Disk-shaped compact tension & compact tension tests on quasi-brittle thick cellular structural adhesive: Experimental and numerical analyses

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Abstract

This paper deals with fracture mechanics analysis to study and understand the effect of density on the crack initiation resistance of a thick cellular structural adhesive. Disk-shaped compact tension and compact tension samples of two different densities have been fractured and analyzed. The crack opening has been stabilized making possible the crack growth resistance curve computation. The behavior of the material has then been shown to be quasi-brittle. A numerical simulation of the tests using finite elements and virtual crack closure technique has been performed to extract the evolution of an equivalent elastic crack length associated to the measurable sample elastic stiffness decrease along the test. The resistance curve has then been estimated by applying the equivalent linear elastic fracture mechanics.

Introduction

Structural adhesives have been used for several decades in different applications (transport, electronic, …) to create lightweight structures difficult or even impossible to manufacture otherwise. These are used traditionally for thin joints that rarely exceed 2 mm in thickness. For hollow bodies in structures where more space needs to be filled, expanding adhesives with a resulting cellular structure have been developed. The variety of gaps to be filled will imply different rates of material expansion and thus different final densities.

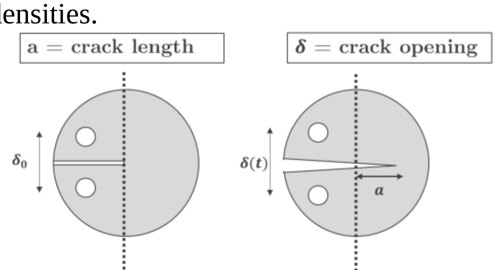

Fig. 1 - Values measured on the samples

These materials combine the behavior of adhesives and foams. It is therefore important to analyze the influence of the relative density ρ_r on the different mechanical properties. The energetic approach of Griffith is one of the possibilities to describe the fracture behavior. The R-curve showing the evolution of the fracture energy as a function of crack length $a(t)$ (see in Fig.1) is the classical tool used. For quasi-brittle materials, the beginning of the curves shows a transient behavior usually related to the FPZ development. Then if the fracture process zone (FPZ) is fully developed and not confined, the crack propagation stabilizes in a self-similar way. The plateau value of G_R, called G_{RC} (see in Fig.2), is then reached. It is sometimes difficult to measure the crack length on heterogeneous materials like woods or foams. In the case of a non-negligeable FPZ size for quasi-brittle materials, it is possible that $a(t)$is difficult to measure. One approach is to use equivalent linear elastic fracture mechanics creating an equivalent homogeneous material and model. It should simulate an equivalent elastic crack growth $a_{eq}(t)$ associated to the test sample elastic stiffness decrease. It is then compared with the measured value. Girardot et al. (2023) shows the use of this method on pharmaceutical tablets.

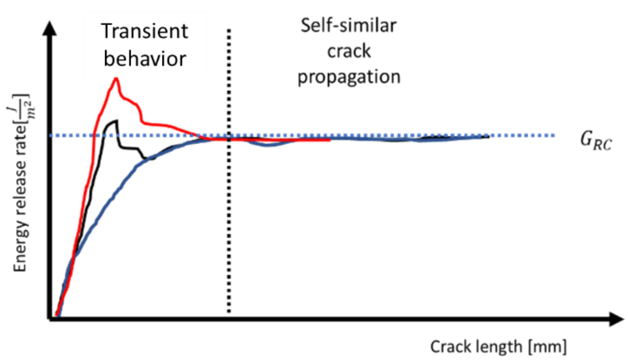

Fig. 2 - Evolution of the energy release rate during the test for quasi-brittle materials

Finally, more points for the R-curves are available. This paper describes the use of CT and DCT tests on a quasi-brittle cellular structural adhesive to study its fracture behavior. Both monotonous and cycled tests have been performed. Results for two sample sizes and shapes for two density values of the material have been investigated. A numerical finite element (FE) equivalent model using virtual crack closure technique was designed to extract the evolution of an equivalent elastic crack length along the test.

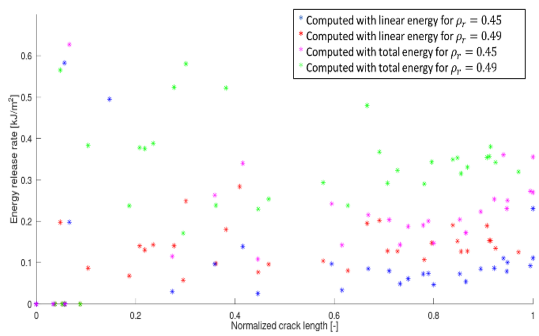

Fig.3 - R-curves of the CT samples for two different densities.

Method & Results

DCT tests with 20 mm wide specimens and CT tests with 40 mm wide specimens were performed on a Zwick Z010 tensile testing machine at a speed of 2 mm/min using cycles. Cycling allowing to observe the energy dissipation phenomenon. For both, samples with relative densities $\rho_r = 0{,}49$ and $\rho_r = 0{,}45$ were tested. Crack opening $\delta(t)$ was acquired locally with a virtual gauge using digital image correlation for the DCT samples. An infrared displacement sensor was used for the CT samples. Acquisition of scaled pictures with a camera at a rate of 0.33 Hz allowed post-test measurement of crack propagation during the test. The R-curves shows (see in Fig. 3) transient behavior at the beginning of the crack. Then, in the second half, it stabilized at a plateau value meaning a self-similar propagation of the crack. The fracture behavior of the material is therefore quasi-brittle. Cycling reveals other mechanisms with residual displacements. It seems that micro-friction creates energy dissipation. The critical energy release rate G_{RC} is two time higher for the lower density sample than for the other. The same observation is valid for energy release rates computed for both total and elastic energies. The finite element model using VCCT was available to reproduce the behavior of the sample during the brittle behavior of the sample during the self-similar crack propagation (see in Fig.4) with ImageJ. The Eq. LEFM approach with homogeneous elastic model seems to confirm the LEFM approach (local measurement of a(t)) for this heterogeneous material.

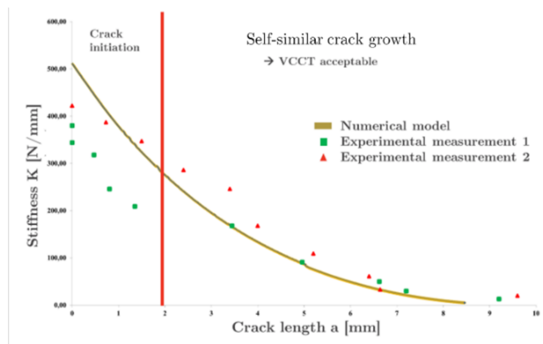

Fig.4 – Stiffness comparison between experience and numerical model

Conclusions

The approach allowed to create a mode I stabilized crack propagation on a TCSA. The quasi-brittle behavior of the material has been revealed. Cyclic and monotonous CT/DCT tests have shown the crack energy evolution during its propagation. It seems that micro-friction creates energy dissipation. Then, R-curves has been computed showing a transient part followed by self-similar crack propagation highlighting a quasi-brittle fracture behavior. The Eq. LEFM approach seems to confirm the validity of a LEFM approach for this cellular material analysis. Finally, the influence of the macroscopic density on the computed energy release rate of the cellular adhesive material has been highlighted.