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FRACTURE TOUGHNESS TESTING OF FOAM AND HONEYCOMB CORE SANDWICH USING THE SINGLE CANTILEVER BEAM (SCB) TEST

Mohammad Tauhiduzzaman[1], Seyed Morteza Sabet[2] and Leif A. Carlsson[3]
[1]Florida Atlantic University, FL, USA. mtauhiduzzam2016@fau.edu
[2]Florida Atlantic University, FL, USA. ssabet@fau.edu
[3]Florida Atlantic University, FL, USA. carlsson@fau.edu

1. INTRODUCTION

Sandwich structures are widely used as weight-efficient structural components, offering high stiffness-to-weight ratio. In recent years, sandwich structures are found in aerospace vehicles, aircrafts and naval structures. The applications will dictate selection of core and face sheets materials. Typical core materials are foam, honeycomb and balsa wood. Foams are open or closed cell structures depending on the processing conditions. Most applications use closed-cell foams. Honeycomb cores consist of thin walled hexagonal cells that provide sandwich panels with a very high stiffness-to-weight ratio. The performance of sandwich structures depends strongly on the bond between the face and core (F/C), and the performance may be severely reduced by propagation of a F/C debond [1]. Hence, it is important to be able to determine the debonding resistance of sandwich structures. Measurement of the static debond fracture for sandwich composites has been approached by several test methods. The SCB tests, shown in Fig. 1, is considered for ASTM standardization [2]. The SCB test consists of a sandwich specimen with a partially debonded upper face sheet. The lower face sheet is attached to the base of the test machine. A concentrated load is applied to the edge of the debonded upper face sheet and increased until the debond propagates. The test allows determination of the face/core debond toughness, expressed as the critical energy release rate, G_C .

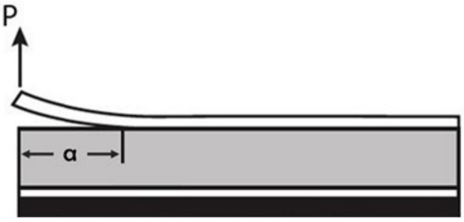

Fig. 1: Schematic of SCB test.

The aim of the present study is to investigate the face/core debonding fracture toughness of foam and honeycomb core sandwich specimens using the SCB test. Various combination of aluminum face sheets, core materials and two types of adhesives will be examined.

2. EXPERIMENTAL

PVC H100 foam core panels of 25.4 mm thickness were provided by DIAB. HC core panels of the type ECA- HC $3/16''$ with 12.7 mm thickness was provided by Eurocomposites. Top face sheets made from 6061-T6 aluminum alloy of 4.76 and 6.35 mm thickness were used. The bottom face was also made from aluminum, same for all specimens, 3.20 mm thick. Some properties of face and core materials are presented in Table 1.

Table 1: Material properties of sandwich elements.

Materials	Mechanical Properties	Density (kg/m^3)
Facesheets (6061-T6 Aluminum)	$E = 68.9GPa$ $\sigma_y = 240MPa$	2700
PVC-H100 Core	$E_c = 130MPa$	100
ECA- HC $3/16''$ Core (Cell Size = 4.8 mm)	$E_c = 140MPa$ (out of plane)	48

Sandwich SCB specimens were prepared. All HC core specimens were prepared with the L direction of the core along the specimen. The 5.1 cm width of the SCB specimen includes about 10 cells across the width (cell size is 4.8 mm). Foam and honeycomb cores were cut from large panels using a band saw. Face sheets were abraded with 120 grit sandpaper and rinsed with acetone. The face and core materials were joined with two types of adhesives, viz. Araldite 2015, a ductile epoxy adhesive and Hysol LOCTITE EA 9309.3NA, a structural paste epoxy adhesive. The length of all SCB specimens prepared by Araldite was 305 mm. The SCB specimen assembled with Hysol adhesive was 203 mm in length. An artificial precrack was defined by placing a ($250\ \mu m$) Teflon film of 3.18 cm length between the core and upper face sheet at the edge of the specimen. To accommodate load application, a hinge was mechanically attached to the top face sheet at the precracked end of the specimen.

A WTF SCB test fixture was mounted to the base of a Tinis-Olsen test frame of 133 kN load capacity. A 30 cm long loading rod pinned at both ends attached to the moving crosshead of the test machine and the loading tab at the edge of the face sheet. Displacement was measured by a linear voltage differential transducer (LVDT). Load was recorded by a 13.3 kN load cell mounted on the moving crosshead. The test matrix is presented in Table 2.

Table 2: Test program of sandwich specimens.

Sandwich Specimen	# Replicate Specimens	Core Thickness (mm)	Specimen Designation	Adhesive	Top Face Thickness (mm)	Length (mm)
PVC H100 Foam Core	3	25.4	PVC 1	Araldite	6.35	305
			PVC 2			
			PVC 3			
	2	25.4	PVC 4	Hysol	4.76	203
HC Core $3/16''$	2	12.7	HC 1	Araldite	6.35	305
			HC 2			305
	2	12.7	HC 3	Hysol	4.76	203

Testing was conducted at a crosshead speed of 2.5 mm/min. Load-displacement data was recorded throughout the test using a LabVIEW data acquisition system. Crack growth was monitored by visual observation of the crack tip region on both sides of the specimen. The location of the crack front was marked by pencil after each cycle to allow subsequent determination of the crack length. Although the first load-unloading cycles tented to be unstable, subsequent cycles were more stable, and the crack was allowed to grow in increment of about $1-2$ cm. Crack length was measured on both sides of the SCB specimens. For each cycle, the difference in crack lengths on both sides of the specimen should be less than 10 mm.

SCB testing on sandwich specimen produces a number of loading-unloading cycles. The load-displacement curves were evaluated in terms of compliance and critical load. Fracture toughness is here expressed as the critical value of the energy release rate, G_C. Modified beam theory (MBT) and area methods [2-4] were used to determine G_C. The MBT toughness value, G_C, is referred to as initiation toughness. The area method provides a direct measure of G_C from the energy dissipation required to achieve a disbonded area increment ΔA. The fracture toughness G_C represents an average value including both initiation and propagation of the crack.

3. FRACTURE TOUGHNESS RESULTS

The fracture toughness was evaluated for all SCB specimens tested to date. Table 3 summarizes the fracture toughness results for the six tested SCB specimens and mode of crack propagation. MBT fracture toughness values are less than those reduced using the area method. Part of the reason for the low G_C values is the definition of P_C (onset of nonlinear response). The nonlinear response of the HC core specimens, also contributed to uncertainly in the compliance determination.

The crack propagation behavior in the PVC1 and PVC2 specimens reveal substantial extent of interfacial debonding followed by kinking of the crack into the core. The interface propagation corresponds to very low G_C values. In the PVC3 specimen, crack propagation occurred inside the core resulting in high G_C values. Similarly, for the PVC4 specimen, the crack propagated inside the core which provides very high G_C values. For the HC1 and HC2 specimens, the crack front consistently traveled through the face/core interface. Crack propagation at the face/core interface and the low G_C values indicate that the adhesive bonding is weak.

Table 3: Summary of face/core fracture toughness.

SCB Specimens	MBT G_C (kJ/m^2)	Area G_C (kJ/m^2)	Mode of Crack Propagation
PVC 1	0.351	0.606	Interfacial + Kinking
PVC 2	0.179	0.364	Interfacial + Kinking
PVC 3	0.734	0.956	Kinking
PVC 4	~	(2.68)*	Growth into Core
HC 1	0.133	0.346	Interfacial
HC 2	0.116	0.291	Interfacial

*) questionable due to nonlinear response.

Fracture toughness results (Table 3) may be compared with previously published fracture toughness data for similar sandwich specimens. Li and Carlsson [5] conducted TSD tests on PVC H100 foam core sandwich specimens. Compliance calibration method was utilized to determine G_C values that raged from $180-415$ J/m^2, in reasonable agreement with our results. Ratcliffe and Reeder [6] tested SCB specimens with carbon and glass fiber face sheets and Nomex honeycomb cores. The G_C values obtained from MBT method ranged between $960-1420$ J/m^2, much higher than our results, which points to inadequate adhesive bonding in our HC core specimens. This was also evidenced by lack of propagation inside the HC core specimens. Rinker et al. [1] conducted SCB tests on Nomex HC core specimens with 3.2, 4.8, 6.4 and 9.5 mm cell size. The crack propagation in the specimens with 3.2 and 4.8 mm cell size occurred near the face/core interface within the core. The fracture toughness was in the range from 700-800 J/m^2. Hence, these results seem to further support weak bonding in our HC core specimens.

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