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NOVEL HONEYCOMB SANDWICH STRUCTURES WITH FIBER REINFORCED FACE SHEETS

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ABSTRACT

Sandwich structures are very lightweight and stiff constructions. Concerning fiber reinforced face sheets the majority of applications are built with thermoset materials. Next to the thermosetting material polyurethane (PUR) current investigations in the TITK have been carried out with thermoplastic polypropylene (PP) to embed the fibers and bond them to the honeycomb core. Within the face sheets nonwoven fabrics made of glass fibers, natural fibers and (recycled) carbon fibers have been utilized. As core material the investigations involved honeycombs made of paperboard/cardboard and polypropylene.
The measured bending properties have been compared to theoretical calculations. The aim of the investigation is to receive a comprehensive overview of the mechanical properties of different sandwich materials.

1. INTRODUCTION

The demand for lightweight structures in the automotive industry is rising. The goal is to increase the dynamic and the energy-efficiency of the vehicles, especially in combination with alternative driving concepts. Sandwich-structures are highly efficient when it comes to lightweight and stiff components.

Established sandwich-structures are made of paperboard honeycomb with glass fiber reinforced polyurethane face sheets. They are used as the rear cargo floor in the trunk of a car, for example. A current research topic at the TITK (Thuringian Institute of Textiles and Plastics Research) investigates different manufacturing methods for new sandwich-structures made of carbon and natural fiber reinforced face sheets with different core materials.

In general, the industrial use of carbon fibers for reinforced parts is increasing and therefore the amount of left over fibers during fabrication is rising as well. For economical and ecologically reasons the reuse of such high-performance fibers seems mandatory. A cost-efficient and high-quality recycling method for carbon fiber waste was developed at the TITK [1, 2]. The obtained staple fibers are very suitable to produce a nonwoven fabric by textile machining. Those semi-finished products have been utilized as part of the face sheets to produce sandwich-structures. Alternatively natural fibers like flax and kenaf have been investigated as well.

2. FABRICATION

Different manufacturing methods can be applied to produce sandwich structures. For the chosen materials a discontinuous hydraulic press (figure 1 – left side) and a continuously working double belt press (figure 1 – right side) have been used.

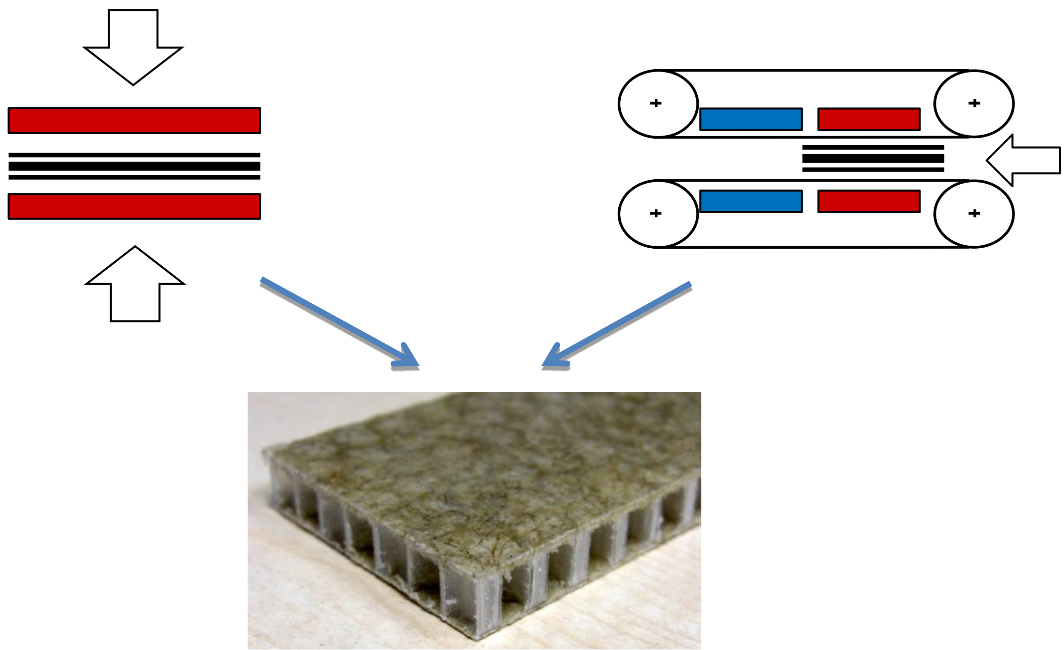

figure 1: Manufacturing methods for sandwich-structures

Typically the reinforcing fibers are embedded in a thermoset polymer like polyurethane (PUR). The components which later build the matrix material are spayed on the fiber fabric which is located on both sides of the core material. During compression molding under high temperature the matrix components chemically react, embed the reinforcing fibers and bond them to the core material. A discontinuous hydraulic press works best for this process because once the chemical reaction of the matrix material is (almost) over the sandwich panel can be taken out of the press without cooling it down.

If a thermoplastic polymer is used as matrix material, the sandwich panel has to be cooled down. A continuously working double belt press consisting of a heating zone where the matrix material melts and a cooling zone where it hardens again is especially suitable.

3. EXAMINED MATERIALS

3.1 Matrix Material

State of the art in the automotive industry is the use of polyurethane (**PUR)** as matrix material for sandwich structures. Therefore it has been used to embed the reinforcing fibers within the face sheets. To achieve maximum stiffness of a sandwich structure the connection between the face sheets and the core material is highly relevant. The PUR matrix is built by the components Polyol and Isocyanate. During the chemical reaction (Polyaddition) CO_2 leads to an expansion of the polymer material into the wholes of the honeycomb core which creates a strong bond.

Next to the thermoset PUR the thermoplastic material polypropylene (**PP**) has been utilized to embed the reinforcing fibers and bond them to the honeycomb core. The investigation of sandwich structures with a polypropylene matrix is especially interesting in combination with a polypropylene core. In particular the crash behavior and the recyclability are positive aspects. Through to the use of the same thermoplastic polymer it is possible to recycle the whole sandwich structure. Granulates for injection molding are imaginable.

3.2 Reinforcing Fibers

Usually nonwoven fabrics made of glass fibers are used to reinforce the face sheets of sandwich constructions. Glass fibers are inexpensive and industrially established. In addition natural fibers and carbon fibers have been investigated as well. Figure 2-4 show examples of the examined nonwoven fabrics.

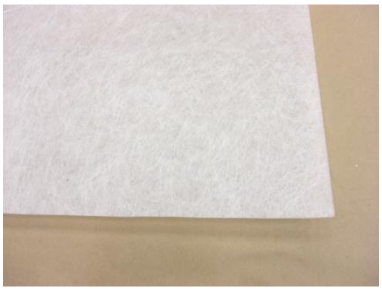
figure 2: Glass fibers (GF)


figure 3: Natural fibers (NF)


figure 4: (recycled) Carbon fibers (CF)

The processing and the production volume of carbon fibers are considerably increasing due to the outstanding mechanically properties of the fiber. During the fabrication of carbon fiber reinforced composites 20-30 % of the fiber material becomes waste. The TITK developed an effective recycling method to obtain staple fibers which can be processed to a nonwoven fabric by textile machining.

Samples with different fiber fractions have been investigated in order to determine optimized fiber contents within the face sheets. Concerning nonwoven fabrics the best mechanical properties can be found for fiber contents between 40-50 mass%. In case of a polypropylene matrix higher fiber contents lead to an increased pore volume and thus the mechanical properties like the E-modulus decreases. During the investigation the fiber content has been set to about 45 mass%. Nonwoven fabrics with grammages from 90 g/m² up to 900 g/m² have been applied.

3.3 Sandwich Core Material

Three different core materials have been utilized. Two are made of paperboard/ cardboard (figure 5 and 6) and one is composed of tubular thermoplastic material (polypropylene) (figure 7).

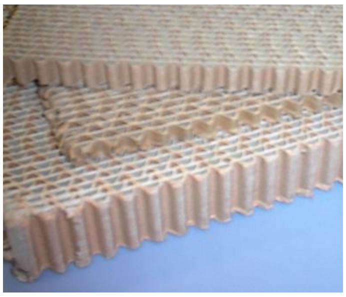

fig. 5: Corrugated cardboard (SWAP)

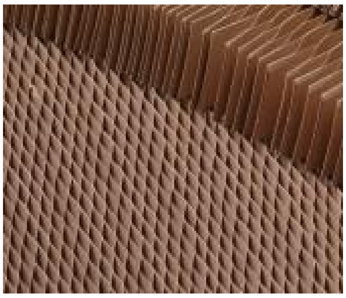

fig. 6: Expanded paperboard

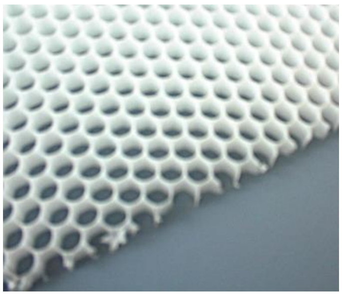

fig. 7: tubular polypropylene (TUBUS WABEN)

The corrugated cardboard produced by SWAP possesses a sinus wave structure between two adjacent flat cardboards. Therefore the core material shows higher shear rigidity in this direction. The other 2 core materials are virtually isotropic. The differences in their densities can be seen in table 1.

Table 1: Densities of the investigated honeycomb core materials

Core material	Density
Corrugated cardboard	72,1 kg/m³
Expanded paperboard	54,8 kg/m³
Tubular polyproylene	91,5 kg/m³

4. SANDWICH DESIGN - THEORETICAL APPROACH

The total deflection of a sandwich panel under a given load is made up from bending deflection and shear deflection. The amount can be calculated by the given formula [1]:

$$w = k_b \frac{F \cdot l^3}{D} + k_s \frac{F \cdot l}{S}$$

w – deflection
k_b – bending deflection coefficient
k_s – shear deflection coefficient
F – force/ load
l – sandwich span
E_f – face sheet E-modulus
b – sandwich width
t – face sheet thickness
d – distance between face sheet centres
G – shear modulus of core
h – sandwich height

The bending stiffness **D** is given by:

$$D = E_f \cdot \frac{b \cdot t \cdot d^2}{2}$$

The shear stiffness **S** is given by:

$$S = G \cdot \frac{b \cdot d^2}{h}$$

In case of a 3-point bending situation (figure 8) the coefficient $k_b = 1/48$ and $k_s = 1/4$.

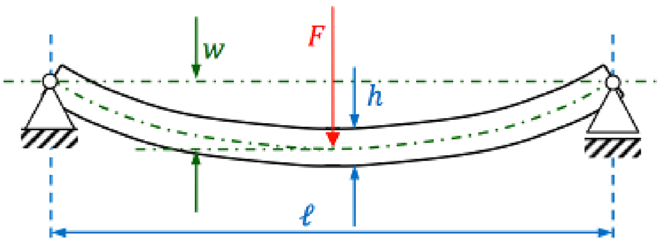

figure 8: 3-point bending

By measuring the deflection of a sandwich panel in a 3-point-bending test the opportunity is given to calculate the effectively realized E-modulus of the face sheet. The achieved values for the different face sheet materials are presented on page 9.

5. SANDWICH PROPERTIES – MEASUREMENTS AND CALCULATIONS

After fabricating different sandwich structures, 3-point-bending tests have been carried out in order to compare the achieved mechanical properties. Figure 9 shows an example of the measured values for a 20 mm high and 300 mm wide sandwich panel with glass fiber reinforced PUR face sheets (450 g/m² fiber grammage) and two different honeycomb core materials. The sandwich span is 800 mm.

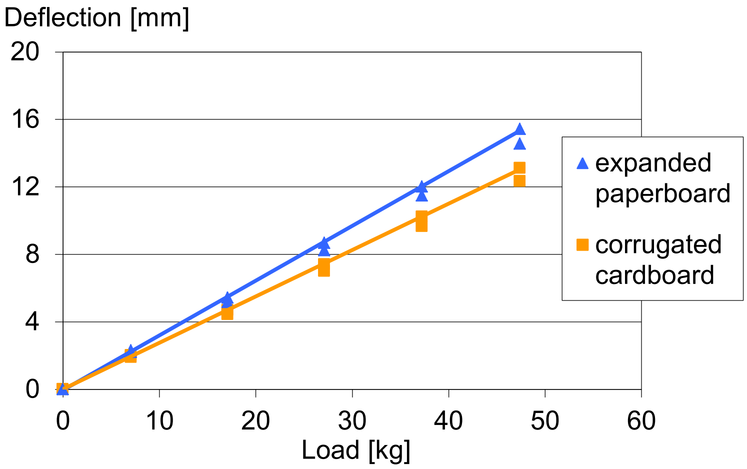

figure 9: result of a 3-point-bending test for glass fiber PUR sandwich panels with paperboard/ cardboard cores

At increasing loads the deflection clearly rises linearly. A distinctive elastic material behavior can be obtained. Sandwich structures fabricated with a corrugated cardboard honeycomb core exhibit about 15-20% less deflection at the same load in comparison to expanded paperboard cores.

The influence of the testing parameters load and sandwich span has been investigated. The results show very good accordance to the sandwich design theory. Therefore, the bending stiffness which is independent on the testing parameters can be used to compare different sandwich constructions. (The sandwich stiffness still depends on the sandwich parameters width, height, face sheet thickness and E-modulus of the face sheet.)

The measurements were used to receive the bending stiffness of 1 m wide sandwich panels. Figure 11 presents the values gained by different face sheet materials.

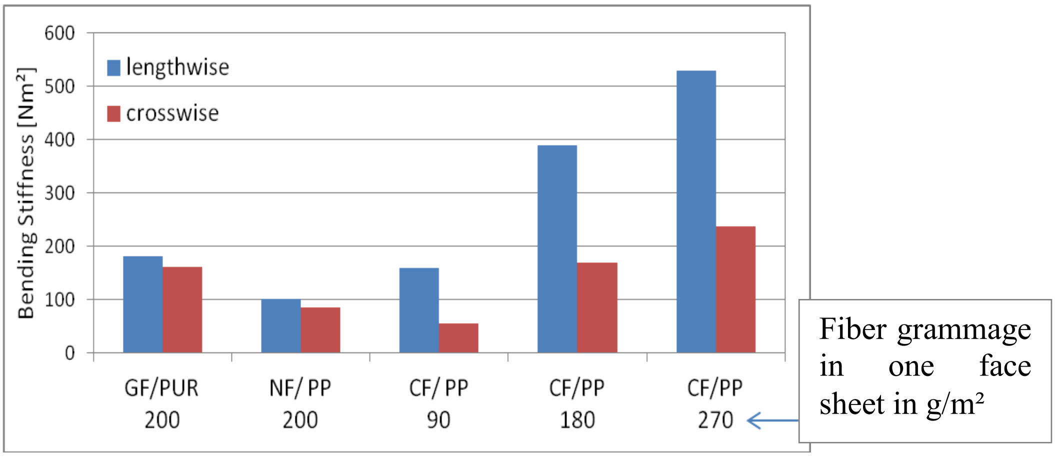

figure 10: bending stiffness of different sandwich panels

The established sandwich structure made of glass fiber/polyurethane (GF/PUR) shows a higher bending stiffness than structures with natural fiber/polypropylene (NF/PP). The use of carbon fibers (CF) with a very high E-modulus leads to the highest sandwich stiffness. The value clearly increases using higher grammages of the fiber material within the face sheet.
As it can be seen in figure 10 the carbon fiber reinforced sandwiches possess an anisotropic behavior. The stiffness values lengthwise are at least twice as high as the values crosswise. This is caused by a distinctive fiber orientation in the nonwoven fabric used for the face sheets. The nonwoven fabrics made of glass fibers and natural fibers are almost isotropic.

The bending stiffness obviously increases taking higher grammages of the nonwoven fabrics. The thickness of the face sheets rises accordingly. Figure 11 shows the stiffness values for 15 mm high sandwich panels with different fiber types and fiber grammages. In accordance to the amount of fibers, the amount of matrix material increases as well, thus making the whole sandwich structure heavier.

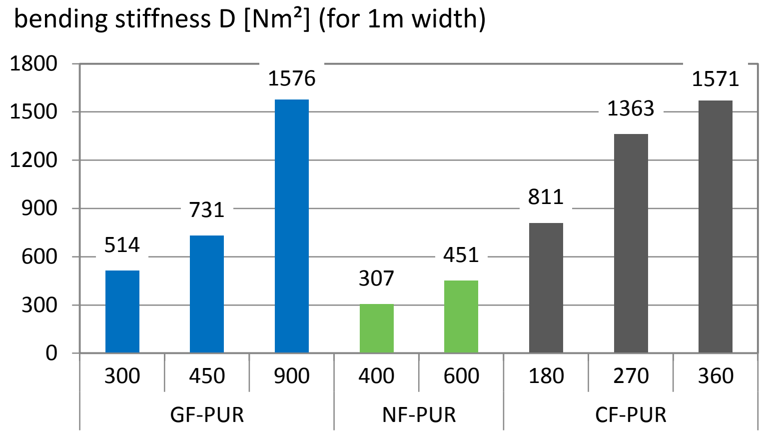

figure 11: bending stiffness of PUR sandwich panels with different fibers and fiber grammages[g/m²]

The bending stiffness can be enhanced significantly by an increasing distance between both face sheets without making the construction much heavier (sandwich principle). The stiffness values for different sandwich heights for PUR sandwiches with different fiber types and almost the same fiber grammages are shown in figure 12.

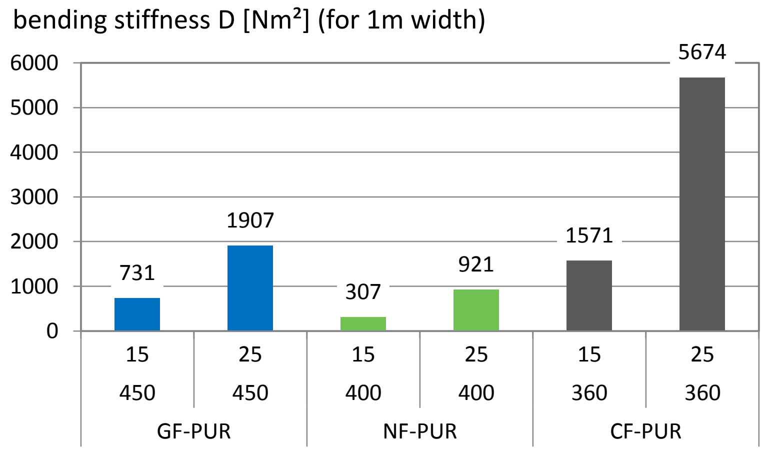

figure 12: bending stiffness of sandwich panels with different fibers and sandwich heights

The bending stiffness depends on the sandwich parameters width and height as well as thickness and E-modulus of the face sheets. Using the measured deflection from a specific sandwich panel (with a certain height, width and face sheet thickness), the E-modulus of the face sheet can be calculated. Having that mechanical parameter, the deflection of sandwich panels with different heights, widths and face sheet thicknesses can be predicted. As shown in figure 13 the theoretical deflections are very close to the measured deflections. Therefore the sandwich design theory is applicable for different sandwich constructions with fiber reinforced face sheets.

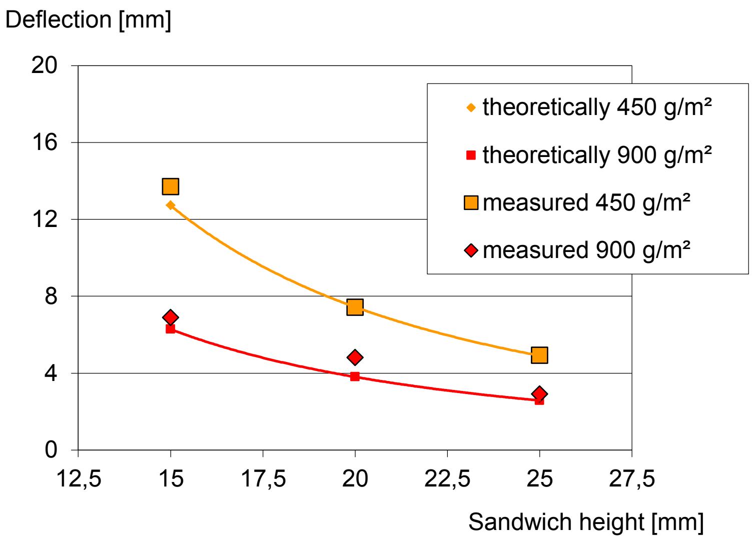

figure 13: Comparison of theoretical and measured deflections for different sandwich heights and face sheet grammages (GF-PUR)

To compare the real potential of different fiber types and matrix materials the achieved E-modulus has been calculated. The results from different sandwich panels can be found in table 2.

Table 2: Achieved E-modulus of the investigated face sheets

Nonwoven fabric:	Matrix: PUR	Matrix: PP
Glass fibers	10 - 11 GPa	-
Natural fibers	3,5 – 5,0 GPa	3,0 - 4,4 GPa
Carbon fibers (oriented)	21 - 26 GPa	17 - 19 GPa

Concerning sandwich structures the thermoplastic matrix material polypropylene is not (yet) as effective as a polyurethane matrix. This is due to a weaker bond between the face sheets and the honeycomb core and a less strong embedding of the fiber material. The influence of coupling agents should be analyzed in further investigations.

6. RESULTS

In general sandwich structures possess very high stiffness values combined with low part weight. Concerning established sandwich structures, consisting of fiber reinforced polyurethane face sheets, the substitution of glass fibers with recycled carbon fibers leads to a significant increase of the bending stiffness. In order to gain the same stiffness value a thinner face sheet can be used thus making the sandwich panel much lighter. (However other properties like pressure resistance usually have to be considered as well.) The anisotropy of nonwoven fabrics can be used to generate a specifically high stiffness in one direction.

The examined bending stiffness of natural fiber reinforced sandwich panels is about half as high as for sandwich panels with glass fiber reinforcement. Therefore sandwich structures made of natural fibers are suitable for less stressed parts.

The usage of polypropylene (PP) leads to decreased stiffness values compared to sandwich panels with polyurethane (PUR) matrix. The influence of coupling agents has to be investigated in order to make the novel sandwich structures competitive. A better crash behavior and recyclability are potential benefits.

Sandwich-structures are a highly adjustable construction. Next to geometrical parameters like sandwich height and face sheet thickness, the honeycomb type and especially the kind of fiber and matrix material of the face sheet determine the mechanical properties.

In order to compare different sandwich compositions the use of the bending stiffness D seems to be appropriate due to its independence on the testing parameters load and sandwich span.
In general the investigations show that the sandwich design theory is applicable for sandwich constructions with fiber reinforced face sheets.

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