11th International Conference on Composites Testing and Model Identification
J. Costa, J. Renart and N. Blanco (Editors)
Girona, 2023

INFLUENCE OF VOIDS ON THICK DCB JOINT BEHAVIOR

Jialiang Fan[1], Anastasios P. Vassilopoulos[2] and Veronique Michaud[1]

[1]Laboratory for Processing of Advanced Composites (LPAC),
Ecole Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland
Email: jialiang.fan@epfl.ch, web page: www.epfl.ch/labs/lpac/

[2]Composite Construction Laboratory (CCLab),
Ecole Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland
Email: anastasios.vassilopoulos@epfl.ch, web page: www.epfl.ch/labs/cclab/

Keywords: DCB, Thick joints, Voids

ABSTRACT

Within large structures such as wind turbine blades, the adhesive layer thickness can be large, exceeding 10 mm. Nevertheless, limited studies have been performed focusing on the fracture behavior of adhesive joints with thick adhesive layers, especially for those within the centimeter range [1]. Understanding thick joint fracture behavior is however essential to predict the lifetime of large composite structures [2]. Compared to thin adhesive joints, thick joints often contain large voids and their influence on fracture behavior is significant although not well understood yet [3].

In this work, the influence of void content on the fracture behavior of thick double cantilever beam (DCB) joints was investigated. Three sets of thick DCB joints with optimized grooved geometry and different void contents were prepared with glass fiber epoxy composite adherends and a two-component toughened epoxy adhesive (SikaPower®-830) designed for wind turbine blade manufacturing. The thickness of the adhesive layer was 10 mm. The test was conducted with an MTS Landmark servo-hydraulic testing machine, calibrated to 5 kN load capacity. The test speed was 0.24 mm/min, Digital Image Correlation was used to monitor the crack propagation.

Figure 1a-c present representative fracture surfaces, and Figure 1d shows mode I strain energy release rate (SERR) curves corresponding to the three specimen types with increasing levels of void content. The SERR calculation was based on the corrected beam theory, only considering the stable propagation region. During the DCB test, crack propagation was stable until almost the end of the joints for DCB joints with low void content (~7%), as observed in Figure 1a, where the white region of the fracture surface corresponds to the stable propagation. At the end of the test, stick-slip crack propagation and crack kinking occurred, corresponding to the dark green region of the fracture surface. Crack kinking, corresponding to crack deviation towards the adherends took place together with the stick-slip (unstable crack propagation) in this case, as the crack deviated towards the adherend and finally propagated there. The average SERR is about 3100 J/m^2, which implies SikaPower®-830 is a tough material with high crack resistance.

In DCB joints with medium void content (~12%), stick-slip is observed earlier, just after several centimeters of stable crack propagation, as shown in Figure 1b. After the first stick-slip crack propagation, the crack remained in the middle plane of the joint and thus could still propagate at the middle plane stably for several cm. However, after the second stick-slip crack propagation, crack kinking took place. The crack was arrested at the interface and propagated at the interface until the end. The presence of voids strongly affects the stick-slip crack propagation. When the crack front encounters large voids, the crack may deviate from the middle plane depending on the void orientation, and crack propagation may thus deviate towards the interface. The SERR calculation was performed for the stable propagation region before the first stick-slip crack propagation, SERR values shown in Figure 1d are stable and around 2700 J/m^2.

One fracture surface example of DCB joints with large void content (~24%) is shown in Figure 1c. The stick-slip crack propagation took place according to the position of large voids. When the crack tip encountered these voids, stick-slip propagation occurred. This proves that the voids can lead to stick-slip crack propagation. Reversely, the crack kinking phenomenon could be inversed by the existence of large voids, i.e. the crack at the interface could propagate back to the adhesive layer by following the path crossing larger voids because this reduced the energy cost. This was observed when the crack propagated near the end of the joint. When the voids are not too large, stable propagation was observed, corresponding to the white region of the fracture surface. A more fluctuating SERR curve was obtained in this case, as shown in Figure 1d, between peaks close to the value found in the small void content case, and values down to 2300 J/m^2. Note that the SERR calculation assumed that the fracture surface is not affected by the voids, whereas the surface decreases when voids are present, possibly leading to this variation.

This work investigated three types of thick DCB adhesive joints with different void contents. The presence of voids influences the crack propagation direction and affects stick-slip crack propagation. If the voids are not too large to cause any crack deviations, they can lead to decreased apparent SERR because the actual surface area without voids is not considered within the calculations.

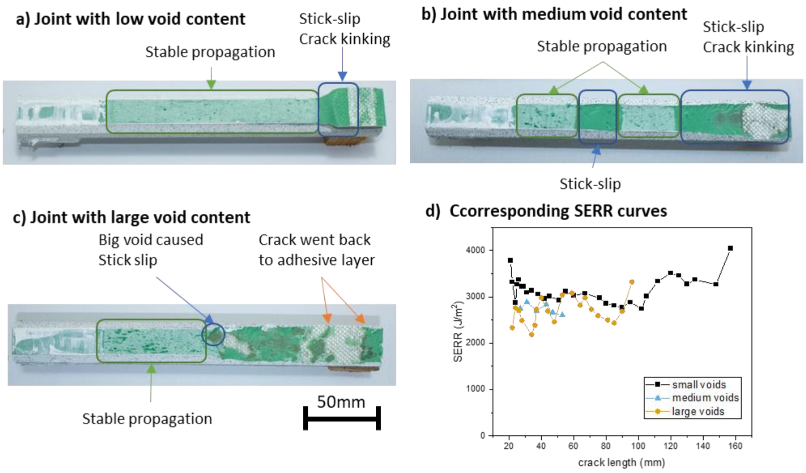

Figure 1: Pictures of fracture surface a) with small void content, b) with medium void content, c) with large void content; d) DCB mode I strain energy release rate (SERR) curves before the first stick-slip crack propagation of the three samples.

The authors acknowledge funding under the Lead Agency scheme from the Research Foundation - Flanders (FWO Vlaanderen) through the project grant G031020N and the Swiss National Science Foundation (SNF) through the project grant 200021E_18944/1 with the title "Combined numerical and experimental approach for the development, testing and analysis of thick adhesive joints in large wind turbine blades". The authors also acknowledge Sika Technology AG for providing materials and support.

REFERENCES

[1] R. Lopes Fernandes, S. Teixeira de Freitas, M. K. Budzik, J. A. Poulis, and R. Benedictus, *From thin to extra-thick adhesive layer thicknesses: Fracture of bonded joints under mode I loading conditions*, Engineering Fracture Mechanics, **218**, 2019, p. 106607.

[2] X.-Y. Miao, X. Chen, R. Lu, and M. A. Eder, *Multi-site crack initiation in local details of composite adhesive joints*, Composites Part B: Engineering, **242**, 2022, p. 110055.

[3] D. Griffin and M. Malkin, *Lessons Learned from Recent Blade Failures: Primary Causes and Risk-Reducing Technologies*, In: Proceedings of the 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, Orlando, Florida, 259, Jan. 2011.