INTEGRATED SEMI-CONVERTIBLE SUNROOF SYSTEM IN GLASS-REINFORCED SMA/ABS RESIN

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Abstract

This paper presents follow-up on work reported in 2011 in automotive sunroof materials [1]. The focus is on the first very-large thermoplastic sunroof module for a serial (production) cabrio (semi-convertible) vehicle. Industrial partners combined their efforts to reduce weight and optimize systems cost. The large innovative tool that was developed molds both sunroof and rear window frames at one time. The part uses glass-reinforced styrene maleic anhydride / acrylonitrile butadiene styrene (SMA/ABS-GR) resin and meets all the OEM's requirements for precise dimensions, weathering resistance, good aesthetics, and adhesion to other substructures. This paper will detail the development process, tooling considerations, and benefits vs. other materials (e.g. metals and thermoset polymers).

Background and Requirements

Cabrio coach (also called cabriolet, semi-convertible, or sliding ragtop) cars feature a retractable cloth roof. Advantages to automakers of such models include the fact that no redesign of the body is necessary to add the semi-convertible feature. A number of vehicles have featured this style of roof over the years, several of which are shown in Figures 1a-1b below.

Figures 1a-1b. Cabrio semi-convertible or sliding ragtop models feature a retractable cloth roof. This type of model is beneficial to OEMs because it requires no redesign of the body, since pillars and roof bows remain intact.

For such top-loaded systems, the sunroof frame is a critical component. The new Citroën DS3 Cabrio from PSA Peugeot Citroën features a large sunroof frame molded in SMA/ABS-GF. This highly engineered part carries the weight of the entire sunroof system, the textile canopy, as well as kinematic devices. It is mounted/fixed to the upper car body structure and combines numerous technical functions essential to proper operation of the sliding sunroof plus visible surface areas with aesthetic requirements.

The DS3 Cabrio sunroof frame must meet severe requirements as spelled out in PSA specifications and test norms for long-term reliability. Key performance criteria include adhesion to polyurethane (PU) adhesives; noise/vibration/harshness (NVH) while driving (measured at 25-35 Hz); resistance to combined dust/temperature/humidity climate conditions; temperature cycling between -30°C and +110°C; ultraviolet (UV) stability under sun exposure; flame retardance; and resistance to common automotive chemical products.
The validation plan includes long-term road tests, life cycle tests, rollover roof-crush test, and water tightness. Additionally, the sunroof must pass high-speed aerodynamic tests (remaining fully operational - open/close - till 120 km/h and remain undamaged at 200 km/h) as shown in Figure 2. Further, the sunroof also must pass the “truck crossing” air-blow test with no damage to canopy functionality after crossing a truck at respective speeds of 80 and 130 km/h as shown in Fig. 3.

**Sunroof Materials and Design Trends**

Until recently, large sunroof frames for semi-convertible cars were multi-piece stamped and welded steel structures that were then subject to black KTL/E-coat rust-protection coating. These metal-intensive frames were subsequently trimmed with a few plastic pieces to complete the desired surface finish. Figure 4 shows what a steel sunroof frame looks like during build out, and Figure 5 shows such a frame installed in a vehicle.

**Figure 2.** PSA tests on sunroof systems include rollover roof-crush test, adhesion test, and aerodynamics tests.

**Figure 3.** Sunroofs are also subjected to air-blow tests to simulate crossing/passing a large truck.

**Figure 4.** Fiat 500 stamped-steel sunroof frame during build-out (source Webasto).

**Figure 5.** Fiat 500 stamped-steel sunroof frame installed.
From Metals to Plastics

For the last 15 years, sunroof manufacturers have used more and more engineering plastics to save weight and costs (Figure 6 shows a typical plastic sunroof frame). Thanks to their lower density, plastics permit on average 40% lighter designs than metals. Design freedom is high, allowing multiple parts and functional features to be integrated in a single-shot molding at no additional cost, this means up to 8 times less parts required to complete a single sunroof frame. Additionally, plastic components are corrosion resistant and their visible surfaces have molded-in texture.

Thanks to parts integration and faster production speeds, another important benefit of the move from stamped steel to molded plastics is that manufacturers can reduce the total number of tool sets required to meet a particular production volume a significant benefit for lower volume, niche models. Since a set of steel stamping tools can cost 50% more than a typical injection-molding tool, this means lower total capital investment and faster amortization of that investment. Further, secondary operations such as welding and assembly can be eliminated, helping further reduce total systems costs by as much as 25%.

Plastics that have typically been used in sunroof frames in the last decade and a half include:

- Compression-molded thermosets such as 30% glass-reinforced (GR) sheet-molding compound (SMC);
- Injection-molded thermoplastics such as:
  - 10-20% GR polybutylene terephthalate / acrylonitrile styrene acrylate (PBT/ASA) or PBT/polyethylene terephthalate (PBT/PET);
  - 30% long-(glass) fiber thermoplastic polypropylene (LFT-PP);
  - 15-30% GR SMA/ABS.

From Thermosets to Thermoplastics

There are a number of reasons why sunroof manufacturers have gradually turned from thermoset polymers like SMC to thermoplastics. Unlike thermoplastics, SMC must be stored at low temperature before molding and has a shelf-life limit. Having a higher density, SMC is typically 20% heavier than engineering thermoplastics when molded in sunroof frames. Molding
cycles for SMC are longer, since extra time is required to cross-link and build chain length, and parts are prone to surface defects (orange peel, voids, glass readthrough, etc.) that often require more post-mold finishing to correct.

The compression-molding process itself has more design limitations than injection molding, where slides and other moveable actions allow production of deep undercuts as well as through-holes and other intricate design features. With injection-molded thermoplastics, even higher levels of parts and functional integration are possible than with SMC. For example, with injection molding, kinematic functions and sliders can be directly molded in, whereas separate parts must be bonded into SMC sunroof frames.

Owing to the higher aesthetics and in-mold decoration options, visible areas of thermoplastic sunroof frames are typically integrally colored, not painted (eliminating the cost, time, and environmental issues associated with painting operations). Further, thermoplastics surface do not need sanding prior to bonding to steel body-in-white structure as is required with SMC. Where a textured surface is desired, thermoplastics allow deeper graining (since a molten polymer can pick up more surface detail than a thick paste); SMC grain is limited to 0.05 mm depth vs. 0.01 mm for thermoplastics. Finally, thermoplastic parts can be melt reprocessed, allowing for reuse of in-plant scrap and for easier recycling at end of vehicle life - a significant concern for automakers. Tables I-III below provide an overview of issues and benefits for stamped steel, compression-molded SMC, and injection-molded thermoplastics.

### Table I. Issues & Benefits for Stamped Steel

<table>
<thead>
<tr>
<th>Issues</th>
<th>Benefits</th>
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<tbody>
<tr>
<td>• No function integration possible</td>
<td>• Familiar and well-understood material</td>
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<tr>
<td>• Labor-intensive assembly</td>
<td>• High stiffness/strength allows thin cross-sections</td>
</tr>
<tr>
<td>• Corrosion issues impose rust protection, plus primer and paint</td>
<td>• Acurate predictive engineering</td>
</tr>
<tr>
<td>• No decorative integration</td>
<td>• CLTE that closely matches body-in-white</td>
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<tr>
<td>• Many parts to produce and assemble</td>
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<tr>
<td>• Highest weight</td>
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### Table II. Issues & Benefits for SMC

<table>
<thead>
<tr>
<th>Issues</th>
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<tr>
<td>• Post-mold finishing operations</td>
<td>• No corrosion issues</td>
</tr>
<tr>
<td>• Surface sanding before bonding</td>
<td>• CLTE is closer to steel than thermoplastics</td>
</tr>
<tr>
<td>• Design limitations vs. injection molding</td>
<td>• Higher stiffness means parts can be thinner than thermoplastics</td>
</tr>
<tr>
<td>• Aesthetic surfaces typically painted</td>
<td>• Lower tooling cost than thermoplastics</td>
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<tr>
<td>• Texture and in-mold decoration limitations</td>
<td></td>
</tr>
<tr>
<td>• Odour and VOC issues</td>
<td></td>
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<tr>
<td>• Higher systems costs than thermoplastics</td>
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</table>
Table III. Issues & Benefits for Injection-Molded Thermoplastics

<table>
<thead>
<tr>
<th>Injection-Molded Thermoplastic</th>
<th>Issues</th>
<th>Benefits</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>• Highest CLTE (greatest mismatch with body-in-white)</td>
<td>• Highest part and functional integration</td>
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<tr>
<td></td>
<td>• Lower stiffness / strength requires thicker sections vs. steel</td>
<td>• Lowest assembly labor</td>
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<tr>
<td></td>
<td>• Raw material is highest cost (although finished part is lowest cost)</td>
<td>• Lower density than steel and SMC</td>
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<tr>
<td></td>
<td></td>
<td>• Highest in-mold decoration options</td>
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<tr>
<td></td>
<td></td>
<td>• Lowest system cost</td>
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<tr>
<td></td>
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<td>• Fastest molding cycle</td>
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Moving to SMA/ABS-GR

New sunroof projects are increasingly moving away from semi-crystalline thermoplastics like PBT/ASA-GR or PBT/PET-GR blends or PP-LGF and selecting SMA/ABS-GR. This change is occurring for a number of reasons. First, compared with most other materials used for sunroof frames, SMA/ABS-GR has a lower specific gravity. That means that SMA/ABS-GR can produce lighter parts in comparable designs: typically 15% lighter than PBT/ASA-GR or PBT/PET-GR; 30% less than SMC; and 40% lower than steel.

Second, given the complexity of sunroof frames and the importance of maintaining dimensions to avoid stack-tolerances issues or warpage that could impede proper operation of the moveable top, another reason sunroof manufacturers are moving away from PBT/ASA-GR or PBT/PET-GR and selecting SMA/ABS-GR is that the latter maintains higher dimensional accuracy and stability after molding. As was previously reported [1], fully-amorphous SMA/ABS-GR is far less prone to warpage or dimensional changes than semi-crystalline polymers like PBT/ASA-GR, PBT-PET-GR, or PP-LGF. To address warpage and deformation issues better in semi-crystalline thermoplastics, molders will often extend setup times in the press (lengthening molding cycles) and make mold cavity geometry changes after the tool is cut. Such warpage is difficult to predict with computer-aided engineering (CAE) and generally requires use of more injection gates and runners, which can increase tooling costs.

To meet surface requirements of visible areas better, an extra-black grade of SMA/ABS-GR has been specially developed for sunroof frames. This material is designed to be molded with a grained surface. Table IV and Figure 7 explain benefits of SMA/ABS-GR vs. other common sunroof frame materials.

Table IV. Key Benefits of SMA/ABS-GF Components

<table>
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<tr>
<th>Key Benefits of SMA/ABS-GF Components vs. other Materials</th>
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<tr>
<td>• Very-low warpage (no need for mold cavity adjustments or cooling fixtures as with warp-sensitive plastics)</td>
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<tr>
<td>• Dimensional accuracy</td>
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<tr>
<td>• Superior adhesion to PU adhesives</td>
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<tr>
<td>• Lower weight parts, lower tooling costs</td>
</tr>
<tr>
<td>• High levels of part and functional integration possible</td>
</tr>
<tr>
<td>• No post-processing rework vs. SMC, no welding operations like steel, no surface painting needed</td>
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</table>
Case Study: DS3 Cabrio Sunroof and Rear Window Frames

The 2013 model year (MY) Citroën DS3 Cabrio sunroof components molded in SMA/ABS-GR is an excellent example of the benefits that switching to this material can provide. For example, the sunroof components are 25-30% lower cost than steel or other plastics when tooling, manufacturing, bonding, painting and anti-corrosion treatment costs are all compared. Figure 8 shows the vehicle and Figure 9 the frame as designed in SMA/ABS-GR.

In this case, the OEM is Citroën, the Tier 1 integrator is Webasto, the Molder is Shapers, the Materials supplier is Polyscope, and the grade used is SMA/ABS-GF15 extra-black as previously mentioned.
Integration and Material Selection

The first sunroof design was a 7 SMC parts assembly: the main SMC sunroof frame, 2 thermoplastic sliders for the rear-window kinematic, 2 steel corner mounting plates, 2 small corner parts to maintain the canopy for a total weight of 5.5 kg.

With such design, tight tolerances in screwing the corner plates onto the frame and riveting the sliders onto the corner plates were nearly impossible to achieve to ensure a smooth kinematic of the rear window and the rear spoiler.

Figure 10. Original 1900 x 1100-mm, 4.5-kg SMC sunroof frame (source Webasto)

Figure 11. The original design also featured 2 steel corner mounting plates screwed to the sunroof frame plus 2 rear-window sliders riveted onto the steel corner plates, as well as 2 small plastic corners to fix the textile canopy bonded to the frame (source Webasto).

After several optimization steps, SMC was abandoned while it became obvious that only an injection-molded thermoplastic part could allow incorporation of all functionalities and components in a single piece.

Webasto engineers desired to reduce post-mold assembly operations to lower weight and cost of the sunroof frame. Given the benefits of SMA/ABS-GF15 as outlined in Table IV, particularly the ability to maintain tight dimensional tolerances, Webasto took on the challenge to evaluate SMA/ABS-GF15 vs. a more conventional PBT/ASA-GF30.

Figures 12 and 13 show the redesigned sunroof frame in SMA/ABS-GF15 with significantly more molded-in functionality. The new frame, which provided the same performance as the SMC version, weighs only 3.4 kg and greatly simplifies post-mold assembly operations.
To further optimize the tool and reduce processing costs, the rear-window frame cavity is positioned in the middle of the sunroof frame cavity. These 2 key components are molded in a single shot, thanks to an innovative hot-runner injection system. After a molding cycle time of 120-140 sec, parts are transferred to a transport rack where they await downstream assembly. Despite the large size and thin sections of this part, no cooling fixtures are needed to maintain the correct dimensions and shape.

Figures 14 and 15 show how the sunroof and rear-window frames are positioned in the tool to maximize efficiency of the molding process. Figure 16 shows the just molded frame. Figure 17 shows the rear window bonded into the rear-window frame.
Figure 14. Sunroof frame and rear-window frame as positioned in the mold.

Figure 15. Sunroof and rear window frames in mold cavities.
Added Functional Integration

During redesign of the SMC sunroof frame, Webasto engineers incorporated additional functional integration to streamline post-mold assembly operations. Figures 18a-18c show details of how sliders are incorporated for the rear-spoiler (which, itself, is integrated into the sunroof system). Figures 19a-19b show how sliders are incorporated for the rear-window.
Value-Added Features

Additional value-added features that were incorporated into the components are exposed in Figures 20a-20b, which show a fixturing device for the rear-parcel shelf assembly (added at PSA's plant), as well as in Figures 21a-21b, which show top fixtures to hold grained top trim parts (also added at the PSA plant). Other features include a rubber water seal that is used as a fitting between trunk lid and rear window, as shown in Figures 22a-22b, and integration of the rear spoiler (as shown in Figures 23a-23c and Figure 24).
Figures 22a-22b. Rubber water seal is used as a fitting feature between trunk lid and rear window.

Figures 23a-21c. Integration of rear spoiler (a & b); rear spoiler structural plate fixed on mounted-in sliders (c).

Figure 24. Rear spoiler base plate (SMA/ABS-GR SG260) bonded to outer spoiler skin (polycarbonate/ABS).
Sunroof and Rear-Window Frames Manufacturing Sequence

The manufacturing sequence for the Citroën DS3 Cabrio sunroof and rear-window frames at Webasto's facility in France is as follows:

1. The sunroof frame and rear-window frame are simultaneously molded by Shapers France in a single tool in one shot.
2. Parts are demolded and shipped to Webasto's dedicated workshop.
3. Primer coat is applied to both frames.
4. Rear glass window is bonded to the SMA/ABS-GR rear-window frame.
5. The complete rear window and rear spoiler are fixed to the cloth canopy.
6. All mechanisms, kinematic devices, and cables are mounted on the sunroof frame.
7. The cloth canopy (with window and spoiler) is mounted on the sunroof system.
8. Sunroof system functionalities are tested by Webasto.
9. The complete sunroof system is shipped to PSA's assembly plant.

The sunroof system is both mechanically fastened by screws to the DS3 Cabrio steel body structure as well as adhesively bonded with a PU adhesive. The primer needs to be reactivated prior to applying the adhesive.

Success and Future Outlook

Sunroof frames molded from engineering plastics are successfully being used all over the world at major OEMs. Thanks to lower tooling investment and manufacturing costs, they offer significant benefits for medium- and low-volume vehicle platforms. The recent advancement in system design and materials innovation detailed in this paper have proven the technical capabilities and cost benefits of using SMA/ABS-GR to add even greater functionality and value-added features to the Citroën DS3 Cabrio sunroof system. New projects are under development in this material with the goal to reduce even more weight, include even more functionality, and further reduce part count on sunroof systems.

References


Acknowledgements

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