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Fracture resistance of GFRP bars analyzed using acoustic emission and finite element method

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ABSTRACT: Composite bars are widely used in many industrial fields such as civil engineering, mining, and marine engineering. They have great mechanical, physical, and chemical properties that are crucial in many applications. In this paper methodology to define fracture energy release rate is described. An experimental test following ASTM standard is conducted using Double Cantilever Beam (DCB). However, due to the circular cross-section (standard suggests rectangular) fracture energy cannot be obtained directly from the equation proposed in ASTM D5528. Finite element method simulations were carried out using the extended finite element method (xFEM) and R curve approach. The cohesive behavior of interface layers modeled using traction separation law. The R-curve approach alloform wed obtaining precise experimental data fitting. The presented approach can be used successfully to obtain fracture energy in the case of materials, for which the standard approach is insufficient.

KEYWORDS: DCB test, acoustic emission, fracture energy, composite bars, GFRP

1. Introduction

Presented work emphasizes one of the critical problems in composite materials: delamination [1]. This fracture process usually takes place between the individual layers, nonetheless, it also appears in unidirectional composite materials such as curved beams or bars. Delamination may result from the following: discontinuities in the structure, local out-of-plane loads, low-velocity impacts, cycling loading, incomplete curing, and eccentricities in the structural load paths [2]. During the design process, the engineer must assess the strength of the part to be designed and find the most stressed and damaged regions. An indirect solution to this problem is the numerical analysis, considering the cohesive zones most exposed to the delamination process. Using the Cohesive Zone Model, xFEM, or Virtual Crack Closure Technique (VCCT), it is possible to simulate the mechanical degradation (stiffness loss) of the object.

During the delamination growth in composite materials, fibers tend to bridge between two separated fracture surfaces behind the crack tip. This phenomenon is called fiber bridging, which influences the critical strain energy release rate to increase with delamination growth. An increase in the apparent fracture toughness with delamination extension is usually described by the resistance curves (R-curves) approach [3].

The work presents a numerical-experimental approach to determining, first, the fracture energy, necessary to describe the cohesive behavior of elements. The energy was determined based on the Double Cantilever Beam test, which was then used as an input parameter in the FEM numerical analysis based on the xFEM. The R-curve approach was introduced and applied to properly fit the experimental data. The simulation was performed in the Simulia Abaqus environment.

2. Material and methods

The investigated samples were manufactured using the pultrusion method. Emphasis is placed on the circular bars reinforced with the glass fibers in an epoxy matrix. The double cantilever (DCB) test required a specially prepared geometry with the initial notch. The provided notch is responsible for the proper direction of delamination. In addition, to transfer the load, special loading blocks were manufactured that adhered to the composite surface using cyanoacrylate glue. A schematic drawing with the basic dimensions is presented in Fig. 1.

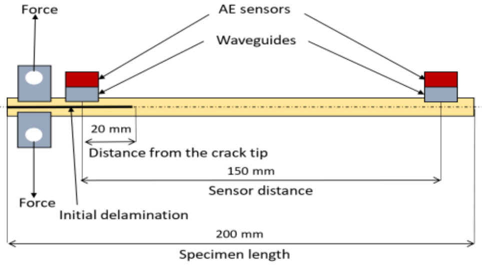

Fig. 1. Basic dimensions of the specimen with the position of the sensors

Composite materials exhibit a complex nature led by various failure mechanisms. To analyze the failure events that appear in the under-investigated loading conditions of the structure, acoustic emission is used. It allows recording acoustic signals that appear in front of the crack tip and are caused by events due to the fiber pullout and breakage. The Vallen AMSYS-6 system was used with two piezoelectric sensors placed as shown in Figure 1. The linear placement of the sensors allows the use of the localization algorithm of the events.

The FE model represents a half cross-section (Fig. 2.) of the circular bar, which is allowed due to the symmetry. The traction separation law was applied to simulate the delamination growth. The middle layer of the bar was modeled using xFEM with the cohesive behavior, this thin layer was divided into small sections. It allows applying various values of fracture energy. This is based on the R -curve approach.

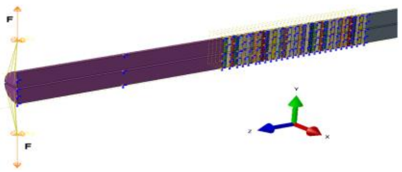

Fig. 2. FE geometry of the investigated object

3. Results and discussion

The DCB test was carried out on the MTS Bionix 793 system with the displacement control mode of 5 mm/min. The experiment followed the methodology proposed by ASTM D5528 [4]. The experimental setup applied in this methodology is presented in Fig. 3.

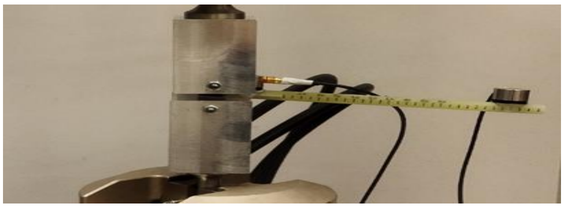

Fig. 3. Experimental setup for investigating fracture energy under mode I

Based on the modified equation proposed by Burda et al [5] the mode I critical energy release rate was calculated. The deviation from the linearity behavior of the force vs displacement curve was set as an initiation value for G_{IC}. It is an NL method described in ASTM D5528 [4]. The calculated value was approximate data to pursue FEM analysis.

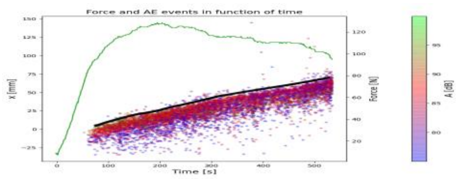

Fig. 4. Force (green line), AE events (amplitudes), and delamination growth are represented by location x, where position 0 is meant to be the initial length of a crack in the function of time

The results show (Fig. 4.) that acoustic events appear before the crack tip, which is caused mainly by fiber pull-out and breakage (fiber bridging effect). The black line refers to delamination growth observed visually. It is noticeable that the nature of the development of the acoustic event is led by the delamination extension.

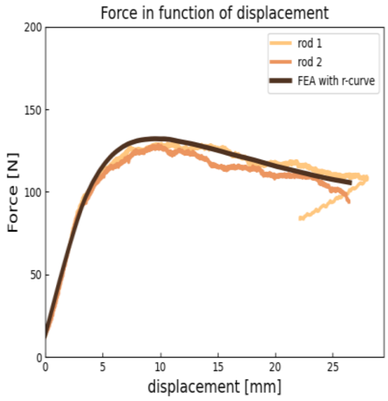

Fig. 5. Comparison of the results obtained from the experiment and FEM

4. Conclusions

Based on the observations and results of the proposed methodology, the following conclusions can be drawn:

- Acoustic emission measurements are useful to composite materials due to the variety of destruction mechanisms in these structures. The analysis of the intensity of measurements, duration, and frequency of signal provides much valuable information about the causes of failure.
- AE provided information about the location of the acoustic event. It is a very practical tool, which enables to designate of the place of destruction. It is also possible to follow the development of the crack.
- FEM method based on the xFEM and R-curve approach precisely reflect the behavior of the composite bars (Fig. 5.). The experimental data (DCB test) were excellently fitted by the applied methodology. These results encourage to use proposed approach to the material with various cross-section areas or curved composite beams or structures.

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