COMBOO - A NOVEL CORE MATERIAL FOR COMPOSITE SANDWICH STRUCTURES FROM RENEWABLE SOURCES

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Abstract

This paper presents the evaluation of a novel bamboo based core material for sandwich structures from renewable sources called COMBOO. By arranging bamboo rings in a honeycomb like pattern and covering them with top and bottom sheets, stiff and lightweight boards are received. Fibre reinforcements with natural fibers like flax or hemp improve the ecological footprint especially if resins from partly renewable sources were used. Glass fiber reinforcements provide a translucence of the material for applications in design, architecture and civil engineering. The mechanical characterization of the early approach in comparison to conventional core materials as well as improvement steps of the new structure will be presented.

1. Introduction

Typical sandwich structures in transportation and aerospace or other structural applications consist of shell layers of fiber reinforced materials e.g. glass or carbon fibers in a polymer matrix e.g. epoxy resin surrounding a core. The combination of these composites enables superior mechanical properties and at the same time extremely low weight. Open- and closed-cell-structured polymer and metal foams, balsa wood, syntactic foams and honeycombs are mainly used as core materials. Production of these materials often consume large amounts of energy. The resin and lots of the polymer foams are usually made of oil and its processed forms, which is problematic.

Additives or complete components from renewable sources are currently under investigation. A “green” resin approach is called GreenPoxy®, which contains 56 % of linseed oil. It provides comparable mechanical results [1]. Natural fibers like coconut, flax or sisal are research topics for substitution of glass or carbon fibers. A common green core material is balsa wood, a lightweight material, and fast growing in tropic regions [2]. Cultivation on monoculture plantations or wood from uncertified sources can cause significant ecological problems.

Bamboo is a grass with wood like appearance and properties native to many regions in the world, except Europe and Antarctica. It consists of extremely fast growing columns divided by intersecting nodes, that can reach heights of up to 24 meters and diameters of 30 cm. The mechanical properties like density and tensile strength vary across the hollow bamboo column wall. It consists of a very hard surface and softer inner region, in contradiction to trees. Bamboo has been already used for centuries in Asia and South America as constraction and building material, while its wider usage in Europe and North America has started in the last century. Typical applications of bamboo are scaffolds even for skyscrapers (in Asia), furniture, flooring or chopping boards. Therefore the bamboo is mainly cut into thin concave strips, trimmed to a rectangular shape with reduced utilization and laminated into planks or sheets. Preparation steps include also boiling and drying. Chopped or sliced bamboo fibers are used as filling material in plastics for dishes or as reinforcements in concrete. ZHOU ET AL. presented an interesting concept for structural applications. They milled or grinded a hexagonal shape onto long bamboo columns and milled afterwards conventional finger joints at both ends to connect the columns.

They created beams of "infinite" length by arranging and gluing these single columns in a quasi rectangular shape. Higher bending strength than comparable pine beams were reported. [3]
An interesting alternative to conventional core materials on bamboo basis with a better utilization of the raw material, a sheet material like honeycomb structure called COMBOO will be presented in this paper. It offers good mechanical properties and additionally translucence, if covered with glass fibers.

2. Material and Methods

2.1. Manufacturing and Materials

Main idea for the new lightweight sandwich composite called "COMBOO" is to cut bamboo (BOO) into parallel rings of the desired length and to arrange them into a honeycomb (COMB) like pattern. Therefore a band saw with linear guidance was used. A nearly similar outer diameter of the bamboo rods helps to receive a uniform pattern. A first grinding step removes extending fibers and burr. After lamination of both sides with resin and suitable fibers, a stiff and lightweight structure is received. The manufacturing is still time consumptive, as the rings were placed manually on the resin coated fibers.
Manufacturing of COMBOO specimen differs a little bit from handling of the conventional core materials. Both sides of these can be made directly one after another with no curing time in between as used for the bamboo rings.
As core materials for comparison BALTEK® SB100 (balsa wood), 3D|CORE™ (Polyethylenterephthalat), TUBUS® PP- honeycomb (Polypropylene), AIREX® C70.55 (closed-cell, cross-linked rigid PVC foam), AIREX® C70.75 (closed-cell, cross-linked rigid PVC foam) and AIREX® T92.100 (closed-cell, cross-linked rigid PET foam) were tested.
An epoxy resin L and hardener CL (R & G Faserverbundwerkstoffe GmbH, Waldenbuch, Germany) were selected and the used fiber reinforcements mat was a glass fabric with a weight of $220\ g / m^2$, finish FK144 and a plain weave (R & G Faserverbundwerkstoffe GmbH, Waldenbuch, Germany). The glass mat has a certificate of approval for aircraft industry.
For a second "more natural" approach a resin from partly renewable sources (Greenpoxy 56, Sicomin) with a linseed oil content of 56 % and flax fibers (LINES UD fabric FlaxPly, Time out Composites) were tested. Figure 1 presents two types of COMBOO specimen. The left one used conventional glass fibers. Single bamboo rings can be distinguished clearly. The "renewable" approach is shown on the right side.

Figure 1. COMBOO structure – bamboo rings with glass fibers (left) and flax fibers (right)

The variation in size and shape of a natural material like bamboo was partly encountered by milling a hexagonal shape on bamboo rods followed by cutting pieces of identical length and forming a real honeycomb structure afterwards.

2.2. Methods

Different mechanical methods have been applied to qualify the materials. Bending tests (3-Point / 4-Point) and an additional shear test will be presented here. The shear test was necessary as a shift of complete rows was identified as main failure in early samples [4]. The wax like outer surface reduces adhesion of resins, color and other coatings.

Shear test
Figure 2 shows the developed shear test stage. Different specimens like large single rings or arrangements of four bamboo rings glued together were secured in the clamps. A pneumatic cylinder pressed against the linear guide mounted combination of lower clamp and force sensor. The resulting forces were measured and recorded (PC with LabVIEW and NI 6009 DAQ device, National Instruments). Four different conditions of small rings were under investigation (unmodified, hexagonal milled, grinded, sandblasted). The occurring failure, breaking of the ring, breaking of the resin, detachments from ring surface or combinations was examined.

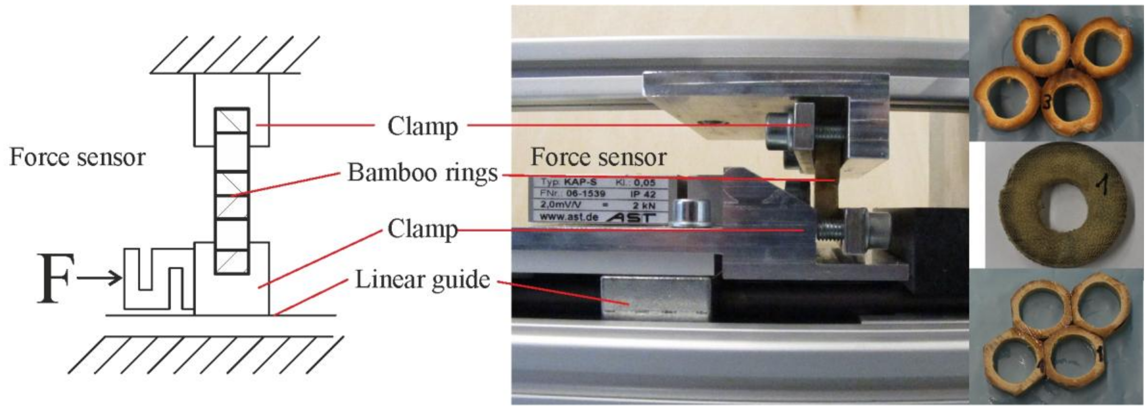

Figure 2. Shear test stage

3-Point bending test
An universal testing machine (Zwick / Roell Z050 (Zwick GmbH & Co. KG, Ulm Germany) was used for this investigation. The specimen size differs from dimensions recommended in DIN 2746 [5], due to the requirements of the bamboo rings. It was set for all specimens to 150 mm x 60 mm x 8 mm. Figure 3 presents the test setup and tested specimen.

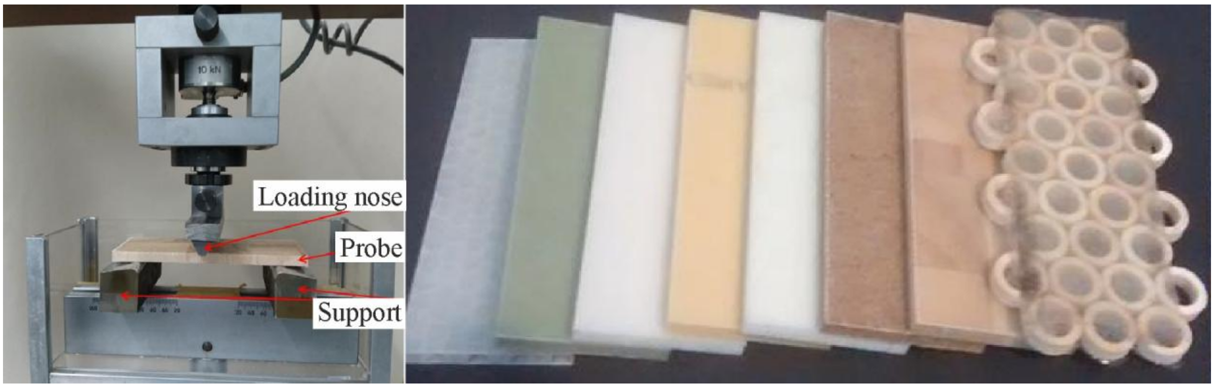

Figure 3. 3-Point bending setup and test specimen

After starting a test, deflection and according forces were recorded for later manipulation. Resulting flexure stress σ was calculated from equation (Eq. 1), where *F* is the force, *L* is the span, *b* is the specimen's width and *h* the height (all dimensions in mm).

$$3*F*L / 2*b*h^2 \tag{1}$$

Failure modes were observed after each test.

4-Point bending test

The test was performed according to DIN 53293 [6] on the same testing machine as before with different loading nose setup. In concordance to regulations the specimen height defined all other testing dimensions like specimen length or distances between loading noses and support. The number of different materials was reduced to three (COMBOO, BALTEK® SB100 and Airex T92.100), as they were representative for previous specimen. The sample size was set to 192 mm x 60 mm x 8 mm. After starting a test, deflection and according forces were recorded for later manipulation.

3. Results and Discussion

3.1. Shear test

The measured, converted and over the number of single specimen averaged results are presented in Figure 4. The three modifications can be clearly distinguished from the unmodified results as an improvement of between 26 and 40 percent was identified. Sandblasting and milling a hexagonal shape show nearly similar results (26 / 27 percent). It is assumed that the grinding procedure removed larger parts of the adhesion reducing surface than the sandblasting step and deeper grooves provide a higher indentation efficacy.

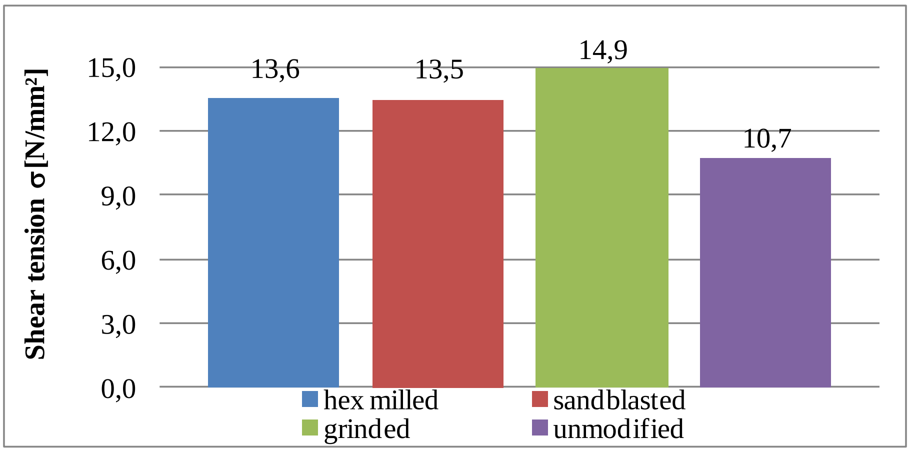

Figure 4. Calculated shear tension for surface modifications of bamboo rings

The observed failure changed from complete detachments from ring outer surface to combinations of breaking of resin and bamboo rings. [7] This led to improved flexure strength of COMBOO boards.

3.1. 3-Point bending test

The rings for the specimen of the bending test were grinded to provide an optimal resistance against affecting forces. The COMBOO specimen showed, after calculating the flexure stress, the highest values in comparison to conventional core materials. Differences of a factor of up to five were identified, as can be seen in Figure 5. Balsa showed also good results, if compared the polymer core materials, but the values are about 20 percent lower than the values of COMBOO structure.

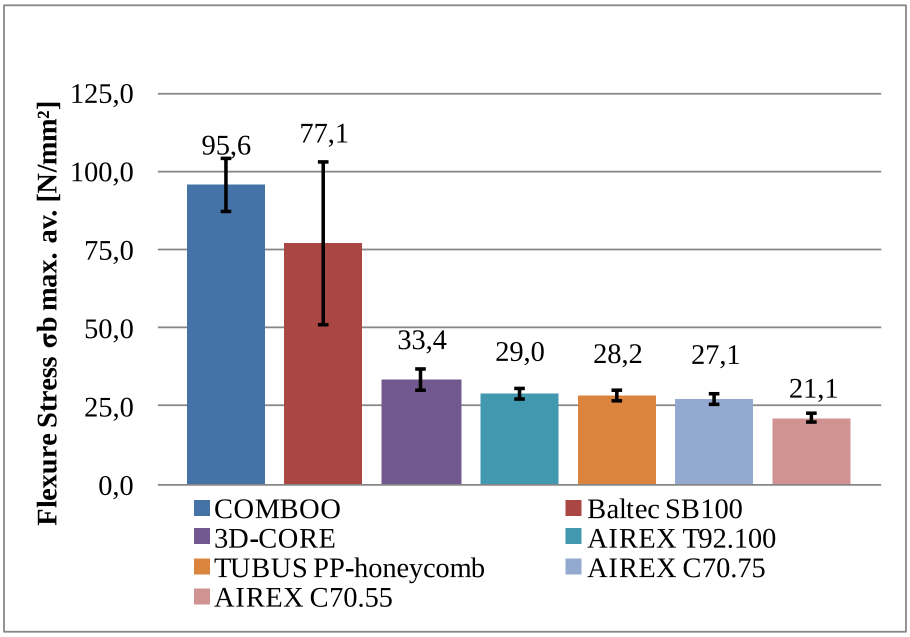

Figure 5. Calculated maximum flexure stress for different core materials

The variation of the results is low, except for the reinforced balsa wood specimen. It is assumed that it is caused by inhomogenities in the arrangement of end-grain.

3.1. 4-Point bending test

The rings for the specimen of this bending test were also grinded for optimized resistance against affecting forces. According to DIN53293 the particular significant value depends on the occurring failure. Bending moment M [Nmm], compressive σ_c [N/mm^2] or tensile strength σ_t [N/mm^2] (failure of face sheets) and shear strength τ [N/mm^2] (failure of the core) were calculated from test data.
COMBOO structure and balsa wood showed a failure of face sheets, while the core material failed always at the Airex specimen [8], [9].
Table 1 contains the aforesaid values. It can be seen that the averaged bending moment of COMBOO reached the highest value, followed by balsa wood (14 percent less) and the polymer foam (60 percent less). A similar ratio can be seen in the comparison of compressive / tensile strength between COMBOO and balsa wood. Airex can't be compared due to the occurring failure (breaking of the core material).

Table 1. Results of 4-Point bending test [9]

Specimen Type	M [Nmm]	σ_c [N/mm^2]	σ_t [N/mm^2]	τ [N/mm^2]
Airex	15107			0,97
Baltec	31763	-188	188	
COMBOO	37116	-220	220	

4. Conclusions

The novel bamboo based core approach provides an excellent mechanical properties compared to conventional materials. An improvement in stability of the COMBOO structure was received by surface modifications of the outer layer. Grinding steps increased the shear tension of about 40 percent, compared to unmodified bamboo rings. Closer investigations of the surface modifications have to be performed to identify the relevant conditions more clearly. Other tests have to reveal a possible dependency of shear strength from affected ring layer (inner, outer, middle).
The flexure stress, identified in 3-Point bending examinations is between 300 and almost 500 percent higher than values of typical foam or polymer cell structures. Even balsa core materials revealed 20 percent smaller values. Highest bending moment and highest compressive / tensile strength were reached too by the COMBOO structure in 4-Point bending tests.
Thus COMBOO approach is an interesting alternative to conventional core materials. Further improvements are necessary for an efficient and affordable manufacturing especially the cutting process and arranging of bamboo rings. Investigations of thermal transfer through the structure, observations of the compressive strength, hardness measurements are currently under research.

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