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FRACTURE TESTING OF HONEYCOMB CORE SANDWICH COMPOSITES USING THE DCB-UBM TEST

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ABSTRACT

Face/core debonds in sandwich structures cause loss of integrity of sandwich structures. The debond problem in honeycomb core sandwich composites has not been widely studied. A suitable fracture approach coupled with experimental validation is paramount to determine the fracture resistance of the face/core interface. In this paper, a novel test-rig exploiting the double cantilever beam-uneven bending moments (DCB-UBM) concept is used to determine the fracture toughness of aircraft type honeycomb core sandwich composites as a function of the phase angle (mode-mixity), within the framework of Linear Elastic Fracture Mechanics (LEFM). The Double Cantilever Beam subjected to Uneven Bending Moments (DCB-UBM) test set-up, which was introduced by Sørensen.et.al [1], circumvents any dependency of the pre-crack length in calculation of G_c.

The new test setup is based on rotary actuators which are able to slide on rails to follow the specimen's deformation kinematics when subjected to pure rotations, as schematically shown in Figure 1. The robustness of the new test rig is demonstrated by performing pure mode-I fracture characterization of the face/core interface of a typical aircraft sandwich specimen consisting of CFRP/GFRP face sheet and a Nomex based honeycomb core. The J-integral was calculated analytically using the moments and subsequently the fracture resistance curve developed over the test domain as a function of time is averaged.

1 INTRODUCTION

Fracture characterization of honeycomb core sandwich specimen with thin face-sheets is performed using the double cantilever beam-uneven bending moments (DCB-UBM) concept. The DCB-UBM test rig (refer to Figure 1) enables fracture testing over a large range of mode-mixity phase angle (ψ), which is a measure of the amount of shear loading at the crack tip. A desired phase angle may be achieved by changing the moment-ratio (MR) which is the ratio of the two moments applied at the pre-crack edge. A finite-element based mode-mixity method is employed to identify the moment ratio that corresponds to a desired phase angle.

2 TEST RIG CONSTRUCTION

A schematic illustration of the test set up with the application of moments is illustrated in Figure 1. Two hydraulic actuators with a capacity of 700 N-m are used on each side of the specimen to apply pure moments on the crack flanks. Torsional load cells (TLC) with a rating of 565 N-m are attached to the actuators along with angular displacement transducer (ADT) on each arm. A bi-axial servo hydraulic controller has been employed. The two crack flanks in the specimen need to deform without any constraints in the plane of deformation to ensure application of pure moments. This is achieved by mounting the actuators on pairs of rails which allow them to undergo any motion in the horizontal and vertical plane. The roller wagons that are used to enable sliding are chosen to minimize the friction effect. A friction characterization study is performed by applying rotation on a high strength steel beam and subsequent comparison with analytical results for a beam subjected to pure moment. This also paves way to understand any spurious stresses developed in the specimens when it undergoes deformation.

The rollers at the end allow the specimen to slide in the length direction of the specimen. The rollers prevent any vertical forces acting on the specimen. The specimen is mounted on the set-up via specimen inserts. The fixture is designed to account different material types and a potential variation of thickness and width. The sandwich specimen tested here comprises of thin face sheets and is reinforced with steel doubler layers. This prevents large deflections and rotations of the crack flanks. The thickness of the doubler layers is selected such that it will not deform plastically during the test thus keeping the fracture analysis in the linear elastic fracture mechanics (LEFM) regime.

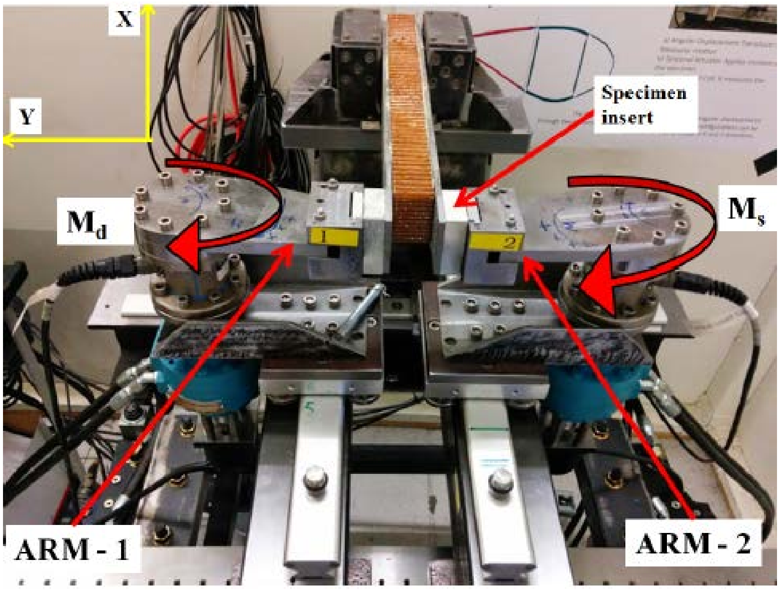

Figure 1: Application of moments and specimen fixture

The *J*-integral for a DCB-UBM specimen with doublers is derived by Lundsgaard.et.al in [2]. The thickness of the doubler layers was found out for a constant moment-ratio of +1 such that the J - integral value remains below 1500 [J/m^2] ensuring that the steel does not undergo plastic deformation. It is also possible to select a thick steel doubler layer which has low yield strength. Thicker layers however will require higher bending moments; hence a trade-off had to be made between the thickness and strength of the steel employed.

The moment-ratio (MR) is defined as the ratio of the moments applied at the deformed side (M_d) to the substrate side (M_s) i.e. MR = M_d/M_s (see Figure 2). Attachment of steel doubler layers implies that it requires high moments to bend the specimen to support a stable crack propagation at a desired moment ratio (MR). The test rig is designed to withstand such high moments and the desired MR is achieved by implementing a Cascade control. The controller manipulates arm 1 (see Figure 1) such that the desired moment ratio MR, is achieved. It can be stated that arm 2 is a slave of arm 1. To show the robustness of the rig a plot of various MR is shown in Figure 3. It can be seen that despite the initial fluctuations, the MR becomes stable and continues to be stable at the event of crack propagation.

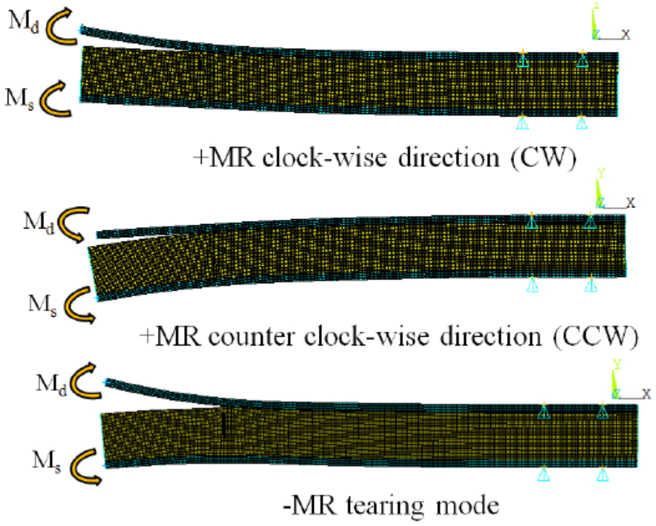

Figure 2: An illustration of applied moments and their directions based on moment-ratio

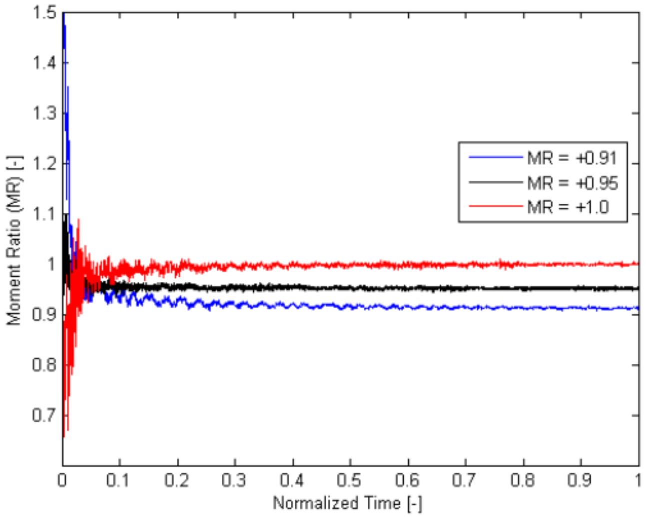

Figure 3: Moment ratio (MR) vs time for different MRs in clock-wise (CW)

3 SAMPLE SCREENING OF SPECIMENS

Testing was conducted to map the fracture toughness on sandwich specimens with 0.47 mm thick glass/carbon epoxy face sheets and a 40 mm thick Nomex honeycomb core under mixed mode (I/II) conditions. The fracture test was carried out by clamping both legs and turning the clamps at a constant angular velocity of 10 [deg/min] while measuring the resulting moments in each arm. To test sandwich specimens with thin face sheets, the DCB-UBM specimens were reinforced with high strength steel doubler layers. The phase angle was determined using the crack surface displacement extrapolation (CSDE) mode-mixity method using a finite element model [3]. The effective elastic properties of honeycomb core in this numerical model are obtained using Gibson-Ashby homogenization model [4]. A pre-crack of 20 mm is introduced in the specimen.

Test results for four sandwich specimens at predominant mode-I conditions, three loaded at MR = -10 (ψ = -6.440) and one loaded at MR = 20(ψ = -6.240) are considered. M_d (Figure 4) and substrate moment, M_s (Figure 5) vs rotation angle are plotted. When the crack starts to propagate the pre-cracked edge rotates more but the controller ensures M_s and M_d are varied keeping the MR ratio constant within close limits. Note that the crack did not kink into the core. The energy release rate G, was calculated from the applied moments using the J-integral for a reinforced DCB-UBM specimen [2]. The fracture toughness for debond propagation expressed as the critical energy-release rate (G_c) is reduced from the measured moments by method of averaging after the crack propagated.

It can be noted from the response of the pre-cracked edge moment that there is a drastic change in the slope of the curve when crack starts to propagate. The point at which the slope changes in the moment curve is identified as the crack initiation point. Average of the plateau obtained from analytical *J*-integral from the initiation point until the stop of the experiment is considered for energy release rate computation. The test is stopped when the crack reached 20 mm away from the rollers. The four specimens tested in mode-I conditions (three in MR= -10 and one in MR = +20) yielded fracture resistance with a scatter of 200 [J/m^2].

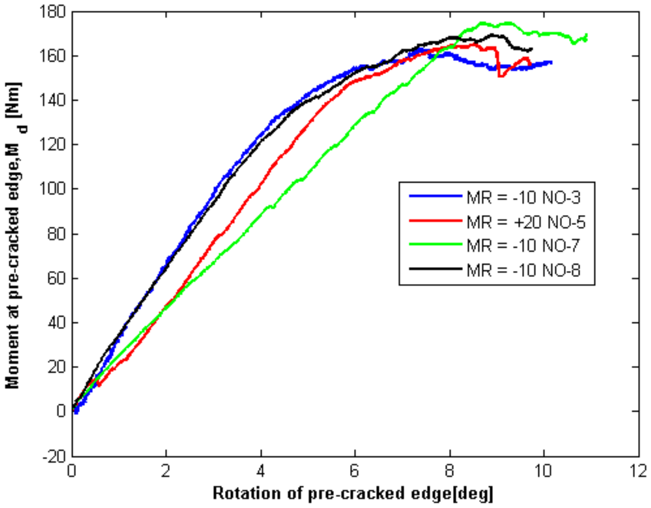

Figure 4: Moment vs rotation at pre-cracked edge

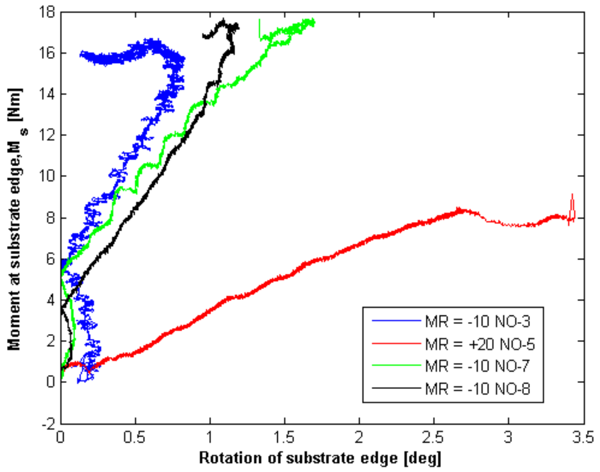

Figure 5: Moment vs rotation at substrate edge

It is observed that it is cumbersome to propagate the crack in mode-II which may be due to the low out of-plane shear modulus of the core. This is also associated with local cell buckling as shown in Figure 4. Additional screening of specimens required to characterize and address the issue of this local phenomenon and the subsequent inhibition of crack propagation.

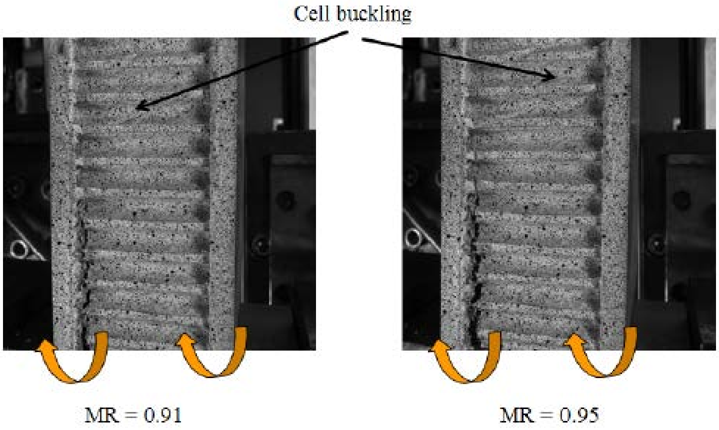

Figure 2: Cell buckling for positive MRs in predominant mode-II in CW-direction

4 CONCLUSIONS

A new test rig based on the double cantilever beam loaded with uneven bending moments (DCB-UBM) is employed to perform fracture analysis of thick honeycomb core specimen comprising of thin face-sheets. Analytical expression for *J*-integral derived for a typical sandwich specimen reinforced with doublers is used to compute the energy release rate. The scatter found in the computed fracture resistance is found to be low. The proposed methodology is a good candidate for fracture characterization of sandwich composites with thin face sheets.

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