

IN MOLD DECORATION FOR STRUCTURAL, WEATHERABLE APPLICATIONS

Randall T. Myers

GE Plastics

Abstract

A method has been developed to produce unpainted, high surface quality, weatherable thermoplastic composite parts. This process utilizes aspects of both traditional compression molding and large part in mold decoration (IMD) and requires minimal secondary operations. The multi-layer system consists of a LEXAN[®] SLX film reinforced by AZLOY[®] laminate, a polycarbonate based glass mat thermoplastic (GMT) produced by Azdel, Inc. The process consists of first thermoforming the weatherable film, trimming and compression molding the composite to for the final part.

Applications which may be a fit for this technology include those which require a higher modulus and which have aesthetic and/or weatherable requirements, such as automotive exterior panels, hoods, trunk lids, fenders, boats and personal watercrafts, outdoor vehicles, snowmobiles and tractors.

Introduction

Exterior body panels can be made from a number of materials and conversion processes. Stamped metal, injection molded engineering thermoplastics and thermoset polyurethane made from reaction injection molding (RIM) are all suitable process and material combinations to make vertical body panels.

Horizontal body panels tend to have more structural requirements. Increased stiffness and low coefficient of thermal expansion (CTE) are typical requirements for horizontal panels. For horizontal body applications, stamped metal and compression molded sheet molding compound (SMC) are typical materials suitable for these applications.

Typically body panels made from any of these materials and conversion technologies are painted to achieve the glossy, high aesthetic, and weatherable requirements associated with automotive "Class-A." Several disadvantages exist to painting parts to Class A. Paint lines tend to take up significant space in a plant; upwards of 50% of a plant's floor space may be dominated by a paint line. Subsequently, paint lines are expensive to purchase and install. Additionally, yield issues from color changes and volatile organic compound (VOC) emissions are also concerns when painting body panels.

GE Plastics, headquartered in Pittsfield, MA, has developed a weatherable, aesthetic multilayer film suitable for automotive Class-A applications¹, eliminating the need for paint. In addition, a process has been defined to in-mold decorate engineering thermoplastics with this film for vertical body panel applications.² This paper details the compression molding of a non-woven, chopped glass fiber, engineering thermoplastic composite, behind an appliqué made

* LEXAN and LEXAN SLX are registered trademarks of the General Electric Company.

* AZLOY is a registered trademark of AZDEL, Inc., a 50/50 joint venture of the General Electric Company and PPG Industries.

¹ *Multilayer Plastic Articles*. US Patent 6,136,441.

² Saggese, L. *Paintless Parts*. **Machine Design** February 19, 2004. 94.

from a resorcinol based film to form a structural, weatherable, paint-free body panel.

Aesthetic/Weatherable Film

The formed skin material used in this process will be the portion of the part that is visible and exposed to the weather. The weather has a degrading effect on all thermoplastic materials. Exposure to ultraviolet rays, oxygen and water may cause hydrolysis, colorant degradation and polymer oxidation. This is perceived as embrittlement, erosion, yellowing or color fading in the plastic part. Ultimately this may result in an aesthetically unappealing part, or worse, a part that can no longer perform the task for which it was designed.

One solution to counteract the effects of weathering is to paint the thermoplastic part. This, however, causes additional cost, weight and labor. In addition, significant volatile organic compound (VOC) emissions may arise from the painting process, which is also undesirable. It is therefore desirable to have a thermoplastic material that is not susceptible to ultraviolet rays. Ultraviolet rays typically attack thermoplastics the fastest and harshest of all components of the weather; therefore for the purposes of this article, weatherable will be used synonymously with resistance to ultraviolet rays. The weatherability of a thermoplastic material is measured in years and is defined as the amount of time that the plastic can be subjected to harsh UV exposure (standards are Florida and Arizona) without appreciable loss of material properties, yellowing or fading.

Two categories of weatherable materials exist. The first one is a material that is not susceptible to UV rays, but allows those rays to pass through. The UV rays can then weather any subsequent layers of material. This material is called a UV transmitter or UV resistant, because it does not yellow or lose properties with UV exposure and does not protect other materials from exposure to the sun. In addition to not yellowing, fading or losing properties with UV exposure, the second category of weatherable material, prevents the passage of UV rays. Hence, any subsequent layer of material would not be exposed to UV radiation. These types or materials are called UV absorbers or UV blockers. Typically, UV transmitting plastics are transparent, while UV absorbers can be either transparent or opaque.

An example of a UV absorbing plastic is LEXAN SLX* film. The top layer of this film is a clear, UV blocking material, based on resorcinol chemistry. Because of this, all subsequent layers do not need to be weatherable. This material typically has one or two layers co-extruded with the clear, UV absorbing top layer. The second layer is opaque and possesses the color. This layer may be polycarbonate based. A third layer may be also be co-extruded to improve properties or serve as a "tie-layer:" improving the adhesion to any other materials which may be added during a secondary manufacturing operation. The multi-layer film has greater than 10 years of UV resistance in the harshest environments without loss of gloss, fading, yellowing or material embrittlement. Because of the clear top layer and the high gloss in both layers, this material is suitable for highly aesthetic applications. Coupled with the excellent weatherability of this system, it is suitable for automotive "class-A" exterior applications.

Structural Substrate

An un-reinforced thermoplastic film or sheet alone cannot meet the coefficient of thermal expansion (CTE) and stiffness requirements for applications such as automotive horizontal body panels. Even large part in mold decoration with a neat engineering thermoplastic, while suitable for less structural applications such as automotive vertical body panels is not suitable from a CTE and stiffness perspective.

Stamped metal and thermoset polyesters such as sheet molding compound (SMC) are

suitable substrates for structural applications. Both materials are currently painted to a class-A appearance today. However, neither material is a suitable substrate for this process. A film appliqué would have to be adhered to a stamped metal part, as there is no alternative mechanism for adhesion. A process to do this while still maintaining a class-A part to date has not been identified. Thermoset polyesters such as SMC pose an entirely different issue. These materials contain styrene monomer, a critical ingredient to the cross linking reaction. Any attempt to in mold cure SMC behind an appliqué would allow intimate contact between styrene monomer and the polycarbonate in the film. Styrene monomer would diffuse into the polycarbonate layer causing two undesired effects. Firstly, the presence of styrene monomer would embrittle the film layer containing polycarbonate. Secondly, the lack of styrene monomer in the substrate both slows the thermosetting reaction and reduces the overall crosslink density. These phenomena would likely happen with all thermosetting polyesters containing styrene monomer such as resin transfer molding, chopper gun FRP, and hand lay-up FRP.

These reasons necessitate a substrate which does not embrittle the film layer and also contains a mechanism for adhesion to the film. A polycarbonate based Glass Mat Thermoplastic (GMT) containing randomly oriented glass fibers provides both the mechanism for adhesion as well as suitable flow characteristics. Depending on the stiffness and CTE requirements, the material may contain between 15 and 60% fibers, with the balance made up of resin, compatibilizers and other additives.

A method for making a Glass Mat thermoplastic is the Wiggins Teape process.³ Fibers, thermoplastic materials and any additives are added to a mixing tank fitted with an impeller for dispersion. The mixture is pumped to a head-box via a distribution manifold. The head box is located above a wire section of a machine similar to what is used for papermaking. The dispersed mixture passes through a moving wire screen using a vacuum, producing a uniform, fibrous wet web. The wet web is passed through a dryer to reduce moisture content melt the thermoplastic material. This fiber and resin matrix is then co-layered with extruded, compatible resin or a previously extruded film in a lamination process to form the laminate of desired thickness and fiber content. This final laminate is then cut to the desired size.

Conversion Process Description

In general, the process for making a part requires three steps: thermoforming the film, trimming the film to form an appliqué and compression molding the composite behind the appliqué.

Thermoforming Aesthetic, Weatherable film

The first step in creating an aesthetic, composite part is to thermoform the film into a skin the shape of the final part. This skin is called an appliqué. The film thermoforming process is described as follows.

1. The film needs to be dried. Lack of drying causes an aesthetically unacceptable part. Drying time is a function of the film thickness, but typical drying conditions are 250°F for between 30 and 90 minutes.
2. The film is loaded into the thermoforming machine. Best results are found when utilizing a machine designed for films and not sheet.
3. The film is heated above its heat deflection temperature (HDT). The absolute temperature is dependent on the shuttling speed of the thermoforming equipment; a slower machine may require the

³ US Patents 3,938,782; 3,947,315; 4,166,090; 4,257,754 and 5,215,627.

film heated to a higher temperature.

4. The film is brought into contact with the thermoforming tool. Either the film is shuttled to a forming station or the tool is brought to the film. In order to minimize "chill marks," the tool temperature is kept hot but below the HDT of the film, typically around 120°C.
5. Vacuum is pulled through the tool to form the film. The part is allowed to cool and then demolded.

Trimming

After the thermoforming, the resulting skin must be trimmed. It is important to trim the skin such that the film is long enough to cover all the exposed structural material, as the composite might not be aesthetic or weatherable. In addition, it is desirable to trim the film such that it is not too long and will catch in the shear edge of the compression tool during the compression molding as this may cause a wrinkle or other defect on the aesthetic surface.

Many methods exist for trimming plastic films, including laser trimming, CNC routing, matched dies and ultrasonic knife. Unit build and part tolerances should dictate which trimming method is optimal for each part design.

Compression Molding

The final step of the structural in mold decoration process is to compression mold the thermoplastic composite behind the formed and trimmed appliqué. The compression molding process is detailed below.

1. The appliqué is placed into the cavity of a compression mold such that the show surface is against the tool steel. If necessary, the appliqué may be held in place using an external means such as vacuum or tabs. The molding tool is similar to those used for compression molding either Sheet Molding Compound (SMC) or Glass Mat Thermoplastics (GMT). The tool is typically made from steel with hardened shear edges. The compression tool is installed in a compression press with high pressure (tonnage) capability.
2. The composite sheet is heated using an external oven to a temperature hot enough to flow the glass filled material. Absolute heating temperature is dependant on the transfer time and speed of the compression press, but is typically between 285 and 345°C.
3. The heated composite sheet is transferred to the compression tool. The laminate may be rolled or folded such that it has a smaller footprint than the actual part.
4. The tool halves come together and tonnage is applied to flow the composite to fill the cavity of the tool. Pressures for compression molding this composite are comparable to SMC or GMT, typically between 140 and 275 Bars. For best surface, it is important to keep the appliqué away from the heated composite until tonnage is applied. A way to keep the two materials separate is to suspend the appliqué in the cavity of the tool on the top platen of the compression press.
5. The part is allowed to cool. The final, structural, weatherable part is then removed from the tool.

Experimental Description

All forming and molding of parts was done at GE Advanced Materials' Polymer Processing Development Center, Pittsfield, MA. All testing and measurements was performed at the headquarters of GE Advanced Materials in Pittsfield, MA.

Requirements deemed important for structural, weatherable applications include surface quality, adhesion and thermal cycling.

Surface Appearance

All surface characterizations were performed using a WaveScan machine from BYK Gardiner.⁴ The Wavescan machine measures the inherent surface quality over a length scale from <1 mm to 30 mm. Typically length scales <1 mm correspond to the part's gloss, 3-10 mm correspond to "orange peel" and longer term waviness at length scales approaching 30 mm. Figure 1 shows Wavescan benchmarks of actual automotive horizontal body panels. In the figure, "UPR SMC" refers to a sample of sheet molding compound molded and painted by the GE Global Research Center, Niskayuna, NY.

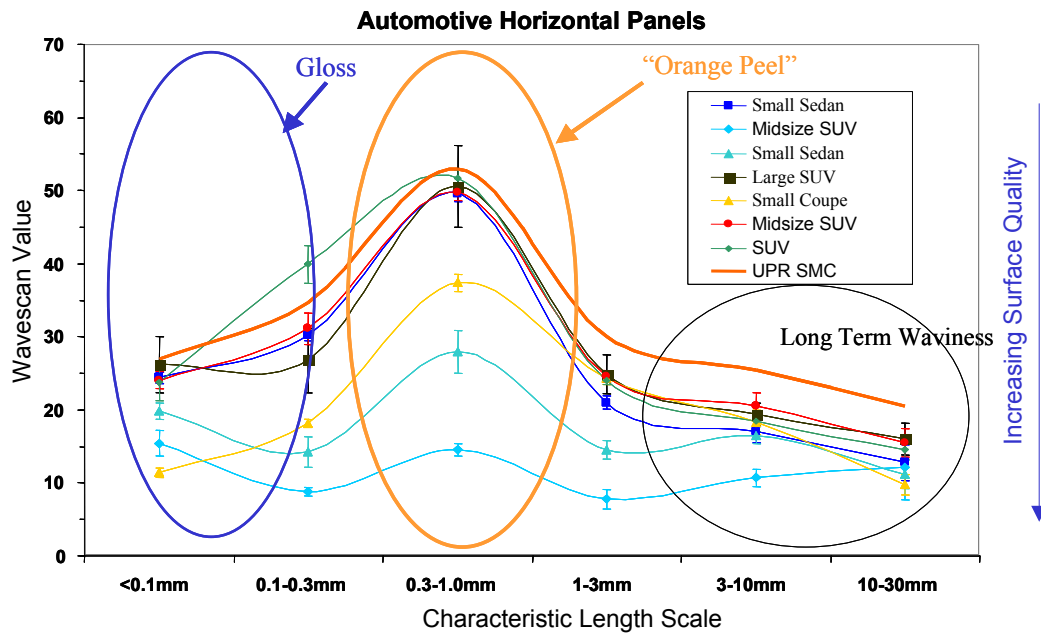


Figure 1: Wavescan Horizontal Panel Benchmarks

Adhesion Testing

Adhesion between film and various substrates was tested using a 90 degree peel test. Samples were prepared at 25 mm widths with the peel initiated manually. A 200 lb load cell was installed on an Instron machine and the crosshead speed was set to 25 mm/min. Average peel strength is reported in units of N/25mm. In each instance, it was noted whether the failure mechanism was cohesive or adhesive. Figure 2 shows a schematic of the 90 degree peel test.

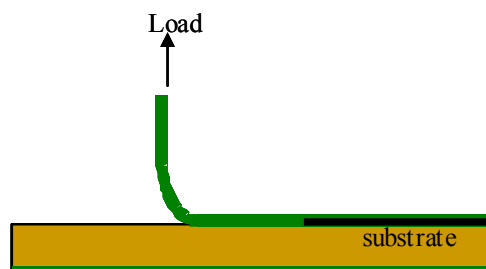


Figure 2: 90 Degree Peel Test

⁴ Brister, E. et al. "Zero VOC SOLLX Film for Weatherable, High-gloss, Chemical and Scratch Resistant Performance." *Proceedings of the 29th International Waterborne, High-Solids and Powder Coatings Symposium*. February 2002. 261-275.

Thermal Cycling and Sun Load Test

A modified automotive thermal cycling test protocol was applied to the samples made by the structural in mold decoration process. A full cycle was set at -30°C to 85°C, and relative humidity up to 98%. Figure 3 shows the thermal cycling and sun test protocol. In addition to the protocol, these samples were subjected to 15 additional minutes of sun loading at 104°C.

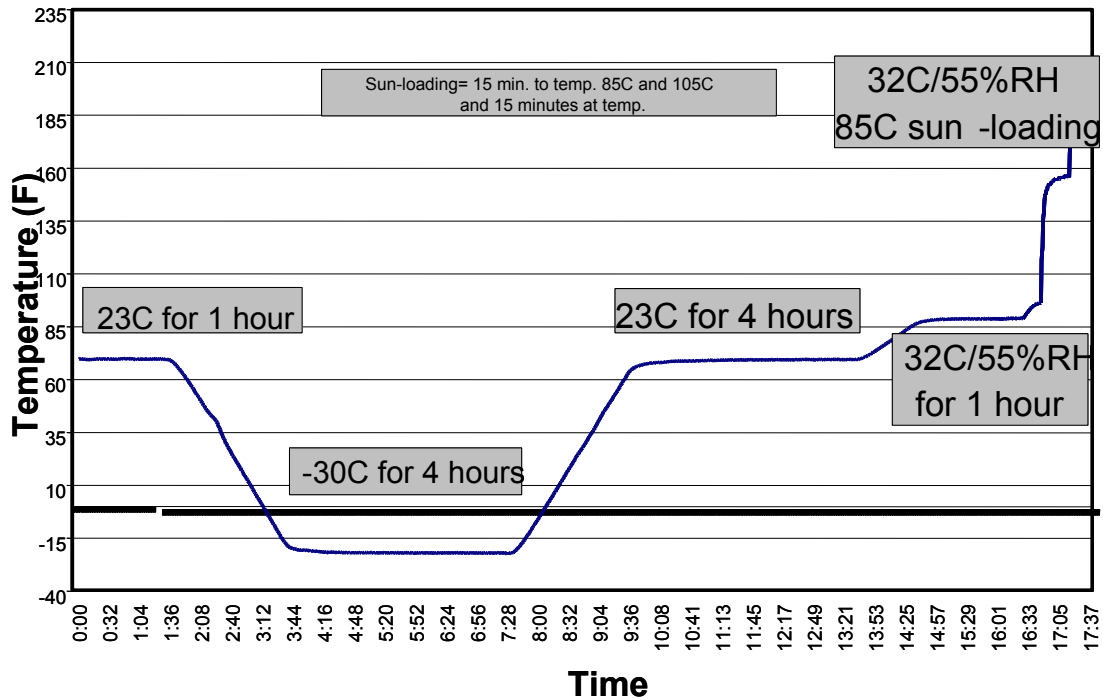


Figure 3: Thermal Cycling and Sun Load Protocol

In order to evaluate the effect of thermal cycling and sun load on the samples, the Diffracto machine was used to measure the overall surface quality of the samples. The Diffracto measures point surface imperfections and the worst imperfection is assigned a “Diffracto D-sight Index number.” From empirical observation, it has been determined that an number of less than 150 corresponds to a surface which is comparable to class-A quality.

Results and Observations

Surface Quality

Figure 4 shows the Wavescan measurements of the composite compression molded behind the aesthetic, weatherable film. For comparison, a painted sedan hood is included. Surface measurements of this over other substrates are additionally included.

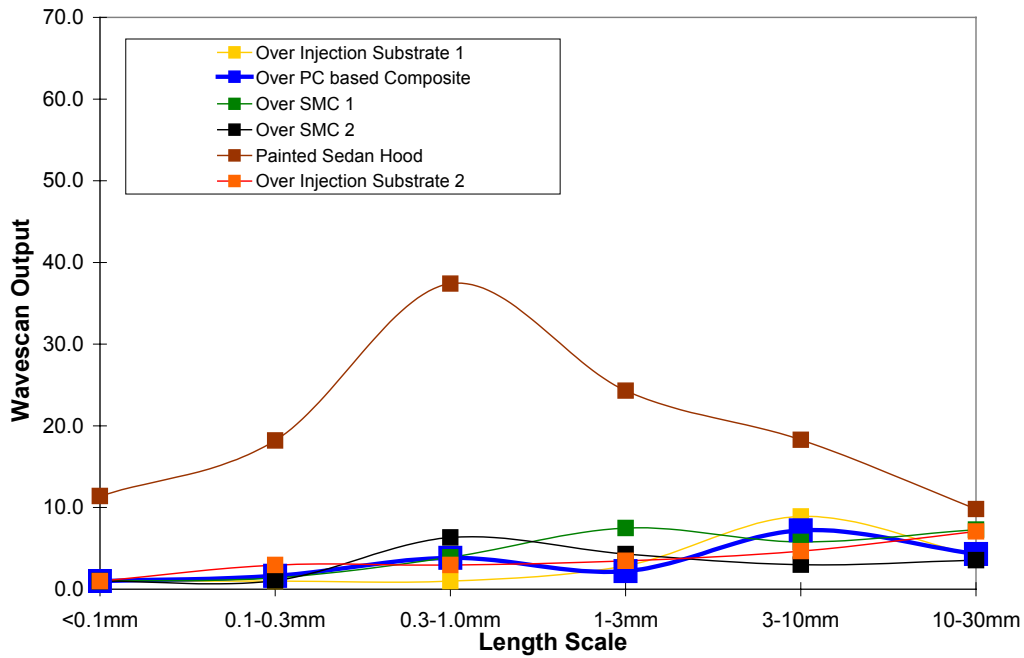


Figure 4: Surface Quality Measurements.

As can be seen, the parts made via the structural, in-mold decoration process have a comparable surface quality to even the injection molded IMD parts. In addition, as lower values correspond to higher surface quality, all of the parts measured were extremely comparable in terms of surface quality to actual class-A applications.

Adhesion Results

Table 1 shows the adhesion of the film to composite and commercially available SMC made via the structural in-mold decoration process. For comparison, the adhesion of the same film to filled and unfilled injection molded substrates is noted in the table. All average peel strength data is provided as a range in the table. These ranges provided encompass the best of a particular resin family. Failure mechanism is also noted in the table.

Table 1: Film Adhesion to Various Substrates

Substrate	Conversion Process	Adhesion Range (N/25mm)	Failure Mechanism
PC based composite	Compression	130-250	Adhesive
SMC	Compression	10-25	Adhesive
Unfilled, PC, PBT and alloys	Injection	90-225	Adhesive
Glass/Talc Reinforced PC,PBT and alloys	Injection	35-50	Cohesive (Substrate)

The adhesion between the film and compression molded composite is comparable to the best in class injection molded substrates. It is also significantly better than typical human peel

strength, which is typically noted to be between 35 and 70 N/25mm.

The low adhesion value between this film and SMC is not surprising; these materials are easily pulled apart. It is likely that the only mechanism for adhesion between the two materials is slight dissolution (solvent swelling) of the polycarbonate due to the presence of styrene monomer in SMC, which results in some minor mechanical adhesion.

It should be noted that the adhesion achieved with this process is significantly better than what is observed between polycarbonate based films and reinforced, injection molded substrates. These substrates contained similar levels of reinforcement. These materials typically failed cohesively in the substrate. One explanation for these low adhesion values is that a glass or talc reinforced resin typically displays a resin rich “skin” when injection molded with a correspondingly glass or talc rich “core.” Under this theory, the adhesion of the resin rich skin to film is greater than the adhesion of the resin rich skin to the reinforcement rich core, leading to cohesive failure of these parts.

Thermal Cycling and Sun Loading

Figure 5 shows Diffracto D-sight index results of an in-mold decorated, composite part before undergoing the thermal cycling, after the thermal cycling and 85°C sun load and also after the final 105°C sun load. For comparison, Diffracto measurements of the exact same part and film with an SMC substrate are included.

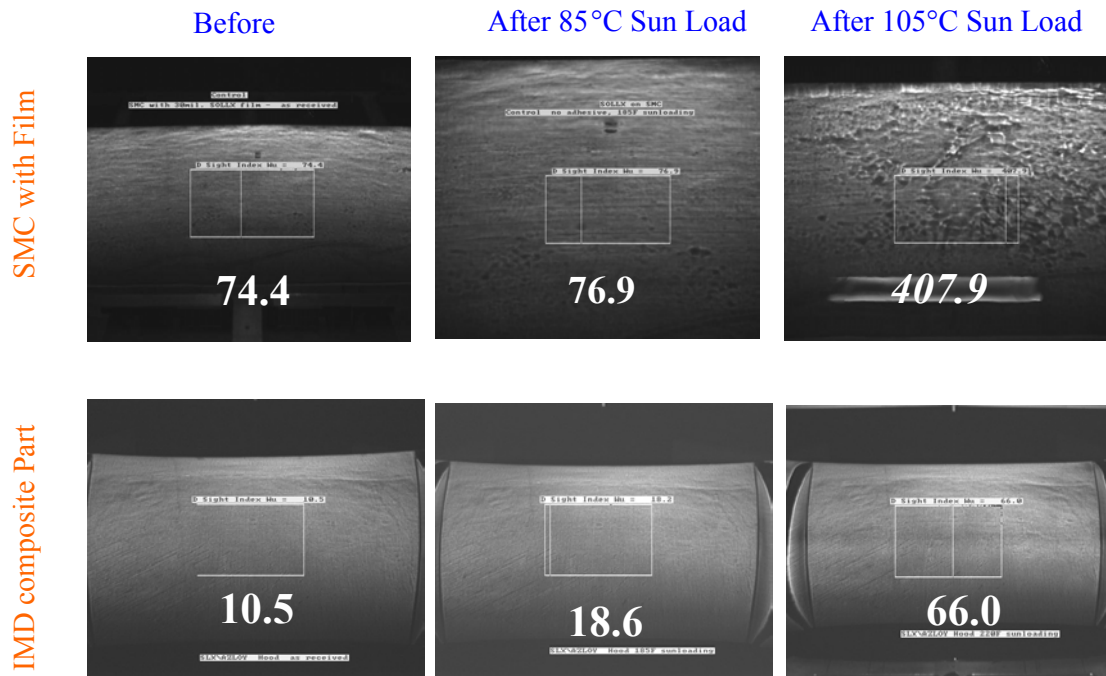


Figure 5: Diffracto D-sight Index Measurements before and after thermal cycling and sun load protocol.

As previously stated, an d-sight index of less than 150 has been empirically correlated to a surface quality of class-A quality. Both parts start below 150 and stay below 150 throughout the thermal cycling and 185°F sun loading. However, when subjected to 220F sun loading, the SMC based part becomes very rough, resulting in a Diffracto d-sight index greater than 400. The part made with the structural, in-mold decoration process still is significantly lower than the

150 standard. This is possibly due to two factors. First, the surface quality of the part is very good, so even after some surface quality deterioration after the 105 °C sun loading, the part is still of a class-A quality. Additionally, because the adhesion of the system is so high, it might be harder to delaminate the two materials under sun loading, maintaining the high surface quality.

Summary

The structural in mold decoration process provides a way to produce paint-free, high aesthetic quality structural parts. Using this process with a UV blocking film material opens this up to applications which require up to 10 years of weatherability. A compatible thermoplastic composite based on polycarbonate chemistry further opens the process to applications which require higher stiffness and lower coefficient of thermal expansion than what is currently seen with injection molded or thermoformed plastic parts.

This structurally in-mold decorated system displays excellent surface quality when measured with the WaveScan DOI machine, comparable to both commercially painted parts and traditionally in mold decorated parts containing the same aesthetic, weatherable film. With this process, the adhesion of this system is comparable to the best in class injection molded substrates and appreciably better than to either SMC or reinforced, injection molded substrates. This system is able to undergo a rigorous thermal cycling and sun loading protocol without appreciable erosion of surface quality.

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References

1. Saggese, L. "Paintless Parts." *Machine Design*. February 19, 2004. 94
2. Brister, E. et al. "Zero VOC SOLLX Film for Weatherable, High-gloss, Chemical and Scratch Resistant Performance." *Proceedings of the 29th International Waterborne, High-Solids and Powder Coatings Symposium*. February 2002. 261-275.