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DETERMINATION OF TRANSVERSE SHEAR MODULI OF COMPOSITE CORE MATERIALS THROUGH SANDWICH BEAM TESTS

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1. INTRODUCTION

The necessity for high performance and low weight structures have increased the demand for development of sandwich constructions. Nowadays, sandwich structures are predominantly used in various fields such as aerospace, automotive, satellite, and bridge construction. Due to the notable flexural stiffness to weight ratio, sandwich structures present lower lateral deformations, higher buckling loads, and greater natural frequencies compared to other structural configurations [1].

The interest in sandwich panels increased considerably in the 1960s. Allen published his book on sandwich structures that is considered as one of the milestones in the sandwich construction field [2]. Ha [3] reviewed finite element analysis methods for sandwich constructions. In the recent years, utilization of fiber reinforced composite materials as facing and/or core material is studied to take advantage of superior properties of composites. In 2000, Daniel and Abot [4] worked on the determination of flexural properties of composite sandwich constructions experimentally and compared the outcomes with the theoretical models. Moreover, the failure mechanisms of composite sandwich structures have been widely examined [5-7].

In this work, transverse shear moduli of composite core materials are determined through three-point bending tests of sandwich beams and compared with analytical and finite element solution. All-composite sandwich structures are produced by using carbon fiber reinforced plastics (*CFRP*) material. The CFRP core material has a nonconventional geometry and presents different shear properties depending on the core orientation with respect to the beam axis; therefore, the tests are carried out for different core material orientations. Results showed that outcomes of experimental, analytical, numerical solutions are comparable.

2. METHODOLOGY

Three-point bending tests are performed by following ASTM C393 [8] test standard for the sandwich structures that have 20 mm composite core with two different core orientations which are parallel and perpendicular to the beam axis, respectively. The experiments are validated with the theoretical solution and finite element analyses.

Analytical Method

Fig. 1 illustrates the geometry of a sandwich structure in a three-point bending test. A force with a magnitude P is introduced to the structure by the above circular cylindrical roller, and the beam deflects by u. In Fig.1, c and h denote the core thickness and total thickness of the sandwich, and the width of the beam is b. The support length is indicated with L, the overhang portion of both ends of the beam is H, and t_f represents the face thickness. The facesheet properties of the structure are determined by following several test procedures [9-10] and the details are not presented in this study. The relevant mechanical properties for facesheet material are modulus of elasticity and the axial strength and are denoted with E_f and σ_f, respectively. The pertinent properties for the core material are E_c, σ_c, and G_c, which are the Young's modulus, compressive strength, and transverse shear modulus of the core material, respectively.

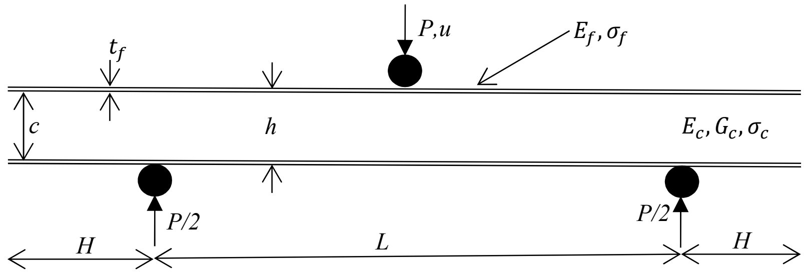


Fig. 1: Three-point bending test setup.

The flexural stiffness of the sandwich structure is determined by Eq. 1.

$$D = \frac{E_f b t_f^3}{6} + \frac{E_f b t_f d^2}{2} + \frac{E_c b c^3}{12} \quad (1)$$

In Eq. 1, the length d represents the distance between the centroids of facesheets and it is determined by Eq. 2.

$$d = \frac{h + c}{2} \quad (2)$$

Allen [4] formulized the transverse displacement due to the applied load P as in Eq. 3.

$$u = \frac{PL^3}{48D} + \frac{PL}{4A_{eq}G_c} \tag{3}$$

In Eq. 3, the term $A_{eq}G_c$ is described as the *shear rigidity* and A_{eq} is the equivalent cross-sectional area which can be determined by Eq. 4.

$$A_{eq} = bd^2/c \tag{4}$$

The axial stress applied on the mid-surface of the composite facesheet is determined by Eq. 5 [2]. In Eq. 5, θ symbolizes the angle that the upper facesheet makes with the horizontal at the support location as shown in Fig. 2.

$$\sigma_f = \frac{P}{bt_f(h+c)}\left(\frac{L}{2} + u\tan\theta\right) \tag{5}$$

Fig. 2: The angle at the support location.

A procedure has been followed to determine the transverse shear moduli of sandwich structures that have composite core materials placed parallel and perpendicular to beam axis, respectively [2]. In this methodology, the experiments should be conducted for at least two different span length: one span length selection must be short enough such that the displacement due to shear is dominant, and the other one should be sufficiently long such that the displacement is driven due to the bending. For this purpose, Eq. 3 brought into the form given by Eq. 6.

$$\frac{u}{PL^3} = \frac{1}{48D} + \frac{1}{4A_{eq}G_c}\left(\frac{1}{L^2}\right) = n_2 + m_2\left(\frac{1}{L^2}\right) \tag{6}$$

It is known that the compliance *C* can be determined as the inverse of the slope of load-displacement curve. Therefore, Eq. 6 can be written as in Eq. 7.

$$\frac{C}{L^3} = \frac{1}{48D} + \frac{1}{4A_{eq}G_c}\left(\frac{1}{L^2}\right) = n_2 + m_2\left(\frac{1}{L^2}\right) \tag{7}$$

In order to calculate transverse shear moduli of core materials, the slopes of load-displacement (*P*-*u*) curves are calculated for each support length configuration and the inverse of the slopes are stored as compliance values, *C*. Then, the plots of C/L^3 versus $1/L^2$ are drawn so as to obtain the slope of the curve, m_2. Transverse shear modulus (G_c) can then be calculated from Eq. 8.

$$m_2 = \frac{1}{4A_{eq}G_c} \tag{8}$$

Transverse shear moduli values are obtained by following the above-mentioned procedure through testing sandwich beams. With this method, realistic core shear moduli can be determined, as opposed to testing of pure core material since the effect adhesive used in the core-facesheet bonding is also reflected in the transverse shear modulus that is calculated. Transverse shear moduli calculated are then used to the draw load-displacement curves by employing analytical solution and finite element analyses for comparison purpose.

Experimental Setup

Three point bending tests are performed in METU Center for Wind Energy Composite Materials Laboratory with MTS 809 Axial/Torsional Tensile Testing system with special three-point bending fixture by utilizing ASTM C393 [8] test standard. The specimens have the dimensions of 380 mm in length, 50 mm in width, and 21.7 mm in thickness with a core thickness of 20 mm. The carbon composite core material has rather nonconventional geometry and its CAD drawing with primary axes and the actual photo are presented in Fig. 3. Additionally, the obtained experimental results are validated by measuring the displacement of the roller that introduces force via Digital Image Correlation (*DIC*) system so as to exclude the compliance of the actuator.

(a) ***(b)*** ***(c)***

Fig. 3: (a) CAD drawing and (b) actual photo of the core material and (c) three-point bending test setup including DIC system.

Finite Element Model

The model is created by using exactly the same dimensions and test configurations as the experimental setup in MSC.MARC. The finite element model is illustrated in Fig. 4. The FE model is created by assigning equivalent 3D orthotropic material properties to the solid elements which are used to model the core material in the sandwich beam. In the FE model, for the transverse shear moduli, experimentally determined values are used and the remaining elastic constants are obtained through FE analysis of a representative volume of the core material. The upper and lower cylindrical rollers are represented by rigid elements and abbreviated as *SPC1* and *SPC2* in Fig. 4.

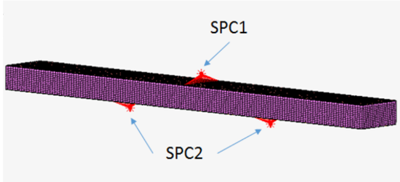
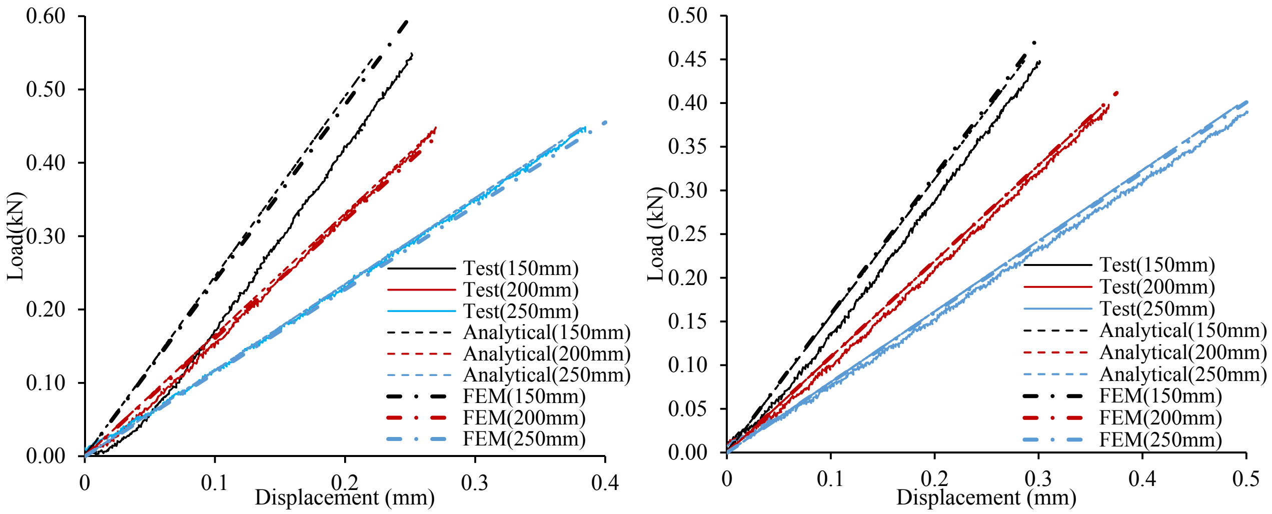


Fig. 4: 3D finite element model of the test configuration.

3. RESULTS AND CONCLUSION

The experiments are performed for three different span lengths and transverse shear moduli of sandwich test specimens are obtained as 99.7 MPa and 57.2 MPa for parallel (G_{13}) and perpendicular (G_{23}) core material orientations, respectively, from both actuator and DIC system. The obtained transverse shear moduli are used in both analytical and finite element models to generate and compare the load-displacement curves with the experimental data. Additionally, the experiments are also monitored with DIC system. Fig. 5 illustrates the load-displacement curves of sandwich structures with different support span lengths that have parallel and perpendicular core material orientation with respect to beam axis. Since the load-displacement curves obtained from the actuator and the DIC system coincide, the plots acquired from DIC system are omitted from Fig. 5 for the sake of clarity. The experimental, numerical, and analytical data produce one-to-one correspondence and validate the obtained transverse shear moduli values. For the 150 mm support span configuration, there is a curve shift which might have been occurred due to the slippage in the early phases of the experiment for the short span beams and this phenomenon is being investigated. For the three different support span lengths, slopes of the load displacement curves determined experimentally, analytically and through finite element analysis agree very well by the virtue of the accurate estimation of the transverse shear moduli through three point bending tests of the sandwich beam.



(a) ***(b)***

Fig. 5: Load-displacement curves of sandwich constructions with (a) parallel and (b) perpendicular core material orientation with different span lengths.

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