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Influence of core joints in sandwich composites under in-plane static and fatigue loads

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ABSTRACT

Most designers are unaware of the influence of core junction in lightweight sandwich structures under axial load. Quantifying this effect and its criticality on the life of the structure is still a challenging task. In this study, a novel testing methodology was used to characterize this effect. Scarf and butt core joints in foam core sandwich composites were subjected to axial static and fatigue loads ($R = 0.1$ and $R = -1$). Under cyclic axial load, differential movement (through-the-thickness) between the foam and core joint was more significant than anticipated. Non-destructive evaluation techniques were used to locate the damage and assess the failure mechanisms. The root-cause-failure analysis showed that cracks were initiated in the facesheets for the butt-joint, and in the core for the scarf-joint samples, respectively. Consequently, at 80% residual strength, the butt-joint reduced the predicted fatigue life by 42% and 32% at low and high cycle fatigue, respectively. Residual tensile tests revealed the sizeable damage induced by the traditional butt-joint design. This research confirmed that despite the facesheets' primary in-plane load carrying mechanisms, core junction will substantially influence the axial fatigue life of the structure.

1. Introduction

Composite sandwich structures are currently being employed in a variety of structural applications where high strength/stiffness to weight ratio is critical. Applications include space structures, bridge decks, boats, transportation, and wind turbine blades. Core joints exist in almost all molded large structures, and special attention with regards to the effect of core joint on the fatigue performance of sandwich shell structures is of particular interest to design engineers. When loaded in-plane, mismatched Poisson's ratio between the joint and the core generates out-of-plane stresses at the core joint/facesheet interface (See Fig. 1). Consequently, stress risers at this location will eventually form and affect the fatigue life of the structure. Most structural engineers are probably aware of this problem; however, quantifying this effect and its consequence on the service life and reliability of the structures is not fully understood. The motivation of this research work is to address this knowledge gap and quantify the effect of different joint configurations under axial static and fatigue loads.

The flexural fatigue behavior and failure of composite sandwich beams with core joints have been discussed extensively in the literature [1–6]. While there has been substantial work directed to improve the core junctions, in-depth characterizations of the core joint to predict the residual strength and fatigue life in sandwich structures are still limited. Couple of studies examined the composite sandwich structures with core joints due to in-plane loads [7,8]. They investigated the effects of butt joints between different core densities with aluminum and GFRP facesheets. They found that the failure mode was initiated in the softer core near the joint followed by facesheet failure, this in turn lead to shorter fatigue life. They also addressed the critical need to better understand the stress/strain state at the core junctions. One recent study investigated the effect of different core joint designs including butt, scarf, and finger joints under axial tension static and fatigue load ($R = 0.1$) [9]. Their research concluded that the scarf core joint increased the axial stiffness of the sandwich panels by 14% and 6% in fatigue-life with respect to the butt joint and plain foam samples (no core joint), respectively. This paper is an extension of their work and deals with a broader experimental characterization of sandwich panels under in-plane loads (static, Fatigue $R = 0.1$, -1 and residual strength) to predict the residual strength and fatigue life of such structures.

The outcome of this paper will not only target sandwich composite structures, but also provide a novel testing methodology and characterization of composite laminates subjected to tension-compression fatigue loading.

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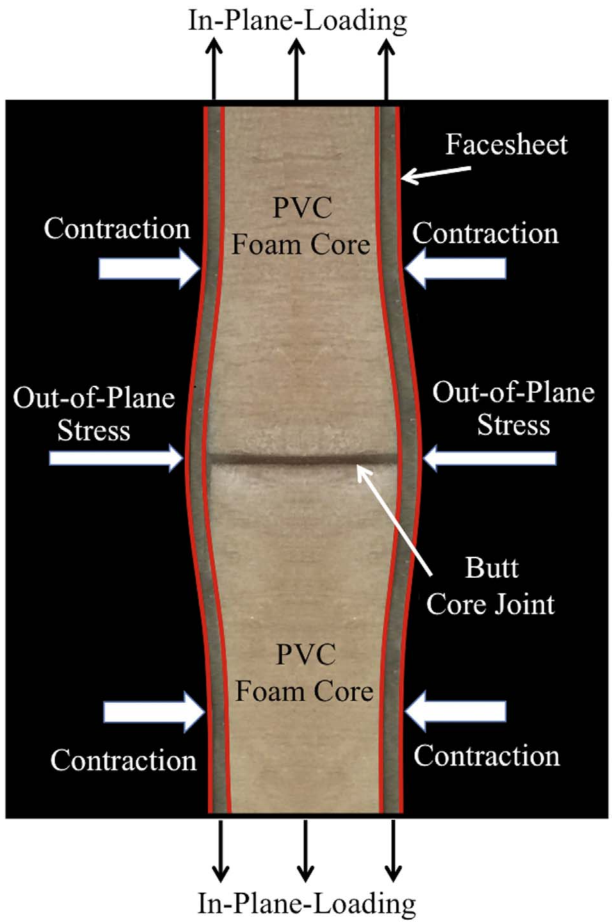

Fig. 1. Anticipated mechanism of a sandwich structure with core joint loaded in-plane.

2. Experimentation

2.1. Materials selection and panel manufacturing

H100 and H200 PVC foam (Divinycell® Inc.) were used as core materials. Vinyl Ester resin (DERAKANE 610C-200 by Ashland Inc.) reinforced with knitted *E*-glass fabric (E-BXM1708 by VectorPly Corporation) was used to manufacture the composite sandwich panels. This specific resin is commonly used in infrastructure applications and provides superior corrosion and durability. Organic peroxide Catalyst (1.25%) by Cadox® LLC was mixed with the resin prior to infusion. The stacking design of the sandwich panel consists of [3-plies/core/3-plies] where each ply is constructed of [+45/−45/Mat; 882 g/m^2] and mat placed against the core. Sandwich panels were fabricated by the Vacuum Assisted Resin Transfer molding process (VARTM). Table 1 shows the material properties of the face sheets, foam cores, and resin. The face sheet laminates had a fiber volume fraction of 52%.The core joint thicknesses (core-to-core joints) were controlled by using a peripheral confined closed molding frame. All panels were then infused and post-cured for 6 h at 60 °C. Panels were cut into dog-bone shape using water jet technique. Epoxy tables (G10 material) with 76 mm long, 102 mm wide and 12.5 mm thick were bonded to the ends of the specimens using urethane adhesive (Lord adhesive 7150A/B High Strength Urethane, LORD corporation). The two end tabbed sections were placed in a mounting tab fixture and drilled using an upright drill press (Fig. 2). All specimens were perfectly machined flat on both ends and shimmed using two wedges on both ends prior to testing. A novel steel-mounting fixture initially designed and presented by [9] was used in this experimental work (See Fig. 2c). The dog-bone shaped specimens were 305 mm long, 102 mm wide and 29.6 mm thick (Fig. 2). The scarf joint is an efficient structural joint commonly used in laminated wood/timber structural members. The scarf joint design included in this study has a diagonal line (through the thickness) forming a 30° angle with the longitudinal axis. Fig. 3 shows the areal weight due to the resin uptake for all plain/joint configurations. As shown in Fig. 3, the scarf joint picked up resin by approximately 2% more than the plain foam core samples.

2.2. Mechanical testing

Initial static tensile test was performed on 11 different dog-bone shaped composite sandwich samples. All dog bone sandwich specimens were strain gauged back-to-back and adjacent to the core-to-core junction. The measured strain indicated herein is the average strain on both sides of the specimen. All static tests were initially conducted at 23 °C and 50% RH using a servo-hydraulic Testing Machine (MTS Model 312.41/132) with 2.5 mm/min constant head displacement rate. Tension-compression ($R = -1$) and tension-tension ($R = 0.1$) fatigue tests with constant load amplitudes and different frequencies were performed on a total of 62 samples. Due to the thermal softening effect of the foam, Burman and Zenkert [5] found that the variation in temperature of 5°C to 10°C could affect the Divinycell foam fatigue life. To mitigate this effect, two fans were used on both sides of the specimen during cycling. The load range spanned from 20% to 40% of the average ultimate static tensile load. Table 2 lists the fatigue test matrix for H100 and H200 specimens and the number of specimens for each fatigue regime.

Continuous displacement readings were taken during cycling. Increased in displacement (stiffness reduction) was recorded with the number of cycles during the fatigue test. Final number of cycles was recorded for every tested specimen at the point of failure. Failure protocol entailed to a 30% reduction in stiffness or facesheet fracture.

2.3. Non-destructive evaluation testing

Post-fatigue non-destructive evaluation (NDE) testing was used to assess and detect the delamination and crack propagations in the core and facesheets. To map out the damage propagation in the factsheets, an Ultrasonic Phased Array Inspection was employed after each target

Table 1
Face sheet laminates, core, and resin properties [9,10].

Face sheet laminate		Foam core H100		Foam core H200		Resin (core-to-core joint)	
E_1 [MPa]	14,123	Compressive Modulus [MPa]	134	Compressive modulus [MPa]	310	Tensile modulus [MPa]	3530
E_2 [MPa]	14,123	Tensile modulus [MPa]	129	Tensile modulus [MPa]	250	Flexural strength [MPa]	129
In plane Poisson's ratio	0.52	Poisson's ratio	0.4	Poisson's ratio	0.4	Flexural modulus [MPa]	3920
G_{12} [MPa]	9912	Shear modulus [MPa]	34	Shear modulus [MPa]	73	Heat distortion temp. ^{0}C	76
Thickness [mm]	2.1 ± 0.1	Thickness [mm]	25.4	Thickness [mm]	25.4	Core joint thickness [mm]	1.7 ± 0.1