experiments was run in order to investigate if panels can be stored at ambient conditions for reasonable amounts of time after heating and prior to powder application without causing any popping. Based on data collected during the plant trials, three hours was defined as a reasonable time to allow the part to travel from E-coat to the powder booth. Three SMC systems, SMC-2/493S, SMC-1/493S and SMC-3/CC-1, that showed promising results earlier were selected for this study. All panels were first heated at 180°C for variable amounts of time. SMC-3 panels were heated for six to eight minutes while SMC-1 and SMC-2 panels were heated for thirteen minutes and ten minutes respectively. The panels were then allowed to cool for up to three hours prior to the powder application. The results are shown in Tables 3a-3c. It can be seen that both commercial SMC's, SMC-1 and SMC-2, coated with 493S can be stored for up to three hours after the specified heating method and still be powder primed without any popping defects. Also, the experimental low moisture SMC, SMC-3 with commercial conductive coating CC-1, heated for just eight minutes at 180°C, can be successfully powder primed even after three hours of cooling at ambient. However, if the heating time was reduced to six minutes at 180°C, the maximum allowed cooling time was less than two hours, i.e., if the panels are exposed to the plant environment for two hours or longer after the heating, it would show popping. The results emphasize the need to optimize the process for heating and cooling times specific to the materials and heating methods to make it robust and production friendly.

Table 3a: *Powder popping on SMC-2/493S SMC preheated in the oven and cooled at ambient prior to powder application.*

Heating **Cooling (min)**	**10 min @180°C**
10	🟩
20	🟩
30	🟩
45	🟩
60	🟩
90	🟩
120	🟩

Table 3b: *Powder popping on SMC-1/493S SMC preheated in the oven and cooled at ambient prior to powder application.*

Heating **Cooling (min)**	**13 min @180°C**
10	🟩
20	🟩
30	🟩
45	🟩
60	🟩
90	🟩
120	🟩
180	🟩

Table 3c: *Powder popping on SMC-3/CC-1 SMC preheated in the oven and cooled at ambient prior to powder application.*

Heating **Cooling (min)**	**6 min @180°C**	**8 min @180°C**
10	-	🟩
20	-	🟩
30	-	🟩
45	-	🟩
60	🟩	🟩
90	-	🟩
120	🟨	🟩
180	-	🟩

Heating Method II: Infrared Lamps

The procedure to prepare and condition the panels in this experiment was similar to the one discussed earlier. The only difference was the type of heating method employed. In this case, a bank of infrared lamps was used to heat the panels for a specified amount of time. The detailed specifications for the lamps are described earlier in the procedure section. It should be noted that three different locations under the IR lamps were used to heat the panels due to the large number of test panels. The temperature profiles at each location are shown in Figure 4, and it can be seen that the temperature profiles are significantly different at each location. Therefore, it would not be reasonable to compare the results at one location to another as the IR exposure in a given time period would be different at each location. To that end, it was ensured that the same location was used for each type of SMC in all experiments to avoid any variation in the heat exposure due to its location.

The results as shown in Table 4 were similar to the ones observed with convection heating (method I). All panels showed improved results with a reduced amount of popping after heating prior to the powder application compared to the control panels, which had no prior heat exposure. As expected the amount of popping decreased with the increase in the IR exposure time. After five minutes of exposure to IR, the commercial SMC SMC-2 and SMC-1 coated with CC-1 showed significant improvement, but the pops were not completely eliminated. In fact, SMC-1, even with experimental conductive coating 493S, showed some popping. Extending the exposure by an additional two minutes did not improve the results. SMC-2/493S and SMC-3/CC-1, on the other hand, showed dramatic improvement with no popping after five minutes of IR exposure. Table 5 shows the effect of cooling time after six minutes of IR exposure prior to the powder application. Based on the results discussed earlier, only two systems, SMC-2/493S and SMC-3/CC-1, were selected for this experiment. As seen, SMC-3 can be cooled for at least three hours after six minutes of IR exposure and still be successfully powder primed without any issues. SMC-2, on the other hand, started showing popping after two hours of cooling time. Thus, the maximum cooling time allowed after the IR exposure for this SMC system is less than two hours.

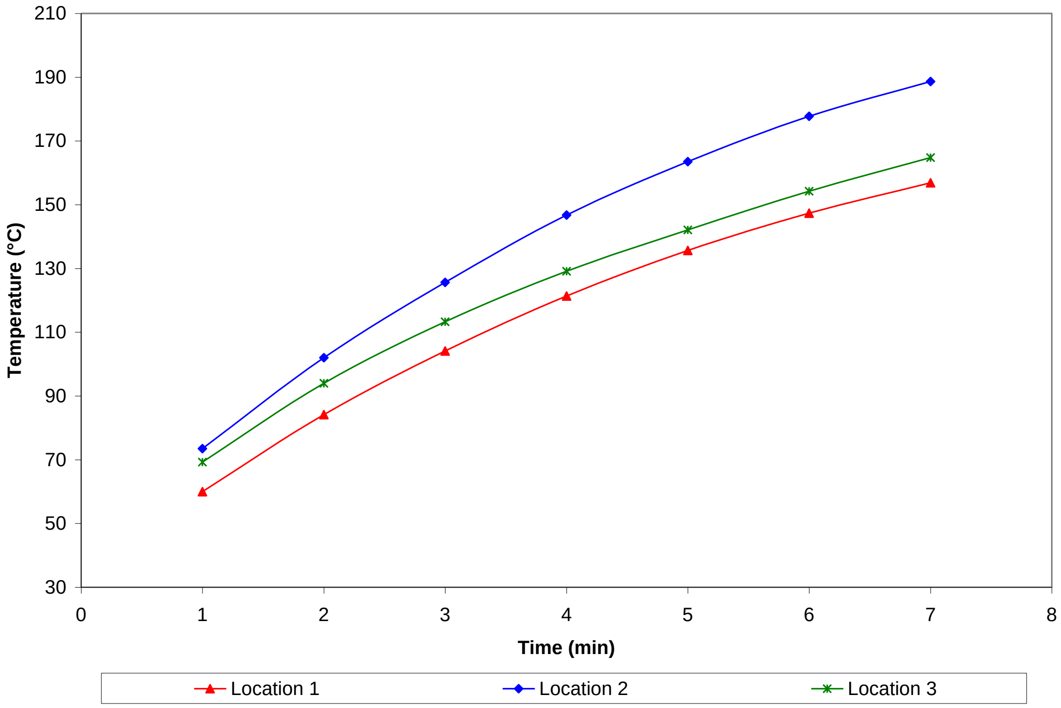


Figure 4: *Temperature profile of SMC under infrared lamps set at 460V and 15 inches away at different locations.*

Table 4: *Powder popping on various SMC formulations heated under infrared lamps prior to powder application.*

SMC Time (min)	SMC-2/ 493S	SMC-2/ CC-1	SMC-1/ 493S	SMC-1/ CC-1	SMC-3/ CC-1
0	🟥	🟥	🟥	🟥	🟥
3	🟨	-	🟥	-	🟧
4	🟩	-	🟧	-	🟩
5	🟩	🟧	🟧	🟥	🟩
6	🟩	-	🟨	-	🟩
7	-	-	🟨	-	-

Table 5: *Powder popping on various SMC formulations preheated under infrared lamps for six minutes and then cooled at ambient prior to powder application.*

SMC **Time (min)**	**SMC-2/493S**	**SMC-3/ CC-1**
10	🟩	🟩
20	-	🟩
30	🟩	🟩
45	-	🟩
60	🟩	🟩
90	-	🟩
120	🟨	🟩
180	-	🟩

In summary, it was concluded that the new proposed process showed dramatic improvement in reducing the powder pops. The required treatment, however, is material specific and varies for the different SMC systems tested. In general, the commercial SMCs coated with the commercial conductive coatings, which are currently being used in GM plants still show popping with the new process. However, one can use a commercial SMC in combination with the experimental conductive coating or a commercial conductive coating in combination with the low moisture SMC and get no popping when powder coated using this new process. For instance, both SMC-2/493S and SMC-3/CC-1 systems showed that they can be powder primed successfully after less than ten minutes of heating at 180°C or five minutes of IR exposure. To further substantiate this approach, the SMC-3/493S system was further studied for the robustness of the process.

Robustness of SMC-3/493S:

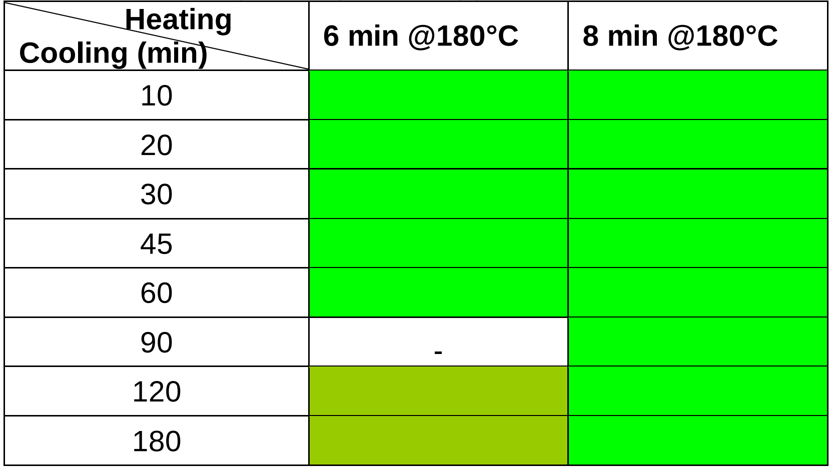
In this study, the new method of heating SMC prior to the powder application was implemented under various conditions to better understand its robustness. The panels were first prepared and conditioned per the procedure described earlier. They were then subjected to 90%RH/40°C environment for 48 hours. Prior to the powder application these panels were heated for specified duration using one of the two heating methods, convection batch oven or infrared lamps. The temperature range studied was 120°C to 180°C and the heating duration was varied from four to ten minutes. The IR exposure varied from three to six minutes. The temperature profiles of the batch ovens set at these temperatures are shown in Figure 1. After the powder application, panels were baked in the batch oven preset at 180°C instead of using the slow heat ramp as in all other experiments, because this particular SMC system did not show popping when baked with a gradual temperature ramp. Table 6 shows the results of panels heated in the batch ovens. It can be seen that the amount of popping was minor compared to the other SMC systems discussed earlier and it decreased with increase in the heating temperature and time. Just six minutes of heating at 180°C was sufficient to eliminate the powder popping under the most severe possible powder bake temperature ramp. Even at 120°C, only ten minutes of heating was needed. Thus, heating the experimental low moisture SMC as low as six minutes at 180°C seems to ensure that it would withstand the faster powder bake with no heating ramp, making the product very robust.

Table 6: *Powder popping on SMC-3/493S SMC heated in the convection oven prior to powder application.*

Temp (°C) / Time (min)	120	150	180
4	🟨	▨	▨
6	▨	▨	🟩
8	▨	🟩	🟩
10	🟩	🟩	🟩

Further experiments showed that the panels that were heated for six minutes at 180°C can be stored for at least an hour prior to the powder application without causing any popping [see Table 7]. By heating the panels for additional two minutes at 180°C, eight minutes total, the storage time can be extended to at least three hours. Similar results were observed when infrared lamps were used to heat the panels instead of convection ovens. Table 8 shows the results of these experiments. It was observed that at least five minutes of IR exposure was needed to eliminate the popping. The panels that had five minutes of IR heating did not show popping even after three hours of cooling, as shown in Table 9. Thus, it is possible with this new process, to powder prime the experimental low moisture SMC in combination with the experimental conductive coating with no popping even when the powder bake profile is very severe. In effect, the powder capability of this SMC system will practically be independent of the powder bake profile.

Table 7: *Powder popping on SMC-3/493S SMC preheated in the oven and cooled at ambient prior to powder application.*



Heating / Cooling (min)	6 min @180°C	8 min @180°C
10	🟩	🟩
20	🟩	🟩
30	🟩	🟩
45	🟩	🟩
60	🟩	🟩
90	-	🟩
120	▨	🟩
180	▨	🟩

Table 8: *Powder popping on SMC-3/493S SMC heated under infrared lamps prior to powder application.*

SMC/Coating Time (min)	SMC-3/493S
0	🟧
3	🟨
4	🟨
5	🟩
6	🟩

Table 9: *Powder popping on SMC-3/493S SMC preheated under infrared lamps for five minutes and then cooled at ambient prior to powder application.*

SMC/Coating Time (min)	SMC-3/493S
10	🟩
45	🟩
60	🟩
90	🟩
120	🟩
180	🟩

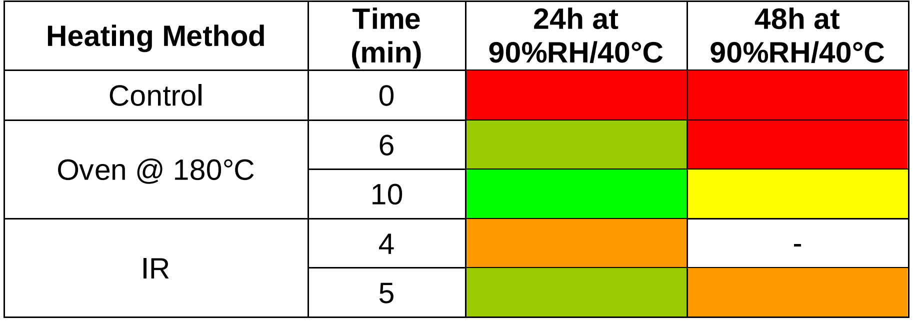
Effects of Moisture

Another key variable that could increase or decrease the heating and cooling time prior to the powder application is the amount of moisture in the SMC. To that end the effect of moisture content was also studied. All SMC systems were tested at two different levels of moisture exposure in this study, i.e., 24 hours and 48 hours at 90%RH at 40°C. Note that the faster heating profile with no ramp was used to bake powder on SMC-3/493S panels as the slower bake did not cause popping in these panels. The results are shown in Tables 10a-f. As seen in Table 10a, SMC-2/493S SMC panels conditioned for 24 hours at 90%RH did not show any popping after heating for as little as three minutes under infrared or six minutes at 180°C in the batch oven. The same SMC, however, when containing a higher amount of moisture, showed popping under similar heating conditions. In fact, as seen in Table 3a and Table 4, at this moisture level, the SMC panels only needed ten minutes at 180°C oven or five minutes of IR heating in order to eliminate the popping. Similar results were observed for all other SMC systems. In all cases much shorter heating times were needed for panels with the lower amount of moisture. Despite the low amount of moisture, it should be noted that the commercial SMC coated with commercial conductive coating could not be powder primed without popping under the heating conditions tested. The experimental low moisture SMC, SMC-3, on the other hand, was powder primed successfully irrespective of the conductive coating used after heating for only three minutes under the infrared or four minutes at 180°C oven. This is very encouraging considering that the typical amount of moisture absorbed by SMC in the assembly plants over two weeks is closer to the 24 hours of exposure at 90%RH/40°C in the lab.

Table 10a: *Effect of moisture on powder popping on SMC-2/493S SMC heated prior to powder application.*

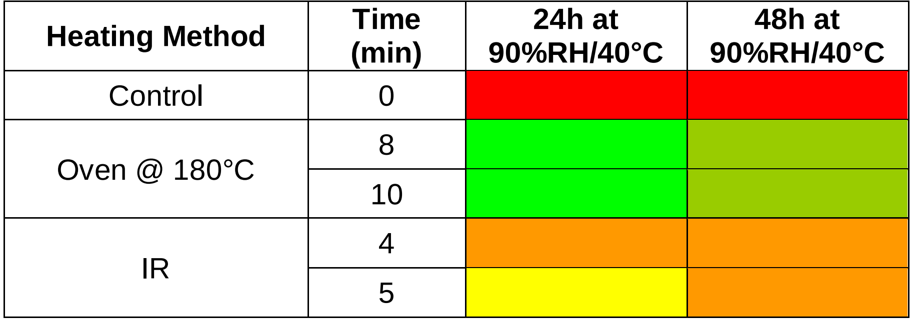
Heating Method	**Time (min)**	**24h at 90%RH/40°C**	**48h at 90%RH/40°C**
Control	0	🟥	🟥
Oven @ 180°C	6	🟩	🟨
	8	🟩	🟢
IR	3	🟩	🟨
	4	🟩	🟢

Table 10b: *Effect of moisture on powder popping on SMC-2/CC-1 SMC heated prior to powder application.*



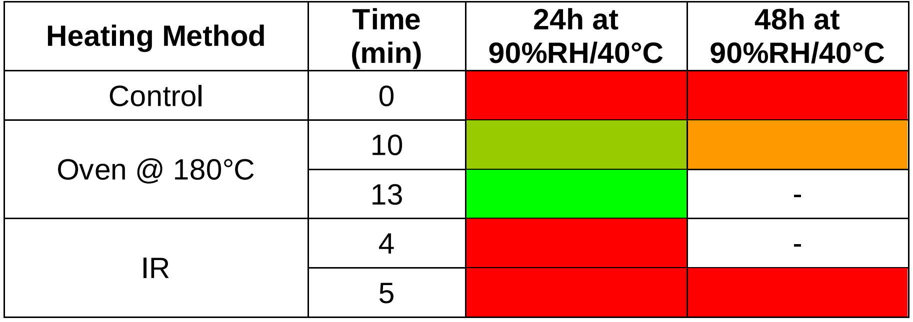
Heating Method	**Time (min)**	**24h at 90%RH/40°C**	**48h at 90%RH/40°C**
Control	0	🟥	🟥
Oven @ 180°C	6	🟢	🟥
	10	🟩	🟨
IR	4	🟧	-
	5	🟢	🟧

Table 10c: *Effect of moisture on powder popping on SMC-1/493S SMC heated prior to powder application.*



Heating Method	**Time (min)**	**24h at 90%RH/40°C**	**48h at 90%RH/40°C**
Control	0	🟥	🟥
Oven @ 180°C	8	🟩	🟢
	10	🟩	🟢
IR	4	🟧	🟧
	5	🟨	🟧

Table 10d: *Effect of moisture on powder popping on SMC-1/CC-1 SMC heated prior to powder application.*



Heating Method	**Time (min)**	**24h at 90%RH/40°C**	**48h at 90%RH/40°C**
Control	0	🟥	🟥
Oven @ 180°C	10	🟢	🟧
	13	🟩	-
IR	4	🟥	-
	5	🟥	🟥

Table 10e: *Effect of moisture on powder popping on SMC-3/CC-1 SMC heated prior to powder application.*

Heating Method	**Time (min)**	**24h at 90%RH/40°C**	**48h at 90%RH/40°C**
Control	0	🟧	🟥
Oven @ 180°C	4	🟩	🟨
	6	🟩	🟩
IR	3	🟩	🟧
	4	🟩	🟩

Table 10f: *Effect of moisture on powder popping on SMC-3/493S SMC heated prior to powder application.*

Heating Method	**Time (min)**	**24h at 90%RH/40°C**	**48h at 90%RH/40°C**
Control	0	🟧	🟥
Oven @ 180°C	4	🟩	🟩
	6	🟩	🟩
IR	3	🟩	🟨
	4	🟩	🟨

Effects of Powder Bake Temperature Profile:

In the previous studies at the Shreveport assembly plant, IR heating in the initial stages of powder bake was found to be detrimental to SMC and caused popping. Therefore, these alternative methods were further examined to find out if they can withstand the IR heating during powder bake to produce a pop free surface. Four systems, as shown in Table 11, were tested. Both preheating methods, infrared and oven heating were evaluated. Optimum heating conditions were chosen based on the results of the experiments discussed earlier. Under the infrared heating method, all panels were heated for six minutes and allowed to cool for ten minutes prior to the powder application. Where the convection oven was used, panels were heated at 180°C from eight to thirteen minutes, as shown in Table 11. All control panels showed severe popping, including the experimental low moisture SMC coated with 493S, confirming the observations in the plant. However, after the heat treatment prior to the powder application all panels showed dramatic improvement, and only SMC-1 showed popping. Thus, the new process seems to be very robust and able to handle any variations in the powder temperature profile.

Table 11: *Powder popping on various SMC baked using infrared lamps.*

Heating / **SMC/Coating**	**Control [No heat exposure]**	**Oven @ 180°C**	**IR**
SMC-1/493S	🟥	🟩 13 min	🟧 6 min
SMC-2/493S	🟥	🟩 10 min	🟩 6 min
SMC-3/CC-1	🟥	🟩 8 min	🟩 6 min
SMC-3/493S	🟥	🟩 8 min	🟩 6 min

To further study the effect of faster bake profiles, SMC-3 with the commercial conductive coating was evaluated under the worst case scenario, i.e., no heating ramp during the powder bake. Based on the results of the experiments discussed above, only SMC-3 was selected for this study. The results for SMC-3/493S system baked under these conditions were discussed in earlier sections. Therefore, here the discussion will be limited to SMC-3 coated with the commercial conductive coating, CC-1. All panels were heated for six minutes under IR lamps followed by ten minutes of cooling prior to the powder application. They were then baked in a batch oven preset at 180°C with no heating ramp after the powder application. Table 12 shows the results. As seen, after five minutes of IR exposure, the panels baked under the slow heating rate did not show popping while the panels baked under the fast heating rate showed popping. However, after seven minutes of IR exposure, the SMC panels did not show any popping. Thus, although a faster heating rate in the bake oven has a negative impact on the SMC powder capability, it is possible to get a pop free surface by extending the IR preheating exposure by just a couple of minutes. Further experiments were run to determine the maximum allowed cooling time prior to the powder application without causing any popping. The results are shown in Table 13. It can be seen that after seven minutes of IR exposure, the maximum allowed cooling time prior to the powder application was less than an hour. This observation indicates that the panels probably need even longer preheating to make it more production friendly.

Table 12: *Powder popping on SMC-3/CC-1 preheated under infrared lamps and baked in a batch oven set at 180°C with no ramp.*

Powder Bake **Time (min)**	**Ramp**	**No Ramp**
0	🟥	🟥
3	🟧	🟥
5	🟩	🟨
7	🟩	🟩

Table 13: *Powder popping on SMC-3/CC-1 preheated under infrared lamps, then cooled and baked in a batch oven set at 180°C with no ramp.*

Heating **Cooling (min)**	**7 min**
10	🟩
20	🟩
30	🟩
45	🟩
60	🟩

Conclusions

1. Heating SMC prior to the powder application eliminated powder popping caused by excessive exposure to humidity. The extent of heating depended on the type of SMC and conductive coating, the amount of moisture in SMC and the powder bake profile.

2. Using the experimental low moisture SMC coated with 493S experimental conductive coating, only four minutes of heating in the oven at 180°C or three minutes of IR exposure was sufficient to enable powder priming in a plant simulation without popping. If implemented, this approach requires slight changes in the bill of process for panels stored in the strip area for an extended shutdown period.

3. The new method also allowed the use of commercial conductive coating on experimental low moisture SMC without compromising its powder capability. An experimental low moisture SMC coated with CC-1 was powder primed successfully after less than ten minutes of heating at 180°C or five minutes of IR exposure prior to the powder application.

4. Similarly, using this method, it was possible to powder prime commercial SMC, such as SMC-2, in combination with the experimental conductive coating with no popping. Less than ten minutes of heating at 180°C or five minutes of IR exposure prior to the powder application produced pop free panels.

5. After heating for a minimum duration specific to each type of SMC, the panels could be stored for at least three hours prior to the powder application without causing any popping when powder coated.

6. A lower amount of heat was required for panels with low moisture content. As low as three minutes of IR exposure eliminated the powder pops in SMC-2 and SMC-3 panels when conditioned for 24 hours at 90%RH.

7. This short time heat exposure could not be used for conventional SMC/conductive –coating systems due to high moisture content and ease of permeation.

Current Status

The plant trials and lab experiments have shown that the new low moisture SMC systems are powder prime ready in normal plant operations. However, after a long line stoppage, such as the July shutdown, there is a chance for moisture absorption and subsequent powder primer popping in the oven. The idea of removing the surface moisture of the panels by IR preheating needs to be tested in a production plant using production parts with an extensive design of experiments to validate robustness.

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