MECHANICAL PROPERTIES OF BAMBOO CORE SANDWICH PANELS

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Abstract- Bamboo is a material that has been used in construction for generations. One of the biggest disadvantages to this material is the natural variability, however, there is the potential for it to be used as core material in sandwich panels. Therefore, to maximise bamboo's potential for usage as a structural material and limit the impact of natural variability, bamboo core sandwich panels were developed. The experimental procedure was broken down into 3 stages. The first stage reviewed the impact of different core configurations on the modulus of rupture and compressive strength of sandwich panels produced with plywood as the outer skin and bamboo rings as the core. The second stage took the best configuration from stage 1 and produced a 2m beam to review the mechanical properties and was thereafter compared to a control beam with no bamboo rings. The final stage of the experimental procedure reviewed the compressive strength of the bamboo rings both parallel and perpendicular to the grain to validate the results obtained in stage 1 and 2. Results showed that the core configuration has a big impact on the modulus of ruptures and that there was a clear relationship between density and modulus of rupture. Stiffness of the beams and cubes tested increased as the cross-sectional area of rings increased and allowed for a greater contact area. Finally, the testing of the bamboo rings aligned with results that were expected when testing parallel and perpendicular to the samples, with split bamboo rings producing good strengths in comparison to good rings.

Keywords- Bamboo, Sandwich Panels, Mechanical properties.

1 Introduction

There are around 1000 different subspecies of bamboo in the world, and many of them are common in temperate, tropical, and subtropical climate zones. Bamboo has been a dependable building material for both temporary and permanent structures for generations, among its many other uses. One of the reasons that bamboo has been used for construction is because of its strength to weight ratio, mechanical properties, rate of growth and seismic performance [1]. Although, there have been comparisons to materials such as steel, studies have showed that the strength properties are similar to that of lumber, with certain species approaching strengths of high grade (D40) [2]. The allowable stresses for most species are found to be between 10 and 20 N/mm^2 [3].

Sandwich panels have been extensively employed in construction because of its inherent thermal, acoustic, and fire insulation capacities and where weight is a major consideration [4][5]. Currently, many of the available sandwich panels employ less dense materials as their core material, but this method is not the most effective when flexural pressures are involved. The core's function in flexural resistance is essential because it must transfer shear forces between the encasing skins. Therefore, the core must provide a stability in resisting shear deformations. A study evaluated how the bamboos core diameter and the type of adhesive used to connect the skin to the core affected the panels' equivalent density, flexural strength, and shear strength with a brand-new sandwich panel made of prepreg flax skins [6]. It was concluded that both the density and diameter of the bamboo rings had an impact on the characteristics of sandwich panels [6]. Both diameter and density were found to have an impact on the mechanical properties. As the diameter of the bamboo cores increased, there was greater flexural strengths and as the diameter decreased there was an improvement in the core transverse shear modulus [6]. A separate study conducted a numerical analysis on the flexural behaviour of how the height of bamboo rings and the thickness of plywood skins affected the bending stiffness in comparison to cross-laminated timber (CLT) sections [7]. It was concluded that that the bending stiffnesses of the sandwich panels constructed from bamboo rings were similar to that of the CLT. Therefore, showed that there is potential for more slender areas and much lighter components [7]. A similar review with bamboo cores with multiplex plywood skins was conducted to understand the impact of both core and skin thickness on the mechanical properties of sandwich panels [8]. With the use of a two-way ANOVA statistical analysis, it was concluded that individually altering the thickness of both elements impacted the results. However, increasing the thickness of both elements together, tended to not impact the bending strength of the panels [8]. It has also been reported that bamboo rings in a honeycomb configuration can improve flexural strength and impact resistance [9]. As well as configuration of bamboo rings, the adhesive plays a crucial role, as bamboo in comparison to wood has a higher density and starch, wax and silica content which impacts its bonding ability [10]. Overall, studies have shown the potential for bamboo to be used as a core in sandwich panels for structural application. The sustainable benefits could prove popular with the strategies that have been placed by many governments across the world. Therefore, the aim of the paper is to determine the structural capability of using bamboo cores in timber sandwich panels. With the purpose of determining if the mechanical properties bamboo sandwich panels have the potential to be used for structural application.

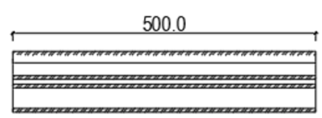
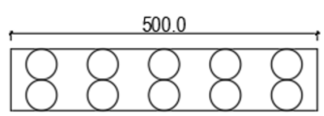
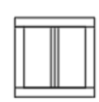
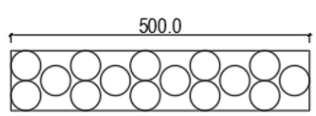
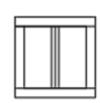
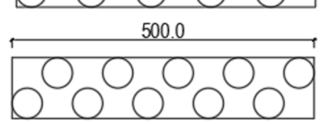
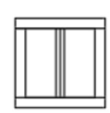
2 Experimental Procedures

To review the impact of bamboo sandwich panels, the experimental procedure was broken down into 3 stages.

2.1 Stage 1

In this stage, there were four beams (500mm x 165mm x 120mm) and two cubes (100*100*100) with different core configurations produced and one beam was produced with no cores as a control sample. Beams were tested for their flexural strength and the cubes were tested in compression. Table 1 provides the details of the specimen number, core configuration and number of cores used for the beam samples. For the cube samples, there were 3 and 4 cores in the two different samples produced. The cores used were 100mm in length and the plywood used for the outer casing had a thickness of 9mm. Figure 1 provides an image of a cube sample that was prepared. The beams were tested under 4-point bending, with loading at a rate of 3kN/sec and two-point loads were applied at 300mm.

Table 1. Details of beam samples

Specimen Number	Core Configuration		Number of Cores
	Plan View	Elevation	
S1-01	Control specimen with no bamboo	N/A	None
S1-02			Longitudinal core configuration, with equivalent length of bamboo as S1-04
S1-03			10
S1-04			15
S1-05			10

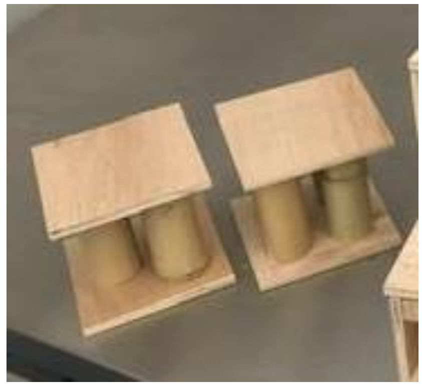


Figure 1. Compression samples

2.2 Stage 2

The second stage of the experimental procedure involved producing 2m sandwich panels and investigating the structural behaviour. A 2m control beam (S2-01-P) was compared to the 2m sandwich panel using the configuration of S1-03 (S2-01-BP) in phase 1, as this has the greatest strength to weight ratio of any samples tested. The beams were tested under 4-point bending, had dimensions of 2000 x 120 x 165 mm and an effective span of 1800mm. Figure 2 provides the setup of the 4-point bending tests and the location of the linear variable displacement transducer (LVDT) which was used to measure the deflection at mid span. The loading rate for the test was 0.15 mm/s

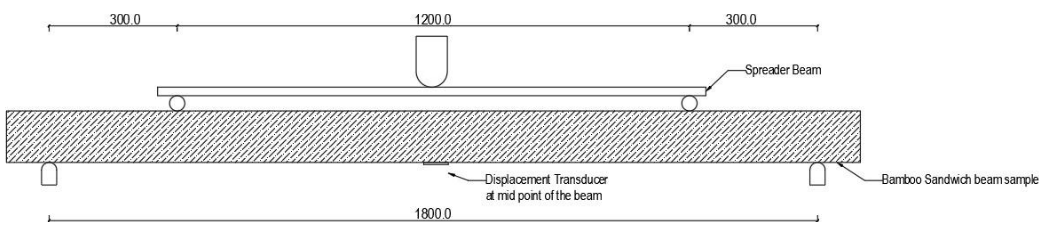


Figure 2: Test setup for four-point loading on 2m beam

2.3 Stage 3

The final stage of the experimental procedure reviewed the compressive strength of the bamboo ring both parallel and perpendicular to the grain. Furthermore, in addition to testing the good quality bamboo rings, bamboo with defects and those rings that had failed in the sandwich panels were also investigated for their compressive strength in both directions. Table 2 provides details of the samples that were tested.

Table 2: Compression test specimen details

Specimencode	Description
PD-1	Parallel to grain of damaged beams
PD-2	
PPD1	Perpendicular to grain of damaged beams
PPD2	
PS-1	Parallel to grain of split bamboo
PPS-2	Perpendicular to grain of split bamboo
PP-1	Perpendicular to grain off good bamboo
PP-2	
P-1	Parallel to grains of good bamboo
P-2	

3 Results

3.1 Mechanical properties of the bamboo sandwich panel

Figure 3 provides the Modulus of Rupture (MOR) vs density of the 5 beams produced in stage 1. Results show that there is a direct link between density and MOR, as density increases so does the MOR. The beam that produced the greatest MOR was S1-02 which had rings arranged longitudinally along the longitudinal axis of the beam. It assumed that this produced the greatest strength as the arrangement allowed for the loads to be distributed parallel to the grain, which has been stated to be its strongest direction [11]. S1-04 failed due bamboo rings being compressed. It is assumed that the higher shear stresses located around the support caused the rings to fail in compression in those areas. From the results it can be noted that S1-04 which has a similar density to that of S1-05 and S1-03 produced a higher MOR value. The reason for this is due to the increase in bamboo rings that were used in S1-04. S1-04 had 33% more rings in comparison to S1-05 and S1-03, which is assumed to have provided greater rigidity due to an increase in the contact area. Similar studies concluded that an increase in the number of rings will increase the MOR due to the rings having a greater contact area with the outer skins and therefore, increasing the rigidity and providing greater resistance [8]. Figure 4 provides an image of the failure mode of one of the beams and it was noted that all beams had similar modes of failure. It was noted that initially the top skin of beam failed and thereafter there was delamination from the core. Similar trends had been noted in other studies where it was observed that failure of top skin occurred in the initial phase of loading, followed by the complete separation of the specimen in the mid-span at failure [12].
Table 3 provides the results of the cube samples that were tested for its compressive strength. Testing showed that S1-C1 failed due to vertical cracks running along the longitudinal axis while S1-C2 failed due the punching of plywood skins. Although S1-C2 had more bamboo rings, the results show that there is a direct link between the cross-sectional area of the rings and the compressive strength. As the cross-section area increased, so did the compressive strength. S1-C1 is assumed to have produced greater strengths as its cross-sectional area was 43% greater than that of S1-C2.

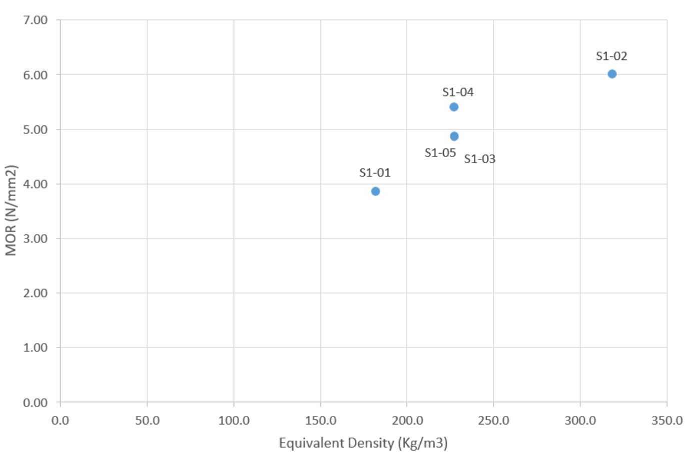


Figure 3: MOR vs Density

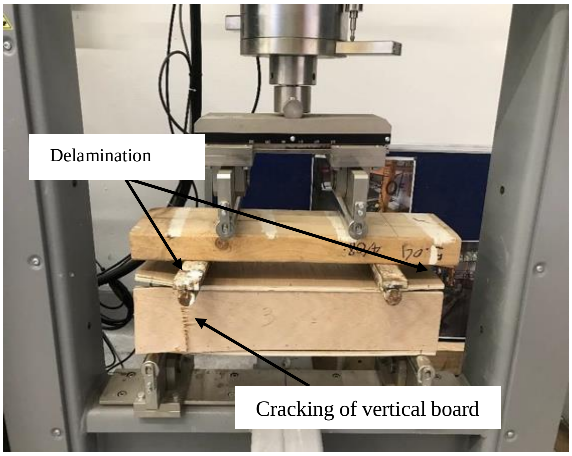


Figure 4: Failure mode of beam

Table 3: Test results and calculations of compressive specimens

Specimen	Number of bamboo cores	Mass (Kg)	Total cross-sectional area of bamboo culms (mm2)	Load at failure (kN)
S1-C1	3	0.35	2490	124
S1-C2	4	0.27	1740	92

3.2 Structural behaviour of the bamboo sandwich panel

Figure 5 provides the load vs deflection of the 2m sandwich panels that were produced in stage 2. Figures 6 and 7 show the failure of S2-01-P and S2-01-BP, respectively. The trends for both control sample (S2-01-P) and sample with bamboo rings (S2-01-BP) are initially similar. However, S2-01-BP produces a slightly greater maximum load and withstands load for a greater period after the initial linear trend. At about 27mm of mid-span deflection, which corresponds to the vertical board of the beams cracking, the initial failure of both beams was visible. Following the initial failure, S2-01-P failed, however S2-01-BP had better capacity resistance by 0.2kN. The nonlinear behaviour that can be noted in S2-01-BP is assumed to be due to the incorporation of the bamboo rings, which is increasing the flexural stiffness of the panel. This in turn could be related to the hogging that was observed near the supports. When reviewing the Modulus of Elasticity (MOE), S2-01-BP had an MOE of 3.97 GPa. These results seem reasonable as they are similar to trends which were noted in other studies where the MOE ranged from 2.2 GPa to 4.2 GPa depending on the diameter and the type of adhesive used [4]. Although the range is similar, it must be noted that different materials were used for the outer skins of the sandwich panels, which would then have an impact on the mechanical properties of the panels. Overall, it may be seen that S2-01-BP gains more strength from the bamboo core as the weight is increased. Even though the beam's midspan has a consistent bending force during the four-point bending test, S2-01-BP fails under the right-side load point. This might be because the bamboo core's properties vary widely, distributing the load unevenly.

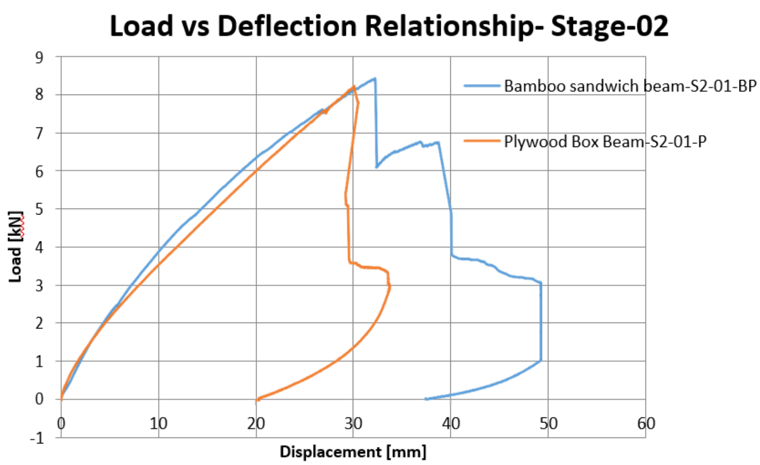


Figure 5: Load-deflection relationship of the beams

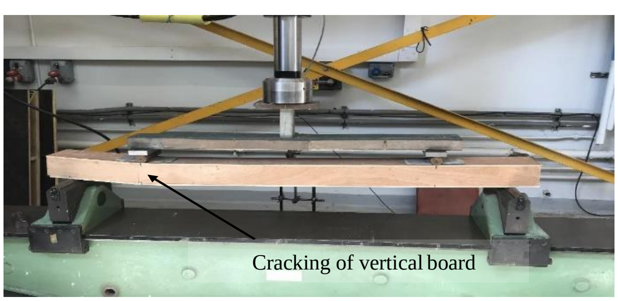


Figure 6: Failure of S2-01-P

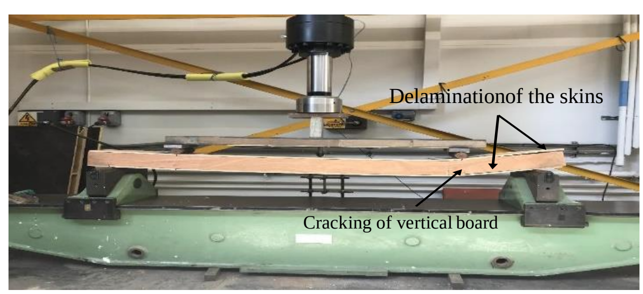


Figure 7: Failure of S2-01-BP

3.3 Compressive strength of bamboo culms

Table 4 provides the results of all sample tested in stage 3 of the experimental procedure. The stress at failure was only able to be determined for those samples tested parallel to the grain as those tested perpendicular to the grain were insignificant.

Table 4: Compression test results of bamboo cores

Specimenn Code	Max. Load (kN)	Avg. Dia (mm)	Thickness(mm)	Stress at failure(N/mm^2)
PD-1	34.4	43.7	4.7	60.2
PD-2	45.1	45.2	4.4	80.5
PPD1	5.7	45.6	6.4	-
PPD2	7.6	39.7	3.9	-
PS-1	65.7	43.8	6.4	87.4
PPS-2	0.0	45.0	5.8	-
PP-1	0.0	47.0	4.7	-
PP-2	0.0	42.3	7.2	-
P-1	71.9	40.3	7.6	91.9
P-2	44.7	43.0	4.0	90.6

The cross-sectional area has a significant impact on bamboo's compressive strength. The test findings show that the impact of a split bamboo ring on the final compressive strength is negligible. Every sample of bamboo examined perpendicular to grain failed with no discernible failure. The two specimens that were removed from the damaged beams were the only exceptions. It can be inferred that the only reason these samples could support some loads was because they included nodes, which served as a strong point to withstand the tensile strains created within the sample. Bamboo ring failure in the direction of the grains can be characterised by longitudinal splitting and bulging, with compressive stresses achieving the expected values. These findings support the longitudinal configuration's failure mechanism that was put to the test in stage 1. Even though the longitudinal direction of the bending stresses was aligned, the beam broke because of the compressive force perpendicular to the grain, which caused the ring to fracture.

When reviewing all results, the flexural strength values were high enough to consider using bamboo sandwich panels for a floor application. The use of bamboo core sandwich panels increases the depth of the structure compared to wood floors, but the increased joist spacing can reduce the overall weight of the floor. Apart from that, services may also accompany within structural zones, mitigating the effects of increasing structural depth. Overall, bamboo core sandwich panels have excellent mechanical properties and have been shown to somewhat minimize practical problems caused by bamboo's natural variability, making it a good candidate for secondary structural applications.

4 sConclusion

The following conclusions can be drawn from the conducted study:

1. S1-04 provided the greatest strength to weight ratio due to the increase in contact area which increased the rigidity and strength.
2. Although S1-C2 contained a lower number of rings, the cross-sectional area of rings used allowed for a greater contact area which in turn increased the compressive strength.
3. the incorporation of bamboo rings in 2m sandwich panels increased the maximum load and stiffness.

4. testing of the bamboo rings aligned with results that were expected when testing parallel and perpendicular to the samples.

The aim of the paper was to determine the structural capability of using bamboo cores in timber sandwich panels. From the results obtained in the stages of this study, it can be concluded that bamboo core sandwich panels have the potential to be used in construction due to the mechanical properties and minimised impact of variability that is expected due to it being a natural product.

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