Potentials for Semi-structural Epoxy-SMC Series Components

Epoxy resin-based Sheet Molding Compounds extend the range of applications for SMC technology to include cost-effective, high-performance applications in the automotive sector. With the Vestalite S product group, Evonik has developed an important component for this area. Within the framework of the European Union project Alliance, the company collaborated with partners to demonstrate its potential in a car part application.

High-performance SMC for Structural Components

For many years now, Sheet Molding Compound (SMC) technology has featured as a robust, fast and cost-effective manufacturing process for non-load bearing or semi-structural components in series applications for cars and utility vehicles. In addition to the generous geometrical design freedom and the possibilities for functional integration, the advantages of the technology include established processes suitable for mass production, which already enable very large production volumes. Today, therefore, SMC components are increasingly being developed for semi-structural and structural applications. A prerequisite are innovative materials with high mechanical properties, which meet today's more exacting requirements and are even an option for leveraging lightweight potentials.

> A new generation of epoxy curing agents can resolve the previous disadvantages in terms of process control and costs.

Besides the deployment of the fibers, the selection of the matrix plays an extremely important role in the performance of the SMC formulations. Epoxy resin-based solutions, which allow better mechanical properties for composite parts compared to conventional polyester or vinylester systems, have proven particularly suitable. Furthermore, with the use of epoxy formulations, it has been possible to significantly reduce emissions during manufacture and processing and also during subsequent deployment (for example in interior applications). Considering the pending regulations with respect to the air quality of vehicle interiors, this is an outstanding material advantage for future applications in interior design. Up to now, however, epoxy curing was slightly inferior to the polyester and vinylester formulations with regard to process control and costs, but the new generation of epoxy curing agents will solve this problem.

The Vestaro Joint Venture

Vestaro was founded in 2016 as a joint venture by Evonik and Forward Engineering to combine the knowledge of the highly specialized fields of chemicals and engineering. Vestaro supports the development and marketing of the automotive composite products of Evonik. The goal of the joint ventures is the successful interaction between material, design and process along the entire development chain.

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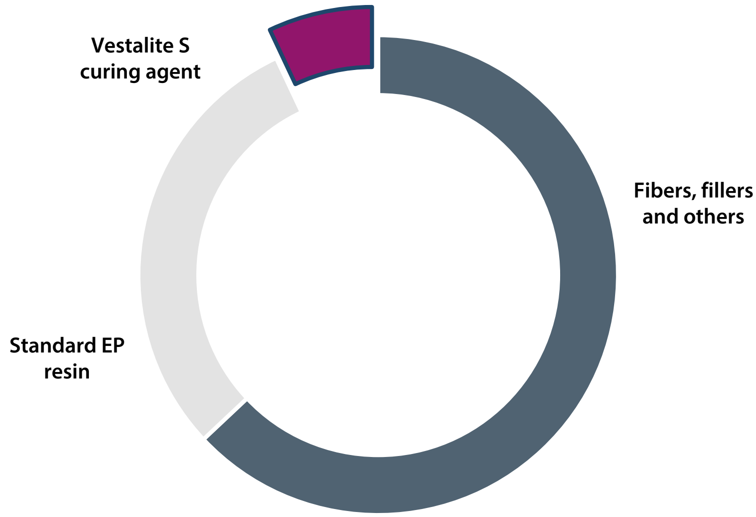


FIGURE 1 Schematic diagram of a Vestalite S-based SMC formulation (© Vestaro)

Next Generation EP-SMC

The amine-based curing system Vestalite S, a registered trademark of Evonic, Figure 1, has been developed and brought to application with the support of Vestaro specifically to meet these technical process challenges, to enable the manufacturing of cost-effective epoxy SMC components for the automotive industry. The KPIs and properties of the Vestalite S sheet molding compounds stated below were determined as part of a material and process study carried out in collaboration with the Fraunhofer ICT in Pfinztal (Germany).

Vestalite S-based sheet molding compounds feature high storage stability in the B-stage and they reduce curing times. This is made possible by a two-step reaction. The first reaction follows the SMC compounding at room temperature and stops at a chemical conversion of approximately 60 %. The second reaction is not triggered until the temperature reaches 120 °C. The result is an SMC material which, in the B-stage, is solid at room temperature and therefore has storage stability of several weeks. The curing agent is effectively tailored to the SMC process so that the material provides ideal initial viscosity during compounding and optimal flow properties during molding, while being suitable for curing within 3 min.

> A two-step reaction leads to a high storage stability in the B-stage.

Cost-effective Process Chain

Due to the solidity of the SMC material in the B-stage, it is advisable to make adjustments to the process chain. This enables a reduction of the process steps and, as a result, cost-effective manufacturing. Figure 2 shows a process chain for Vestalite S-based sheet molding compounds.

The Vestalite S curing system has a par-ticularly low viscosity. This means that, during compounding, an impregnation viscosity of 500 to 800 mPa s for the total formulation can be attained. This enables excellent fiber wet-out, which allows for typical fiber mass percentages of over 65 %. The good adhesion between fiber and matrix, and the

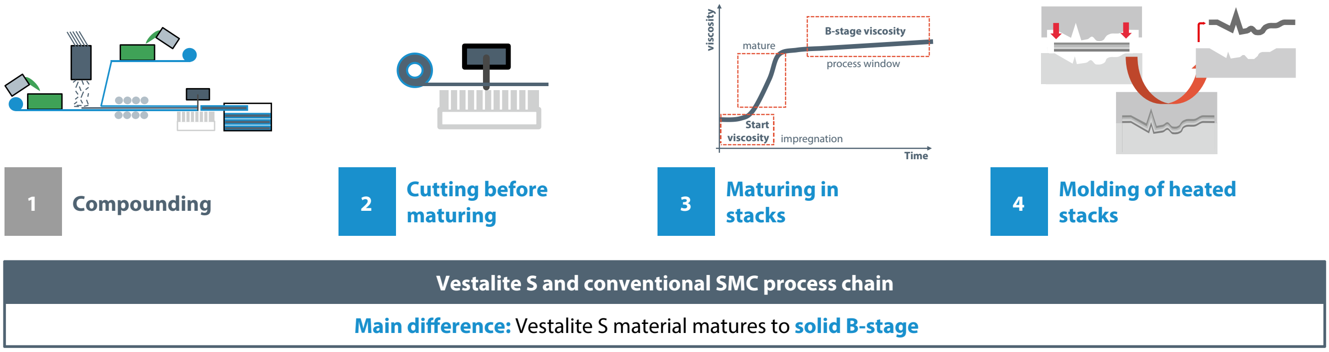


FIGURE 2 Sample Vestalite S process chain (differences from conventional SMC processes shown in blue) (© Vestaro)

high fiber volume content are key to providing the outstanding mechanical properties of the Vestalite S-based SMC systems.

After the compounding process, the SMC material is cut into part application-specific sheets. The cutting properties of the material can be improved by an additional fast maturing process, whereby the B-staging process is accelerated, and exothermic reactivity is reduced. With a defined heating profile, for example using heating plates or a conveyor oven, the SMC material is brought to a leather-like state. The temperature profile and the duration of the fast maturing process are dependent on the line-speed and other process parameters of the compounding process.

Following three days of maturing in storage at room temperature, the SMC sheets can be molded. The final B-stage, where the SMC material has a glass transition temperature of approximately 55 °C, is reached after approximately one week. To ensure a fast heat transfer into the SMC material, the sheets are heated before the molding process. This can be implemented either using a separate heating process, such as a drying chamber, or with an intermediate step in the molding process, where the press is closed only to the point of contact.

The high line speeds, which are possible due to the low impregnation viscosity, the in-line cutting, and the short cycle times during molding of the material, enable fast and cost-effective processing of the Vestalite S-based SMC parts.

Technical Process Advantages

In addition to the technical process advantages compared to conventional epoxy resin-based SMC materials, the Vestalite S curing agent makes it possible to manufacture SMC components with excellent mechanical properties. Figure 3 shows strength and stiffness values of Vestalite S-based SMC compared to conventional systems based on polyester, vinylester, and epoxy. In particular, the high tensile modulus of the carbon fiber-reinforced Vestalite S SMC and the tensile strength values of the glass fiber-

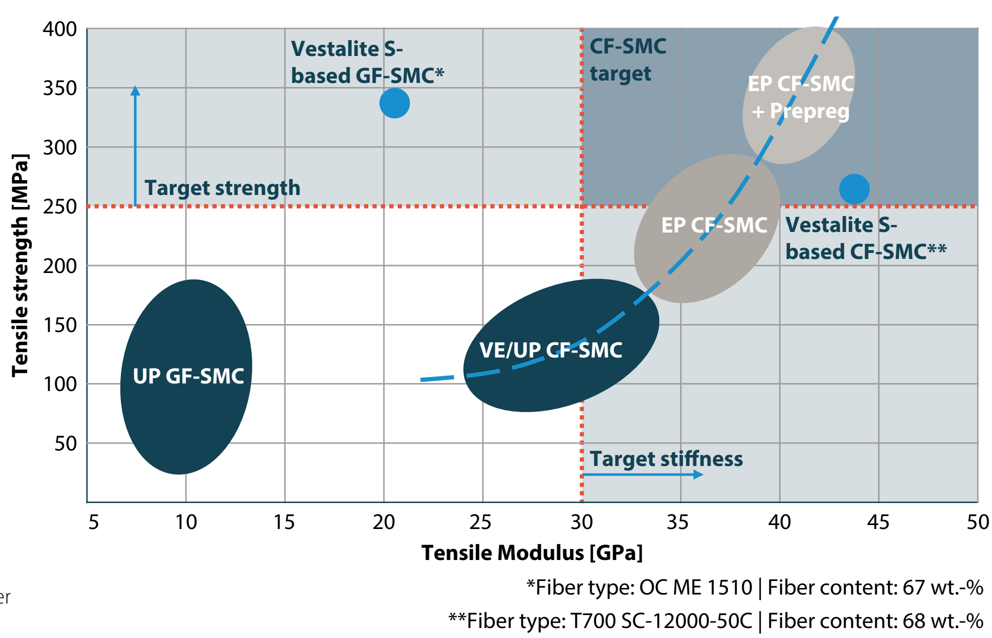


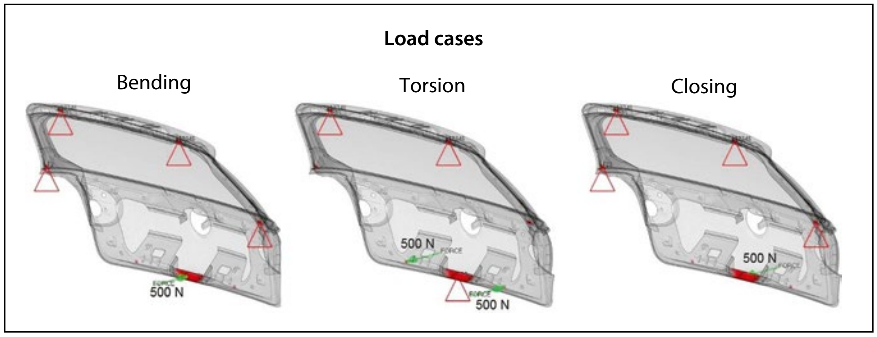
FIGURE 3 Comparison of mechanical properties of different SMC systems with the Vestalite S coefficients, based on the material characterization at the Fraunhofer ICT (© Vestaro)

reinforced Vestalite S SMC offer significant potential for lightweight designs.

As with all epoxies, Vestalite S-based formulations have no styrene emissions and extremely low Volatile Organic Compounds (VOC) emissions in components. In tests carried out in accordance with VDA 278, VOC and fogging values were found in the < 10 µg/g range.

Potentials in Car Parts

In the Open Innovation Challenge within the Alliance project, the potential of Vestalite S-based CF-SMCs in a car part prototype was demonstrated. The reference part was a steel tailgate and, in accordance with the specific goals of the Alliance project, the inner panel of the tailgate was replaced by a Vestalite S-based CF-SMC. For the design of the SMC part, requirements for the stiffness values for specific load cases were defined by the Institute for Automotive Engineering at RWTH Aachen University (ika). As part of the simulation at ika, the rib structure and the wall strength of the SMC part were adjusted to comply with the stiffness requirements. The simulation results in Figure 4 show that the stiffness values of the various load cases match the values of the steel reference while it was possible to reduce the component weight by almost 50 %. With the use of the Vestalite S-based SMC material, it was possible in this preliminary design to reduce the weight of the tailgate internal structure from the original 3.96 (steel-based) to 2.01 kg. Looking forward, it can be concluded that, with an SMC appropriate design of the entire tailgate, further weight savings are possible by way of the functional and component integration, and these will have similar positive effects on the manufacturing-related and economic considerations.



		Steel reference	Vestalite S-based CF-SMC
Stiffness [kN/mm] (for torsion [kNm/°]	Bending	0.11	0.11 (±0 %)
	Torsion	0.81	1.02 (+25 %)
	Closing	0.17	0.20 (+17 %)
Mass inner panel [kg]		**3.96**	**2.01 (-49 %)**

FIGURE 4 Results of the tailgate stiffness tests as part of the simulation tests at ika (© Vestaro)

Alliance Project

In the framework of the European research project Alliance, a total of 18 partners, consisting of automotive manufacturers, parts suppliers and research institutes have joined forces to address the topic of cost-effective and sustainable lightweight design. Alliance has the goal of developing a holistic methodology to enable it, at an early concept stage, to make realistic statements with regard to weight savings, vehicle emissions, and lightweight design costs. The methodology is to be validated by the use of application examples, which are developed within the project.

As part of the project, a lightweight design competition (Open Innovation Challenge) was initiated, in which 22 companies from all over the world participated. The winners of the lightweight design competition were given the opportunity to present their innovative material and manufacturing technologies at the Future Lightweighting Days 2018. The automotive manufacturers have identified components from vehicles that are currently in series production and they are committed to implementing the lightweight design technologies in prototypical demonstrator components.

Cost Reduction Through Functional Integration

The concept comparison illustrated here, a steel reference versus a carbon fiber-based composite solution, is intended to demonstrate the strong lightweight design opportunities and it does not yet show the economically optimized concept. This is clear when one considers the costs, which are dominated by the high material costs of fibers and which, despite the technical process advantages, result in a significant increase in final component costs. The goal in subsequent concepts will therefore be to verify the economic potential with the use of a holistic concept. In an initial assessment for this tailgate concept, assuming a component reduction of 50 % and an overall weight saving of 3 kg, lightweight design costs for the tailgate of less than 10 euros/kg were achieved. When the entire component life cycle is considered, the weight reduction allows further cost advantages to be realized. These can be shown as secondary weight savings or through the reduction of the Total Costs of Ownership (TCO).

Life Cycle Assessment

In addition to the cost savings, the weight reduction also has a significant influence on the ecological balance of the overall vehicle.

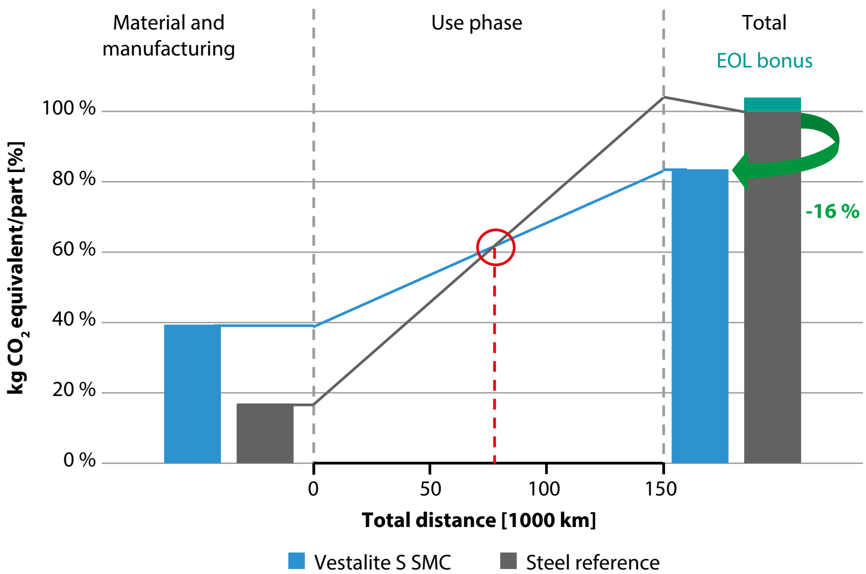


FIGURE 5 Results of the life cycle assessment for the steel-based and Vestalite S-based SMC tailgate as part of the project (© Vestaro)

Within a Life Cycle Assessment (LCA), the environmental influences of the component were shown over the entire lifetime of the component. In the framework of the Vestalite S study, the CO_2 equivalent emissions for each component were considered as environmental influences, which illustrate the influence on global warming potential by the SMC part and the steel part, respectively. All phases of the life cycle, including material processing, part manufacture, the operating phase, and the end-of-life phase were taken into account. Figure 5 shows the results of the LCA. The energy-related environmental pollution is assumed on the basis of the German energy mix. In particular, due to the energy-intensive manufacture of the carbon fibers, and also due to the increased energy requirement in the production of the SMC tailgate, there is a CO_2 deficit at the start of the life cycle. Over the entire life of the component, however, the contribution to global warming can be reduced by more than 15 % due to the weight reduction.

Within the LCA, only weight-specific influences and no further aerodynamic influences on the component were considered. Despite this simplified consideration and the additional end-of-life bonus of the steel (due to the lower energy requirement in secondary processing of the material), the result shows a significant advantage for the SMC option. A potential bonus regarding the SMC part can be realized using recycling processes. Especially the high energy consumption during the carbon fiber production can partly be compensated. Within this case study, no quantitative end-of-life bonus for the SMC option is considered, as the recycled carbon fibers have substantially lower mechanical values than the primary fibers. This affects the comparability of the fibers.

Summary

Using the case study as part of the Open Innovation Challenge of the Alliance project, it was possible to demonstrate the potential of epoxy resin-based SMC material in tailgate applications. The amine-based curing agent Vestalite S enables the technological, economic and ecological use of epoxies in sheet molding compounds.

Compared to conventional SMC formulations, the Vestalite S curing agent enables excellent mechanical properties and low emission values in material processing and vehicle utilization. With adapted and optimized process control, it is possible to achieve fast and cost-effective part manufacturing compared to competitive epoxy SMC formulations. The verification of the potential illustrated here in customer projects is currently ongoing.