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Effects of core grain orientation on the mechanical properties of wood sandwich composite

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Abstract

Utilization of sandwich composite during recent year has been driven by the fact that composite material has ultimately high strength and stiffness by weight than any other materials. The skins of sandwich composites technically bear most of the applied loads, however, the core materials also play an important role as it functions in providing continuous support to resist the shear stress. Hence, proper selection of core materials is required to establish a sturdy sandwich composite structure. This paper presents an experimental investigation on the sandwich structure consists of fibreglass/epoxy face skins and a mahang wood core. Sandwich composite with core grain oriented in parallel and perpendicular to the flat plane direction were tested for mechanical performance in tension, compression and flexure. The results indicate that sandwich composite with grain oriented in parallel direction performed better in tensile properties with strength of 201.98 MPa whereas sandwich composite with perpendicular core grain produced a higher value of compression properties with strength of 70.11 MPa. However, no significant effect of grain orientation was observed in flexural strength. The strength of sandwich composite is dependent on the grain alignment of the wood core as it functions exclusively as mechanical supporting cells to support the wood structure.

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1. INTRODUCTION

Sandwich structured composite is a class of structural composites having relatively high bending stiffness, lightweight and high strength to weight ratios (Anjang et al., 2014; Belouettar et al., 2009; Mohamed et al., 2015). It consists of a pair of thin, stiff, strong skin and a thick, lightweight core to separate the skins and carry loads from one skin to the other. They are one of the fundamental aspects of numerous structural constructions. Current applications have proven that sandwich composite in the civil infrastructure and various critical weight constructions can be very economic and viable. Adoption of sandwich composite during recent years has driven the demand to study the structural behaviour and failure characteristics of sandwich composite.

The skins of sandwich composites technically bear most of the applied loads; however, the core material also plays an important role in this structure as it functions in providing continuous support for the skins (Tagarielli et al., 2007). The core of sandwich composite must be low density at the same time thick enough to provide bending rigidity and prevent buckling (Carlsson & Kardomateas, 2011). Wood is one of the frequently used materials for sandwich core due to its low cost and environmental friendly properties. It is highly anisotropic (Brémaud et al., 2011). The properties vary depending on the direction. Proper orientation must be considered to ensure the wood can perform effectively. Hence, this study aims to investigate the effects of wood core orientation on the mechanical properties of sandwich composites. In this study, lesser known wood species (LKS) mahang (macaranga) wood is utilized as a core of sandwich composite due to low density as well as exhibits fast growing properties.

2. MATERIALS AND METHODS

2.1. Materials and composite fabrication

Sandwich composite was constructed by attaching fiberglass faceskins to mahang wood core at the upper and lower surfaces. Faceskins were fabricated from plain woven E-glass fabric (0.166 kg/m3, Fiberglast Company) and epoxy resin (Fiberglast Company) by using hand lay-up technique. Resin was applied by using hand brush and roller to remove trapped air bubble and excessive resin. 50:50 fibre-matrix volume ratios were used to impregnate the fabric. The core of sandwich composites

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was manufactured by combining individual block of mahang wood measures 100 x 100 mm into panel of 300 x 300 mm. Two types of cores were prepared according to the grain direction namely parallel (PL) and perpendicular (PR) to the flat plane (Figure 1). Blocks of mahang wood were extracted from the lumbers of a 10 m tall mahang tree with diameter at breast height (DBH,1.3 m above the ground) of 78 cm. The process of cutting the logs into lumbers was done by the Forest Research Institute Malaysia (FRIM). Lumbers were pre-dried in a force convection oven at 50°C for 12 days until 12 % moisture content attained. The sandwich panels with face skins attached to mahang wood core were consolidated by using vacuum-bagging process for 24 hours. Consolidated panels were then post-cured in an oven at 80 °C for 2 hours.

Figure 1: Mahang cores of sandwich composite with grain oriented in parallel (left) and perpendicular (right) to the flat plane

2.2. Tensile test

The specimens for tensile test were prepared according to ASTM D3039 : Standard Test Method For Tensile Properties of Polymer-Matrix Composite (ASTM, 2014). All mechanical tests were executed by Testometric M500-50CT Universal Testing Machine (UTM). Specimens were made into rectangular shape with dimensions of 250 mm in height, 25 mm wide and 10 mm thick. The machine was set to elongate the specimen at a constant head-speed of 2 mm/min. Tensile strength is obtained from the following equation:

$$TS = \frac{P_{t,max}}{b_t h_t} \quad \text{(Equation 2.0)}$$

Where:

TS = Tensile strength, MPa
$P_{t,max}$ = Maximum load before failure, N
b_t = Width of tensile specimen, mm
h_t = Height of tensile specimen, mm

2.3. Compression test

Compression test was conducted in accordance to ASTM C-365 : Standard test Method for Flatwise Compressive Properties of Sandwich Cores (ASTM, 2016a). Specimens of sandwich composite with dimensions of 30 x 30 x 45 mm3 were compressed at standard head-displacement rate of 0.5 mm/min. Compressive load was applied flatwise by using loading platens attached to UTM. The formula to obtain compressive strength is shown in the following equation:

$$CS = \frac{P_{c,max}}{b_c h_c} \quad \text{(Equation 2)}$$

Where:

CS = Compressive strength, MPa
$P_{c,max}$ = Maximum load before failure, N
b_c = Width of compression specimen, mm
h_c = Height of compression specimen, mm

2.4. Flexural test

Rectangular sandwich composite specimens with dimensions of 200 mm in length, 75 mm in width and thickness of 20 mm were tested in 3-point bending test with support span of 150 mm. Testing was performed in compliance with ASTM C-393: Standard Test Method for Core Shear Properties of Sandwich Construction by Beam Flexure (ASTM, 2016b). Load was continually applied at a rate of 6 mm/min. Flexural strength also known as modulus of rupture is calculated by using the following equation:

$$MOR = \frac{3P_{f,max}L}{2b_f t_f} \quad \text{(Equation 3)}$$

Where:

MOR = Modulus of rupture, MPa
$P_{f,max}$ = Maximum load before failure, N
L = Length of support span, mm
b_f = Width of the flexural specimen, mm
t_f = thickness of the flexural specimen, mm

3. RESULTS AND DISCUSSION

The results of mechanical testing on sandwich composite is shown in Figures 2,3 and 4. The figures compare the strength values obtained for sandwich composite with parallel and perpendicular oriented core grain.

Tensile strength of sandwich composite with parallel and perpendicular core are 201.98 MPa and 97.67 MPa, respectively. The strength value is higher by more than 100% for sandwich composite with PL core. Tensile force is applied parallel to the wood fibre in sandwich composite with PL core. The wood fibres elongate and slipping by each other to sustain the applied tensile loading (Council, 1992).

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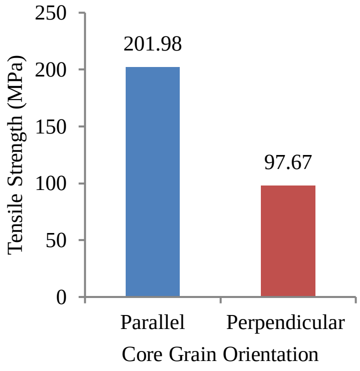

Figure 2: Tensile testing of sandwich composite and the comparative results of sandwich composite with parallel and perpendicular oriented core grain

Tensile strength of sandwich composite with parallel and perpendicular core are 201.98 MPa and 97.67 MPa, respectively. The strength value is higher by more than 100% for sandwich composite with PL core. Tensile force is applied parallel to the wood fibre in sandwich composite with PL core. The wood fibres elongate and slipping by each other to sustain the applied tensile loading (Council, 1992). Tensile loading in sandwich composite with PR core specimen is subjected perpendicularly to the grain. It separates the wood fibres and induce splitting or cleavage along the grain (Ritter & Service, 1990). Thus, eliminating the efficiency of fibres to work together as a bundle to resist applied force. Wood is least strong when tensile force is applied perpendicular to its grain (Council, 1992). Arises of high tensile stress perpendicular to wood grain in structural design must be avoided (Ardalany et al., 2011). It results in a weaker structure with tensile strength usually less than 6.89 MPa. In this study, tensile strength of sandwich composite with PR core grain is higher than Barrett (1974) due to the presence of fiberglass faceskins.

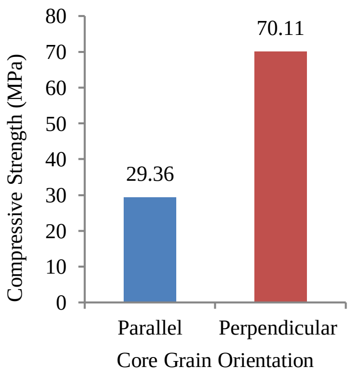

Figure 3: Compression testing of sandwich composite and the comparative results of sandwich composite with PL and PR core

In contrast to tensile, compressive strength is higher by 141 % for sandwich composite with PR core rather than PL. This can be explained by the fact that load is subjected at axial direction or parallel to grain for sandwich composite with PR core, the fibres can support load greater than their weight. The applied compressive load compressed the wood fibres in lengthwise position and induces stress that shortens the fibres. The wood cells working together as hollow columns and support adjacent cells by forming lateral support and at the same time strengthen its own hollow column by the support received from its internal structure. It fails under significantly lower loads when compressed at perpendicular direction to its grain (Ritter & Service, 1990).

Sandwich composite with PR core exceeding the flexural strength of PL core by slightly 2.9 %. The strength difference is less significant for MOR. Similarly, Srivaro et al. (2014) found the effect of core grain orientation of sandwich composite is less pronounced on the MOR. In his study, MOR for sandwich composite consists of rubberwood veneer skins and oil palm wood core differs by only 2.77 % for parallel and perpendicular grain orientation. During bending sandwich composite along with the core experienced compression at the upper surface while lower surface experienced tension.

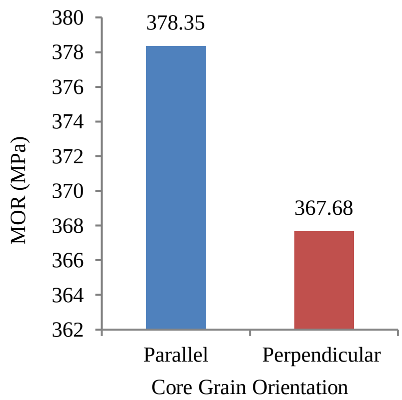

Figure 4: 3-point bending testing of sandwich composite and the comparative results of sandwich composite with PL and PR core

Several modes of failure can be observed from the fractured specimen namely face wrinkling, face yielding and core shear. Face wrinkling or short-wavelength buckling occurs when the compression stress at the upper surface of sandwich composite reaches the level of critical (Daniel, 2009). Whereas face yielding is a result of critical tensile stress exceeding the allowable stress at the lower surface of sandwich composite. Core shear failure occur at maximum force which initiates crack and propagates through the core (Marșavina et al., 2017).

4. CONCLUSION

The effects of core grain orientation on the performance of sandwich composite were investigated. The performance of sandwich composite generally depends on the properties of both face skins and core, the adhesive bonding between them and the geometry of sandwich composite (Daniel, 2009). Sandwich composite

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with PL core performed better in tensile properties while compression properties is better for sandwich composite with PR core. This is attributed to the fact that sandwich composite with core grain oriented along the axis of loading performed better tensile and compression properties. However, no significant effect of core grain orientation found on the flexural strength of sandwich composite. The results of this study indicate that proper orientation of wood core grain must be considered to ensure the performance of sandwich composite can be maximised.

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