Bamboo Composite Lamination

Boosting mechanical properties through hybridization

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Tobias Eberwein

Structural timber and engineered wood products have limited mechanical properties due to their inherent material features. A new bamboo composite material developed in the Advanced Fiber Composite Laboratory at the FCL in Singapore has been shown to boost the flexural strength of a structural wooden element by manifold when laminated as a thin layer on the top and bottom surfaces. Due to the extraordinarily high mechanical strength of bamboo fibers, the newly developed bamboo composite material reveals properties that exceed those of most wood species or engineered wood products. This makes it feasible to reach a particular strength with less material and a lighter setup, as the structural height of an application can be significantly reduced. The new material can be used more economically, if applied in areas with demanding structural requirements. Additionally, it can be combined with standard wood products such as chipboard, medium-dense-fiber boards or structural timber. The aim of the herein presented research on Bamboo Composite Lamination is to explore such new material combinations and probe their mechanical properties.

A beam element subjected to a bending moment develops a linear distribution of normal stress along its cross section. The stress prompts from a bending compression to a bending tension zone with peaks of normal stress in the top and bottom parts. The stress concentration results to zero respectively along the center of the cross section. With this knowledge a design can be approached, that uses an intelligent distribution of material. Conventional structural steelwork follows this mathematical correlation by increasing the cross section in the flanges and keeping the middle sector light in form of a web plate, which operates as a bar spacer.

Fig. 01 Bending test at the Advanced Fiber Composite Laboratory in Singapore

With that a large amount of structurally not necessary material can be saved, which creates a lighter and more economical construction element. The presented Bamboo Composite Lamination beam structure follows the same principle of the steel I-beam by applying the stronger bamboo composite material in the outer sections and using wood as a filling element. Consequently the stronger bamboo composite material absorbes the majority of the resulting normal stress and therefor makes the design of smaller and more economical cross sections possible.

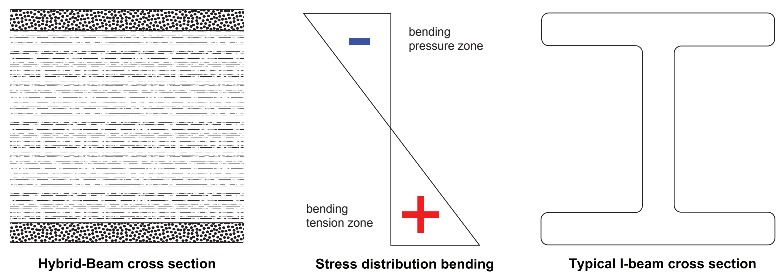


Fig. 02 Stress distribution in a structural bending applications

In order to display the effect of the bamboo lamination principle, first reference samples were produced and their bending behavior was compared to conventional non-laminated specimens. Thin layers of the material were hot pressed with a two-component glue system on the top and bottom surfaces of standard engineered wood materials such as chipboard or medium-dense-fiber boards. The employed glue is a commercially available binder system. The overall cross section of the bamboo composite laminated layers represents less than 10% of the engineered wood core material, i.e. for an 8.0 mm chipboard or medium-dense-fiber board, a bamboo composite layer of less than 0.5 mm is attached to each surface. All resulting hybrid specimens were tested according to the European standard for structural timber and glued laminated timber EN 408:2010 in a four-point bending test with a height to length ratio of 1:18. The feed rate was set to 1mm/min, which led to an average testing length of 300ffl120 seconds. With these tests it was possible to determine the ultimate flexural strength as well as the modulus of elasticity.

Whereas all of the tested standard medium-dense-fiber boards and chipboards failed in a clear vertical crack between the loading points, the majority of the bamboo composite laminated specimens failed due to shear stress. This, however, did not harm the bamboo composite material but led to a horizontal rupture within the weaker chipboard or medium-dense-fiber boards. Shear stress due to a bending moment shows the maximum concentration along the middle part of the cross section. Timber and engineered wood materials possess a comparably low shear strength perpendicular to the grain. Hence cracks developed parallel to the grain during the failure of the specimen.

Table 01 shows the summary of the obtained values and as evident, the Bamboo Composite Lamination samples show a significant increase in flexural strength and modulus of elasticity as compared with the reference samples.

	Pine Wood	**Bamboo Composite**	**MDF**	**MDF reinforced**	**Chipboard**	**Chipboard reinforced**
Flexural strength (MPa)	75.0	250.0	29.0	130.2	16.0	210.1
Modulus of Elasticity (GPa)	7.0	30.0	1.9	8.5	1.3	10.2

Table 01 Comparison of bamboo composite laminated hybrid constructs and pristine engineered wood materials such as chipboard and medium-dense-fiber boards (MDF)

In a next step, the lamination principle was transferred onto a larger scale using a bamboo composite lamination hybrid-beam with a cross section of 100 x 100 mm and an overall length of 2000 mm (Fig. 03). Here, the bamboo composite laminated layers correspond to exactly 20% of the cross section and were attached using a standard wood glue. The mechanical properties of the bamboo composite laminated beam have then been compared to a standard glued laminated timber beam.

Both specimens were produced out of New Zealand Pine wood and were tested likewise in accordance with the European standard EN 408:2010 in a four-point bending test. The standard glued laminated timber beam performed as expected in terms of elasticity, flexural strength and failure mode. The rupture occurs clearly in the tension zone at an average maximum flexural strength of 76 MPa. The modulus of elasticity was 7.2 GPa. Comparable values have been evaluated with smaller laboratory samples before.

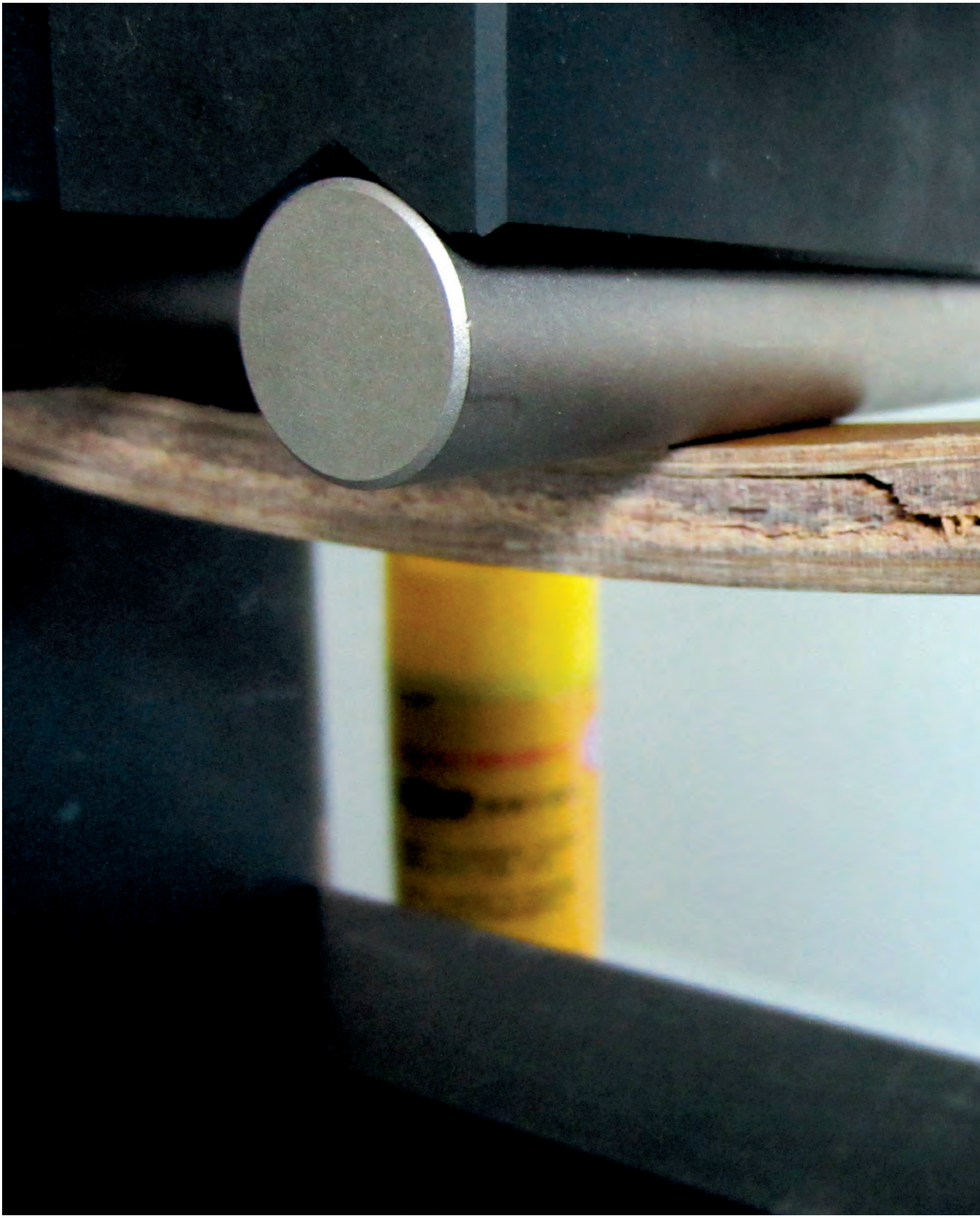
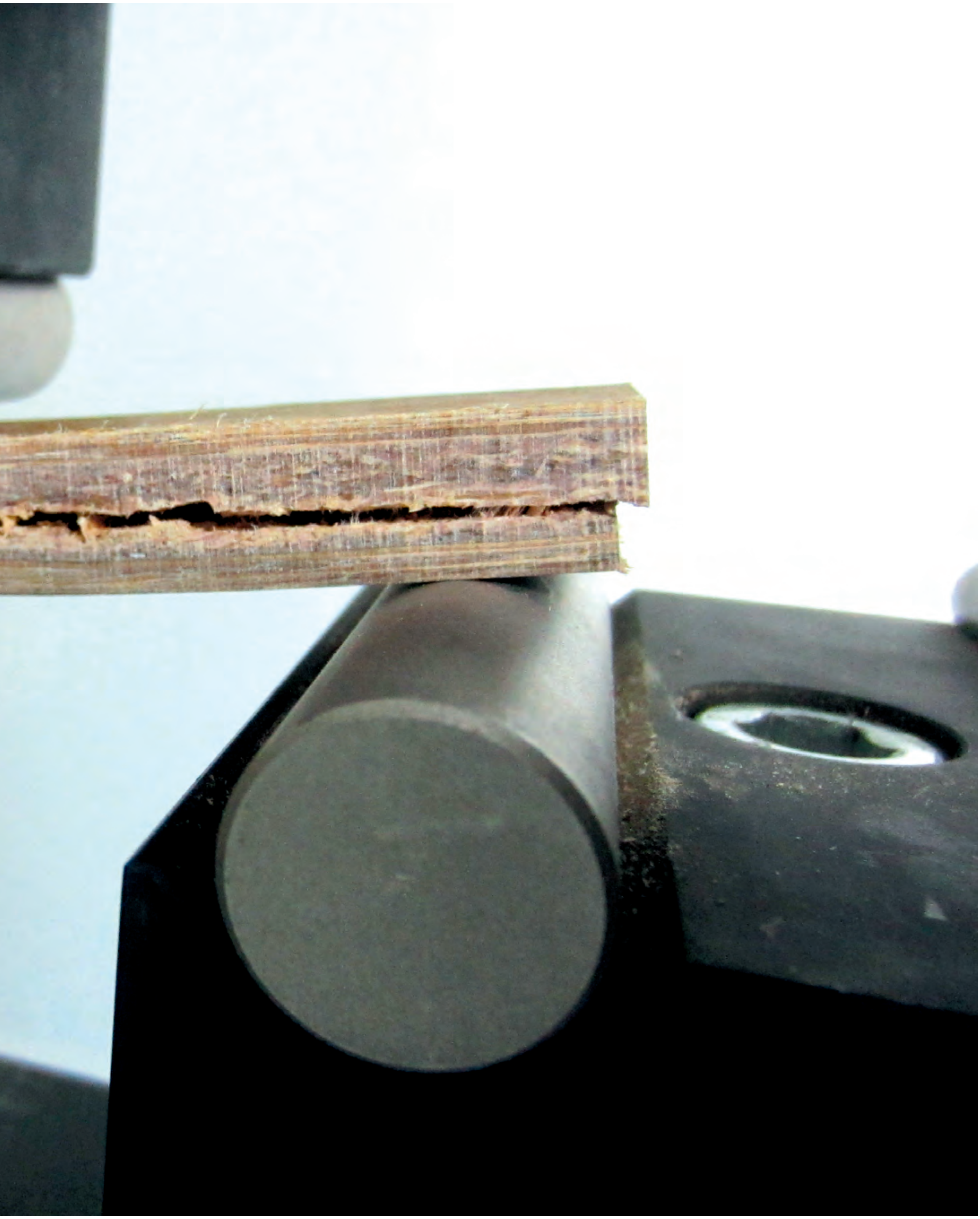


Fig. 03 Shear failure in Bamboo Composite Laminated chipboard



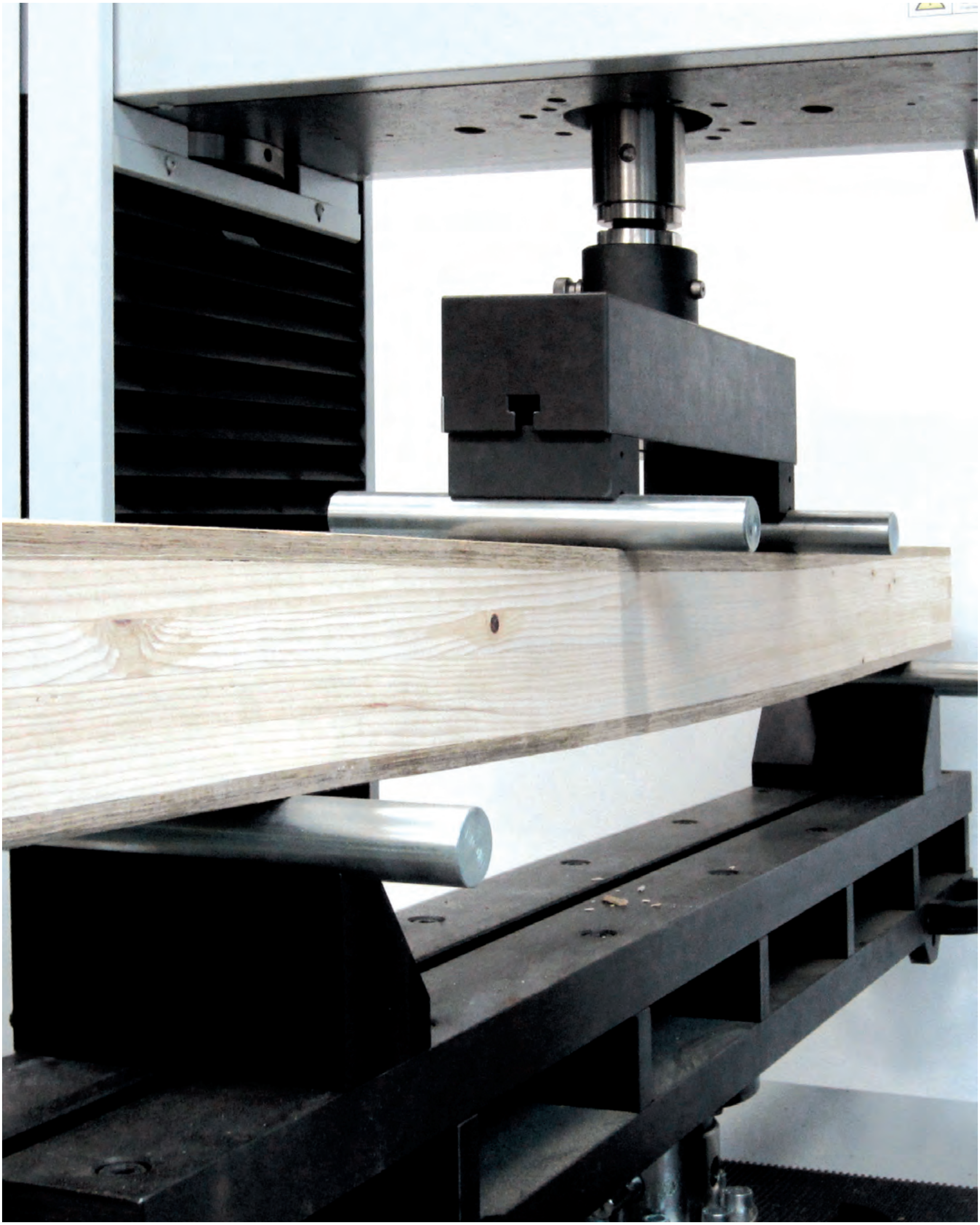


Fig. 04 Bamboo Composite Lamination hybrid-beam test setup

In the linear section of the deformation, the bamboo composite laminated hybrid-beam reveals a modulus of elasticity, which is two times higher as compared with the standard glued laminated timber beam. The stronger bamboo composite laminated layers overtake a large part of the resulting normal stress and prevent the weaker timber layers from cracking. However this peak of normal stress is similarly to the smaller specimens transferred into a horizontal force, which resulted likewise in a shear failure. Overall, the tested bamboo composite laminated hybrid-beam withstood a bending force of 110 MPa with a significantly smaller deflection than the corresponding standard timber beam (Table 02). In summary, the first test series on the larger specimens shows that the system may be utilized more efficiently regarding the ratio between both materials. The required amount of bamboo composite layers may be varied and the effect on the flexural strength can therefore be adapted. Hence it is believed that further investigation will lead to bamboo composite laminated hybrid-beams that can withstand even higher forces.

	Standard beam	**Hybrid beam**
Bending capacity (MPa)	76.1	110.3
Modulus of Elasticity (GPa)	7.2	14.5

Table 02 Flexural strength and elasticity of the tested specimens

The large scale tests as well as the bamboo composite laminated chipboards and bamboo composite laminated medium-dense-fiber boards show analogous performances. In general, all produced bamboo composite laminated specimens turned out to be significantly stronger than corresponding non-laminated structures. The combination of the two natural materials bamboo and wood exhibits a promising potential for structural applications and will be carried on further with variations of layer thicknesses and core materials. The goal is the design of a bamboo composite laminated hybrid system with as little bamboo composite as possible in order to provide a smaller, lighter and more economic structural material.

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Fig. 02-04: Tobias Eberwein

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