INVESTIGATION ON BENDING AND CRACK PROPERTIES WITH A CARBON FIBER SANDWICH STRUCTURE

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ABSTRACT

As a students' project we investigated two different carbon fibre composite structures for a students' racecar: FBH (front bulkhead) is used at the forefront of the car. FBHS is used at the sidewalls of the car. The differences are analysed by a mechanical 3-point bending test as well as visually by appearance of their crack appearance and propagation. The gained information allows for future improvement of the monocoque structure of the car.

1 INTRODUCTION

Project work enhances the students' motivation to work with innovative materials such as composite materials [1]. They get the opportunity to implement their own ideas and to put their study contents directly into practice. Whilst designing a racecar the students must implement new and innovative problem solutions. They search for innovations to make the car faster, lighter and better. If a part fails, the students can get firsthand information from the broken part and improve their design. Furthermore, they are able to examine the part. Material sciences are a big portion during the investigation about the cause of the failure [2, 3]. Designing, building, validating and afterwards examining a racecar is a very exciting way to improve the personal thinking and skillset permanently. The obtained knowledge will be useful for their further career after their graduation.

2 GENERAL SPECIFICATIONS

2.1 Raw Materials

The panel is manufactured as sandwich structure with prepreg. Layers of twill and unidirectional prepreg are used. The honeycomb is made from EN AW-5056 and bought from Plascore with a cell size of 6.4 mm and a density of 83 kg/m³. The used twill prepreg was acquired from R&G Faserverbund-werkstoffe GmbH. The twill is a 3k fiber with a weight of 200 g/m². The unidirectional CFRP is the prepreg from DeltaPreg with the DT120 epoxide matrix with the Torayca M40J fiber from Toray Carbon Fibers.

2.2 Manufacturing process

We studied a special part of the monocoque, the front bulkhead (FBH). This is a sandwich structure with a 20 mm aluminium honeycomb core. The laminate construction itself for the outer skin is composed as follows: 14 layers of twill in 0°/90° orientation, 4 layers of UD in + and – 45° orientation, 1 layer of twill in 0°/90° orientation. The core is the 20 mm aluminium honeycomb. For the inner skin the lay-up is as follows: 5 layers of twill in 0/90° orientation, 2 layers of UD in + and – 45° orientation, 1 layer of twill in 0°/90° orientation. The reason for the specific layering with the unidirectional prepreg is to build a long fibre that goes helically through the entire monocoque.

The fleece is the last layer that is on the laminate. The vacuum bag seals the laminate and creates an evenly distributed pressure onto the ply so that the layers are properly bonded together. The laminate was cured out of autoclave in an oven with a pressure of -90000 Pa. The curing cycle had a heat up ramp from 3 °C/min with a hold temperature of 100 °C. The hold duration was 6 hours and the decrease temperature was also 3 °C/min. Demoulding was done after reaching below 30 °C.

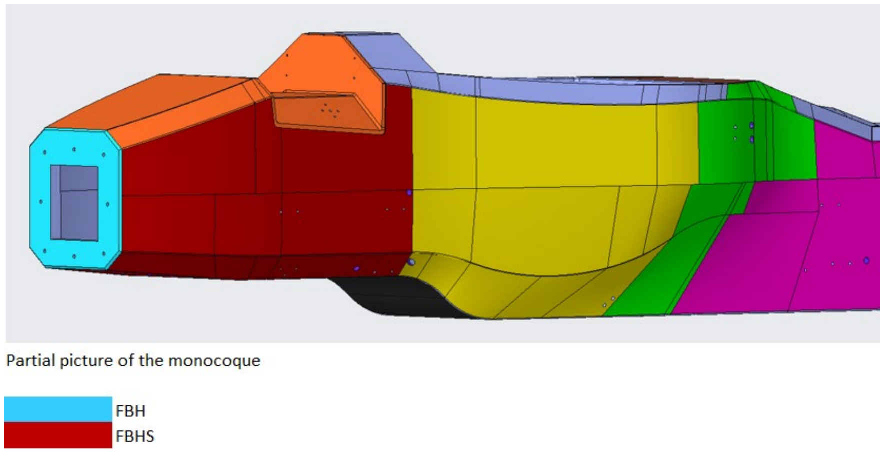

Figure 1: Positioning of FBH and FBHS at the monocoque.

Since not every part of the monocoque must meet the same requirements the FBHS has been designed. The FBH and FBHS structures differ in their position in the monocoque (Fig. 1). The FBHS is the support structure of the FBH in case of impact.

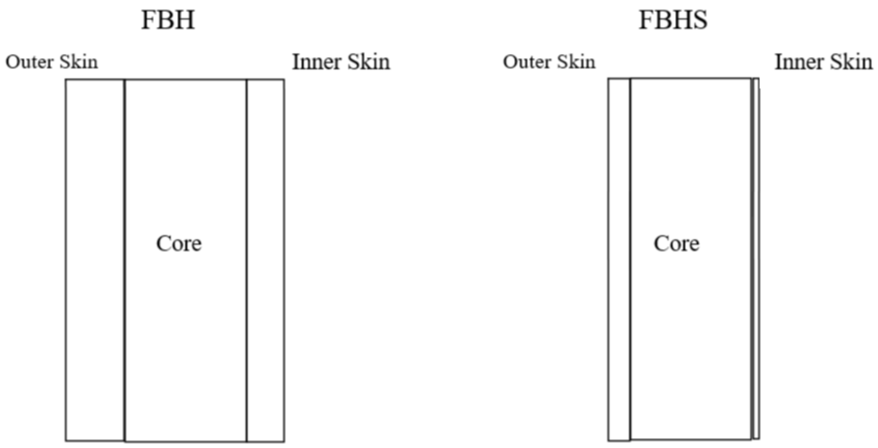

Figure 2: Schematic diagram of the difference between FBH and FBHS.

2.3 Composite structures

FBH and FBHS can be distinguished with respect to their layer composition (Fig. 2): Whereas the core is the same alloy in both cases, the FBH and FBHS structures differ in thicknesses of their CFRP layers. Since FBH is used at the forefront of the car, it has to absorb more energy and therefore is designed more robust with thicker surrounding layers (Fig. 2, Table 1). In case of the FBHS structure, which is applied at the sidewalls of the car, priority was given to a lightweight composite structure with thinner surrounding layers.

	FBH	FBHS
core thickness (mm)	20	20
inner skin thickness (mm)	1,5	1,08
outer skin thickness (mm)	3,5	1,56
inner skin layup	5*twill, 0°/90°; 2*UD,+-45°; 1*twill, 0°/90°	3*twill, 0°/90°; 2*UD,+-30°; 1*twill, 0°/90°
outer skin layup	14*twill, 0°/90°; 4*UD,+-45°; 1*twill, 0°/90°	4*twill, 0°/90°; 4*UD,+-30°; 1*twill, 0°/90°

Table 1: Comparison between FBH and FBHS structure.

2.4 Laminate testing

The 3-point bending test was done on a Zwick/Roell RetroLine tensile testing machine (Fig. 3). The distance between the two test panel supports was 400 mm and the radius of the load applicator measures 50 mm (Fig. 1). The load applicator overhang the test panel to prevent edge loading. This test is considered as a quasi-static test and will not reflect any crash situation, where dynamic loads are applied. The speed of the load application is 10 mm/min.

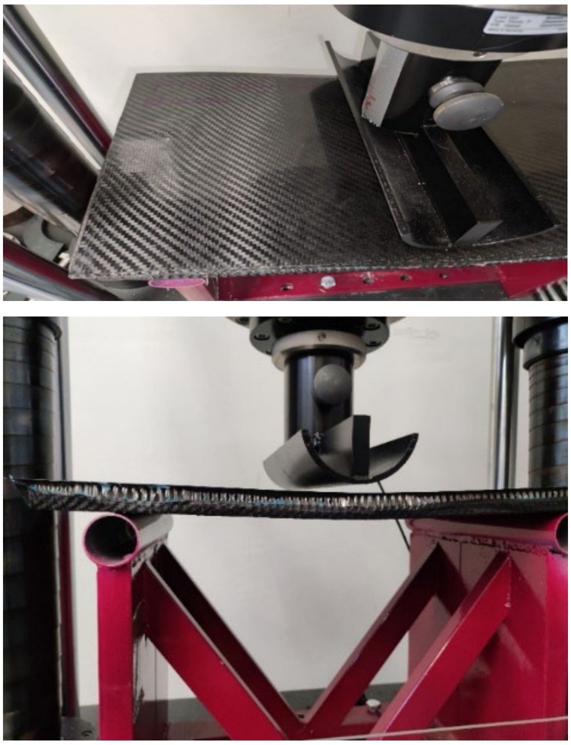

Figure 3: Three-point bending test setup in top view and side view.

3 RESULTS

With respect to the fatigue behavior the sample could withstand a maximum force of about 35 645 N. The total deflection at the failure point amounts 22.6 mm (Fig. 4). At the beginning the graph is about linear. After reaching about 25 000 N the graph loses its linearity and failure in the laminate can be observed. The flattening of the curve is an indicator for interlaminate failure [2].

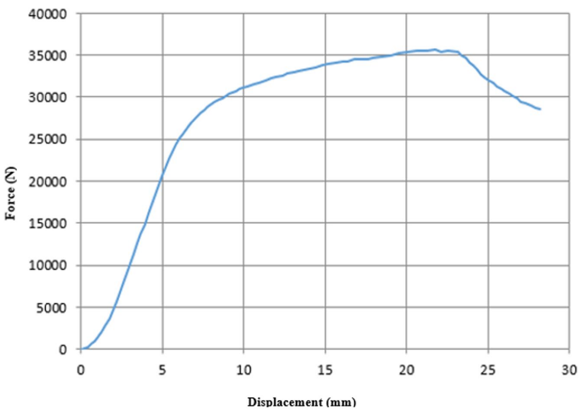

Figure 4: Front bulkhead (FBH) deflection as a function of impact force.

When the rigidity is completely lost the panel cracks and is broken. Another indicator of the interlaminate failure is the crack on the surface (Fig. 5). We observe not only one but two crack lines. So there might be multiple failure points underneath the first layer. Interestingly, most of the fibers on the first layer are not broken. The aluminum honeycomb is squeezed and could not withstand the applied force (Fig. 5). The acting shear forces are optically visible with neutral fiber right in the middle without any visible damage [3].

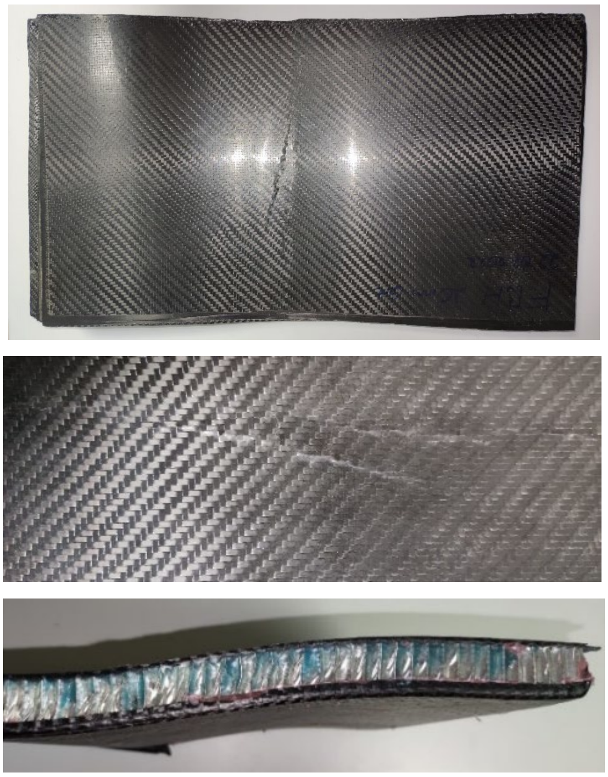

Figure 5: FBH cracked panel top view (top, middle)
and in side view (bottom).

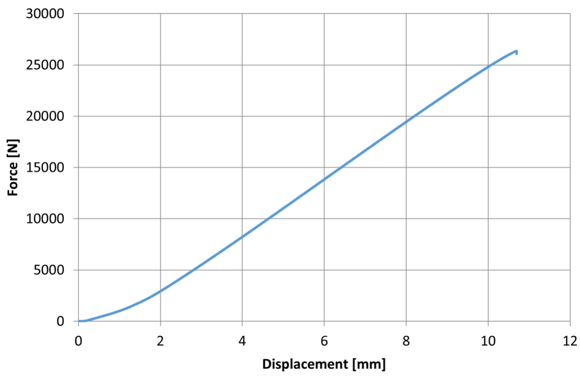

Figure 6: FBHS deflection as a function of impact force.

Figure 6 shows the deformation behaviour of the FBHS structure as a function of impact force. The FBHS structure displays a more linear behavior in the graph, which starts at around 2 mm deflection. The FBHS test has significant lower interlaminate shear forces and the CFRP can withstand them until the test breaks at around 26000 N (Fig 6). With a linear curve the behavior becomes more predictable, helping the experienced engineer to design further CFRP parts and predict their failure.

Figure 7: FBHS test panel with crack in top view (top),
side view (middle), and bottom view (bottom).

Figure 7 shows the FBHS structure in different views after the bending test. The curves from Figures 4 and 6 correlate with the cracks that are observed in Figures 5 and 7. The FBH has not a clean break instead it has lots of broken plys even deep down in the laminate. This is reflected by the nonlinear curve and shows that the interlaminate forces in this thick lay-up are significantly higher than in the FBHS structure. The FBHS has in accordance with the test curve in Figure 6 one clean break along the load applicator, where all plys of the pressure side of the panel are broken.

In table 2 significant parameters obtained from the Three-point bending testing are compared for FBH and FBHS structure.

	FBH	FBHS
maximum force (N)	35645,39	26375,74
deflection at panel failure (mm)	21,8	10,69
Gradient (N/mm)	14977	4153
Skin modulus of elasticity (GPa)	114,3	67
UTS of skins (MPa)	255	361

Table 2: Comparison between FBH and FBHS from 3-point bending test.

4 CONCLUSIONS

Since FBH has more CFRP plys in its composite structure, the obtained interlaminate shear forces are higher as compared to the thinner and more lightweight FBHS structure: FBH fails at 35645 N which is nearly 10000 N more than the FBHS with 26375 N. These bigger forces end up in interlaminate failure. The deflection at panel failure, the gradient and the skin modulus of elasticity of the FBH are much higher than the values of the FBHS. So, the FBH can deflect more and has a higher skin resistance to elastic elongation.

The big disadvantage of the nonlinear FBH curve with interlaminate shear failure is the reduction in structural integrity. The part is designed to withstand a certain load and with failure of parts the load that the part can handle lowers over time until it breaks unforeseeably.

FBHS exists because it does not need the structural integrity and the intrusion rigidity like the FBH. FBHS constitutes a lighter lay-up with less plys. This results in lighter mass parts of the carbon fiber monocoque and reduces the overall weight of the car with part specific lay-ups.

The ultimate tensile strength (UTS) of skin layers shows different behaviour: Here, the value of the FBHS is higher. This is due to the thinner skin thickness as compared to FBH. Considering maximum force in relation to skin thickness, the FBHS is favourable since FBHS is almost half as heavy as the FBH.

The interlaminate failure might be improved with an adjusted laminating process. The pressure acting onto the laminate while curing could be optimized. For example, an autoclave would help. The squeezed honeycomb is a sign that it is overloaded. A more robust version will increase the overall stability at higher force application in the future.

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