DOI: 10.5075/epfl-ICSS12-2018-229-231

FRACTURE CHARACTERIZATION OF AEROSPACE GRADE HONEYCOMB CORE SANDWICH USING SCB AND DCB-UBM TEST METHODS – A COMPARISON

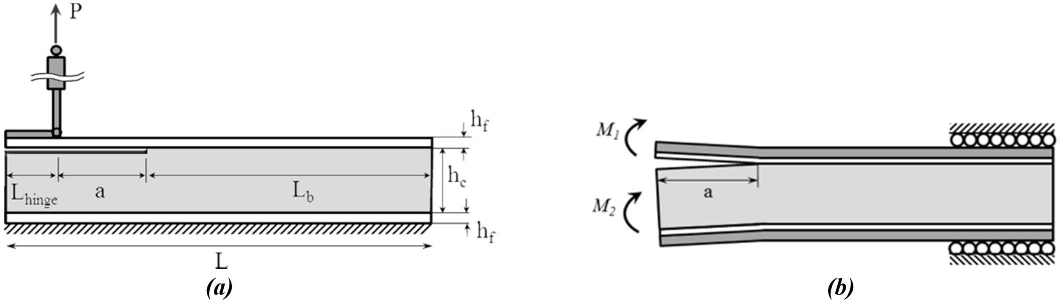
Ralf Schäuble[1], Yannick Albertone[2], Vishnu Saseendran[3], Christian Berggreen[4] and Ralf Hilgers[5]
[1]Fraunhofer Institute for Microstructure of Materials and Systems IMWS, Halle, Germany. ralf.schaeuble@imws.fraunhofer.de
[2]DuPont International Operations, Geneva, Switzerland. yannick.albertone@dupont.com
[3]Department of Mechanical Engineering, Technical University of Denmark, Denmark. vsas@mek.dtu.dk
[4]Department of Mechanical Engineering, Technical University of Denmark, Denmark. cbe@mek.dtu.dk
[5]Airbus Operations GmbH, Hamburg, Germany. ralf.hilgers@airbus.com

1. INTRODUCTION

Honeycomb core sandwich composites are attractive for aerospace applications due to its high specific bending stiffness. The sandwich technology has been widely utilized in flight control surfaces and interior of the aircraft, which have accumulated significant amount of flight hours. In addition, a considerable proportion of the modern day commercial aviation fleet comprises of sandwich constructions, employed both in primary as well as secondary aircraft structures. One of the primary failure mechanisms of a sandwich component is face sheet/core debonding, which can pose a risk to compromise of the integrity of the entire structure. In recent years, several structural failures have been caused due to debonding [1]. The disbond growth is influenced primarily by face sheet and core material characteristics, interface properties, face sheet and core thicknesses, geometric dimensions as well as the operating conditions.

The operating loading conditions determine the inclination of the crack to propagate along the interface or to kink into the core. Therefore, the interface fracture toughness must be ascertained accurately to be used in the development of reliable sandwich damage assessment tools. Due to the inherent elastic mismatch across the sandwich face sheet/core interface, the crack propagation will be invariably under mixed mode conditions [3]. Hence, the fracture toughness must be mapped for a range of mode mixity conditions, spanning from pure mode I to mode II. As with laminates, a peel load scenario corresponding to a mode I dominant loading is the most critical failure mode in sandwich composites. The Single Cantilever Beam (SCB) sandwich specimen [4] applied to sandwich composites has been found as the most suitable test method to obtain peel dominant interface fracture toughness. In addition, the Double Cantilever Beam loaded with Uneven or unequal Bending Moments (DCB-UBM) specimen, which was first introduced by Sorensen et al. [5] for laminate composites and later extended to sandwich composites by Lundsgaard-Larsen et al. [6] have been proven to be effective for mixed mode fracture characterization. Fig. 1 provides a schematic illustration of both SCB and DCB-UBM sandwich specimens.

In this study, interface fracture toughness of aerospace grade honeycomb core specimens is investigated for a variety of material combinations and environmental conditions using SCB sandwich specimens. DCB-UBM tests were carried out on a subset of specimens and adjusted to constant mode I loading for the purpose of validation. The study aims to understand the influence of honeycomb core density, crack propagation direction, face sheet thickness and honeycomb core material on the interface fracture toughness. Moreover, mode I fracture toughness is also compared against room, sub-zero and elevated temperatures. The investigated sandwich specimens comprised of Cormaster C1 and CN1 type cores from Schütz. The face sheets were made from CFRP prepreg (Hexcel fabric with HexPly®913 epoxy resin).

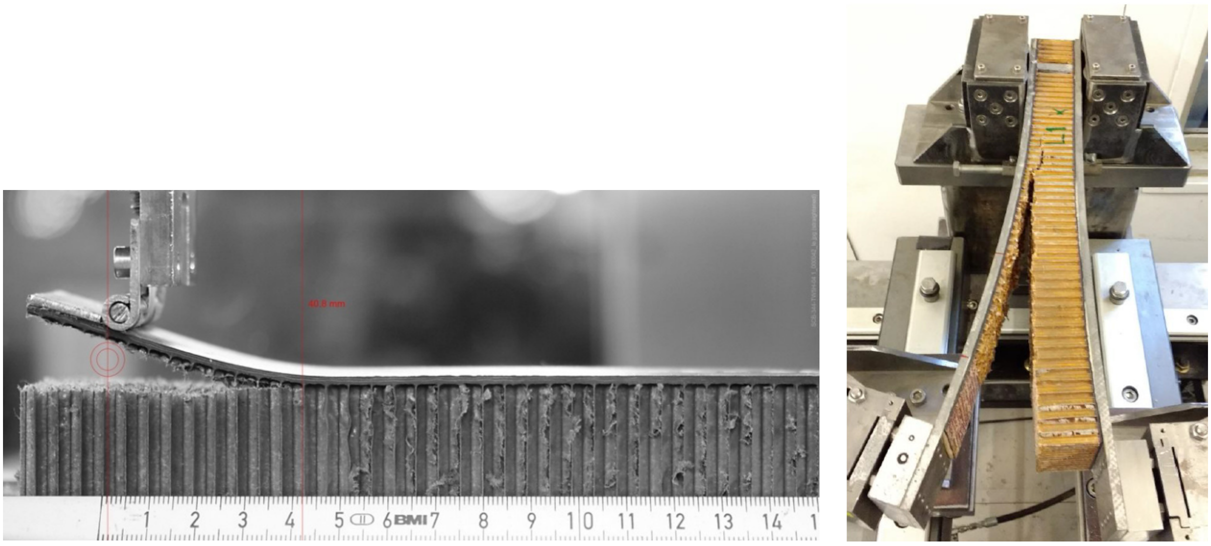


(a) (b)

Fig. 1: Schematic illustration of (a) SCB sandwich specimen, (b) DCB-UBM specimen reinforced with doubler layers.

2. SCB TEST PROCEDURE

The SCB test involves loading the upper face sheet in displacement control until the crack propagates by certain Δa, followed by unloading the face sheet to a zero displacement level. Both, load and displacement, are recorded for each cycle, and the critical energy-release rate or fracture toughness is obtained using the area method (AM) [7]. An image recording device is used to ascertain the crack location. A two-cycle loading/unloading approach is adopted. The first cycle with $\Delta a = 20$ mm is made such that the manufactured pre-crack is converted to a natural crack front. The second cycle consists of $\Delta a = 40$ mm, which is used to deduce the fracture toughness. Fracture testing of SCB specimen was conducted by loading the face sheet at a constant rate of 5 mm/min. Fig. 2 (a) shows interface crack propagation in a Cormaster C1 core specimen with a 4-layer CFRP fabric face sheet (h_f = 1.4 mm).



(a) *(b)*

Fig. 2: Interface crack propagation in Cormaster C1 honeycomb core, (a) SCB, (b) DCB-UBM sandwich specimen.

3. DCB-UBM TEST PROCEDURE

In the DCB-UBM test procedure, pure moments are applied on the crack flanks, see Fig. 1 (b). The mode-mixity, expressed using phase angle (ψ) is held constant by keeping the ratio of moments between the two arms constant. A numerical mode-mixity method, Crack Surface Displacement Extrapolation Method (CSDE) [8] is used to select the moment ratio (MR) corresponding to a mode-mixity phase angle (ψ). A unique test rig capable of applying edge moments based on independent torsional actuators is employed. The MR value obtained for each sandwich configuration is provided as input prior to each test. The test rig is programmed such that the ratio of moments is held constant throughout the crack propagation. For the DCB-UBM sandwich specimen, a dedicated crack monitoring device is not necessary as the energy-release rate in a moment loaded specimen is independent of crack length. Steel doubler layers were attached to both sides of the specimen, which reduced the excessive rotation of the specimen. The specimen is loaded at a constant rate of 10 deg/min and unloaded manually when the crack propagates approximately 10 mm. Interface crack propagation in a Cormaster C1 core DCB-UBM specimen is shown in Fig. 2 (b).

4. CONCLUSIONS

The mode I fracture toughness data can be seen to be consistent at room, sub-zero and elevated temperatures. It was found that production process can influence the performance of sandwich structures along with the operating environment. The investigation carried out signifies the impact of environmental factors, such as humidity and temperature, have on the interface fracture toughness. The crack path was observed to shift slightly depending on the test temperature. At room temperature, the crack was found to advance just beneath the meniscus layer (face sheet/core transition region). Fig. 3 presents a summary of the impact of temperature on fracture toughness G_{IC} for different sandwich materials in the range of -55°C to 135°C. The SCB test results were validated exemplarily at room temperature for the Cormaster C1 and CN1 4.8 mm cell width core types by using the DCB-UBM test method, adjusted to mode I condition. Fig. 4 summarizes the effects of the core density and core orientation at room temperature for sandwich specimen comprising a 4-layer CFRP face sheet and Cormaster C1 cores with densities of 32 kg/m^3, 64 kg/m^3 and 96 kg/m^3. The study was carried out throughout three different labs (marked with colors green, black and red in Fig. 4). The majority of specimen was tested without preconditioning using SCB and DCB-UBM procedures. Furthermore, a number of SCB specimen was preconditioned at 60% relative humidity before testing. It can be seen that, for all considered core densities, disbond propagation in L (ribbon) direction yields lower fracture toughnesses than in W (expansion) direction. Increased humidity can reduce the fracture toughness, albeit the effect evidently seems to depend on the specific cell wall material. Moreover, for higher density core the measured fracture toughness became more sensitive to the test method. In general, due to the use of stiff steel doublers in DCB-UBM test the face sheet bending deformation in the immediate vicinity of the crack tip is significantly lower than in the case of SCB specimen, which obviously can affect the fracture process. Moreover, from the comparative study it can be remarked that the interface fracture toughness is a material property.

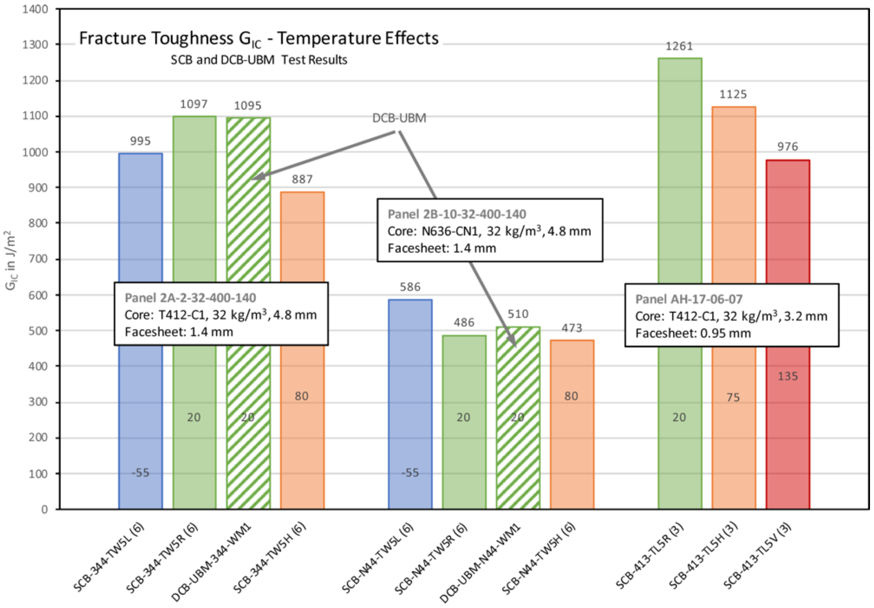


Fig. 3: Summary of temperature impact on fracture toughness G_{IC} for different core types with same density.

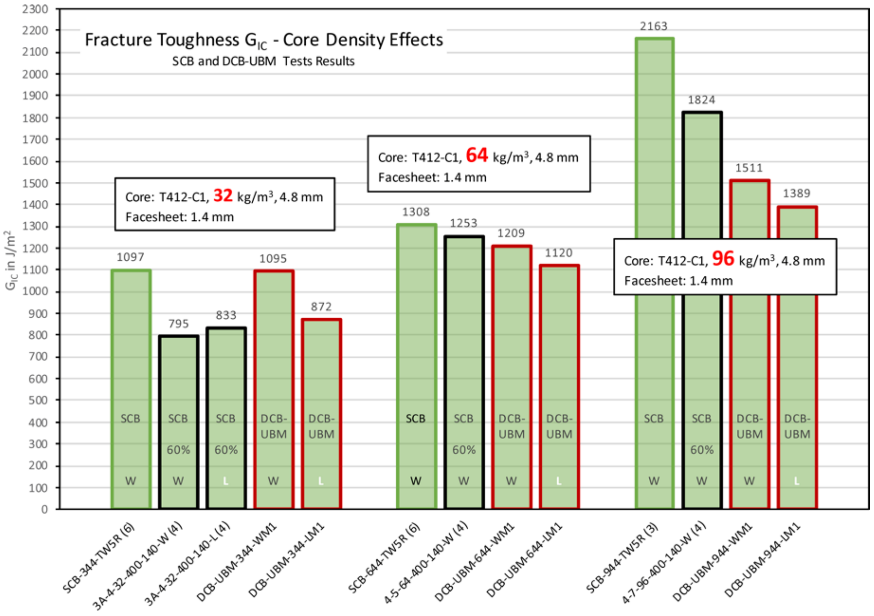


Fig. 4: Summary of core density, core orientation and humidity impact on fracture toughness G_{IC}.

ACKNOWLEDGEMENT

This study was conducted under the ambit of *Disbond of Sandwich Structures* (DoSS) project, funded by the European Aviation Safety Agency (EASA), as well as in collaboration with the *Thin Face Sheet Sandwich Disbond* (TFSanDis) project, supported with funds from the Federal Ministry for Economics and Energy, Germany.

REFERENCES

[1] Transportation Safety Board of Canada, “Loss of Rudder in Flight”, Aviation Investigation Report A05F0047: Minister of Public Works and Government Services, Canada, 2007.
[2] E. H. Glaessgen et al., “Debonding Failure of Sandwich-Composite Cryogenic Fuel Tank with Internal Core Pressure”, JSR, 2005, vol. 42, no. 4, pp. 613-627.
[3] J. W. Hutchinson et al., “Mixed mode cracking in layered materials”, Adv. Appl. Mech., 1991, vol. 29, pp. 63-191.
[4] W. J. Cantwell et al., “A test technique for assessing core-skin adhesion in composite sandwich structures”, J. Mater. Sci. Let., 1994, vol. 13, no. 3, pp. 203-205.
[5] B. F. Sørensen et al., “DCB-specimen loaded with uneven bending moments”, Int. J. Fract., 2006, vol. 141, no .1, pp. 163-176.
[6] C. Lundsgaard-Larsen et al., “A modified DCB sandwich specimen for measuring mixed-mode cohesive laws”, Eng. Fract. Mech., 2008, vol. 75, no. 8, pp. 2514-2530.
[7] “Preliminary Round Robin SCB Test Procedure - ASTM Preliminary Standard”, 2015.
[8] C. Berggreen et al., “Experimental and numerical study of interface crack propagation in foam-cored sandwich beams”, J. Compos. Mater., 2007, vol. 41, no.4, pp 493-520.