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ANALYSIS OF THE SCB TEST PROCEDURE APPLIED TO HONEYCOMB SANDWICH WITH THIN FACE SHEETS UNDER REPRESENTATIVE TEST CONDITIONS

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1. INTRODUCTION

Sandwich structure comprising of low density honeycomb core and thin CFRP face sheets can offer superior mechanical performance and excellent stiffness-to-weight ratio. Therefore, high performance honeycomb core sandwich construction is widely used in aerospace applications. However, this type of structure can exhibit severe damage and failure modes. One of the primary failure mechanisms of a sandwich component is face sheet/core disbonding. The face sheet can locally separate from the core structure, for example, as a result of a critical impact load. If not detected or prevented by design features, the disbond can extent to a critical size which poses a threat to the integrity of the entire structure. In recent years, numerous efforts were made to develop reliable methods to assess the damage tolerance of sandwich structures with disbond.

The disbond, or plane interface crack, respectively, can be appropriately described by means of fracture mechanics. Crack propagation is predicted if the load at the crack tip exceeds the corresponding fracture toughness of the material. The resistance of the material against crack propagation along the weakest path not only depends on the absolute load but also on the mode mixity along the crack front. The crack opening fracture mode (mode I) is assumed to be the most critical one, as known from many other composite materials. The fracture toughness of the specific sandwich material regarding a disbond damage must be determined experimentally. The Single Cantilever Beam Test (SCB), Fig. 1, is seen to be the most simple and robust test method available to determine the critical energy-release rate G_{IC} under peel load. Motivated by the high relevance of damage tolerance analysis of complex shaped and loaded lightweight sandwich structures, e.g. for aerospace application, the SCB test has been widely investigated over the last years and guidelines are available to properly apply the SCB test to various kinds of sandwich materials. Standardization of the test method is currently being prepared [1].

Nevertheless, particularly in the case of lightweight honeycomb sandwich materials with very thin face sheets, various effects are observed, which are not yet entirely understood. The proposed test conditions are still under discussion [2]. The present study was initiated not only to define optimal test condition for this specific sandwich class but mainly to understand the effect of inadequate test conditions which, for some cases, cannot be avoided. For example, if the test rig must be installed within a climate chamber, the recommended minimal length of the loading rod often cannot be realized due to limited space. Furthermore, the shape of the load/displacement response of the specimen diverges from an assumed, nominal shape, e.g. see Fig. 2, where the data reduction is based on. The reason for the deviating behavior can be the material characteristics itself, but also induced by handling errors or barely detectable, minor malfunctions of the test assembly while testing in ambitious environment, e.g. at sub-zero temperature.

In this study, typical real conditions and inadequacies were identified from a large number of SCB tests performed on honeycomb sandwich as well as examined by means of detailed Finite Element Analysis. Furthermore, proposals for suitable solutions were derived.

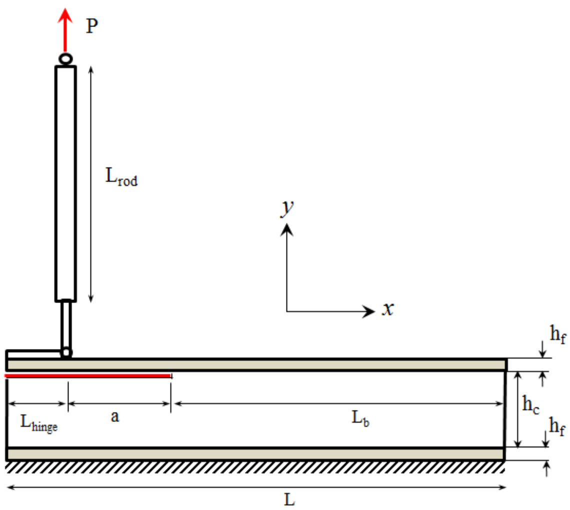

Fig. 1: Schematic illustration of the SCB test assembly.

2. SCB TEST PROCEDURE

The upper face sheet of the sandwich specimen was connected to a movable loading rod of variable length using a piano hinge. Alternatively, to avoid undesired face sheet bending near the piano hinge caused by out-of-plane torque in case of thin and flexible face sheets, a clamping device was designed to position the pivot axis in line with the neutral fiber of the cantilever beam. The lower face of the specimen is fixed to the base plate of the test rig. The specimen is loaded via the loading gear in displacement control until the crack propagates by Δa, followed by unloading the face sheet to the origin at zero displacement. The procedure is repeated several times for subsequent load cycles. Both load and displacement are recorded for each cycle, and the critical energy-release rate or fracture toughness, respectively, is obtained using the area method (AM) [1]. Images from both the left and right specimen side are recorded by two single lens reflex cameras to keep track of the crack propagation and to determine the crack length exactly after test termination. Within the first cycle, crack growth is initiated starting from a manufactured pre-crack and is converted to a natural crack in terms of shape and location. The propagation length Δa of the second and subsequent cycles are varied in order to study the influence of various test parameters. The width of the specimen is 50 mm, following the recommendations in [1], and the length is chosen to be at least 300 mm to avoid undesired shear deformation of the specimen. Fig. 3 shows a snapshot of the loaded specimen, depicting sub-interface crack propagation. The test temperature is 80°C. The sandwich is made of 32 kg/m^3 density core Cormaster C1 from Schütz GmbH and 4-layer CFRP fabric face sheet (h_f = 1.4 mm). In Fig. 2 the resulting load/displacement curve is presented.

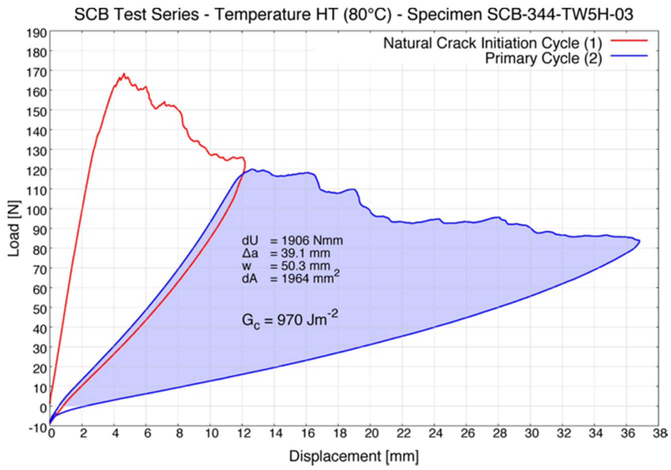

Fig. 2: Load vs. displacement curve of a 1.4 mm thick face sheet sandwich specimen from SCB test at elevated temperature.

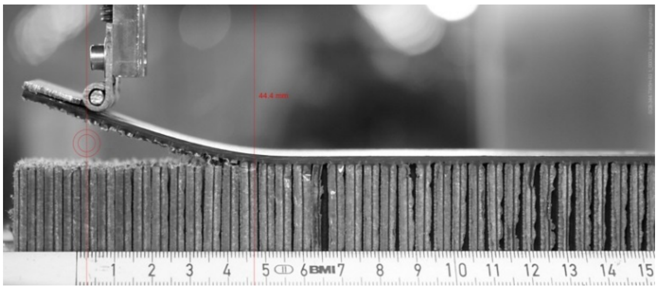

Fig. 3: Face sheet deflection at maximum stroke in load cycle 1 (1.4 mm face sheet sandwich specimen according to Fig. 2).

3. NUMERICAL MODEL OF THE SCB SPECIMEN

The SCB specimen is modelled by means of 3-dimensional solid elements for the core as well as for the face sheets using *Abaqus/Standard FEA* code. The honeycomb structure of the core is represented by a homogenized 3-d continuum. A separate study has been conducted to determine the complete set of orthotropic elastic constants as exact as possible for the honeycomb core types under consideration [3]. In particular, the in-plane Poisson's ratio of a homogenized honeycomb structure actually is close to one, $\nu_{xy} \cong 1.0$ [4], which also prevents extensive element distortion at the crack tip in case of numerical modeling. Otherwise, the Virtual Crack Closure Technique (VCCT), used to calculate the mode related parts G_I, G_{II}, and G_{III} of the total energy-release rate G, can be corrupted. Fig. 4 provides a representation of the FE model as well as detail view on element deformation at the crack tip at an intermediate load level. The graph shows simulated load/displacement curves (black) at certain crack lengths as well as corresponding energy-release rate levels. The blue graph was obtained from an experiment for comparison.

The model was designed to simulate disbond propagation both exactly at the face sheet/core interface as well as in the core underneath the adhesion layer. Various load introduction scenarios, like a piano hinge connection as well as a loading block, can be simulated to study typical experimental assemblies. Furthermore, slip-out of the specimen from the base plate clamping jaws can be studied.

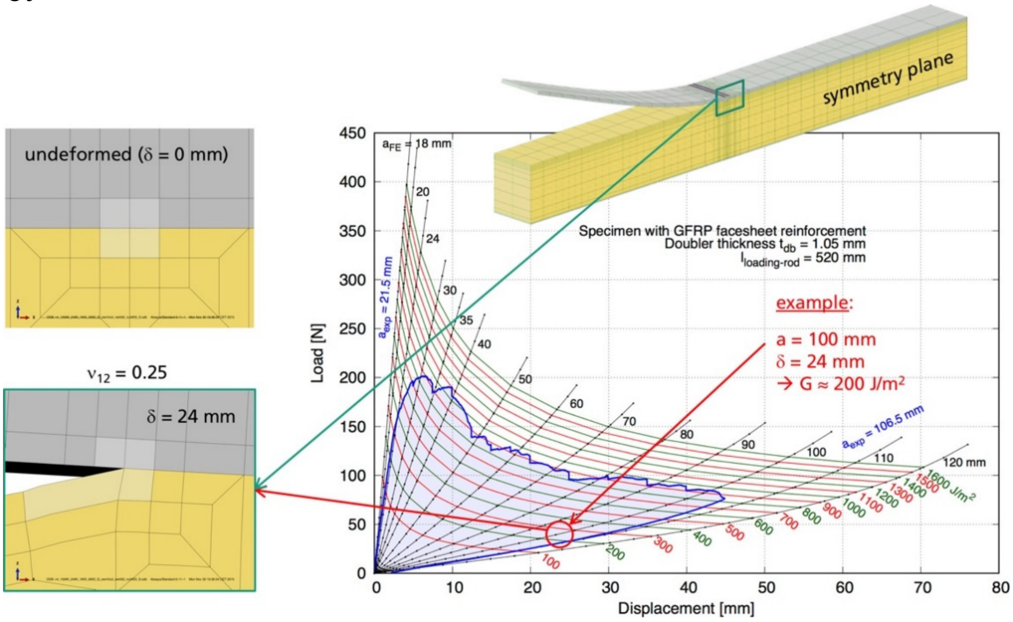

Fig. 4: 3-d FE solid model of a SCB specimen and numerically simulated behavior, compared to experiment (blue curve).

4. CONCLUSIONS

In this study, the performance of the SCB test was examined in detail by means of experimental and numerical methods to understand influencing boundary conditions and to identify the limits of applicability for low density honeycomb sandwich with very thin face sheets. The first part of the investigations was focused on certain adjustable test parameters, e.g. the loading rod length, and its effect on mode mixity for various material combinations. In the second part, typical measuring and handling errors that can occur while testing were identified and examined from a large amount of SCB tests conducted at Fraunhofer IMWS as well as based on an international round robin [5]. Examples include (a) misalignment of the piano hinge; (b) partially insufficient clamping of the specimen to the base plate; (c) bending of the face sheet at the load introduction point; and, (d) play or friction in the bearings (e.g. at sub-zero or elevated temperatures within a climatic chamber). Some of these faults are barely detectable during a running test, but can be identified from the load/displacement plot afterwards and corrected before applying the data reduction procedure. Furthermore, based on the comparison of numerous experimental and numerical results, influencing parameters of a laboratory specific test assembly on the recorded load/displacement curve - and finally on the fracture toughness - could be clearly separated from the mechanical response caused by the sandwich material. As a result, for example, an experimental procedure can be proposed to determine the proportion of energy typically dissipated during unloading, due to a mismatch of the adjacent crack surfaces, but is not related to the disbond process. This proportion then can be excluded from the data reduction, otherwise the fracture toughness will be overestimated by a certain amount. It can be shown that, for aramid honeycomb core, the fracture toughness typically is overestimated by approximately 3 up to 10 per cent when using the standard AM data reduction method without correction.

ACKNOWLEDGEMENT

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