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Improved fatigue performance for wood-based structural panels using slot and tab construction

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ABSTRACT

This paper presents static and fatigue bending behavior for a wood-based structural panel having a slot and tab (S/T) construction technique. Comparisons were made with similarly fabricated panels without the S/T construction technique. Experimental results showed that both types of panels had similar bending properties in the static tests. However, the panels with S/T construction had better fatigue results. The failure modes were different for the two fabrication techniques. The panels without S/T debonded at the core:face interface. Whereas, the panels with S/T had cracks that propagated within the rib of the core after debonding damage at the core:face interface. The fatigue deflection-life relationship indicated that the S/T construction improved the connection between the faces and core. The S/T construction decreased the deflection growth rate that delayed panel failure. The fatigue stress-life relationship or degradation was better for the panels with S/T construction than the panels without the S/T construction.

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1. Introduction

Structural composites have been widely used in many applications such as shipping, aerospace, transportation, and building construction due to its high strength-to-weight ratio [1–4]. Various materials, designs, and manufacturing, methods for structural composites attempting to improve performance have been developed and investigated in recent years. Isogrid core designs made from aluminum to fabricate structural composites for aerospace applications have shown that the isogrid configurations were more structurally efficiency than either foam or honeycomb structures [5,6]. The simple manufacturing process using interlocked grid structures with improved mechanical performance by unidirectional pultruded glass fiber rib was presented by Han and Tsai [7]. It was easier and more efficient than the traditional pultruded method. Fan et al. [8] fabricated interlocked kagome structural panels using carbon fiber composites and evaluated the mechanical behaviors using static compression and bending tests. The results indicated that debonding was one of the more significant failure modes for the mechanical tests. For fatigue tests, Belingardi et al. investigated the fatigue behavior of a sandwich beam using the four point bending test, two different failure mechanisms of face compression and core debonding were observed using both undamaged and initially damaged panels [9]. Jen et al. analyzed the effect of the amount of adhesive on the bending fatigue strength of bonded aluminum structural beams, the results showed the fatigue strength of structural beams was improved as the amount of adhesive increased [10]. Their research also demonstrated that the thickness of the face sheets showed no evidence of effect on the fatigue strength [11]. From the researches cited above, there was a common behavior observed that the core:face interface strength had a significant effect on the mechanical behavior of the structural composites, especially for fatigue.

Forest Products Laboratory (FPL) is working to develop engineered structural materials made from wood-fiber-based composites that have enhanced performance for some engineered applications such as air pallet, tactical shelter, transportation, or building construction materials [12–19]. In an initial study, phenolic laminated paper was used for a tri-axial core configuration within a structural composite panel. The mechanical behavior for these tri-axial core panels were obtained using static bending and compression tests [12–17]. The results showed these wood-based structural panels had good mechanical performance. However, debonding at the interface between the structural core and face caused premature failure during the mechanical tests. Failure was due to insufficient epoxy resin bond strength at the rib and face interface. For our configuration, the epoxy could not provide

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enough capacity to resist core:face interface shear failure. One method to strengthen the interface and avoid premature debonding failure was to develop a slot and tab (S/T) construction technique at the core:face interface. The purpose of slot and tab construction technique was to improve the load transfer between the core and faces utilizing both increased surface area and mechanical interlock load transfer. In this paper, the S/T construction was used to compare the static bending and fatigue bending behavior for the tri-axial core wood-based structural panels.

2. Materials properties

The main material used for both the core and face components to then fabricate the panels was NP610 phenolic impregnated laminated paper obtained from Norplex-Micarta Inc. (Postville, Iowa, USA). Its mechanical properties were obtained using in-house ASTM D638-10 [20] and D695-10 [21] standard coupon tests. Epoxy resin was used to bond the laminated paper faces and core components of the panels. It was obtained from U.S. Composites (West Palm Beach, Florida, USA). The ratio of epoxy to hardener was 3:1. The shear strength for the epoxy was determined using the lap shear test, ASTM D5868-01 [22]. The average epoxy shear strength between the laminated papers was 17.9 MPa, which was significantly less than the laminated paper composite's shear strength of 84.1 MPa. The material properties of the individual components used in the structural panels are listed in Table 1.

3. Design and construction

3.1. Configuration of wood-fiber-based structural panels

The structural composite panels were fabricated by the tri-axial core configuration using the laminate paper as linear ribs in each of three axes with an interlocked structure (Fig. 1). The core rib height was 33.0 mm. The slots in the linear ribs were cut slightly oversized to accommodate the 60° angular orientation between the ribs when assembled. For this study, the slot spacing for all pieces was 117.3 mm, thus creating an equilateral triangle. The thickness of the ribs was 2.4 mm. Two layer laminated paper sheets were used for the faces with or without slot configuration. The combined thickness for both face components used in this study was 5.2 mm including the glue interface. Three centrally located ribs were used to fabricate the core. Cross ribs were cut flush with the width of the panel.

3.2. Slot and tab (S/T) construction technique

For our configuration, the core:face interface was basically only the width or the thickness of the laminated paper ribs, 2.4 mm, times the length of each rib. Due to the relatively small shear interface area and low bonding strength of the epoxy, a new fastening construction technique of S/T was developed to increase the mechanical and interaction epoxy bond area between the ribs and faces. The combined mechanical and adhesive interaction was intended to provide improved interfacial stress transfer to enhance panel strength and avoid premature interface failure. The core components were all machined without or with tabs that were 19.1 mm long spaced every 38.1 mm apart on both sides of the rib. The height of the tabs was 2.3 mm and slightly less than the thickness of the laminate paper (2.4 mm). On the first face layer on either side of the ribs, slots were machined with one-third of the slots arranged along the length of the panel, a second one-third of the slots were aligned 60 degrees off-axis from the first, and a third one-third of the slots were aligned −60 degrees off-axis from the first slots. The slot pattern was made with round

Table 1
Material properties for the panel components.

Materials	Density (kg/m^3)	Comp. strength MD[a] (MPa)	Comp. strength CD[b] (MPa)	Tensile strength MD[a] (MPa)	Tensile strength CD[b] (MPa)	In-plane shear strength (MPa)	MOE MD[a] (GPa)	MOE CD[b] (GPa)	In-plane shear modulus (GPa)	Poisson ratio MD[a]	Poisson ratio CD[b]
Laminated paper (LP)	1387	195.1	168.7	173.9	118.6	84.1	11.6	8.3	3.4	0.36	0.22
Epoxy resin	1101	105.9	–	31.0	–	17.9	1.4	–	–	0.42	–

[a] MD: machine direction.
[b] CD: cross-machine direction.

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