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New Methods for Computing and Developing Hybrid Sheet Molding Compound Structures for Aviation Industry

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Abstract

The combination of Sheet Molding Compounds (SMC) and pre-impregnated, tailored continuous fiber fabrics in a single-stage compression molding procedure is a promising technology for the time-saving as well as cost-efficient manufacturing of functional aircraft structures. However, reliable methods for designing, material modeling and predicting of the mechanical behavior of those hybrid composite materials have to be developed for the use in aviation industry. This paper deals with the development of hybrid SMC materials with local tailored continuous fiber reinforcements, appropriate manufacturing procedures and a microstructural modeling approach for the prediction of the material behavior.

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Keywords: Composite; Aircraft; SMC; Hybrid SMC; Micro-mechanical modeling; simulation

1. Introduction

Within the next decades, the global demand on civil aircraft will rise. This requires efficient processes for the manufacturing of lightweight, especially composite, parts. In terms of a sustainable and cost-efficient high-volume production of such components the Hybrid Sheet Molding Compound (SMC) technology is a promising manufacturing process. It combines the advantages of Sheet Molding Compounds such as the possibility for manufacturing geometrical complex structures with high performance properties of continuous fiber reinforcements. Furthermore there exist huge potentials in the field of tailored and local continuous fiber reinforcements to increase the mechanical properties of a part along its load paths and according to its specific requirements.

Especially in geometrically complex cases, the SMC fiber orientation is no longer random and the mechanical behavior is highly dependent on its microstructure. As the application in lightweight structural components requires detailed knowledge of the mechanical behavior, there is the need of precise micromechanical modeling techniques.

Therefore, this paper deals with the development of a microstructural modeling approach for predicting the SMC mechanical behavior based on statistical microstructural information (e.g. fiber orientation distribution and fiber length distribution). Moreover ways of developing hybrid composites with local tailored continuous fiber reinforcements are presented. An adequate manufacturing process for a cabin application in aircraft based on the simulation results underlines the benefits of the so called *Hybrid SMC* technology.

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Nomenclature

ATH	Aluminum trihydrate
CT	Computer Tomography
FE	Finite Element
SMC	Sheet Molding Compound
TFP	Tailored Fibre Placement
RVE	Representative Volume Element
UP	Unsaturated polyester resin

2. Hybrid SMC Technology

For an expanded use of SMC technology in aviation industry new materials have been developed and the compression molding procedures have been advanced [1, 2]. Due to using SMC for cabin, cargo and secondary structure applications, special SMC formulations which are based on UP resin with chopped glass fiber reinforcements and a high percentage of flame retardant additives, especially aluminum trihydrate, have been introduced. These additives are starting to release water at temperatures of 200°C for self-extinguishing purposes [2, 3]. However, these inorganic flame retardants will adversely affect the fiber-matrix adhesion due to their particle size and chemical composition. For an optimum impregnation and flow behavior during the compression molding process, various chemical modifications and further additives are necessary. As a result, the general requirements for using these new SMC materials for cabin and cargo aircraft components can be met.

Moreover, new material and process combinations of SMC, continuous fiber reinforcements and metallic elements, called *Hybrid SMC* technology have been developed for aircraft applications. Possible pre-impregnated continuous fiber reinforcements can be unidirectional non-woven, woven and TFP fabrics. Fig. 1 shows a general process scheme of the mentioned SMC technology. First of all, the semi-finished products are cut, prepared and preformed in reference to the stacking plan, reinforcement structure and geometry of the part. Then the whole preform is placed into to the isothermal heated press molds. If necessary, the continuous fiber reinforcements have to be fixed by special positioning devices such as needle systems, frameworks, clamping elements or by using metallic load introductions of the component. After a compression molding time of 120 to 300 seconds the cured component can be demolded and removed from the mold. Final process steps for finishing such as deburring, priming and painting follow. [1, 4]

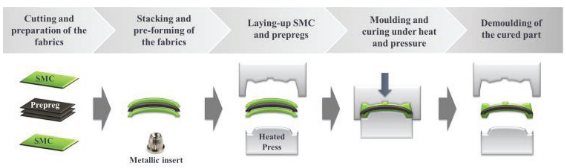

Fig. 1. Schematic process cycle of the *Hybrid SMC* technology.

The described *Hybrid SMC* technology obtains the time-saving and cost-efficient production of geometrically complex, highly functional and lightweight components. The ability of full automation and the relatively high material usage in the range of 90 to 95 percent higher the economical potentials of this material and process technology. In addition, the compression molding process is characterized by the possibility to integrate various functions directly such as metallic elements and coloring. Due to the high level of functional integration, time and costs for rework assembly and further finishing steps can be reduced. The described potentials promise the use of this technology for various cabin and cargo applications such as load-carrying cabin monuments, highly functional overhead storage systems as well as complex fittings, holders or brackets. By the load-path-optimized integration of continuous fiber reinforcements and the use of epoxy resin systems also structural applications can be realized. [1, 4]

Due to the random orientation of the chopped fibers of the SMC and the complex combination of different fiber types and fabrics, completely new computing and design approaches for the *Hybrid SMC* technology are necessary.

3. Computing of the SMC material behavior

3.1. Motivation

In this section a concept for predicting the elastic properties of the SMC based on its constituents and morphology is presented. This predictive model may help reduce experimental testing for improving process and material design and deepens the understanding of the underlying micromechanical mechanisms.

The assumption of transversal isotropic SMC material properties is only valid for constant fiber volume fractions with randomly oriented, straight fibers and constant fiber lengths. Even for highly filled cavities, the fibers orient during the compression molding in complex shaped areas like ribs, so that their fiber orientation distribution has to be taken into account.

Various analytical models for predicting the stiffness of discontinuous fiber composites exist. They are e.g. based on the Eshelby's inclusion problem [5] and extended for non-dilute concentrations, see the Mori-Tanaka model [6] or based on Hill's self-consistent homogenization scheme [7] that leads to the Halpin-Tsai equations [8] which are widely used for discontinuous fiber composites. A detailed literature review can be found in [9].

However, these analytical models do not cover micromechanical effects such as fiber waviness and fiber-fiber-interactions.

Micromechanical finite element models describe the constituent's geometry explicitly and can thus include the above mentioned effects. In contrast to short fibers, long fiber reinforced polymers have very high aspect ratios (length/diameter, here approx. 1250) that complicate the creation of a representative volume element in two ways: As the RVE's in-plane dimensions have to exceed the length of the longest inclusion, a high element count and thus high computational efforts result. Additionally, reaching the desired fiber volume fraction is difficult due to the "jamming