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A beam specimen to measure the face/core fracture toughness of sandwich materials under a tearing loading mode

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ABSTRACT

A new test specimen named the sandwich tearing beam (STB) is proposed as a fracture test method to measure the face/core debond fracture toughness of sandwich materials loaded under mode III. The STB specimen consists of a sandwich beam made of a single laminated composite face sheet reinforced by a thick steel beam and bonded to the sandwich core, which is adhesively bonded to the edge of a metal base plate allowing for rotations of the face sheet. The sandwich beam has an initial crack introduced at the face/core interface and a tearing force (parallel to the crack front) is applied at the free end of the face sheet which extends beyond the length of the core. Finite element analysis (FEA) shows that the energy release rate distribution at the crack front of the STB specimen is highly dominated by loading mode III, with significant contributions of mode II only near the specimen edges. STB tests conducted to a steel beam-reinforced glass/vinyl ester face sheet bonded to an H100 PVC foam core show that crack propagation occurs as a sub-interface crack running parallel to the face/core interface. The measured compliance and face/core mode III fracture toughness are in good agreement with FEA predictions.

1. Introduction

Sandwich composite materials are nowadays widely used as structural materials in aeronautical, civil, marine and energy industries (among many others), especially because of their combination of high stiffness and strength at low weight [1–4]. However, sandwich structures could contain defects, and cracks at the interface between the face sheets and core are typically introduced during manufacturing process or generated during service. These manufacturing flaws or in-service defects could cause debonding of the face sheet and core during load application [5–7]. Therefore, development of test methods to characterize the face/core debond fracture toughness of sandwich structures represents an important research topic for the scientific and engineering community. A variety of fracture test methods have been developed to measure the face/core debond fracture toughness in sandwich structures, but none of the proposed methods have become an international standard to date. The most promising test methods proposed to determine the face/core debond fracture toughness under mode I loading are maybe the sandwich version of the double cantilever beam (DCB) [8] and the tilted sandwich debond (TSD) [9]. For mode II, the cracked sandwich beam (CSB) [10] is maybe the most popular method. For mixed I/II mode, the DCB with uneven bending moments (DCB-UBM) developed at RISØ [11] and the mixed mode bending (MMB) [12] seem to be the most promising methods. However, there is not yet an internationally recognized sandwich test specimen to measure the face/core debond fracture toughness of sandwich materials under a tearing loading mode (mode III). It is recognized that characterization of the fracture mode III could be of importance to complete the fracture criteria for a safe design, construction and certification of sandwich materials [7]. Furthermore, mode III loading may be of particular importance for the industry dealing with design, manufacturing and testing of wind turbine blades and helicopter rotors [1,13]. Several test methods have been proposed for the determination of mode III interlaminar fracture toughness in laminated composites [14–22], although all of them have yet unresolved issues which hold back their standardization. The main issues in these test methods relate to difficulties to produce a pure mode III fracture state at the delamination front, difficulties to track the crack propagation, uncertainty in the data reduction methods and/or complexity of the test rig. The two most widely accepted test specimens for characterization of mode III fracture toughness in laminated composites are the edge crack torsion (ECT) specimen invented by Lee [16] and the split cantilever beam (SCB) first proposed by Donaldson [15]. The ECT specimen consists of an edge cracked laminated plate loaded in torsion by point loads [16–18], and its major drawbacks have been recognized as the

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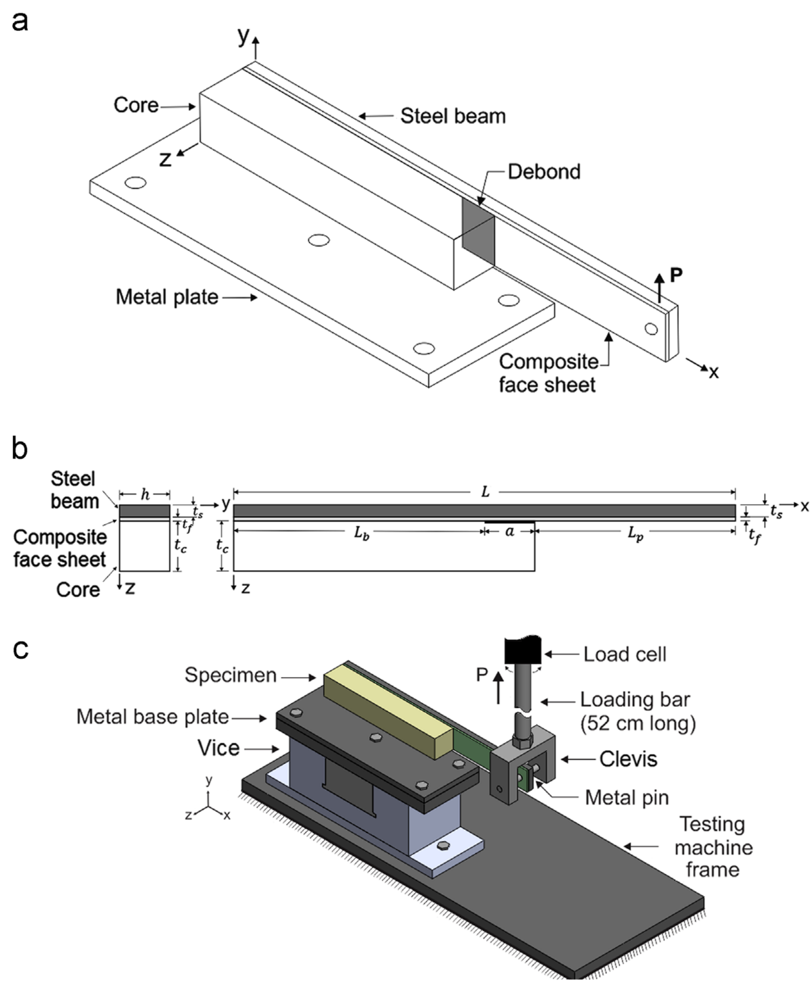

Fig. 1. Schematic of the STB specimen. (a) Isometric view of the specimen, (b) back (y–z) and top (x–z) planes showing the definition of geometrical parameters, (c) full test rig and loading.

impossibility to monitor crack propagation, the occurrence of only one crack growth per specimen, the dependence of the fracture toughness on the crack length, and the possible damage of the specimen before delamination failure [17]. The SCB specimen consists of a laminated composite beam bonded between two rigid aluminum bars, which are loaded in opposite directions, parallel to the crack plane and normal to the beam length. Its major drawbacks is the dominant mode II contribution at the specimen edges due to the existence of bending moment at the crack front, as well as specimen twisting during testing. The original SCB specimen introduced by Donaldson [15] was evaluated by Martin [23], finding a very large G_{II} component at the specimen edges. Martin also found that the ratio G_{II}/G_{III} increased with increased delamination length and he concluded that the laminated SCB specimen is not a pure mode III test. Due to these issues, this test was later modified by Sharif et al. [19] and Robinson and Song [20] in order to reduce the mode II component generated by the bending moment at the crack tip. Most recent efforts to reduce the mode II component in beam-type specimens have been conducted by Szekrenyes [21] and Davidson and Sediles [22] who proposed interesting test methods where the bending moment at the crack front is counteracted by a torque of the same magnitude but opposite sign. However, these improvements demand a high level of sophistication of the test rig. For characterization of sandwich materials loaded under mode III, only Hernández-Pérez et al. [24] have presented initial research efforts using a sandwich variant of the ECT for foam/steel specimens. The use of a beam-type specimens (such as the SCB) has very attractive features over the use of plate-type specimen (such as the ECT), such as the potential for a more uniform crack growth, the possibility of in situ monitoring of crack propagation (not achieved in the ECT), and the use of simpler beam theories for data reduction.

Table 1
Parameters and dimensions of the STB specimen.

Parameter	Dimension (mm)
Total length of the specimen (L)	250
Bonded face/core length (L_b)	125
Extended length of the face sheet (L_p)	90
Initial crack length (a)	25
Sandwich beam height (h)	25
Core thickness (t_c)	25
Face sheet thickness (t_f)	2
Steel beam thickness (t_s)	6

Given this motivation, this work investigates a new test specimen in beam geometry in an attempt to characterize the face/core debond fracture toughness of sandwich materials under a tearing loading mode (mode III). The beam specimen is hereafter named “the sandwich tearing beam” (STB) and its design, development and evaluation are conducted here by means of finite element analysis (FEA) and limited testing.