Ph.D. Topic: Prediction of Fatigue Failure of Bonded Composites with Application to Structures Containing External Ply-Drops

Introduction and Significance

Carbon fiber reinforced polymers (CFRP) are strong and lightweight composite materials that are used in the aerospace, automotive, pressure vessel, wind energy, and many other industries. In particular, the fuselages of the Airbus 350 and the Boeing 787 are fabricated from such materials and structures. With growing demand, it is expected that the global CFRP market will reach $31.8 billion by 2024 and the USA will remain the largest market player. The Composites industry in Israel is also strong and possesses huge potential for future growth. Therefore, there exists significant interest in theoretical, numerical and experimental studies of performance and failure of CFRP structures.

One type of CFRP structure used in industry (for example, in the Airbus 350 fuselage) consists of a flat or curved panel, which is called the skin. The skin is made stiffer by long ribs called stringers or stiffeners that are connected to that panel. The two parts are bonded together using some type of thin adhesive layer. An increase in the load can trigger initiation of fractures, delamination, and, eventually, can lead to the failure of the structure. Therefore, accurate predictions of failure of CFRP structures are extremely important for safety reasons.

Background

Typically, lightweight and strength of CFRP structures are achieved by varying the thicknesses of laminates using ply-drops (i.e. by dropping off plies) in proper locations inside that structure. This geometric discontinuity, in combination with the loading conditions, might trigger delamination propagating within the adhesive, along the interface between the adhesive and one of the adherends, or within one of the ahderends. Thus, the study of the parameters that govern the initiation and growth of the delamination are important components in designing damage-resistant composite structures.

To perform such studies and identify the failure mechanisms, composite specimens with ply-drops should be tested and analyzed. As failure typically initiates at the tip or edge of the skin/stringer interface, there is general agreement in the literature that a small specimen that contains that tip is adequate to investigate the failure modes and verify the integrity of a stiffened panel. This eliminates or at least reduces the need to produce a large panel, which is expensive. Quasi-static testing of several specimens made from carbon fiber reinforced pultrusion unidirectional material with external ply-drops was carried out. An example of one specimen is shown in Fig. 1. It consists of a lower skin and an upper flange. The flange and skin are joined together by an adhesive layer that is significantly thinner that the skin and the flange. The ply-drop tapering might have different angles. Additional beam type specimens from this material were tested to acquire critical fracture toughness properties.

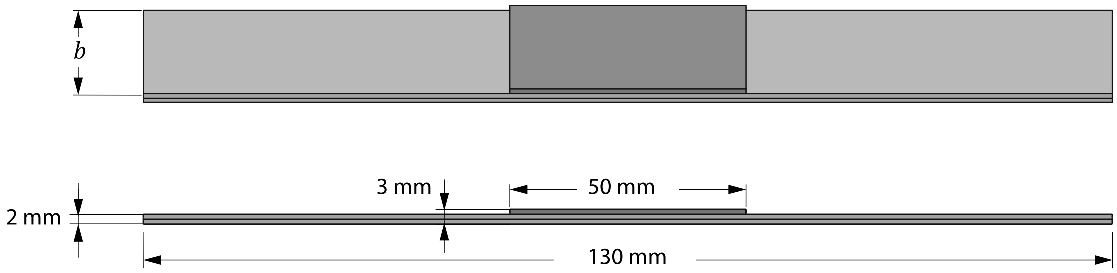

Figure 1: Illustration of the ply-drop specimen including nominal dimensions

In addition, a numerical tool incorporating a combination of the virtual crack closure technique and a cohesive zone element into the finite element program Abaqus was used to model the specimen. A fracture criterion was proposed based on the fracture toughness test results of the beam type specimens. Using the numerical tool, failure prediction of the ply-drop specimens was achieved.

Thesis Topic

A project similar to that presented above is proposed. Instead of quasi-static loading, fatigue cycling will be applied.

1. Fatigue delamination propagation tests will be carried out on beam type specimens. These include double cantilever beam (DCB) specimens for mode I, calibrated end loaded split (C-ELS) specimens for mode II, mixed moded end loaded split (MMELS) specimens for mixed mode and possibly mixed mode bending (MMB) specimens also for mixed mode. These tests will provide the material data base and the reference for predicting fatigue delamination propagation in the ply-drop specimen.
2. Fatigue tests will be carried out on ply-drop specimens to assess the effect of fatigue cycling on this structure.
3. Finally, similar to the quasi-static loading, a cohesive zone element will be developed to predict delamination propagation in the ply-drop specimens. The element will be based on that developed for quasi-static loading. Numerical and experimental results will be compared.