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IMPACT RESISTANCE AND DAMAGE TOLERANCE ASSESSMENT OF COMPOSITE SANDWICH MATERIALS FOR AIRCRAFT

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1. INTRODUCTION

Composite materials constitute a prime prospect to reduce the weight of aero engines and are now considered for several parts in modern turbofan engines. Polymer matrix composites are primarily used for components in the engines' cold section. KTH and GKN Aerospace perform research to develop technology for structural engine sandwich components. Being part of the load carrying structure in the aircraft engine, these components have to be designed for damage tolerance. With respect to the classic definition of sandwich structures the face-sheets (in the present study) cannot be considered as thin in relation to the foam core. An extensive experimental investigation on the damage tolerance of sandwich composite panels has been performed and an overview is presented in this work. Flat composite sandwich panels are subjected to low velocity impact at several energy levels in order to establish barely visible impact damage (BVID) and visible impact damage (VID) levels. According to aircraft airworthiness requirement, a component having either a BVID or VID impact damage should still be damage tolerant and airworthy to fly without jeopardizing the functionality of the aircraft [1,2]. The damage from impact in terms of dent depth, peak contact force, peak displacement and absorbed energy is measured.

2. MATERIAL SYSTEM

The face-sheets are quasi-isotropic carbon fiber, Tenax HTS45, NCF composites and three different thicknesses – 1.6, 2.4 and 3.1 mm – are investigated. The foam core is Rohacell 200Hero and a core thickness of 9 mm is used consistently for all configurations. All the test panels are manufactured using vacuum infusion with an epoxy (Araldite LY556) resin.

3. IMPACT TESTING

In order to perform the impact testing a state of the art, vibration-free, instrumented drop weight impact rig (DWR) was designed and built [3,4]. The working principle of the DWR is to separate the crosshead from the impactor assembly once the impactor tip comes in contact with the specimen. By doing so, dynamic oscillations from the drop rig are prevented to disturb the load cell attached to the impactor assembly during impact, meaning that the true impact response can be recorded relatively unaffected by noise.

The drop weight rig test setup is shown in Fig.1 (left) together with the force vs. time impact response (right) for different impact energies. The impact response is virtually free from adulteration from external vibrations and it is thereby possible to distinguish details related to different damage mechanisms from the force-time response.

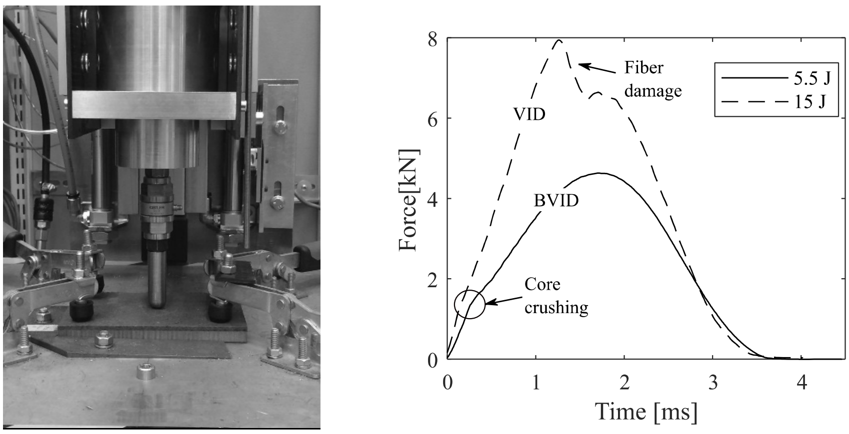

Fig. 1: Drop weight rig test setup (left) and force-time impact response for two different impact energies (right).

As seen in the graph in Fig.1 (right) the response is elastic for low energy impact (5.5 J) and does not show any significant load variation other than a hump near the start of a loading curve. This hump corresponds to the ultimate strength of the core material and is caused by core crushing [5,6]. In cases of higher impact energy (15 J in Fig. 1), a significant load drop is observed near the maximum contact force, which can be attributed to significant face-sheet damage in the specimen.

In order to understand the damage mechanism for both BVID and VID impact damage, a destructive inspection technique is used where by the impacted samples are sectioned in various directions with respect to the face-sheet ply orientations. The cut samples are polished and then inspected under a microscope. Fig. 2 shows examples of microscopy images from cut samples, where half of the impact area, around the point of impact, is shown for both BVID and VID damage samples.

For the BVID damage the main failure mode is delamination with multiple transverse shear cracks. Some core crushing and face-core de-bonding can also be noticed.

In case of a VID damage, several types of damage are observed. In addition to delamination and transverse shear cracks, significant fiber breakage and core crushing is visible. The magnitude of delamination also increases through the thickness. The delaminations predominantly grow along plies with radial fiber orientation with respect to the impact site. This significant damage in VID is also observed in the load-time response (Fig.1).

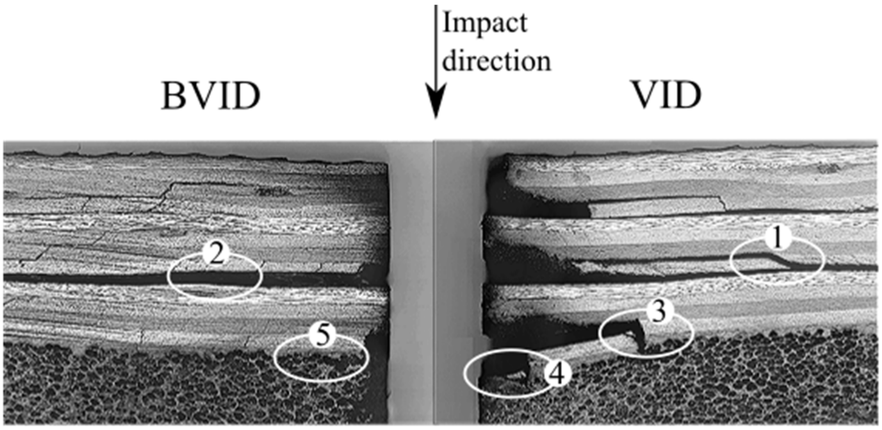

Fig. 2: Microscopy images of BVID and VID impact damages
1: Transverse shear crack, 2: delamination, 3: fiber breakage, 4: core damage, 5: Face-core de-bonding.

4. COMPRESSION AFTER IMPACT TESTING

A damage tolerance assessment of the impacted specimens is performed by subjecting the panels to in-plane compression. Instead of compressing the whole sandwich cross-section, only the impacted face-sheet cross-section is compressed in-plane. This is done to avoid the compressive by-pass load through the non-impacted side of the face-sheet and thus to prevent possible over-estimation of the residual compressive strength. Fig. 3 shows both the classical sandwich specimen compression and also compression after impact (CAI) in a single skin test case. CAI single skin specimens are manufactured by cutting the edge of the core material and the non-impacted face-sheet. The remaining core then provides sufficient lateral support to prevent global buckling without significantly affecting the load-bearing capacity. The loaded ends of the impacted face-sheet are tabbed in order to prevent local crushing and the compressive load is applied by gripping the tabbed ends.

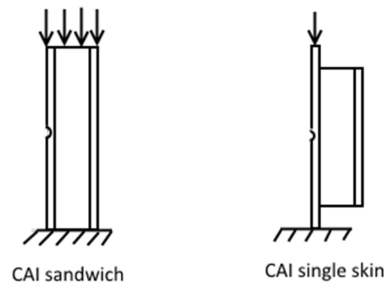

Fig. 3: Type of test configuration for compression after impact test.

Fig. 4 (left) shows the normalized residual strength vs. impact energy for all three specimen configurations. For each face-sheet configuration three impact damage levels are shown, i.e. LLD, BVID and VID, whereas their residual strengths are normalized with the strength of their non-impacted specimens, i.e. the ultimate load of the respective reference configuration. The residual strength decreases with increased impact energy. For BVID damage the knock down strength for the three face-sheet thicknesses, 1.6, 2.4 and 3.1 mm, came out as 14%, 20% and 25%, respectively, and for VID impact damage the measured loss of residual strength was 28%, 25% and 30%, respectively.

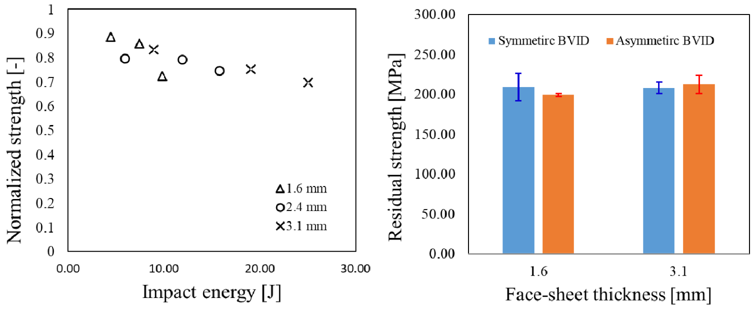

Fig. 4: Normalized residual strength vs impact energy for different face-sheet thicknesses (left), and effect of symmetry on the residual strength of the impacted specimens (right).

In addition to the symmetric sandwich specimens, asymmetric specimens were also manufactured and tested both under low velocity impact and damage tolerance testing. Asymmetric specimens are manufactured with varying face-sheet thicknesses, i.e. one face-sheet side with a thickness of 1.6 mm and the other with a thickness of 3.1 mm. Impact testing is performed on each side of the face-sheet separately and left the other side un-impacted. Damage tolerance testing is performed on the impacted samples by compressing the impacted side alone. The effect of symmetry on the residual strength was studied and the results are shown in Fig. 4 (right) where the residual strength of two different face-sheet configurations are plotted. There is no significant difference in residual strength for asymmetric sandwich specimens compared to the symmetric ones.

5. NUMERICAL STUDY

A finite element model was developed in Abaqus Explicit and the low velocity impact event was simulated for the different face-sheet configurations. The face-sheets were modeled with continuum shell elements whereas the core was modeled with 3D solid elements. For intra-laminar failure, the Hashin damage initiation criterion was used, whereas inter-laminar failure was modeled by inserting cohesive surface elements between each ply in the face-sheet laminates. In Fig. 5 the numerical impact force-time response from FE model is compared with the experimental results. The FE model predicts the peak load with good accuracy and the model is also able to capture the sudden drop in load for the VID impact damage.

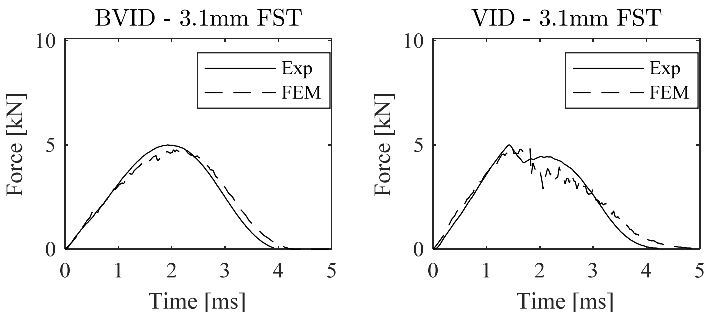

Fig. 5: Force-time impact response, comparison of results from FE simulations and experiments.

6. CONCLUSION

Impact and damage tolerance assessment of sandwich components with relatively thick face-sheets was performed. A vibration free drop weight impact testing rig successfully captured the true impact response. Impact testing is performed to identify the impact energies causing BVID and VID damage. Fractography inspection shows different types of damage in VID specimen whereas delamination is prominent for the BVID case. Thorough testing of compression after impact shows how the residual strength decreases with increasing impact energy and the developed FE models predict the impact response with good accuracy.

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