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Combination of carbon fibre sheet moulding compound and prepreg compression moulding in aerospace industry

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Abstract

The demand for fuel efficient aircraft led to the development of innovative lightweight constructions and the use of lightweight materials, such as carbon fibre reinforced plastics. In the same manner competences in new production technologies have been built up in the aerospace industry. However, current processes for producing lightweight composites with an excellent mechanical performance cause high costs and long process cycles in comparison with approved metal processes. Furthermore the used raw materials, such as carbon fibres and resin, are very expensive. In contrast to these technologies Sheet Moulding Compound is characterised by a very high productivity, excellent part reproducibility, cost efficiency and the possibility to realise parts with complex geometries and integrated functions, e.g. inserts or colouring. The biggest disadvantage of Sheet Moulding Compound parts is a low level of stiffness and strength because of a low fibre-volume fraction, a short fibre length and isotropic fibre distribution. In this context the combination of Sheet Moulding Compound and Prepreg compression moulding in an one-shot compression moulding and curing process merges the advantages of both materials to create load-bearing and autoclave-quality parts without an autoclave. In the following article, this new technology and its potential will be presented. This paper will also deal with the resulting material characteristics.

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Keywords: SMC; Sheet Moulding Compound; Prepreg; Compression Moulding; Carbon Fibre; CFRP; Hybrid; Light Weight; Aircraft

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1. Introduction

Innovative light weight design led to a new generation of fuel efficient and cost effective aircraft. In this regard the development of composites like carbon fibre reinforced plastics and appropriate production technologies played an important role. Furthermore, the demand on new aircrafts will grow significantly during the next twenty years. As a consequence composite technologies have to be developed or existing manufacturing processes should be improved to achieve the aims of future aerospace production. Production rates, reproducibility, automation, costs and also ecological sustainability are important aspects in this context. However, current composite technologies for aircraft production are creating high costs, a poor utilization of material and long process cycle times compared to metal-based technologies. In terms of automotive production the optimization and improvement of these aspects are fundamental conditions for introducing carbon fibre components in future series-production vehicles. An auspicious solution to manage these challenges in future aerospace and also automotive production could be the combination of carbon fibre Sheet Moulding Compounds and continuous, oriented and pre-impregnated carbon fibre fabrics, called Prepregs, in an one-shot compression and curing process. With the help of this technology the advantages of both materials could be combined in a new kind of hybrid thermoset composites. Moreover, this material combination enables the direct integration of metal components like inserts, panels or plates to generate complex metal-composite-hybrids with a thermoset matrix system.

The main objectives of this article are reflecting on the potential of this technology regarding to aerospace applications and first investigations on different material samples, which have to come up to requirements for commercial aircrafts.

2. State of art

In the field of thermoplastic composite-hybrids and composite-metal-hybridization some successful developments and research efforts do already exist. In this regard injection over-moulded organo-sheets offer the best chances to combine short and continuous carbon fibres for integral thermoplastic composite parts with excellent mechanical performance, light weight properties and complex shapes. Mass production components have appeared in electronics and automotive industry recently. In addition, this over-moulding technology can be extended by integrating metal components [1].

In contrast to these developments there does not exist any comparable technology for thermoset composites and appropriate material combinations at the market. In the area of Sheet Moulding Compound with random fibre distribution mechanical properties can be increased by using carbon fibres as reinforcement or by embedding unidirectional layers in the Sheet Moulding Compound formulation. These material versions are used in a few industrial sectors, especially in the automotive branch. Typical applications for vehicles or trucks are fenders, hoods, decklids, spoilers, scuttle panels, floor panels, tailgates, wheel arches and many more [2, 3]. In aerospace industries Sheet Moulding Compound and advanced versions are not well-established because of the high mechanical and weight-saving requirements. Nevertheless, there are several developments on cabin, cargo and other interior parts because of the excellent fire safety properties, high flame retardancy and high-quality surface finishing of special Sheet Moulding Compound formulations. Particular aerospace applications for structural parts are already commercialized in the field of prepreg compression moulding, for example by using HexMC® or Same Qualified Resin Transfer Moulding®. However, the combination of oriented, continuous carbon fibres prepregs, carbon fibre Sheet Moulding Compound combined and metal components represents a new technology approach for aircraft production and aerospace engineering. Therefore highly integrated parts could be designed and produced by means of this hybrid composite technology. [4-11, 12, 13]

3. Aim and purpose of present work

The intention of this work is the development of a new hybrid composite technology for aerospace applications which includes innovative material combinations and an efficient production process in at the same time. The combination of carbon fibre Sheet Moulding Compounds and pre-impregnated, oriented carbon fibre fabrics in a compression and curing process permits the production of lightweight, load-bearing and highly integrated aircraft parts, illustrated in Fig. 1. Especially the mixture of flowable Sheet Moulding Compound formulations with long fibre reinforcements and oriented fibre fabrics allows the production of parts with complex shape, high freedom of design and excellent mechanical properties. In this regard the level of fibre content and mechanical characteristics like flexural strength and tensile strength could be adapted exactly on the part requirements.

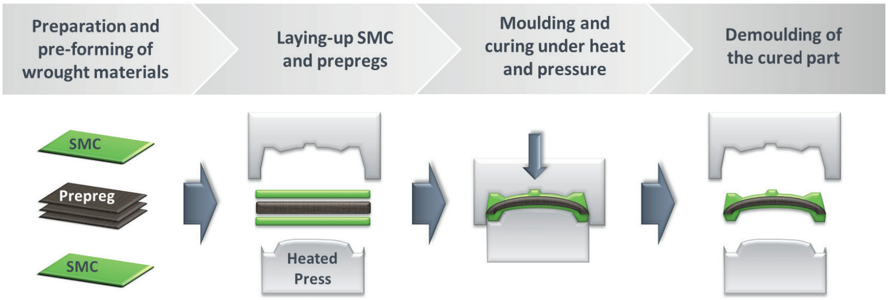

Fig. 1. Process cycle with the combination of pre-impregnated carbon fibre fabrics and carbon fibre Sheet Moulding Compound.

According to the part and the required material complexity this thermoset composite material could also be combined with metallic components in an one-step forming and compression process. These composite-metal-hybrids can generate a new material class. On the one hand these composite parts could be used for load-bearing cabin and interior parts which include fittings to structural components, attachments for system installations or other directly integrated functions, e.g. colouring. On the other hand structural parts with complex shape, different types of load cases and integrated fittings, fasteners and openings could be realized in one step. Furthermore future grid structures on inner shells of aircrafts could be put into practice with this technology. Besides the possibility of integral construction, oriented carbon fibre reinforcements for optimized mechanical properties and a reduction of adhesives, rivets, shim or additional fittings can minimize weight and costs. In addition, lower material costs and a better buy-to-fly ratio, as a consequence of an optimized cutting process, are causing lower part costs. Moreover the proposed hybrid press process creates higher productivity and lower production costs because of the possibility of complete automation and reduced cycle times compared to current carbon fibre composite processes. In this context compression processes lead to less energy consumption in aerospace production.

Possible materials for reinforcements are carbon fibres and also glass fibres, which can be combined with different thermoset matrix materials, e.g. unsaturated polyester resins or epoxy resin. Hereby, it is possible to use recycled carbon fibres, especially as long fibres for Sheet Moulding Compound formulations. Using recycled carbon fibres as reinforcements for Sheet Moulding Compound components can close the ecological value added chain referring to future aircraft. These carbon fibres come from end-of-life cycle aircraft parts or cutting scrap of the current aerospace production. The recyclates can result from recycling processes like pyrolysis. They offer a lower price level than new carbon fibres and possess up to 95 percent of the original mechanical properties. In this context, this technology can realize the reuse of expensive and energy-intensive resources as reinforcement materials for aircraft parts of the cabin, the interior and secondary structures. Consequently, the resource efficiency and the ecological sustainability of aerospace production for composite aircraft parts will be improved.

For investigations on material combinations and process parameters using the described technology a project was started by an interdisciplinary consortium. Different components from the cabin, the cargo area and the secondary structure of commercial aircraft will be realized. In this context these aircraft elements have to fulfil appropriate aerospace requirements. To obtain some information about technical, economic and ecological performance these components will be compared according to relevant requirements with the original ones. In addition a complete analysis shall relate this production process to current composite technologies to highlight its expected advantages for aerospace industries. Finally special simulation methods and FEM-models will be developed for design, dimensioning and calculation of composite or hybrid aircraft parts which should be produced with this new technology.

In a first study a cargo foot step made of titanium for a current commercial short and middle range aircraft from *Airbus* will be substituted. Cost savings and weight reduction as a result of increased mechanical properties, especially tensile strength, flexural strength, stiffness and impact strength, are the key aspects for the planed optimization. Subsequently, the substitution of other current aircraft components and the development of a completely new generation of aerospace composite structures and hybrid components will follow.

4. Experimental Procedures

For aircraft cargo area applications *Polynt* has developed a special Sheet Moulding Compound formulation called HUP 27. It is based on an unsaturated polyester resin and contains many additives. Because of a high percentage of flame-retardant components HUP 27 can fulfill the hard requirements on fire safety and flame retardancy. In this regard, aerospace materials have to pass special fire, smoke, toxity and burning tests, which are required in the cargo area of commercial aircraft. This material for cargo applications is produced with chopped glass fiber reinforcements. The general formulation is given by the requirements of the airworthiness limits of non-flammability and the necessary mechanical properties of appropriate applications. The processing additives are necessary, because the flame-retardant formulations, compared to the standard formulations with 150 phr non-volatilies, contain a high amount of non-organic materials. The proportions of non-organic components in regard to the organic ones for the Sheet Moulding Compound process are a big challenge. In general the Sheet Moulding Compound process is configured for viscosities from lowest level 10.000 mPas to 50.000 mPas. Without any process additives it is not possible to produce a homogenous paste for a stable process. To influence the burning behaviour negative is not allowed by using such additives. To obtain better impregnation of the reinforcement the viscosity has to be reduced. The building of the reinforcement works if the matrix-reinforcement-bonding is adequate to transfer the mechanical properties on the complete Sheet Moulding Compound material system. Otherwise the mechanical improvement is not given in the system. The flowability of the system is an important parameter for the impregnation of the complete system and the orientation of the fibres. In the first step different material combinations are tested to receive first material characteristics refering to flexural modulus, flexural strength, tensile modulus, tensile strength and impact strength. In this case nine reasonable material systems were analysed because of different possiblities of reinforcements, shown in Table 1.

Table 1. Material combination matrix (GF…glass fibre; CF…carbon fibre).

Outer layer \ Inner layer	HUP 27- GF, fibre content 25%, chopped fibres	HUP 27- GF, fibre content 50%, chopped fibres	HUP 27- CF, fibre content 50%, chopped fibres	HUP 27- CF, woven fabric	HUP 27- CF, unidirectional fibre reinforcment
HUP 27- GF, fibre content 25%, chopped fibres	X			X	X
HUP 27- GF, fibre content 50%, chopped fibres		X		X	X
HUP 27- CF, fibre content 50%, chopped fibres			X	X	X

The materials with the chopped reinforcements are used as inert systems for mechanical data base and for the outer systems. The materials with reinforcement fabric or unidirectional fibres are used for the inner layer. The mechanical properties determined for flate Sheet Moulding Compound plates are moulded according to DIN EN 14598. These plates have a thickness between 2.0 - 3.0 mm. The test specimen are cut from the non-flow area of a sample plate with the dimension of 250 x 120 mm and with mould conditions of 180 seconds at 145 °C. Afterwards the cut specimen is milled to the accurate dimension of each specimen. The Sheet Moulding Compound formulations for these different material samples were produced on a laboratory machine with a material width of 500 mm in a continuous production step. This lab scale machine allows several manual adjustments and the usage of different reinforcements. For investigations of the mechanical properties of each material combination following test methods were used:

- Flexural modulus and flexural strength according to DIN EN ISO 14125:1998 + AC:2002 + A1:2011.
- Tensile modulus and tensile strength according to DIN EN ISO 527-4:1997.
- Tensile modulus and tensile strength according to DIN EN ISO 527-5:1997.
- Impact strength according to DIN EN ISO 179-1:2010

These tests illustrate a first tendency refering to the improvement of mechnanical properties in consequence of integrated and continous fibre reinforcements.

5. Results and discussion

The results generated by the experimental investigations on the different material combinations are illustrated in Fig. 2 - 4. The parameters investigated are flexural modulus, flexural strength, tensile modulus, tensile strength and impact strength. As shown in this table, there is a significant difference between the measurements, especially in reference to the used type of fibre and depending on the combination of the different fibre reinforcements. In general, the measurements indicate that higher fibre contents and the use of chopped carbon fibres, instead of glass fibres, for Sheet Moulding Compound formulations can realise an improvement on flexural and tensile modulus, illustrated in Fig. 2. Moreover, woven fabrics and unidirectional layers of carbon fibre combined with Sheet Moulding Compound tend to result in an increase of the mentioned mechanical properties. Especially, HUP 27 with chopped carbon fibres (50 percent fibre content) combined with an unidirectional carbon fibre layer and also in combination with carbon fibre woven fabric can realise a significant improvement of flexural and tensile modulus. In contrast, Fig. 3 shows that the flexural strength is hardly influenced by additional and oriented reinforcements. The reason for this could be the chemical adaption of HUP 27 to glass fibres. As a consequence, HUP 27 samples with carbon fibre reinforcements are partially delaminating. This is caused by poor interlaminar shear strength behaviour. Furthermore, the high percentage of flame-retardant components lowers the fibre contents and leads to degradation of the interlaminar connection between the carbon fibres and the matrix material.

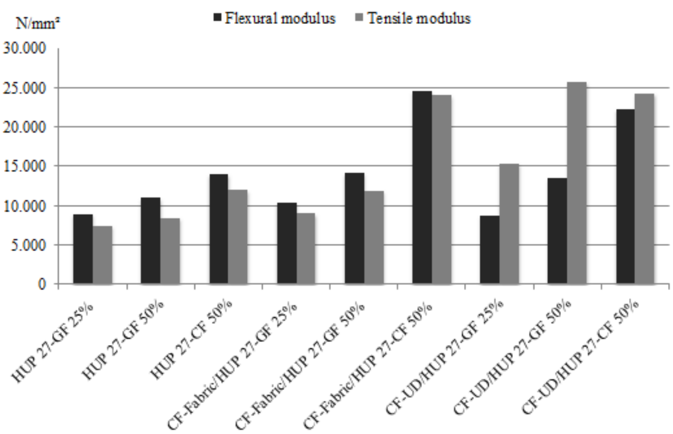

Fig. 2. Flexural and tensile modulus for different material combinations.

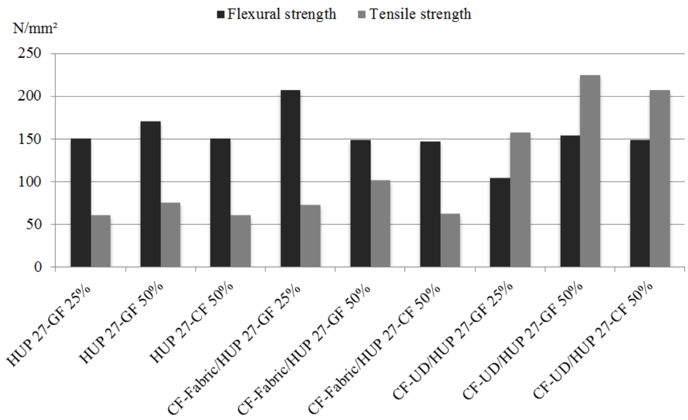

Fig. 3. Flexural and tensile strength for different material combinations.

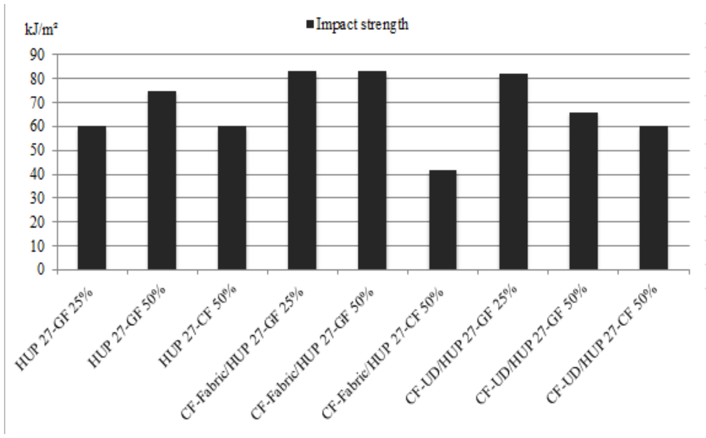

Fig. 4. Impact strength for different material combinations.

Generally, the tensile strength can be increased by additional continuous fibre reinforcements, shown in Fig. 3. In this regard, the integration of unidirectional layers of carbon fibre doubles the tensile strength in comparison to the original Sheet Moulding Compound formulations. In opposition to that the combination of HUP 27 and carbon fibre fabrics realizes just a small improvement of the tensile strength.

The impact strength is positively affected by material combinations of glass fibre reinforced HUP 27 and additional carbon fibre reinforcements, especially woven fabrics of carbon fibre, illustated in Fig. 4. Due to the poor interlaminar shear strength between carbon fibres and HUP 27 there is no improvement of the impact behaviour. In the case of HUP 27-CF 50% combined with carbon fibre fabrics the impact strength is even reduced. All in all a positive trend of the mechanical properties by the combination of Sheet Moulding Compounds and continuous fibre reinforcements can be stated. For further optimisation of the material characteristics Sheet Moulding Compound formulations have to be adapted to the particular fibre reinforcements. As a result, interlaminar shear strength will be improved. Furthermore, Sheet Moulding Compound materials have to be optimised for the impregnation of the reinforcements and to increase the flowability of the Sheet Moulding Compound material during the moulding process. The stacking of the layers, the fixing of the continiuos fibre reinforcement during the moulding process and the mechanical requirements of the components are additional topics to improve the mechnical properties. All things considered, the key aspect for realising a hybrid composite component is the exact adaption of SMC formulation, oriented fibre reinforcements and part requirements like mechanical properties or flame redardancy.

6. Conclusion

The results obtained in this study lead to the conclusion that the development of the combination of SMC and pre-impregnated, orientated carbon fibre fabrics is auspicious refering to an improvement of mechanical properties. This technology promises optimsed light weight and load-bearing properties in connection with complex shapes and design freedom. However, for aerospace appilications there does not exist a special SMC formulation. Consequently, each material combination has to be developed for or adapated to the requirements of the particular application. In this regard the design and geometry of the components are important too. For the design, the dimensioning and the simualtion special material models and finite element method simulation tools have to be developed. In reference to the process the pre-forming, preheating, positioning and fixing of the wrought materials, especially the orientated carbon fibre fabrics, have to be considered. Further studies will focus on the analysis and optimisation of process parameters like flowability, moulding temperature, moulding pressure and moulding time. In addition the integration of metal components like inserts, fasteners or panels will be realized. For the industrialisation of the process an automation concept with different batch sizes and part designs has to be evaluated in regard to the technological, economical and ecological aspects. Altough there are many open questions, this innovative, hybrid composite technology offers many benefits, extented potentials and a lot of applications within the aerospace and also other industries.

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