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Data Article

Dataset of mixed-mode R-curves from DCB-UBM fracture tests of a UD glass/epoxy composite

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ABSTRACT

An extensive dataset with mixed-mode fracture resistance experimental data (R-curves) and fracture process parameters is presented. The fracture resistance values are extracted from double cantilever beam specimens subject to un-even bending moments. The tested specimens are made of a unidirectional composite which undergoes large-scale fibre bridging during fracture. The data set contains both raw data (forces from two load-cells, time, acoustic emission signals, and opening displacement measurements) and processed data (J-integral, end-opening displacements, fracture process parameters) of each test. In the repository, MATLAB scripts are also provided to facilitate recreating the processed data from the raw data.

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Specifications Table

Subject	Material Science
Specific subject area	Cohesive laws, fracture of composites, cohesive zone model, fracture mechanics,
Type of data	Tables Image Chart Graph Figure Scripts
How the data were acquired	The data was acquired from a macroscopic fracture mechanics test. The double cantilever beam with un-even bending moments (DCB-UBM) configuration [1] was used.The instrumentation used for acquiring the raw data is the following: • Load cells (up to 2 kN) • Extensometer (Instron 2620-601 range +/- 5 mm) • LVDTs (RDP GT 5000 range +/- 5 mm) • Acoustic Emission (MISTRAS Micro-II Express)
Data format	Raw (time, loads, extensometer, and LVDT displacements) Analysed (time, moments, J-integral, normal and tangential opening displacements)
Description of data collection	A total of 44 valid experiments were carried out. To ensure repeatability, 4 test specimens were tested for each of the 10 different loading groups (different applied moments ratios).
Data source location	• Institution: Technical University of Denmark, DTU Wind and Energy Systems, Risø Campus • City: Roskilde • Country: Denmark • Latitude/Longitude: 55.69267043359176/12.097785281791271
Data accessibility	Repository name: Mendeley data Data identification number: 10.17632/tck7k5257y.3 Direct URL to data: https://data.mendeley.com/datasets/tck7k5257y/3
Related research article	Erives, R., Sørensen, B. F., & Goutianos, S. (2023). Extraction of mix-mode cohesive laws of a unidirectional composite undergoing delamination with large-scale fibre bridging. *Composites Part A: Applied Science and Manufacturing*, 165. https://doi.org/10.1016/J.COMPOSITESA.2022.107346

Value of the Data

- Extensive mixed-mode fracture resistance data of composites materials undergoing large-scale fibre-bridging is limited in the literature.
- The data can be used to develop advanced fracture material models that account for large fracture process zones (non-linear fracture). In particular, the data can be useful to improve cohesive law formulations.
- The data can be used to create, improve and/or validate fracture mechanics tools e.g., cohesive zone models that adequately account for large-scale (non-linear) fracture process zones.
- The data can be used by researchers and industry to develop new, more damage tolerant composite materials.
- The data can provide knowledge to engineers that may result in improved design of composite structures. It could help towards the implementation of damage resistance designs that account for large-scale fracture (e.g., fibre bridging which is currently completely neglected in the design).

1. Objective

The data introduced in the present paper was collected during a large experimental campaign thatwas carried out to develop a mixed-mode cohesive law for delamination on composites with large-scale bridging using experimental observations (R-curve behaviour) [2]. The data paper is published so that the results presented in [2] can be rreproduced, but more importantly to provide peer researchers with data for developing and validating new methods for the experimental extraction of cohesive laws. The provided data is of high value because of the very large number of tested mixed modes. In the literature it is very common that mixed-mode fracture characterisation includes tests with nominal mode I, nominal mode II and a mixed-mode (3 mixed-modes). However, if any of the fracture parameters describing the fracture resistance (e.g., fracture onset) varies in such a way that more than 3 values are needed (see [2]), then only 3 tested modes (e.g., nominal mode I, nominal mode II, and a mixed-mode) are not sufficient to properly fit the fracture resistance envelope. In the present data paper 10 different modes are tested.

2. Data Description

The data repository [3] where the data can be accessed contains 4 folders at the root:
Input data:

1. The file **DCB specimen and material data.xlsx** contains the specimens geometric, and material data. It also summarizes all data needed to create an input file (i.e., **input.txt**) for the post-processing script.
2. The input file mentioned above is provided here.

Raw data:

1. The **README.txt** file explains the name convention for each file.
2. The Daisy_lab folder contains one **.asc** file per test with the mechanical data recorded during the test (column 1=time, column 2=load from load cell 1, column 3=load from loadcell 2, column 3=opening from extensometer, column 4=opening from LVDT1, column 5=opening from LVDT2, column 6=Reference load, column 7=no meaningful data as there was only one extensometer mounted), as well as general testing data (e.g., recording date, specimen number, displacement speed, and data acquisition) of each test. The data is in **.asc** format.
3. Video can be provided upon request. Videos are not uploaded due to the very large size of the files. However, if needed, they can be made available upon request.
4. The AE folder contains the raw acoustic emission data (column 1=microphone ID number, column 2=detection time, column 3=channel number, column 4=wave rise, column 5=hit count, column 6=energy, column 7=duration, column 8=amplitude, and column 9=amplitude frequency) for each test.

Processed data:

1. The file **AE_t0.xlsx** contains the time of crack initiation obtained from AE data. The file summarises the onset time $\boldsymbol{t}_0$ for each tested specimen.
2. The file **R-curves.xlsx** contains the fracture resistance curves as a function of the normal and tangential end-openings, $\boldsymbol{J_R} = \boldsymbol{f}(\boldsymbol{\delta_n}, \boldsymbol{\delta_t})$, for each experiment.
3. The file **Fracture_parameters.xlsx** summarises the fracture parameters obtained from each experiment, which are needed to extract the mixed-mode cohesive laws as described in [2]. A list of these parameters is provided in the methods section.

Post-processing scripts:

1. The R_curves folder contains one main file (**MAIN.m**) and 7 sub-programs (**AssignFracParameters.m, CalcOpenings.m, FitJRb.m**, I**mportASCdata, PhaseAngle.m, ReadInputData.m**).

The scripts can be used to obtain the R-curve of each tested specimen. The folder also contains a **README.txt** file with a brief explanation of each sub-program.

2. The cohesive laws folder contains two folders **i)** interpolation of fracture parameters, which contains a script to interpolate the required fracture parameters for the model (explained in the Methods section), and **ii)** plot tractions which contains one main script (**Plot_cohesive_tractions.m**), and one sub-program (**PolyfitwDeriv.m**). The code uses the procedure from [2,4] to plot the experimentally determined cohesive tractions.

There is a README.txt file with a description of each main program (e.g. inputs/outputs, number of subprograms, etc.) located in each of the folders

3. Experimental Design, Materials and Methods

3.1. Materials

The glass/epoxy composite used for manufacturing the DCB specimens was made from 20 unidirectional stitched layers (with all the backing facing downwards). The laminate had 10 UD layers above and below the mid-plane (symmetric laminate), however, all the laminates had backing bundles in the lower side of each lamina so that the interface where fracture takes place is not strictly symmetric. The glass fabrics were E-1182 Saertex and the matrix material was a Hexion RIMR 035c epoxy. A vacuum infusion of 12 hours at 40C +10 hours at 80C was employed during manufacturing. A 58% overall fibre volume fraction was attained [5]. The elastic properties of the UD glass/epoxy laminate are reported elsewhere [2].

3.2. Specimen Geometry

The test specimen geometry used for a double cantilever beam with uneven bending moments (DCB-UBM) is the well knonw DCB geometry. The geometric information of each specimen (and instrumentation) is provided in the input_data folder located in the data repository (**DCB specimen and material data.xlsx** file).

3.3. Test Configuration

The test configuration used in the experiments was the double cantilever beams with proportional un-even bending moments (DCB-UBM) [1]. The test setup for the present experimental campaign is shown in Fig. 1.

A detailed description of the test procedure is given in [1,2,6], but a brief description is provided here for completeness. The DCB specimen is fixed at one end (The one opposite to the initial notch, which is at the bottom in the pictures above), and each of the two beams at the other end is subject to pure bending moments. The moments are applied through the steel end-blocks using a wire to transfer load as shown in Fig. 1. The load was introduced at a speed of Δ=10 mm/min (displacement of the lower beam) and the data sampling frequency was 20 Hz.

The test specimen was instrumented with 2 Acoustic Emission microphones placed on the DCB specimen 110 mm apart (see Fig. 1). Each of the tests was recorded with two cameras, one with a zoom in the crack-tip and another one covering the entire specimen. An extensometer and an LVDT were mounted on each specimen to measure the end-opening displacements as a function of time/load. Two load-cells were measuring the load as a function of time at the two ends of the wire system.The test-setup is designed with inclined lever-arms with an initial rotation of θ_0=10^o (the direction of the initial rotation is chosen so that the angle formed by each of the lever arms reduces as the beam is initially displaced). This was done to extend the range of the valid beam deflection as defined in the Appendix C of [1].

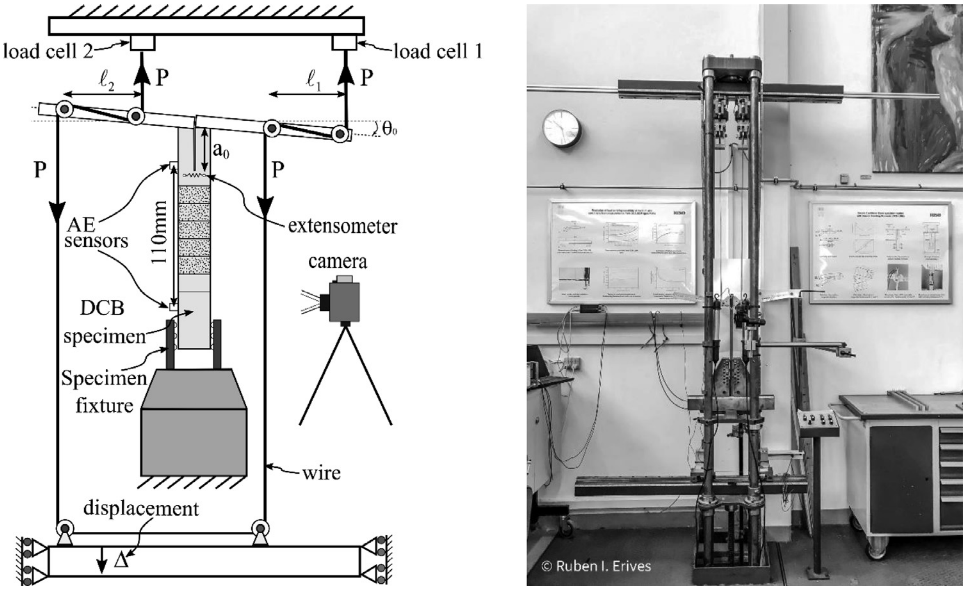

Fig. 1. Test setup schematic (on the left. Fig. modified from [2], and picture (on the right).

3.4. Test Procedure

The test procedure consisted in loading the specimens until reaching steady state (determined from real time measurement of the loads). Once the specimens are considered to have reached steady state, the test was stopped and then the specimen was unloaded. Although only the loading part has been used in the analysis, both the loading and unloading part are captured in the raw data. For specimens tested under near-nominal mode II conditions (i.e., with moment ratios close to 1), the crack-tip progressed down the specimen surpassing one of the AE microphones and eventually reaching (near) the specimen fixture (see Fig. 2) before reaching steady-state. This results in large deflections that exceed the maximum value of beam deflection, θ_{max}, which is used as the validity threshold (as reported in see [1]). To address these issues, some test specimens were rotated at the fixture to attain a larger initial inclination (θ_0). This reduced the beam rotation ($\theta - \theta_0$) to remain within the maximum lever-arm angle deviation of 10° during cracking as described in [1]. This is illustrated in Figs. 2 and 3. The information regarding whether a specimen reached a steady-state and/or whether it was initially rotated is provided in the file data set (file **DCB specimen and material data.xlsx**).

3.5. Methods

3.5.1. Mixed-Mode R-Curves

The R-curves are described in terms of the J-integral, and the normal and tangential end-openings. An analytical solution for the J-integral evaluated along the external boundaries of a DCB-UBM specimen has been used (for plane strain) [7]:

$$J_R = (1 - \nu_{12}\nu_{21}) \frac{21\left(M_1^2 + M_2^2\right) - 6M_1M_2}{4B^2H^3E_1}$$

where M_1 and M_2 are the applied moments on the left and right of the DCB (see Fig. 1), B and

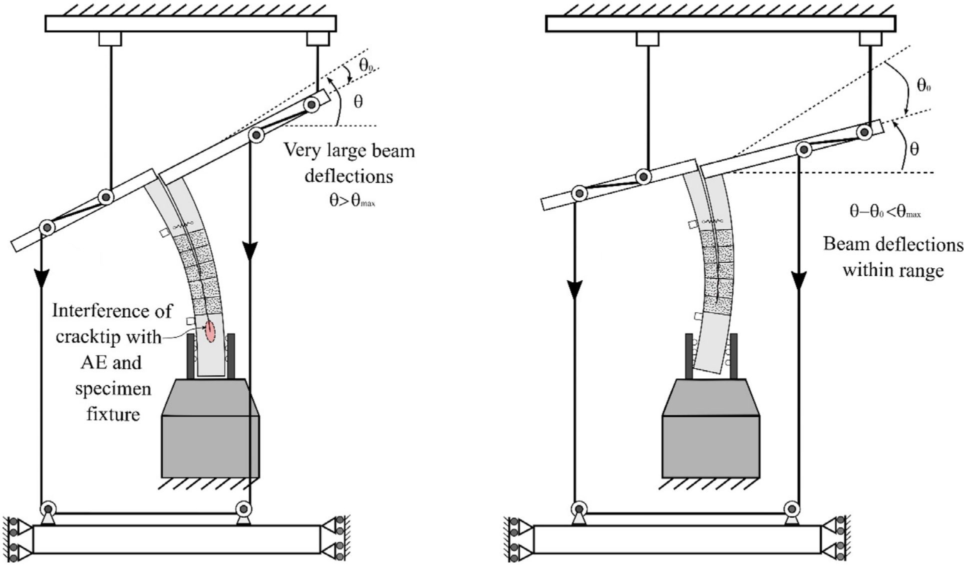

Fig. 2. Schematic of near-nominal mode II tests with a) normal fixture and exceeding threshold for beam deflection and b) rotated fixture not exceeding the beam deflection threshold.

Fig. 3. Picture of the specimen fixture with no initial inclination of the specimen and b) with an initial inclination of the specimen.

H are the width and thickness of the specimen, E_1 is the Young's modulus in the fibre direction and ν_{12}, and ν_{21} are the primary and secondary Poisson's ratios respectively. The normal and tangential openings (δ_n, δ_t) are computed from readings of the extensometers and the LVDTs according to [6].

The combined end-opening, δ^*, and the phase angle, φ^*, are:

$$\delta^* = \sqrt{\delta_n^2 + \delta_t^2}$$

$$\varphi^* = \tan^{-1}\left(\frac{\delta_t}{\delta_n}\right)$$

here an asterisk is used to denote a measurement/quantity at the end of the fracture process zone.

3.5.2. Loading Groups

The mixed-mode DCB-UBM testing campaign was grouped according to the applied moment ratio (or the nominal phase angle, ψ [8]). During the testing campaign, 10 different loading groups were tested. A table with the list of the loading groups corresponding to all the tested specimens is provided in [2]. In the table, the value of the measured (average of the loading group) end-opening phase angle, φ^*, is also provided. The data presented here contains both a set of post-processed mixed-mode R-curves as well as raw data (and tools) to recreate the post-processed data.

3.5.3. Mixed-Mode Cohesive Laws

The data provided (R-curves) here can be used to determine a potential function of the mixed-mode fracture resistance, which in turn can be used to compute the mixed mode cohesive laws of the material interface. A method where the potential function is can be constructed from polynomial forms of fracture parameters is presented in [2,4]. The input parameters for this method can be found in the **Fracture_parameters.xlsx**. file located in the Processed_data folder. These parameters can also be re-created from the R-curves. The parameters are listed below.

$\boldsymbol{J_0}$ is the fracture resistance at crack onset
$\boldsymbol{\delta_0}$ is the combined end-opening at crack onset
$\boldsymbol{J_{ss}}$ is the fracture resistance attained when the crack propagates in a steady state
$\boldsymbol{\delta_{ss}}$ is the combined end-opening measured when the crack runs in a steady state
$\boldsymbol{\zeta}$ is the shape parameter of the potential function at the bridging region
$\boldsymbol{\delta_{00}}$ is the end-opening at the inflexion point in the fitting of the potential function at the crack-tip
$\boldsymbol{J_{00}}$ fracture resistance at the inflexion point in the fitting of the potential function at the crack-tip

Details on the physical significance of these parameters, as well as on how they are obtained from the R-curves can be found in [2,4].

The proposed method in [2] requires interpolation of the fracture parameters. In such work, the authors opted for polynomial fitting of the parameters. A script to fit each of these parameters is provided (file **Interpolation_plots.m** located in the Post_processing_scripts folder). The polynomial form of these parameters is then used as input to the model to obtain the mixed mode cohesive laws of the interface. A tool to plot the obtained cohesive tractions is also provided (file **Plot_cohesive_tractions.m**).

Ethics Statements

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

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Mixed mode fracture resistance data set from DCB-UBM experiments (Original data) (Mendeley Data).

CRediT Author Statement

Rubén Erives: Conceptualization, Methodology, Writing – review & editing, Data curation.

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References

[1] B.F. Sørensen, K. Jørgensen, K. Jacobsen T, C. Østergaard, DCB-specimen loaded with uneven bending moments, Int. J. Fract. 141 (1-2) (2006) 163–176.
[2] R. Erives, B.F. Sørensen, S. Goutianos, Extraction of mix-mode cohesive laws of composites undergoing delamination with large scale bridging, Composites, Part A 165 (2023).
[3] R. Erives, Mixed mode fracture resistance data set from DCB-UBM experiments, Mendeley Data V3 (2022), doi:10.17632/tck7k5257y.3.
[4] R. Erives, B.F. Sørensen, S. Goutianos, A coupled mix-mode cohesive law based on a cylindrical potential function, Eng. Frac. Mech 271 (2022).
[5] A. Antoniou, L. M, S. Goutianos, O. Bagemiel, I. Gebauer, R. Flindt, F. Sayer, Influence of the glass non-crimp fabric intrinsic undulation on thestiffness of the composite ply: A micromechanical approach, IOP Conference Series: Materials Science and Engineering, 2020.
[6] B.F. Sørensen, T.K. Jacobsen, Characterizing delamination of fibre composites by mixed mode cohesive laws, Compos. Sci. Technol. 69 (3-4) (2009) 445–456.
[7] B.F. Sørensen, P. Kirkegaard, Determination of mixed mode cohesive laws, Eng. Fract. Mech. 73 (17) (2006) 2642–2661.
[8] Z. Suo, G. Bao, B. Fan, T. Wang, Orthotropy rescaling and implications for fracture in composites, Int. J. Solids Struct. 28 (2) (1991) 235–248.