ENABLING ELECTRO-MOBILITY BATTERY SYSTEM SERIAL PRODUCTION WITH HIGH PERFORMANCE RAPID CURE EPOXY SMC

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I. Motivation and background

In recent years electro-mobility is undergoing a radical change. In light of increasing demand and numbers of electric vehicles (EVs), new material and process technologies and eventually new designs are emerging [1]. Drivetrain and energy storage systems require new solutions in particular, not only with regards to productivity, but also lightweight design as well as stringent safety requirements. Next generation designs, advanced materials and process technologies are needed.

Advanced plastic materials are offering solutions for these demands. Evonik, a global leader in specialty chemistry, has been developing a new curing agent for next generation Sheet Molding Compound (SMC) materials based on epoxy that addresses these emerging demands. Currently, polyester-based SMC are already used in some of today’s battery case designs alongside metallic (aluminum and steel) materials that are used in the Tesla Model 3 or BMW i3 for example. Nevertheless, epoxy-based SMC can radically reduce the weight (up to 30%) of existing solutions at an elevated productivity and safety level.

Within the framework of a consortium project, Evonik guided by its Joint Venture Vestaro GmbH has showcased the potential of epoxy SMC in a battery box application – using the new curing agent VESTALITE® S. A comprehensive concept demonstrates the advantages of epoxy SMC in performance, processing and functional integration compared to state of the art SMC and metallic solutions. Key performance attributes such as flame retardancy, thermal management, integration of electrical/electronic architecture and the technical connection to the car structure were considered.

II. Electro mobility market trends

Over the past decade, the development of EVs has been extremely advanced. With less than half a million vehicles in 2013, the global electric car fleet has increased tenfold by 2018 exceeding 5.1 million EVs [1]. This development is mainly driven by political and ecological motives, such as reduction of CO_2, NOx and other emissions of combustion powered vehicles. Market forecasts are expecting a market share of up to 30% and a total electric car fleet of 250 million in 2030 [1]. Therefore, car manufacturers are facing the technology transition from combustion engines to different electric drivetrains (figure 1). Beside the appropriate drivetrain, new energy storage solutions for the electricity powered vehicles are required. The types, sizes and safety requirements of these energy storage systems affect their functions, especially with regards to the integration into the car body structure.

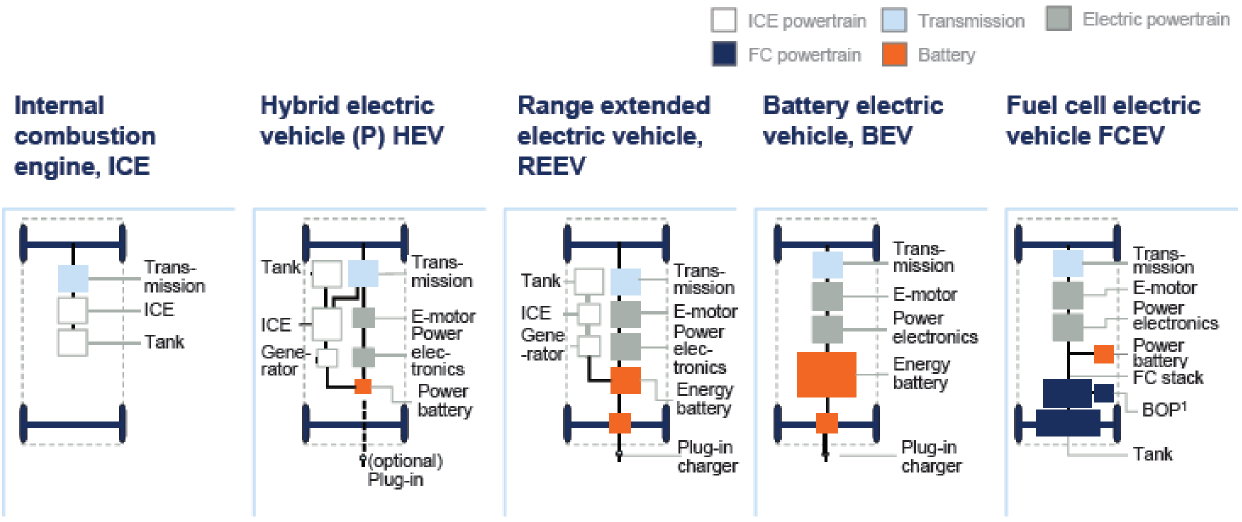


Figure 1: Different powertrain technologies and their related energy storage methods [2]

Battery case solutions today

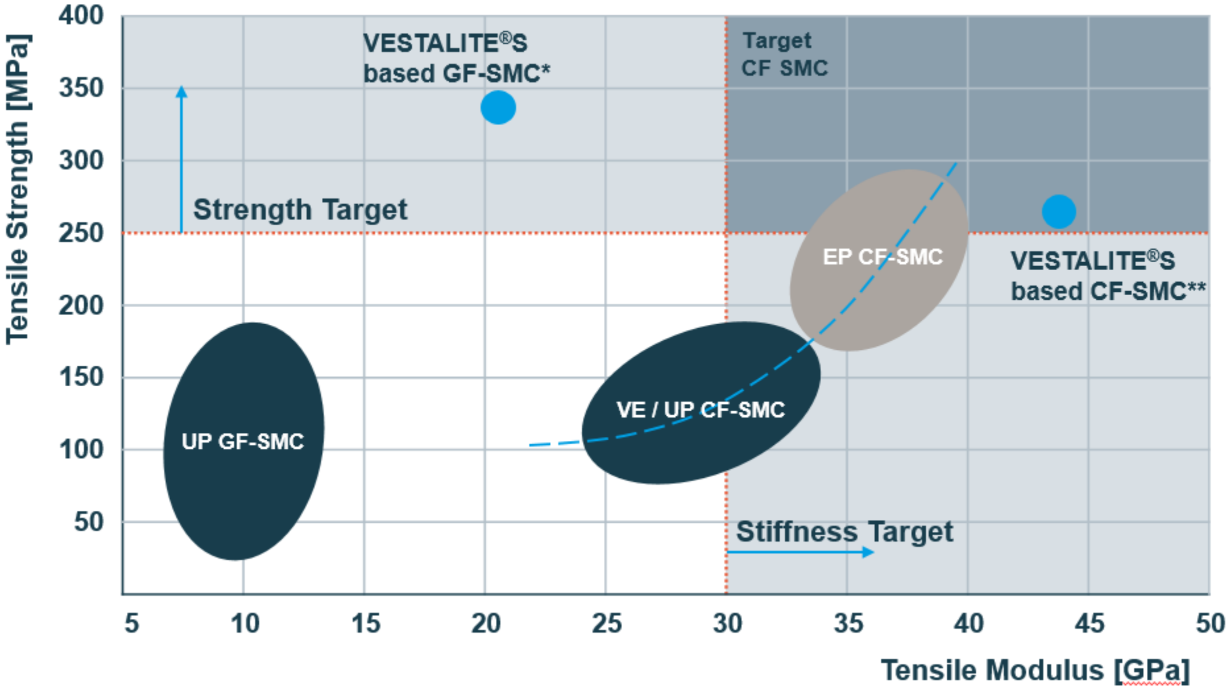
Except for Fuel Cell Electric Vehicles (FCEV) the energy of EVs is usually stored in battery modules. The size and energy capacity of the battery depends on the EV type and the battery technology. Due to its high specific energy density, lithium-ion batteries are mainly used for the largest battery types, but also nickel-metal-hydride batteries can be found in EVs. A typical battery system consists of the battery modules, a casing and a suspension system as well as peripheral equipment for the electric connection, battery cooling and other devices addressing several required functions. One of the most important requirements on the battery system is safety, which is mainly addressed by the battery casing [3]. Depending on defined standards, battery systems have to pass several use phase and abuse tests to be approved in the vehicle. With regards to the battery case itself, mechanical loads in case of crash but also other functions like fire retardancy, chemical resistance, leakage prevention or electromagnetic shielding have to be considered.

Sheet molding compounds in automotive industry

The SMC technology is widespread in the automotive industry. Long fiber- (glass or carbon) based sheets are produced as semi-finished goods that are formed to shape in a second compression molding step. Main advantages of SMC materials are the fast and cost-efficient processing of complex geometry components [4]. The molding process enables a reduction of the total part number and the integration of different functions, like (metallic) inserts and connection points, which further reduce assembly efforts dramatically. Current state of the art unsaturated polyester- or vinyl ester-based SMC materials are mainly used for non- or semi-structural applications like engine housings or trunk lid assemblies, as their mechanical properties are limited. High performance epoxy-based SMC solutions can expand the fields of applications allowing also structural parts to be designed with the SMC technology.

III. Material & product development approach

Evonik has developed an amine based curing agent (VESTALITE® S) to enable the usage of epoxy chemistry in SMC materials for high performance rapid cure applications in the automotive industry. Beside the high mechanical properties shown in figure 2, the key advantage of VESTALITE® S based sheet molding compounds is the ease of processing. Via a two-step reaction, high storage stability of several weeks in the B-stage and curing times of three minutes can be realized. The curing agent is chemically tailored to the SMC process so that the material provides ideal initial viscosity during compounding for excellent fiber wetting and optimal flow properties for fibers and resin during molding. As with all epoxies, the formulation has no styrene emissions and extremely low VOC emissions in final components and parts.



*Fiber type: OC ME 1510 | Fiber content: 67 wt.-%

**Fiber type: T700 SC-12000-50C | Fiber content: 68 wt.-%

Figure 2: Performance increase of VESTALITE® S based materials enables high-performance SMC applications (© Vestaro)

Product development process

A project consortium with comprehensive competencies was established to develop a holistic solution for a battery case. Beside the material and engineering know-how of Evonik, Vestaro and their JV partner Forward Engineering GmbH, different vehicle and battery technology partners were included. Within this consortium project the product development process approach of Forward Engineering (figure 3) was followed. The project included the four steps: analysis, concept and validation as well as the CAE based simulation of the concept and the potential redesign loop. Concept development and validation are described in the following chapter.

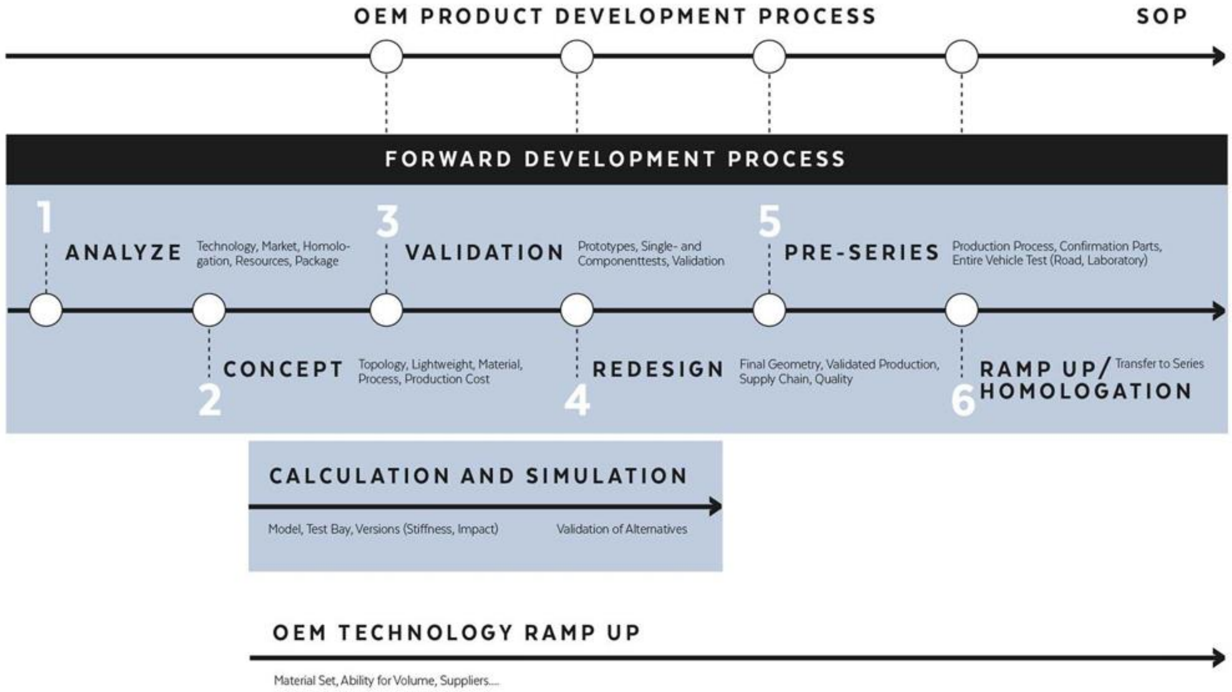


Figure 3: Product Development Process to achieve a holistic solution for a battery case (© Forward Engineering)

IV. Concept development of holistic battery case solution

Beside the safety requirements, the integration of a battery thermal management, electromagnetic shielding and battery contacting was part of the project. To address all those functions, the interaction of design, materials and process technologies represented the main challenge during the development of different concepts. In a systematic approach morphological boxes were used to set up, screen and assess potential solutions for the different requirements and functions. Based on the expertise of the consortium combined with several evaluation methods, different concept solutions for the holistic battery case were chosen and developed further. A hybrid material solution based on epoxy SMC with unidirectional (UD) fiber reinforcements, metallic profiles and inserts proved to be the most promising concept. A conceptual and preliminary sketch of the concept is shown in figure 4.

Using the SMC material for the battery case structure, connection points and integration of functions, a glass fiber (GF) based formulation was chosen. Although carbon fiber (CF) based SMC would increase the stiffness and strength of the structure, fiber flow and additive compatibility were considered beneficial for the GF-based system. Appropriate additives were used to achieve flame retardancy and to increase the electromagnetic shielding of the system. Integrated metallic inserts, were used as connection and mounting points for the battery modules (inside) and for the connection to the car body structure (outside). Additionally the ribbed structure and the high mechanical properties of the GF-SMC increase the mechanical performance of the entire battery case.

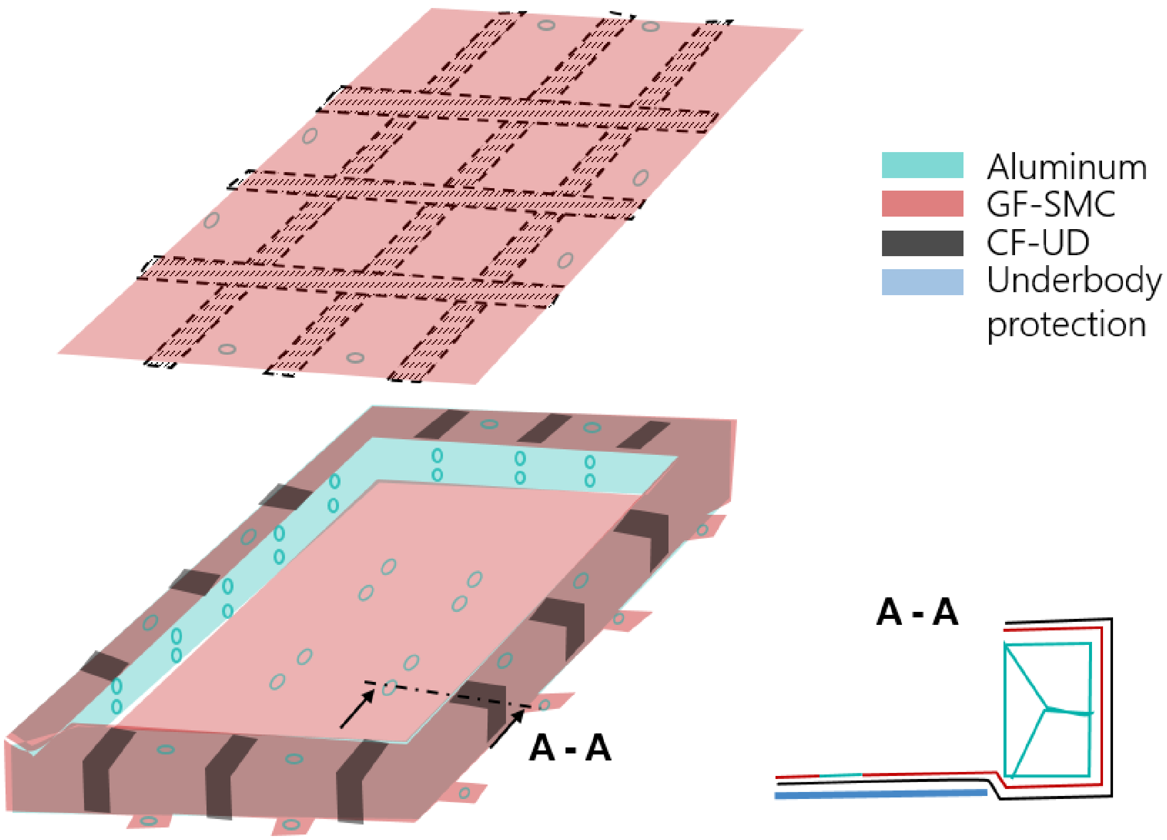


Figure 4: conceptual sketch of battery case solution (© Vestaro)

Nevertheless, continuous fiber reinforcements were considered to be mandatory to fulfill all relevant safety requirements. Therefore, carbon fiber UD-tapes were used as local reinforcement elements. The load appropriate design of the cross-shaped UD-strips ensured the mechanical load capability of the battery case and additionally created a Faraday cage, increasing the electromagnetic shielding of the casing. To guarantee a continuous connection of the electrically conductive carbon fibers, the UD-strips of the battery case cover were placed on the lower side. Metallic inserts may support the conductivity in the contact area. To enable a ductile behavior in case of crash and to allow a simple integration of the battery modules contacting, metallic profiles were placed at the sides of the battery case. This reduced the wiring inside the battery case to a minimum and increased the space for more energy capacity. In combination with the GF-SMC and the CF-UD-strips all mechanical safety requirements regarding vibration, mechanical shock and mechanical integrity according to test norm ECE R100-2 can be fulfilled. For underbody protection a material with high toughness properties is attached at the lower side of the battery case.

This concept should demonstrate the high potential of hybrid material solutions with epoxy SMC as a structural material. The flow molding process enables the combination of different materials and their various advantages for specific functions which are summarized in table 1.

Table 1: Used materials and addressed functions in the concept

Materials	Addressed functions
Epoxy GF-SMC	• Insert integration (connection/screwing points in- and outside of battery case) • Shape of battery case • Thermal stability / flame retardancy • Electrical & thermal insulation • Chemical resistance (corrosion) • Leakage protection (integration of sealing groove in the casing cover) • Electromagnetic shielding
UD-carbon fiber	• Mechanical stresses • Electromagnetic shielding
Aluminum profiles	• Battery modules connection/fixing • Cooling medium circulation • Connection points for battery thermal management • Structural integrity

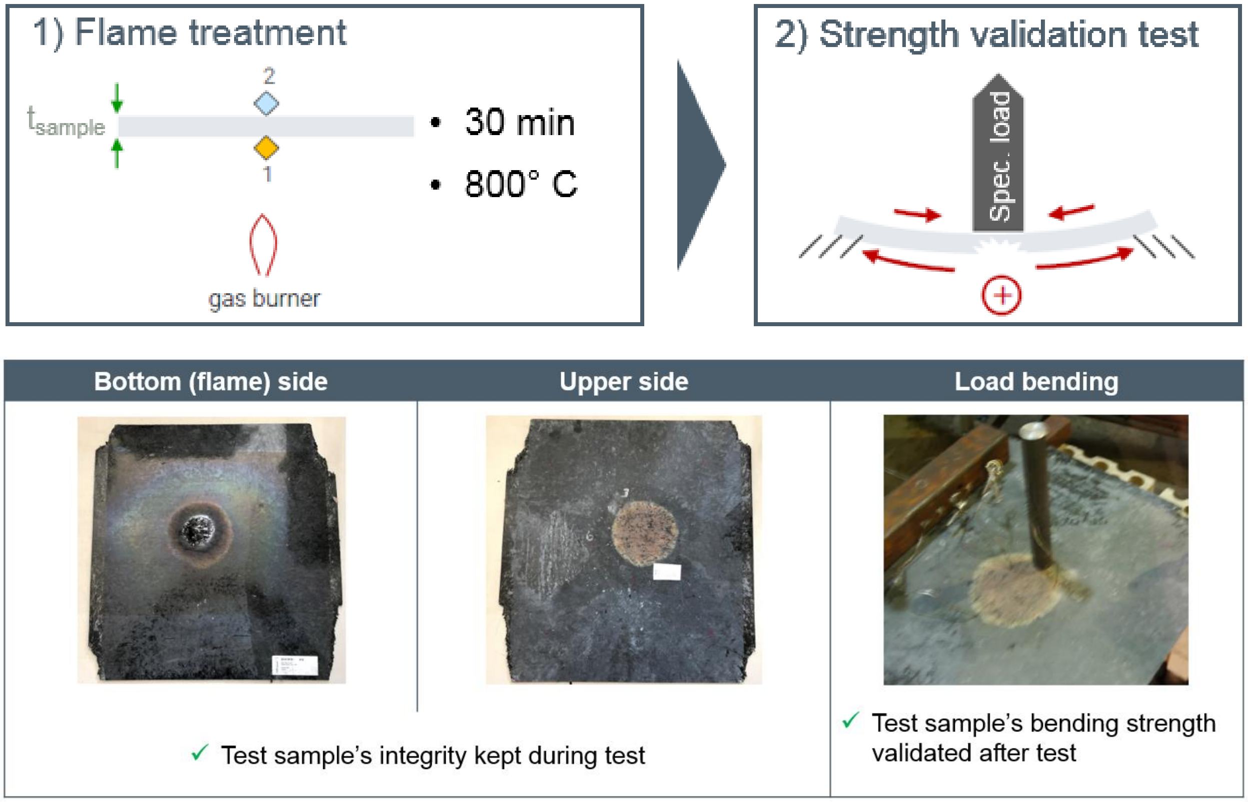
Concept Validation

The concept provides a scalability of the design, depending on required EV battery sizes. Therefore, the safety and abuse requirements are varying. For the CAE evaluation of the design and the mechanical load capability a specific size and layout for the battery case was selected. This was also necessary for the thermal and electrical abuse testing, as the total stored energy capacity is decisive for the behavior of the overall system. The required safety tests according to the test standard ECE R100-2 for lithium-ion batteries are shown in table 2.

Table 2: ECE R100-2 requirements for lithium-ion batteries [5]

Test type	Tests
Mechanical	• Vibration • Mechanical Shock • Mechanical Integrity
Thermal	• Thermal Shock • Excessive Temperature • Fire Resistance
Electrical	• Short-Circuit Resistance • Overcharging/Overvoltage • Deep Discharging

Within the project, all the requirements are tested and depending on the results, a redesigning process is considered. First results of the fire resistance / flame retardancy are displayed below. In contrast to the test setup of ECE R100-2, where a flame is directed to the battery case for only a few minutes, VESTALITE® S based SMC was tested for 30 minutes at 800°C. This test was performed within a customized test setup shown in figure 5. As a result, the material kept its integrity during the test and even passed a bending strength test after the burning procedure.



✓ Test sample's integrity kept during test

✓ Test sample's bending strength validated after test

Figure 5: Customized fire resistance testing setup and results of VESTALITE® S based SMC (© Forward Engineering & Vestaro)

V. Summary and next steps

The concept project showcases the enormous potential of epoxy SMC in new vehicle architectures and / or EV battery case applications. Due to the high safety requirements, standard SMC materials are limited with regards to their mechanical performance. The high performance epoxy SMC material extends this range of application for the SMC process technology. Moreover, the flow mold technology enables functional integration and a reduction of part quantity which reduces the assembly effort and the total process costs. Besides initial concept evaluations within the project, first positive test results regarding the fire resistance of the material were validated.

As a next step, the concept will be evaluated on the mechanical performance based on CAE analysis. Depending on the results and the further testing according to the ECE R100-2 standard, a potential redesign loop will take place. To compare the concept with existing battery case solutions, a comprehensive cost and manufacturing assessment of the final battery case concept will be provided.

VI. References

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