HYBRID STRUCTURES OF METALS AND FIBER REINFORCED THERMOPLASTICS FOR CHASSIS COMPONENTS

Katja A. Tenhaeff[1], Klaus Drechsler[2]

[1]Department for Axle Components, BMW Group, Knorrstraße 147, 80937 Munich, Germany
Email: katja.tenhaeff@bmw.de, Web Page: http://www.bmwgroup.com
[2]Institute for Carbon Composites, Faculty of Mechanical Engineering, Technical University of Munich, Boltzmannstraße 15, 85748 Garching b. München, Germany
Email: drechsler@lcc.mw.tum.de, Web Page: http://www.lcc.mw.tum.de

Keywords: hybrid structures, fiber reinforced thermoplastics, chassis components

Abstract
Conventional same-part strategies used in the automotive industry lead to functionally redundant weight for most vehicles and impede necessary component modifications in later development stages. One possible approach for a more flexible modular system is the systematic use of hybrid synergy parts. Using local tape reinforcements allows for designing the metallic base components for a less demanding vehicle; hence the weight of the metallic component can be reduced. For car models with higher requirements, full functionality is achieved by local tape reinforcements which are applied in an Automated Fiber Placement process.
A potential study for composite reinforcements for components with stiffness-driven design is conducted using geometrically simple principle parts. These are derived from chassis parts and equipped with Polyamide-based fiber reinforced tapes. Monoaxial stiffness tests based on metallic and reinforced specimens are performed. Fiber type (glass, carbon) and fiber orientation (0°, ±45°) are varied at a constant laminate thickness. The results are presented by the example of pressure tests; they show the highest stiffness increase of up to 44 % for carbon reinforcements in the parts' longitudinal direction. Finite-element pressure tests demonstrate a similar behavior regarding variation of tape material and fiber orientation. The simulation overestimates the measured stiffness values for most configurations.

1. Introduction

In recent decades the automotive industry has experienced a multiplication of model and equipment variants. This rapid increase in part numbers necessitates the implementation of modular strategies in order to limit development, manufacturing and logistics costs [1]. A conventional modular system has the following drawback: Components are designed for the car with the highest mechanical requirements. This results in functionally redundant weight – and fuel consumption – for all other vehicles within this product group. One possible approach for a more flexible modular system is to use hybrid structures with a metallic base component and local composite reinforcements for car models with higher requirements. Extensive research has been done for vehicle body applications regarding crash performance of hybrid structures [2]. For instance, [3, 4] designed an automotive body platform with enhanced crash performance through local reinforcements made of organic sheets. The potential of hybrid B-pillars was investigated using thermoset [5] and thermoplastic composite reinforcements [6].

Excerpt from ISBN 978-3-00-053387-7

For the design of chassis components, however, one of the major functions is stiffness since it is a prerequisite for precise vehicle dynamics. For this purpose, the potential of fiber reinforced plastic (FRP) scaling measures is examined using principle parts which are derived from structural chassis components. The hybrid specimens are tested regarding torsional, flexural and tensile rigidity; this study focusses virtual and hardware pressure test results.
The application aims at automatable part modifications with low tooling costs and at geometrically complex components. Hence an in-situ Automated Fiber Placement (AFP) process with thermoplastic UD tapes is chosen as manufacturing process [7, 8, 9].

2. Materials and Experimental Setup

The potential of FRP reinforcements is examined using prismatic principle parts. In the following, the utilized materials, scaling configurations and test setups for the virtual and hardware studies are described.

2.1. Principle Parts and Materials

In order to ensure relevance of the principle part examiations for the planned application, they are derived from chassis components. Structural parts such as axle carriers and control arms of the wheel suspension serve as a reference for the principle parts. Due to economic and risk management reasons, initial series production of FRP-reinforced chassis components is more likely for smaller production volumes. Therefore, the selection of reference components focusses on higher-priced product lines. For the axles of these vehicles the usage of aluminum alloys is widely spread. For this reason, the substrate material for the principle parts is restricted to aluminum. As shown in Figure 1, the cross-sections of the selected components serve as reference for the generic parts. Their simplified geometries are a tubular, a hollow rectangular and a full-section rectangular profile. The dimensions are chosen from standard extrusion profiles; the base material is an Al MgSi alloy.

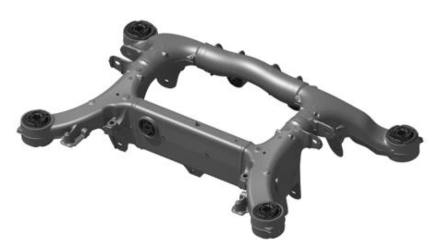
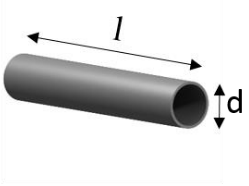
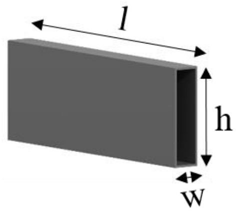
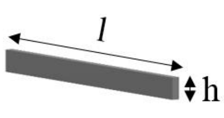
Reference parts			
Principle parts			
Dimensions	• d = 85 mm • l = 500 mm • t = 5 mm	• h = 180 mm • w = 40 mm • t = 4 mm • l = 500 mm	• h = 40 mm • w = 15 mm • l = 500 mm

Figure 1. Reference components and principle parts.

Excerpt from ISBN 978-3-00-053387-7

The reinforcements are applied in an in-situ Automated Fiber Placement (AFP) process with thermoplastic UD tapes. The utilized semi-finished products are Polyamide-based (PA) glass and carbon fiber tapes as defined in Table 1.

Table 1. Utilized tape materials.

Matrix polymer	Fiber type	Fiber volume content	Nominal tape thickness
PA66	E-glass	40 %	0.15 mm
PA66	Carbon (standard modulus)	47 %	0.30 mm

2.2. Specimen Configurations

As fiber orientations for the hybrid specimens, the assumed maxiumum reinforcement angles for pressure/bending and torsion are selected. The angles are 0° and ±45° referred to the profile's longitudinal axis. Both glass and carbon tape reinforcements are tested. They are applied to the entire outer surface of the generic parts. In order to achieve comparability regarding usage of available space, the thickness of the reinforcement is kept constant. A 1.2 mm thick laminate is chosen which is equivalent to 8 layers CFRP and 4 layers of GFRP, respectively. This results in four different reinforcement configurations as shown in Table 2.
For manufacturing reasons, the application of ±45° tape layups is most uncritical for the tubular profile; therefore all four reinforcement configurations are implemented for this part. The rectangular profiles are examined in two configurations each. Since axial stiffness is most relevant for the refererence component of the full section profile, the two UD configurations are realized for this part. The hollow rectangular profile is reinforced in both configurations of the higher modulus material (CF tape).

Table 2. Specimen configurations.

Reinforcement / Profile	None	Carbon fiber tapes		Glass fiber tapes	
		0°, 1.2 mm	**±45°, 1.2 mm**	**0°, 1.2 mm**	**±45°, 1.2 mm**
	X	X	X	X	X
	X	X	X		
	X	X		X	

Excerpt from ISBN 978-3-00-053387-7

2.3. Hardware Manufacturing and Test Setup

In order to evaluate the scaling potential of FRP reinforcements for metallic components, hybrid specimens are manufactured using a laser-assisted Automated Fiber Placement system. Prior to the process, the aluminum parts are coated with an adhesion promoter of approximately 75 µm thickness. The tapes are then welded directly onto the prepared profiles without subsequent consolidation process.

To take account for manufacturing and measurement variations, six parts per configuration are manufactured and tested. The experiments are performed with a Zwick universal testing machine of precision class 1 and a maximum load of 250 kN. This study presents the stiffness scaling by example of a pressure test. The specimens are compressed between two pressure plates under axial load. The deformation is measured directly at the specimens using strain gauges which are applied in longitudinal direction of the profile. The quasi-static load is applied with a traverse speed of 1 mm/min. The test is repeated three times to prove absence of test-induced damages on the basis of unchanged load-strain-curves. The gradient is determined using linear regression and averaged over the 18 tests (6 specimens, 3 repetitions) per configuration.

2.4. Model Setup

Reliable simulation models are crucial for efficient development processes. For this reason, the virtual prediction capability is evaluated by comparing the hardware test results to finite-element (FE) pressure tests. The principle part ist modeled as an aluminum base profile consisting of quadratic solid elements (type CD20, 2.5 to 5 mm edge length). The FRP reinforcements are simulated as a composite shell layup comprising the adhesion promoter and the tape layers; they are connected to the base profile through coincidental nodes. At one end of the profile, the nodes are clamped. The force is applied to the nodes of the specimen’s other end face. The axial stiffness is determined similarly to the hardware test by measuring the distance alteration of two nodes at the outer surface of the part. The distance in undeformed condition is 20 mm which corresponds to the strain gauge’s length.

3. Results and Discussion

In the following, the results from the virtual and hardware examinations are presented. The axial stiffness is assessed by the gradient of the linear part of the force-strain-curves. Figure 2 shows the percentagewise stiffness increase compared to the base profile both for hardware and simulative tests.

Excerpt from ISBN 978-3-00-053387-7

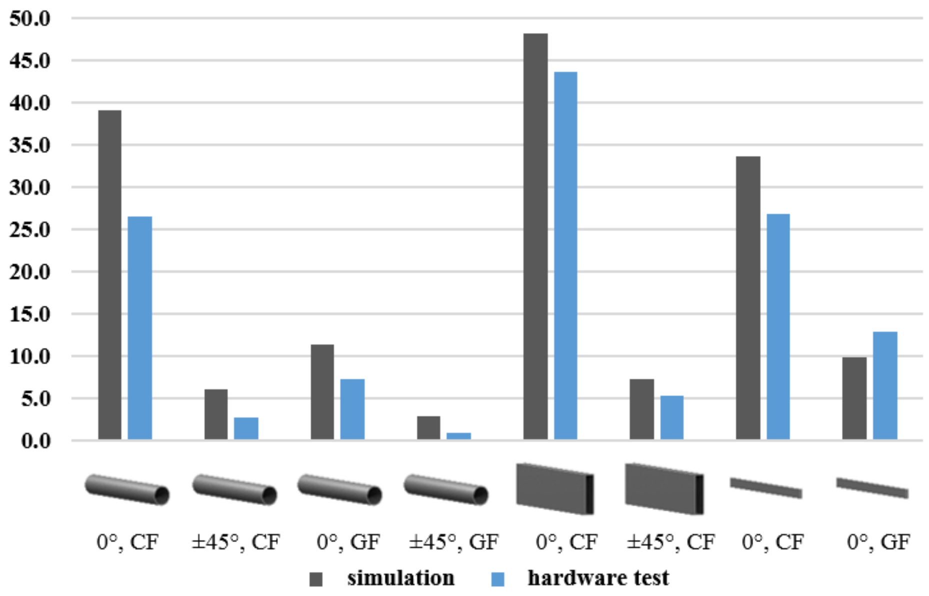


Figure 2. Increase in axial stiffness compared to metallic parts.

3.1. Simulation Results

The simulated rise in axial stiffness compared to the metallic base profiles is represented by the left (dark grey) bars in Figure 2. The highest computed rigidity increases are achieved for the 0° reinforcements. They range from 34 % for the full-section rectangular to 48 % for the hollow rectangular specimen for carbon tape reinforcements; the scaling effect of the UD glass reinforcements is below one third of the carbon tapes with values of 10 to 11 %. Both carbon and glass configurations with ±45° fiber orientation achieve moderate scaling effects between 3 and 7 %.

The simulative results are in good agreement with analytical calculations as the simulative stiffness increase is approximately proportional to the reinforcements' end face area and elastic modulus in load direction. The different scaling effects for same FRP layups between the principle parts can be explained through the different ratios of metallic to FRP cross-section areas. Referred to the metallic end face area, the full-section profile offers the smallest circumference for the application of FRP reinforcements, the non-tubular hollow profile the largest. The modulus of the glass tapes is more than two thirds lower than the one of the CFRP tape. Therefore, the scaling effect is reduced to approximately one third; for the full-section rectangular part it decreases from 33 % for carbon to 10 % for glass reinforcements.

3.2. Hardware Results

The increase in the load-strain gradient is visualized by the right (blue) bars in Figure 2. Similar to the simulation results, the greatest increase in stiffness is detected for 0° reinforcements. The values range from 27 % for the full-section rectangular and tubular profile to 44 % for the hollow rectangular profile. The scaling effect for the ±45° reinforcements is between 1 % for glass reinforcement of the tubular part and 5 % for the carbon tape-equipped hollow rectangular profile.

The influence of tape material and fiber orientation on the scaling effect is comparable to simulative test results. The values for the stiffness increases differ from the FE results though. Therefore the results' interpretation requires further research. Causes of the deviations could be due to material, application process (AFP), measuring equipment or test method. For instance, the moduli for the

Excerpt from ISBN 978-3-00-053387-7

utilized semi-finished products (profiles, tape) can vary from the utilized material properties. Moreover, the AFP process affects through temperature and pressure distribution the mechanical properties of the tape and the connection to the adhesion promoter. Deviations due to the test setup could be identified through comparison to other test types, e.g. bending tests.

4. Conclusions and Future Work

Principle parts were derived from typical chassis components in order to examine the potential of glass and carbon FRP scaling measures. The results show that usage of carbon fiber tapes is required for higher scaling effects and that knowledge of load directions is crucial for efficient implementation of local FRP reinforcements. Hardware and simulative tests displayed similar behavior regaring fiber orientation and tape material changes; the values however varied. Therefore, further analysis of the hardware samples and inclusion of bending and torsion tests results is required. Furthermore the transferability to more complex structures such as axle carriers and control arms has to be examined. Considering the components' operating conditions, the influence of temperature and media loads on the scaling effect has to be investigated.

Acknowledgments

We would like to thank Stefan Ehard and Thomas Wetteman from the Institute for Carbon Composites of the Technical University of Munich for the manufacturing of the hybrid specimens. Special thanks go to Dr. David Keller for his editorial advice.

References

[1] F. Tesch. Bewertung der Strukturvariabilität von PKW-Karosseriederivaten. *Dissertation, Technical University of Munich.* 2010.
[2] C. Mildner. Numerische und experimentelle Untersuchungen des Crashverhaltens von FVK-verstärkten Metallstrukturbauteilen. *Dissertation, Technical University of Munich.* 2014.
[3] L. Eckstein, L. Ickert, M. Goede, N. Dölle. Leichtbau-Bodengruppe mit Verstärkungen aus CFK und GFK. *Automobiltechnische Zeitschrift (ATZ),* 113 (4): p. 256-261, 2011.
[4] L. Ickert. FVK-Metall-Hybridbauweise für die automobile Großserie. *Dissertation, RWTH Aachen University.* 2014.
[5] C. Lauter. Entwicklung und Herstellung von Hybridbauteilen aus Metallen und Faserverbund-kunststoffen für den Leichtbau im Automobil. *Dissertation, Padernborn University.* 2014.
[6] P. Kellner. Zur systematischen Bewertung integrativer Leichtbau-Strukturkonzepte für biegebelastete Crashträger. *Dissertation, Technichal University of Dresden*. 2013.
[7] F. O. Sonmez, H. T. Hahn. Analysis of the on-line consolidation process in thermoplastic composite tape placement. *Journal of Thermoplastic Composite Materials,* 10 (6), pp.543 – 572. 1997.
[8] Z. Quereshi, T. Swait, R. Scaife, H.M. El-Dessouky. In-situ Consolidation of Thermoplastic Prepreg Tape Using Automated Tape Placement Technology: Potential and Possibilities. *Composites Part B: Engineering,* 66: p. 255–267, 2014.
[9] C. Brecher, D. Werner, M. Emonts. „Mulit-Material-Head" One Tool for 3 Technologies: Laser-Assisted Thermoplast-Tape Placement, Thermoset-Prepreg-Placement and Dry-Fiber-Placement. *Proceedings of the 20th International Conference on Composite Materials ICCM-20, Copenhagen, Denmark,* July 19-24 2015.

Excerpt from ISBN 978-3-00-053387-7