

An impact loaded blister test for studying de-bonding

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Abstract. The de-bonding of a glass fibre reinforced composite adhesively bonded to steel was investigated using the impact loaded blister test. A single Hopkinson bar was used to achieve controlled impact loading and the load and load-point displacement were obtained by processing the strain signals recorded in the bar. The growth of the de-bond boundary was synchronously recorded using high speed imaging. Finite element (FE) simulation with embedded cohesive zone (CZ) was carried out and the parameters of the CZ were determined by matching the load-displacement response and de-bond growth history obtained from FE simulations to that obtained from the experiment.

Introduction

De-bonding is one of the most common failures observed in adhesively bonded systems. One of the available test methods for evaluating de-bonding is the shaft loaded blister test (SLBT). In this test, debonding of one layer from the other is induced by applying load using a shaft or bar [1]. SLBT has been successively used for studying de-bonding in different material systems under quasi-static loading [2,3]. For studying de-bonding under impact loads, the double cantilever (DCB) and end-notched flexure (ENF) tests with modifications have been used with varying degrees of success [4,5]. Recently an inverse approach involving FE simulations and experiments with DCB to extract the CZ parameters and the de-bond toughness under impact loading has been reported [6]. SLBT has several advantages over DCB and ENF tests for impact loading. In SLBT, the de-bond growth is axi-symmetric for isotropic layers and hence eliminates free edge effects. Further de-bond growth in SLBT can be achieved at relatively lower level of displacement of the de-bonding layer, which is a significant advantage in impact loading. An impact loaded blister test (ILBT) is employed in this study to determine the de-bond toughness and CZ parameters for de-bonding of a glass fibre reinforced composite (GFRC) adhesively bonded to steel, when subjected impact loading.

Experimental details

The uni-directional GFRC layer was prepared through the hand layup process. After curing, the 1.9 mm thick and 90 mm diameter GFRC layer was bonded to a 3.0 mm thick steel plate of size 140 x 140 mm² using the same epoxy resin used as matrix in the GFRC. The steel layer had a hole of diameter 15 mm which served as the initial de-bond, also referred as the initial blister. A schematic of the ILBT setup is shown in Fig. 1(a). The edges of the steel plate were clamped using a fixture as shown in Fig. 1(b). A polycarbonate bar of 3 m length and 12 mm diameter, henceforth referred to as the incident bar, was used to apply the impact load on the GFRC and induce its de-bonding. The striker, also made of polycarbonate, was 0.4 m long and had a diameter of 12 mm. The striker, propelled from a gas gun, on impacting the incident bar generates a compressive stress wave in the incident bar. This compressive wave travels through the incident bar and loads the GFRC layer which is in contact with the incident bar. A pair of strain gages installed on the incident bar was used to record the incident and reflected strain signals. The load and load point displacement histories were calculated from these strain signals following the method suggested in [7]. The de-bonded region changes to white colour, and this colour change was recorded at the rate of 10⁶ frames per second using a Photran SA1.1 high-speed camera. From the recorded images the blister boundary was measured by image processing. This way the load, load-point deflection and the blister growth were synchronously recorded.

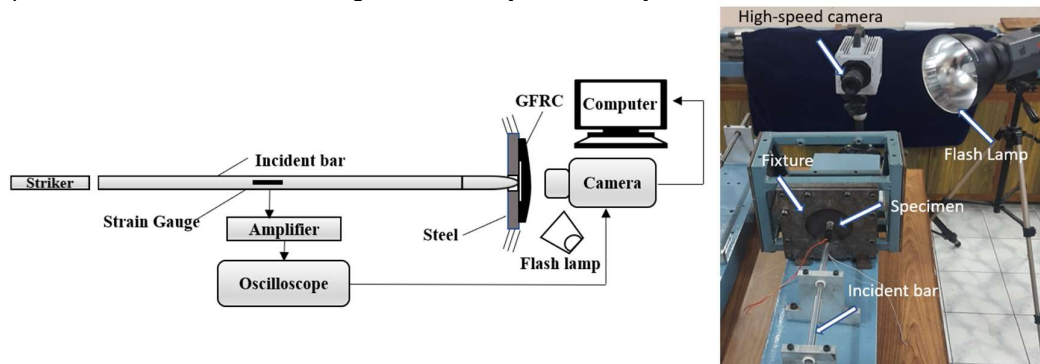


Figure 1. Experimental setup of ILBT, a) Schematic and b) Photograph

Finite element simulation

A quarter symmetric model, as shown in Fig. 2, was employed for the specimen in the FE simulation. Only a small length of the incident bar was modelled and a section of the bar was assigned the velocity history obtained from experiment. The GFRC, steel layer and the incident bar were modelled using linear brick elements with reduced integration. The adhesive layer was modelled with cohesive elements. The explicit FE simulation was performed using the commercial software ABAQUS. The GFRC layer was modelled as an orthotropic material and was assigned the properties listed in [8]. The parameters of the CZ were obtained following an inverse approach, in which the parameters were updated until a good agreement between the FE prediction and experimental measurement was obtained.

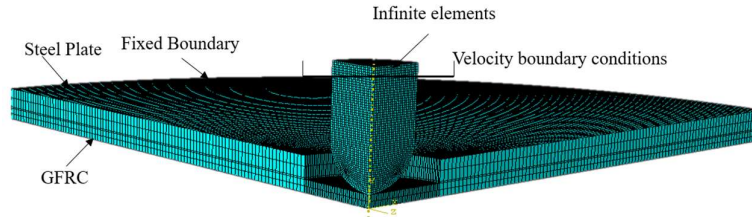


Figure 2. FE model of ILBT test

Results

The load-point velocity obtained from experiments was 3.5 m/s. The load and de-bond area both as a function of load-point displacement, measured from three different experiments are shown in Fig. 3. The load-displacement response, shown in Fig. 3, is bi-linear linear with the slope decreasing once the de-bond starts growing. Though the initial be-bond was circular, as the de-bonding progressed the be-bond boundary changed to an ellipse with its major axis coinciding with the fibre direction in the GFRC. The de-bond area was observed to grow at the rate of 5.5 mm²/s. The load and de-bond area as a function of displacement obtained from FE simulation is also shown in Fig. 3. Both are in agreement with that obtained from experiments.

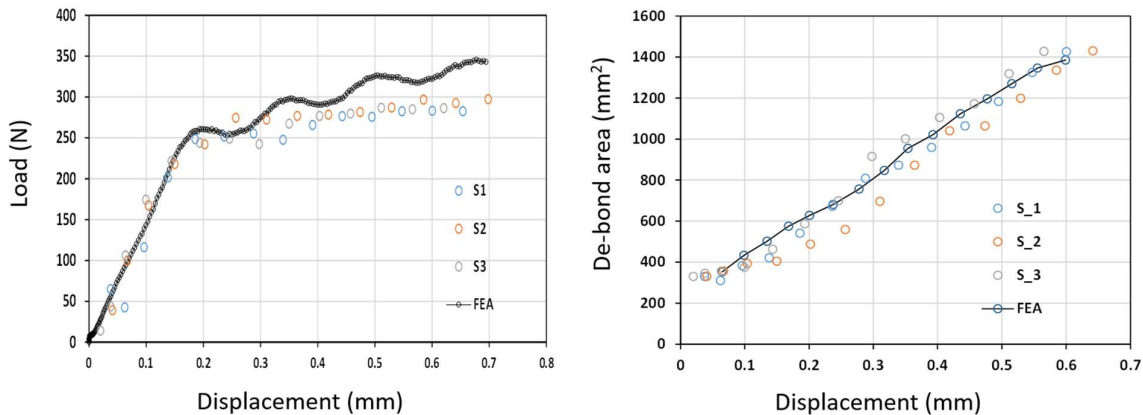


Figure 3. Load and de-bond area as a function of load-point displacement

Conclusion

The results of the study indicate that ILBT is a promising test method for studying de-bonding in adhesively bonded systems subjected to impact loading. Using the inverse approach along with ILBT, the de-bond toughness and cohesive zone parameters can be evaluated.

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