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Data Article

Fracture resistance dataset of composites under mixed-mode non-proportional loading☆

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ABSTRACT

Cohesive zone modelling is one of the main tools to simulate fracture of materials and structures. As a result a number of cohesive laws are being developed continuously. In most cases, due to experimental challenges, the response under mixed-mode fracture is assumed based on various models and it is unclear if fracture is path independent or not. In the co-submitted publication (Goutianos, 2021) it is shown, based on mixed mode fracture experiments under non-proportional loading, that for unidirectional composites path independence is to a large extent a reasonable assumption. The datasets of this publication are presented here with the aim to provide a set of experimental data, mixed-mode fracture under non-proportional loading, for testing the predictive capabilities of developed mixed-mode cohesive laws. The datasets include the raw mechanical data (force and end-opening displacement), analysed data (fracture resistance from the raw mechanical data), video recordings of the experiments and data from acoustic emission sensors.

☆ Fracture under non-proportional loading.

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Specifications Table

Subject	Materials science, Mechanics of materials, Mechanical Engineering
Specific subject area	Composites, fracture resistance, large scale fracture, cohesive laws
Type of data	Raw: Force, opening displacement data of composites loaded with pure bending moments in ".asc" format zipped together. Raw: Acoustic emission data in ".txt" format zipped together. The data correspond one-to-one to the fracture resistance dataset. Video: Video recordings of the fracture resistance experiments in ".mp4" format zipped together. Analysed: Excel files to calculate the applied moments and fracture resistance form the raw mechanical data zipped together.
How data were acquired	Double cantilever beam specimens loaded with uneven bending moments (DCB-UBM). Instruments: In-house testing machine which applies pure uneven bending moments. 2.5 kN load cell (model 1210AJ-2.5KN-B, Interface Inc., Scottdale, Arizona, USA.) Extensometer (Instron, type 2620602), range ±2.5 mm R15α narrow band resonant piezoelectric sensors. from Physical Acoustics Corporation. Nikon-D7200 camera.
Data format	Raw and analysed
Parameters for data collection	Unidirectional glass fibre epoxy composites with an initial notch.
Description of data collection	Unidirectional composites were loaded at a certain mode mixity (bending moment ratio) until crack grew significantly. The specimens were unloaded prior to steady-state condition and then they were loaded again at a different mode mixity (bending moment ratio) to steady-state fracture. During loading, the force,the crack opening displacement and the acoustic emission activity were recorded simultaneously. The experiments were video recorded.
Data source location	Institution: Norwegian University of Science and Technology City: Gjøvik Country: Norway Latitude and longitude: 60.8941, 0.5001
Data accessibility	Repository name: Zenodo.org Data identification number: 4661813 Direct URL to data: https://zenodo.org/record/4661813#.YWlmZ7hBybg
Related research article	S. Goutianos, An experimental investigation into the path independent fracture of composites. Composites Part B, 226, 109352, 2021

Value of the Data

- Fracture resistance data of composites under non-proportional loading are not available in literature. All existing data refer to proportional loading. However, the majority of structures are subjected to non-proportional loading.
- Fracture has a strong influence on the structural integrity of components and structures. A large number of numerical models, e.g. cohesive zone modelling, to simulate fracture are being continuously developed. In nearly all cases these numerical models are compared against fracture tests performed under proportional loading. The data provided, e.g. mixed mode fracture and non-proportional loading, can benefit industry and academia in developing more accurate models to simulate fracture.
- The data can be used by the computational fracture mechanics community to develop more accurate fracture simulation tools by comparing the numerical predictions with the experimental data taking into account the effects of mixed-mode and non-proportional loading. The additional provided data (video recordings and acoustic emission) can be used for a

rigorous evaluation of the accuracy of mixed mode fracture cohesive laws. From the video recordings, the length of the fracture process zone at each load level can be extracted and compared with simulations. Using the markers on the surface of the specimens, the local openings along the fracture process zone can be extracted by Digital Image Correlation (DIC) and compared with numerical predictions. The acoustic emission data can be used to determine more accurately the onset of mixed mode fracture and compared with the predicted onset of fracture.

1. Data Description

The datasets are made available at the Zenodo repository [2]. For each experiment the following data are included:

- **asc-file**: Raw mechanical data: column 1 = time, columns 2 and 3 = force (from the two load cells see Fig. 1), column 8 = displacement from the extensometer (Fig. 3)
- **xlsx-file**: Calculation of bending moments (columns O, P) and fracture resistance (column U) from Eq. (1). The file includes the moment arms length (columns M, N), the specimen dimensions (columns I, J) and elastic properties (columns K, L).
- **txt-file**: Acoustic emission data from the two AE sensors. ID 1 refers to the AE sensor at the root of the initial notch and ID 2 refers to the AE sensor at a distance d from the initial notch (Fig. 1).
- **mp4-file**: Video recording of the experiment.

Note: Files ending with **'a'** refer to first loading step (crack initiates and grows followed by unloading prior reaching steady-state). Files ending with **'b'** refer to the second loading step at a different moment ratio until steady-state fracture occurs (see section Methods).

2. Experimental Design, Materials and Methods

2.1. Experimental design, materials

The mixed mode fracture experiments were performed using the fixture shown in Fig. 1 (from Sorensen et al. [3]). By changing the moment arms length, ℓ_1 and ℓ_2, different mode mixities can be applied.

The specimen geometry is given in Fig. 2. The specimens were cut from a laminate manufactured by vacuum infusion of an epoxy resin into layers of non-crimp unidirectional E-glass fabrics. The fibre direction is along axis x_1 (Fig. 2).

The details of crack start and the position of the extensomter are shown in Fig. 3.

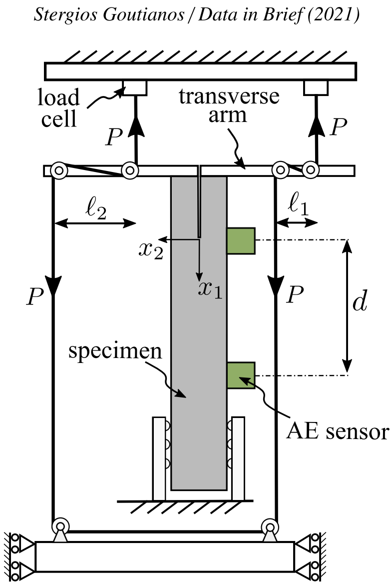

Fig. 1. Schematic illustration of (a) the test fixture to apply pure uneven bending moments using a wire and rollers and (b) the position of the acoustic emission (AE) sensors [1,3].

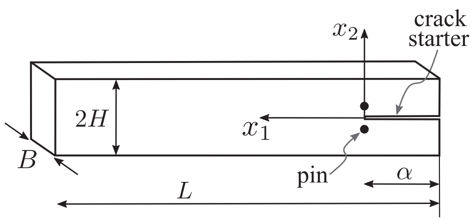

Fig. 2. The Double Cantilever Beam (DCB) specimen (from [1,3]). The position of the slip foil (crack starter) and the pins are shown. L=500 mm, $2H$=14 mm, α=60 mm, and B=30 mm.

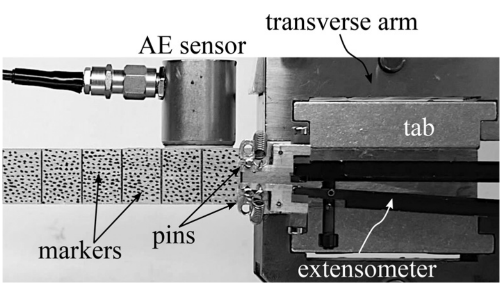

Fig. 3. Photograph of a DCB specimen showing the position of the extensometer and the fixation to the transverse arms (from Goutianos [1]).

Table 1
Bending moment ratio in the first (**'a'**) and in the second (**'b'**) loading step.

Specimen	1st loading step	2nd loading step
1	−1.0	0.0
2	0.943	0.0
3	0.0	-1.0
4	0.299	-1.0
5	0.943	-1.0
6	-1.0	0.943
7	0.0	0.943
8	0.299	0.943

2.2. Methods

The fracture energy is calculated by evaluating the J integral along the external boundaries of the specimen [3]. For an orthotropic specimen and under plane strain, the J integral along the external boundaries is:

$$J_{ext} = (1 - \nu_{12}^2)\frac{21(M_1^2 + M_2^2) - 6M_1M_2}{4B^2H^3E_{11}}, \text{ for } |M_1| < M_2 \quad (1)$$

where M_1 and M_2 are the bending moments, E_{11} is the Young's modulus in the fibre direction and ν_{12} is the Poisson's ratio. The 'mode mixity' is characterised by the moment ratio M_1/M_2, which is the appropriate parameter for problems with large scale fracture process zone (non-linear fracture mechanics).

Each DCB specimen is loaded first with a fixed bending moment ratio, M_1/M_2, up to a load level high enough to cause crack growth of several millimeters and then it is completely unloaded. It was ensured that during this loading step, steady-state fracture is not attained. Subsequently, the same DCB specimen is loaded with a different moment ratio until steady-state fracture is reached. It should be emphasized that during this second loading step, the fracture process zone develops in a process zone morphology left by the first loading (non-proportional loading). The bending moment ratio, M_1/M_2, for each specimen in both loading steps is given in Table 1.

Ethics Statements

This article does not contain any studies with human participants or animals performed by the author.

Declaration of Competing Interest

The author declare that he has no known competing financial interests or personal relationships which have or could be perceived to have influenced the work reported in this article.

CRediT Author Statement

Stergios Goutianos: Conceptualization, Methodology, Writing – review & editing, Writing – original draft.

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References

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