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Failure analysis of composite structures subjected to three-point bending

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ABSTRACT: This paper presents the experimental and numerical study of three-point bending realized on composite plate profiles. The composite profiles were manufactured from carbon-epoxy laminate and characterized by symmetric $[0/90/0/90]_s$ laminate lay-ups. Experimental study was conducted on a universal testing machine, using three-point bending heads. Macroscopic evaluation was performed using a digital microscope with a mobile head. Numerical simulations were carried out using the Finite Element Method in ABAQUS software. The application of the mentioned interdisciplinary research methods allowed for a comprehensive analysis of the failure phenomenon of the composite structure. The research results provided a better understanding of the failure mechanism of the composite structures.

KEYWORDS: three-point bending, laminates, numerical simulation, experimental tests, finite element method, failure

1. Introduction

Thin-walled composite structures are commonly used for stiffening elements in the aerospace, construction and automotive industries. These types of structures are primarily subjected to compression and bending. The composite materials are still expansive group of materials which are characterized by the occurrence of multiple complex forms of damage, thus requiring in-depth research. The cognitive value of the behavior of thin-walled structures made of composite materials is still very important, and despite the many studies conducted in this area, the behavior of the structure subjected to bending [1] taking into account the complex failure mechanism is not yet clearly defined.

It is important to understand how to identify the damage phases that occur during testing. The above demands a comprehensive analysis, both on the basis of experimental studies and numerical simulations (using the FEM) [2]. In the case of structural failure analysis, it is important to know the phenomena such as damage initiation, damage evolution and delamination.

For experimental testing, the universal testing machine [2] and acoustic emission method [2] are most commonly used to evaluate the failure phenomenon. Within the framework of numerical simulations, it is possible to determine the failure phenomenon using advanced special damage models (such as PFA – progressive failure analysis [3], CZM – cohesive zone model [4], XFEM – extended finite element method [5]).

The scope of the study was primarily to conduct experimental tests (using universal testing machine as well as digital microscope with mobile head) [2] and numerical FEM simulations (using CZM and XFEM damage model) [2] of three-point bending of a thin-walled composite structure.

2. Methodology of the study

The test specimens were made of carbon-epoxy composite [2, 6] (the specimens consisted of 8 layers; length x width x thickness = 135 x 15 x 1.048 mm; stacking sequence $[0/90/0/90]_s$) using autoclave technique.

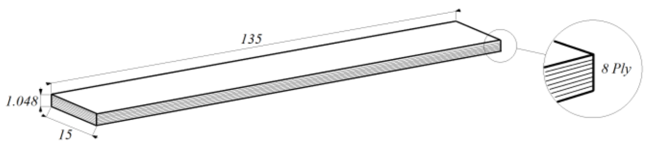

Fig. 1. Test specimen

The experimental investigations were carried out primarily using a universal testing machine COMETECH model QC-508 – type M2F, as well as a modern digital microscope KEYENCE model VHX 970F, containing a mobile (portable) measuring head.

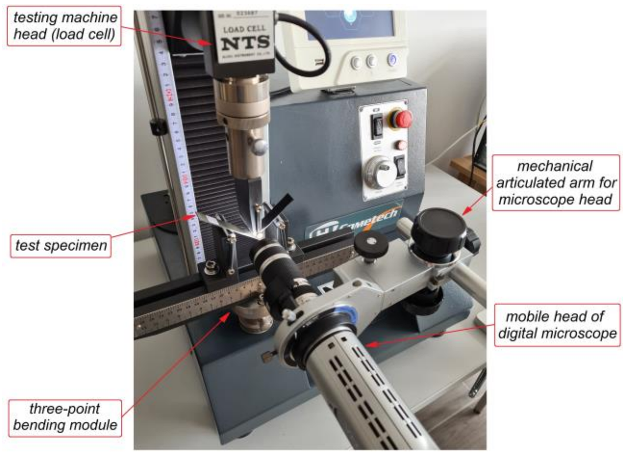

Fig. 2. Test stand during three-point bending test

The experimental tests were performed using the above-mentioned devices, which made it possible to realize the process of three-point bending with registering force-displacement relationships, and failure forms of laminates.

In the numerical simulations (using ABAQUS software), two damage models were applied simultaneously within the numerical model in order to allow for delamination (CZM) and material fracture (XFEM) phenomena of the composite.

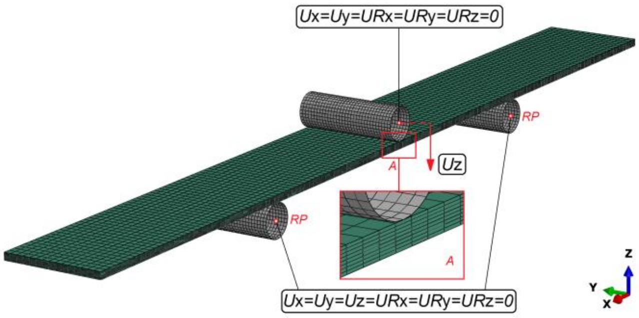

Fig. 3. Numerical model

3. Results

The current section presents the results of experimental studies and numerical simulations, in the context of structural failure analysis under three-point bending tests.

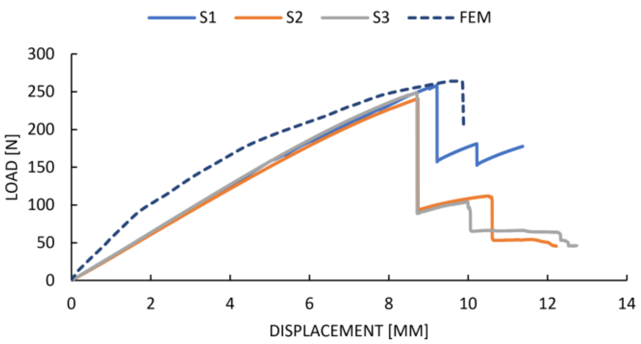

Fig. 4. Load-displacement characteristics

Table 1. Limit load values

Experimental study [N]	Average value of experimental study	Numerical study [N]
S1 – 258.39	249.36	264.05
S2 – 240.75		
S3 – 248.93		

In the quantitative evaluation, a very high agreement between the experimental and FEM simulation results was estimated, in which the discrepancy between the mean value of the failure load from the experimental tests and the numerical analysis result was only 5.56%.

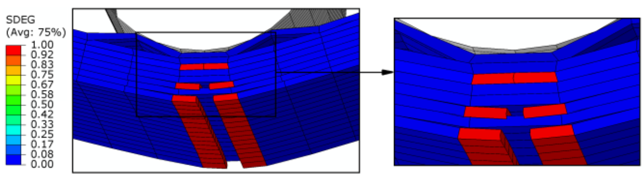

Fig. 5. Failure result - numerical simulation

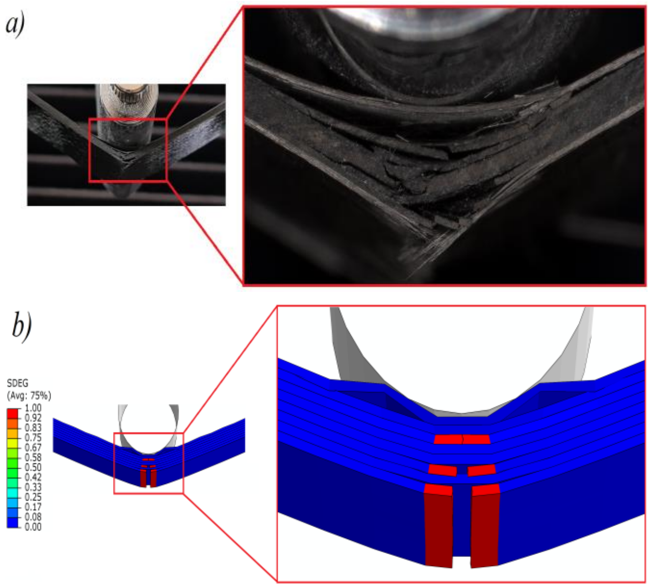

Fig. 6. Comparison of failure modes: a) EXP, b) FEM

In the qualitative evaluation, a complex failure mechanism including both layer fracture (cracking) and delamination phenomena was demonstrated.

4. Conclusions

Based on the study, the following general conclusions were formulated:

- It is possible to evaluate the failure analysis especially with regard to the delamination and crack propagation phenomena of thin-walled composite profiles, using experimental study (universal testing machine as well as digital microscope) and numerical simulations using FEM (using CZM and XFEM),
- Simultaneous use of several independent numerical damage models, allows for representation of the actual damage phenomenon,
- The use of a mobile (portable) digital microscope head allows registering of the complex failure mechanism, which in turn allows comparison of failure forms with FEA.

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Literature

[1] Gliszczynski, A., Kubiak, T. Load-carrying capacity of thin-walled composite beams subjected to pure bending. Thin-Walled Struct, 2017, 115, 76-85.

[2] Rozylo P. Stability and failure of compressed thin-walled composite columns using experimental tests and advanced numerical damage models. Int J Numer Methods Eng. 2021, 122, 5076-5099.

[3] Camanho, P.P.; Matthews, F.L. A progressive damage model for mechanically fastened joints in composite laminates. J. Comp. Mater. 1999, 33, 2248-2280.

[4] Borg R., Nilsson L., Simonsson K., Simulating DCB, ENF and MMB experiments using shell elements and a cohesive zone model, Composites Science and Technology 2004, 64, 269-278.

[5] Dolbow J, Moës N, Belytschko T. An extended finite element method for modeling crack growth with frictional contact. Comput Methods Appl Mech Eng 2001,190(51-52), 6825-46.

[6] Debski, H. Experimental investigation of post-buckling behavior of composite column with top-hat cross-section. Eksploat. Niezawodn. 2013, 15, 106-110.