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CRASHWORTHINESS OF HYBRID STRUCTURES

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ABSTRACT

This study describes possible weight reductions, achievable by the use of hybrid automotive structures. The hybrid structures studied here consist of steel profiles reinforced with carbon fibre reinforced plastics (CFRP). The manufacturing of these components is realised by prepreg press technology. Different crash tests on these structures compared to mere steel solutions are presented. It can be shown that weight reductions of up to 25 % are possible.

Keywords: hybrid structure, fibre reinforced plastic, prepreg press technology, high-strength steel, lightweight design.

INTRODUCTION

Economic and ecological constraints have meant that the development of lightweight concepts for high volume automotive applications has become extremely important. Reducing the mass of vehicles also reduces various driving resistances. Hence, the mass is directly linked to the fuel consumption and the CO_2 emissions of an automobile.

For structural applications, where crashworthiness is the determining factor, material-based lightweight construction is a very important approach for reducing masses. Currently, three main trends are obvious: Lightweight design can be achieved by utilizing high-strength metal alloys, substituting metals with composites, and locally combining different materials to hybrid structures.

Using high-strength metal alloys offers the opportunity to reduce wall thickness of structures (Zhang, 2006). However, once a critical minimum thickness is reached, designers can expect stiffness and stability problems. Thus, the potential of high-strength materials for light weight construction is limited. Besides the use of high- and ultra-high-strength metal alloys, also a replacement of conventional construction materials with fibre reinforced plastics (FRP) can result in significant weight reductions (Adam, 1997, Jacob, 2010, Mamalis 2004). This substitution is currently restricted to high-priced vehicles because of long cycle times and high material costs (Zhang, 2012).

Another approach is to combine different materials to form multi-material or hybrid structures. Because most components are non-uniformly loaded, the structure may be adapted to the load situation to achieve the minimum weight. Such an adaption can be realized easily with hybrid structures where a sheet metal basic layer is locally reinforced with a CFRP patch in the highly loaded areas. Due to the local use of CFRP, the costs are effectively limited and the component can easily be integrated into existing vehicle production processes. Stamp forming of these metal-composite sandwich structures provides an efficient manufacturing method to produce products in high volumes (Gresham, 2006).

In this study results for crash tests on hybrid structures are presented. The structures were manufactured by the prepreg press technology. The prepreg press technology is one approach to produce structural automotive parts in high volumes (Asnafi, 2000, Lauter, 2011).

PREPREG PRESS TECHNOLOGY: OVERVIEW AND PROCESS FLOW

The process of prepreg press technology can be divided into four steps (Fig. 1). First, prepregs (pre-impregnated, semi-finished fibre products) are produced continuously on special machines and shipped on coils. The layer structure is realised according to the expected loads in the component, for example a b-pillar. The laminate is cut corresponding to the later structure geometry. Second, a robot handles the prepregs. After inserting an already formed steel structure into a heated steel tool the prepreg is applied to the steel structure by automated handling. Then the tailored prepreg is pressed onto the sheet metal by a heated punch. As the epoxy resin functions as an adhesive the joining of sheet metal and CFRP is realised in this third step, too. After a pre-curing of about 90 to 120 seconds, depending on the thickness of the prepreg, the hybrid component is removed by a robot and stacked. The post-curing of the components is realised during a downstream cataphoretic painting process.

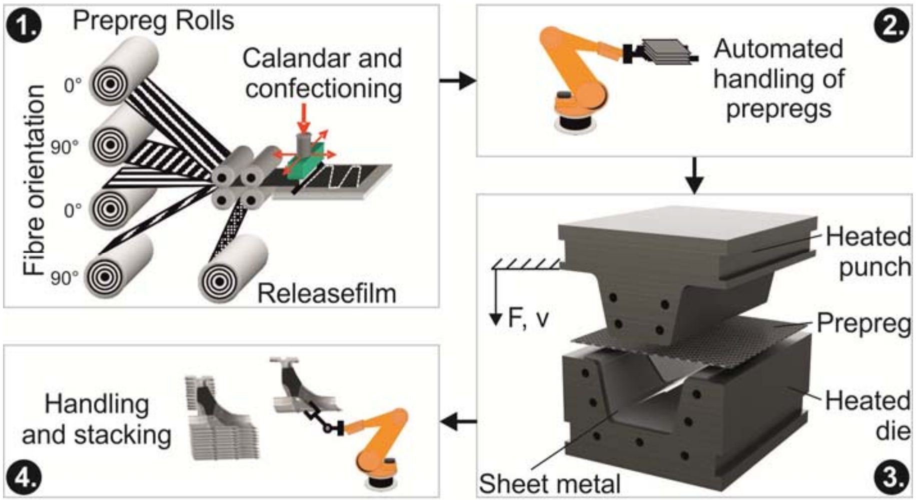

Fig. 1 Process steps for prepreg-pressing to produce hybrid automotive structural parts, for example a b-pillar

PREPREG PRESS TECHNOLOGY: INVESTIGATIONS ON PROCESS PARAMETERS

The closed mould of the prepreg-press-technology can be identified as a bottleneck. A high cycle time reduces the qualification of prepreg-pressing for a large volume production. Adequate process parameters correlate directly with the cycle time of the press process. Thus, process parameters should allow low cycle times and good mechanical properties at the same time. The influence of different parameters is discussed below.

To investigate the process parameters epoxy-resin prepregs with 9 layers were used. The layer structure of the bidirectional carbon fibre scrim was (90/0/0/90/$\underline{0}$/90/0/0/90°). As matrix resin a SGL type E201 was employed. For the steel component a DD11 and a 22MnB5 alloy, respectively, was utilised. In a first step, test plates (sheet metal material: DD11) and hat sections (sheet metal material: 22MnB5), respectively, were manufactured by prepreg-pressing. After a press process using a pre-curing time t_{prc}, a consolidation pressure and temperature, the plates were post-cured in a furnace heating of 180 °C and t_{poc} = 30 minutes.

In a next step three-point-bending samples were cut from the test plates and hat sections, respectively, and analysed with a testing machine. Using the matrix resin as an adhesive to bond the sheet metal and the CFRP makes an additional joining process superfluous.

Fig. 2 shows the results of hybrid three-point-bending samples cut out of test plates. In the force-displacement diagram four curves for different process parameters are plotted. The consolidation temperature was not varied in this case. Varied parameters were the consolidation time (t_{prc} = 60 and 90 seconds) and the consolidation pressure (p = 0.1 and 0.6 MPa). For the curves a characteristic run can be identified. After a first rising the run flattens slightly. At the maximum force the main breakage occurs. Afterwards, single layers break step by step. In the end the fibre component fails completely and only the steel component absorbs the working forces.

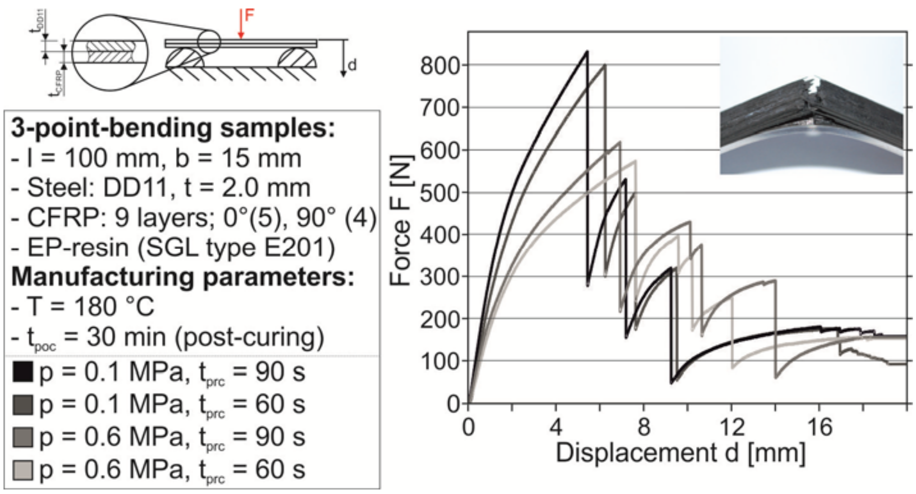

Fig. 2 Force-displacement diagram for hybrid three-point-bending samples

To realise short cycle times the pre-curing time is the most important process parameter. Several hat sections were manufactured by prepreg press technology with a consolidation pressure of p = 0.3 MPa and a temperature of T = 180 °C by prepreg-pressing. The pre-curing time t_{prc} differed from 0 to 8 minutes. The hat sections were post-cured for t_{poc} = 30 minutes at T = 180 °C. Afterwards, three-point-bending samples were cut out of these hat sections. The results of the tests are illustrated in a force-pre-curing-time diagram (Fig. 3). The maximum forces for the bending samples reach a steady level for at least about t_{prc} = 60 seconds. A higher pre-curing time does not lead to higher maximum forces. The maximum forces vary between 3000 N and 3300 N. The failure of the CFRP is analogous to the samples described before. Thus, a minimum pre-curing time of 90 to 120 seconds is realistic for a prepreg-thickness of 2 mm and the use of standard epoxy resins. Due to variances in the tool temperature a safety factor should be taken into account.

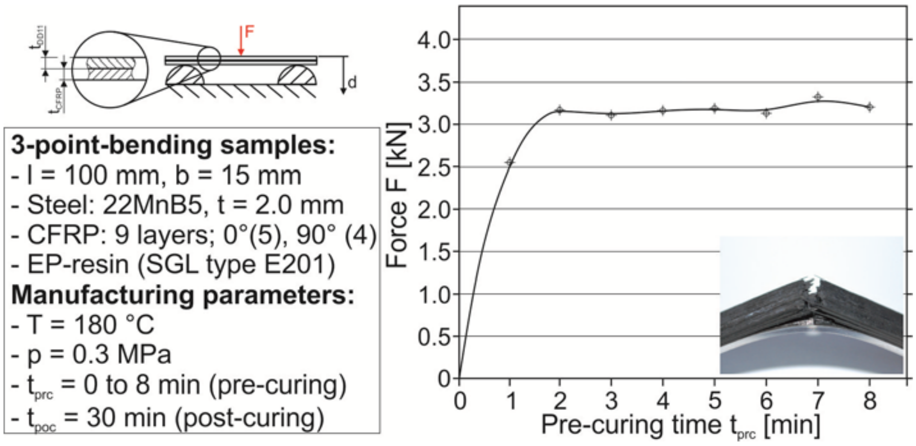

Fig. 3 Force-pre-curing-time diagram for hybrid three-point-bending samples

MECHANICAL PROPERTIES OF HYBRID STRUCTURES

For the studies on hybrid structures, double-Z- and hat-profiles have been selected as simple test geometries (Fig. 4). These profiles represent typical cross sections which can be found in automotive structures like pillars or rocker panels.

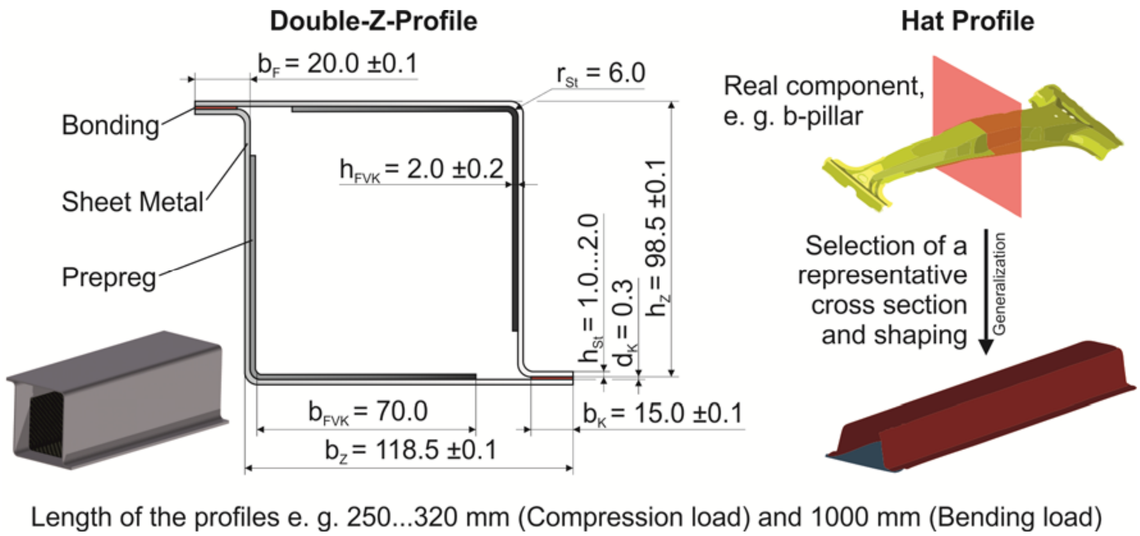

Fig. 4 Reference geometries: double-Z- and hat profile

For the crash and quasistatic tests two different configurations have been chosen. On the one hand, the profiles were hit by a plain impactor in the direction of their axis (compression load) and on the other hand by a cylindrical impactor perpendicular to their axis (three-point-bending test). The test facilities and setups are shown in Fig. 5.

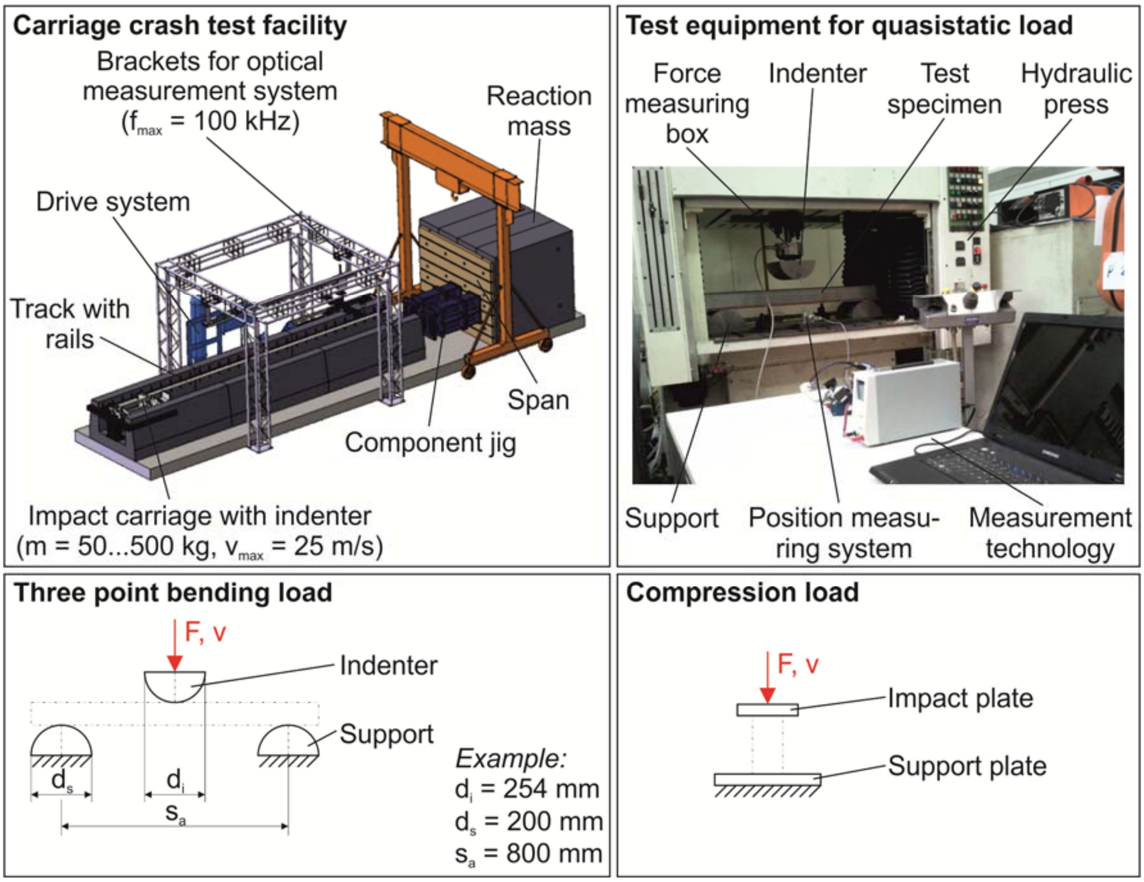

Fig. 5 Test facilities for crash and quasistatic loads

Results of the quasistatic and crash tests are shown in Fig. 6 and Fig. 7 (cf. Bambach, 2009). In all cases, a mere steel solution has been compared with hybrid profiles consisting of steel reinforced with CFRP. In the case of the three-point-bending, the hybrid profiles were dimensioned for the same stiffness as the steel reference. In this case, by varying the steel sheet thickness and parameters of the CFRP reinforcement (number, orientation and size of unidirectional layers), a weight reduction of about 25 % has been achieved.

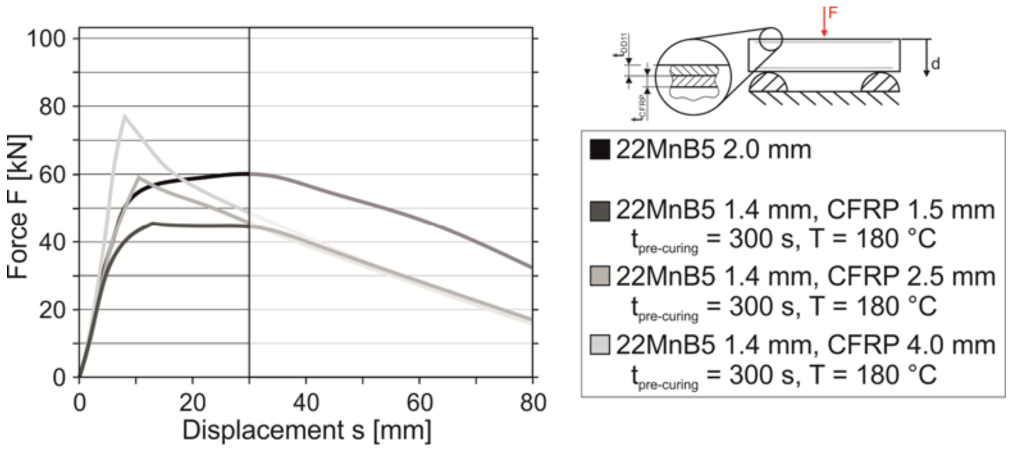

Fig. 6 Results for different quasistatic tests on double-Z-profiles

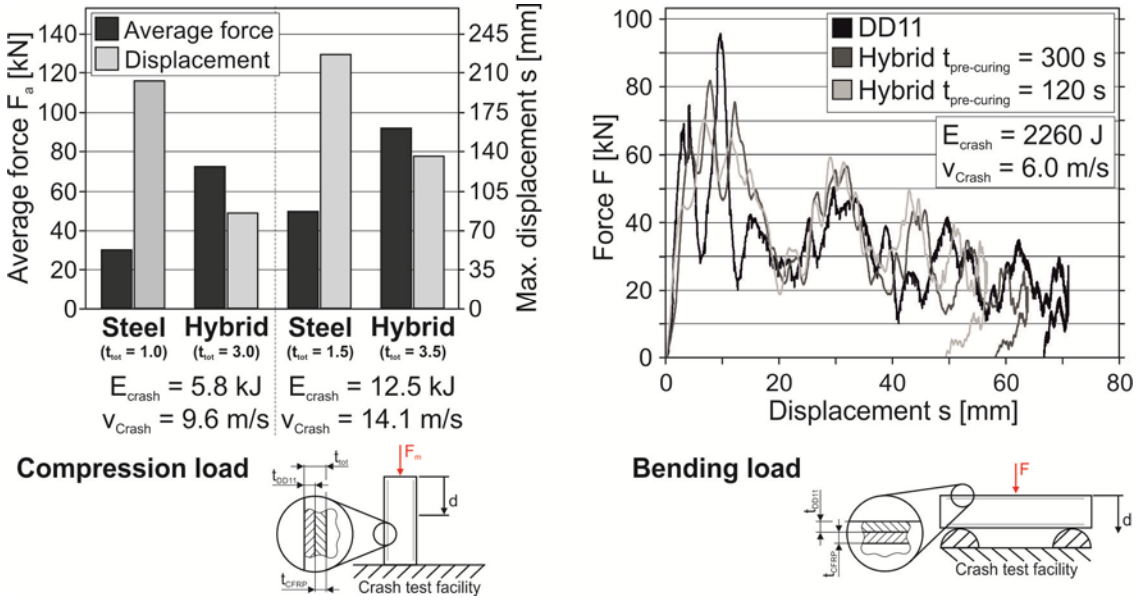

Fig. 7 Results for different crash tests on double-Z-profiles

In the case of the compression loading, the fraction of the energy absorption of the materials can be estimated to 12.4 kJ/kg for the steel and to 31.1 kJ/kg for the CFRP. In the case of the three-point-bending, the both tests reveal a very similar behavior of the steel and the hybrid component at the beginning. However, at a certain deformation, the outermost layers of the CFRP breaks stepwise, resulting in a steep decrease of the force level. Thus, such a configuration is suitable only for components which are intended to guarantee a high structural integrity.

CONCLUSIONS

Hybrid structures consisting of sheet metal and fibre-reinforced plastics offer a major potential for lightweight design in the automotive industry. The prepreg-press-technology allows a significant reduction of process steps as well as process time. By using prepreg-press-technology CFRP prepregs are formed into steel structures. The bonding is realised by the use of the epoxy resin as an adhesive, which offers an adequate joint strength. Further, it has been shown that the structures offer a good performance under quasistatic and crash loads.

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