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EVALUATION OF THE EFFECT OF OPERATIONAL FACTORS ON THE DURABILITY OF POLYMER COMPOSITE MATERIALS

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Abstract: This paper presents the verification of a constitutive behavior model for polymer matrix composites by comparing calculated and experimental loading diagrams; a good correlation between numerical and experimental data was obtained.

Keywords: Polymer matrix composites, modeling, deformation, strength, finite element method, three-point bending test.

Аннотация: В работе проведена верификация модели поведения полимерных композиционных материалов с путем сравнения расчетных и экспериментальных диаграмм нагружения, и получено хорошее соответствие расчетных и экспериментальных данных.

Ключевые слова: Полимерные композиционные материалы, моделирование, деформирование, прочность, метод конечных элементов испытания на трехточечный изгиб.

Introduction. Currently, key research areas include fracture mechanisms, durability prediction, damage accumulation modeling, and evaluating the impact of operational factors on the service life and static strength of composite structures [1–5]. Significant progress has been made in investigating failure processes in polymer composites, particularly carbon-fiber-reinforced (CFRP) and glass-fiber-reinforced polymers (GFRP), as reported by both domestic and international researchers. Various models have been proposed to describe the strength characteristics of polymer matrix composites; however, most remain limited to specific loading conditions and distinct material classes [6–10].

Research Methods. Simulation of the tests was carried out using the developed composite constitutive model and failure criterion. Monolayer parameters were derived from tensile and compressive experimental results of unidirectional specimens. The specimens were discretized using shell elements with a cross-section consisting of a 16-ply laminate, each ply being0.125 mm thick with different layup orientations. The total thickness of the specimen was 2.0 mm.

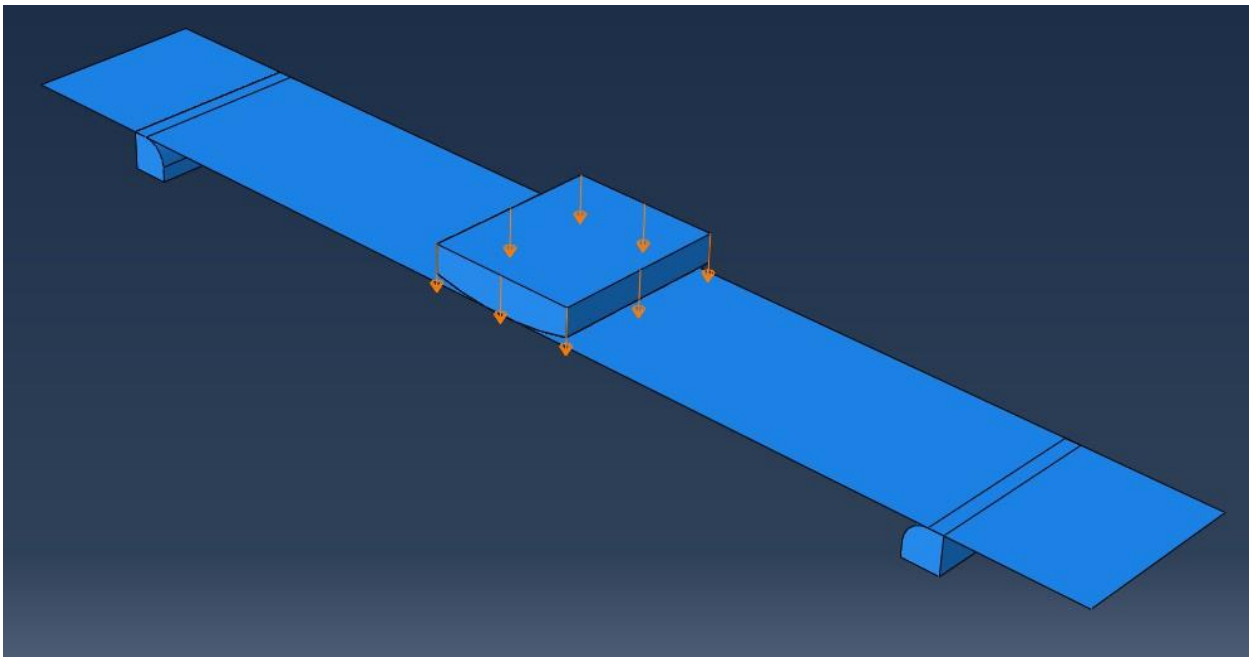
For the bending test simulation, the finite element model reproduced the boundary and loading conditions identical to the physical experiment. The supports and punch were modeled as 3D rigid bodies. Surface contact interactions between the specimen, supports, and punch were defined. The loading of the specimen was applied via prescribed displacement of the punch. The three-point bending test setup is shown in Fig. 1.

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Fig. 1. Computational model of loading a PCM specimen under bending

Figure 2 shows the distribution of axial stresses on the surface of a specimen made of



unidirectional PCM when simulating the test in the direction of reinforcement at the moment corresponding to failure.

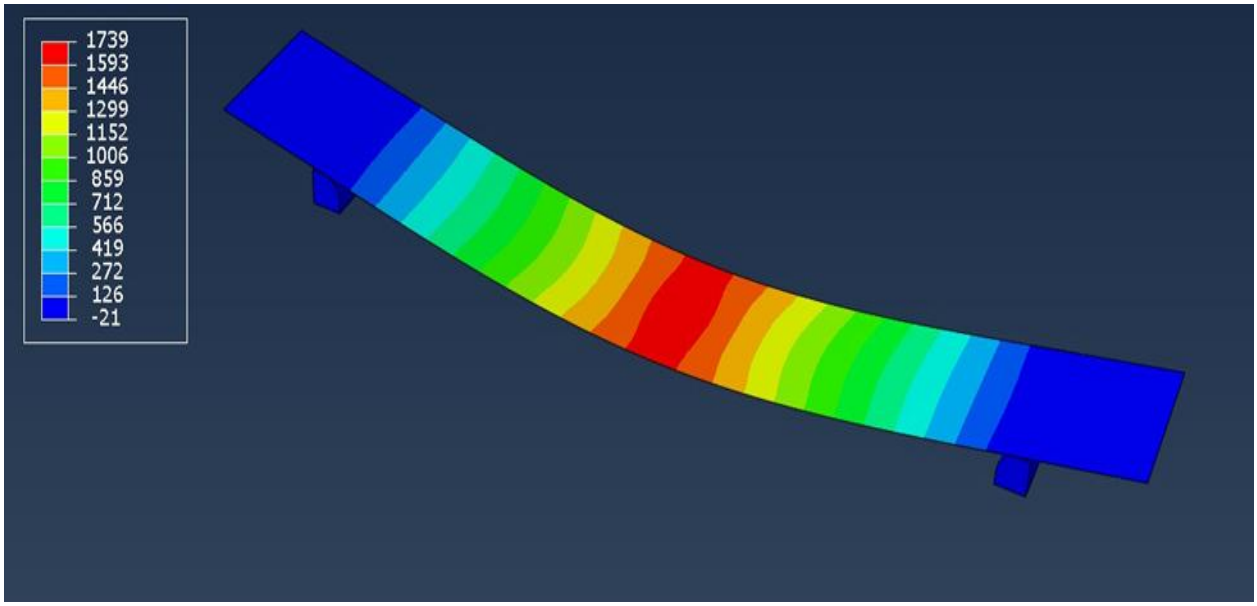


Fig. 2. Axial stress map stresses in a unidirectional PCM under bending at the moment of failure

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Based on the calculation results, the dependencies of the sample's deflection on the load applied to the the punch. A comparison of these relationships with the experimental ones is shown in Figs. 3 – 6.

Fig. 3. "Load-deflection" diagrams under bending of a unidirectional PCM reinforced in the axial direction

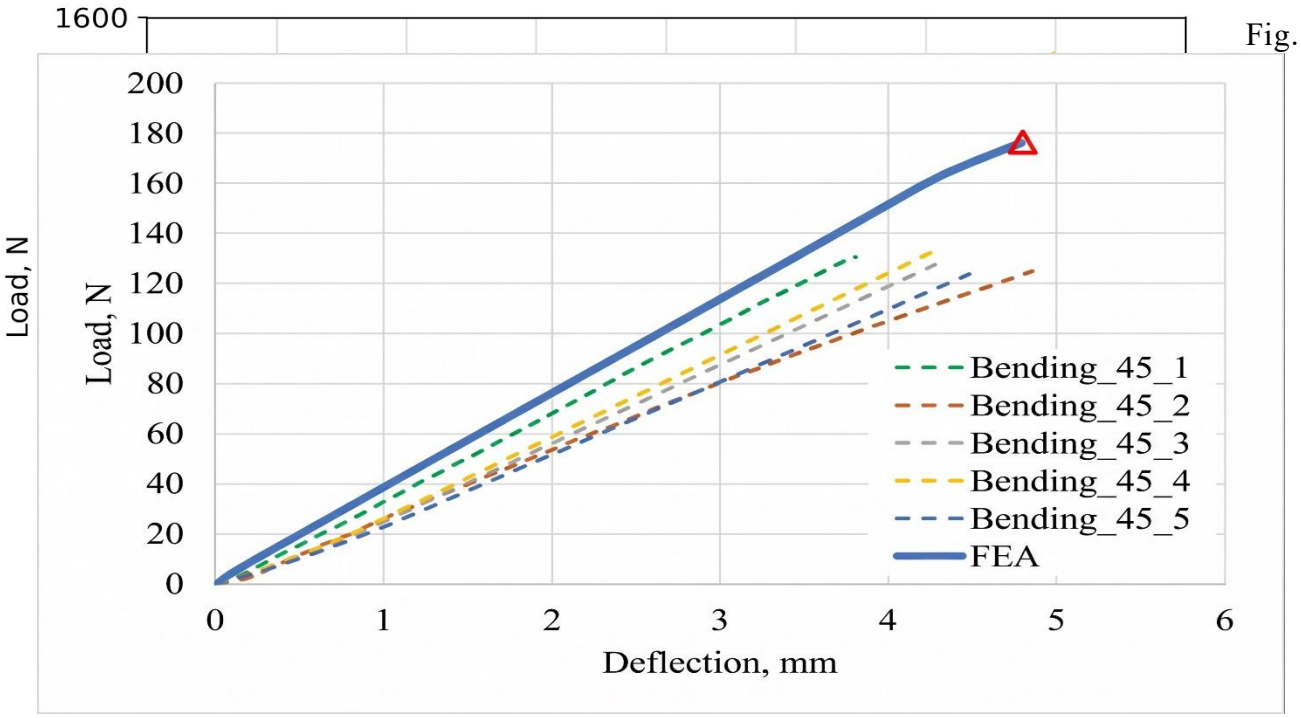
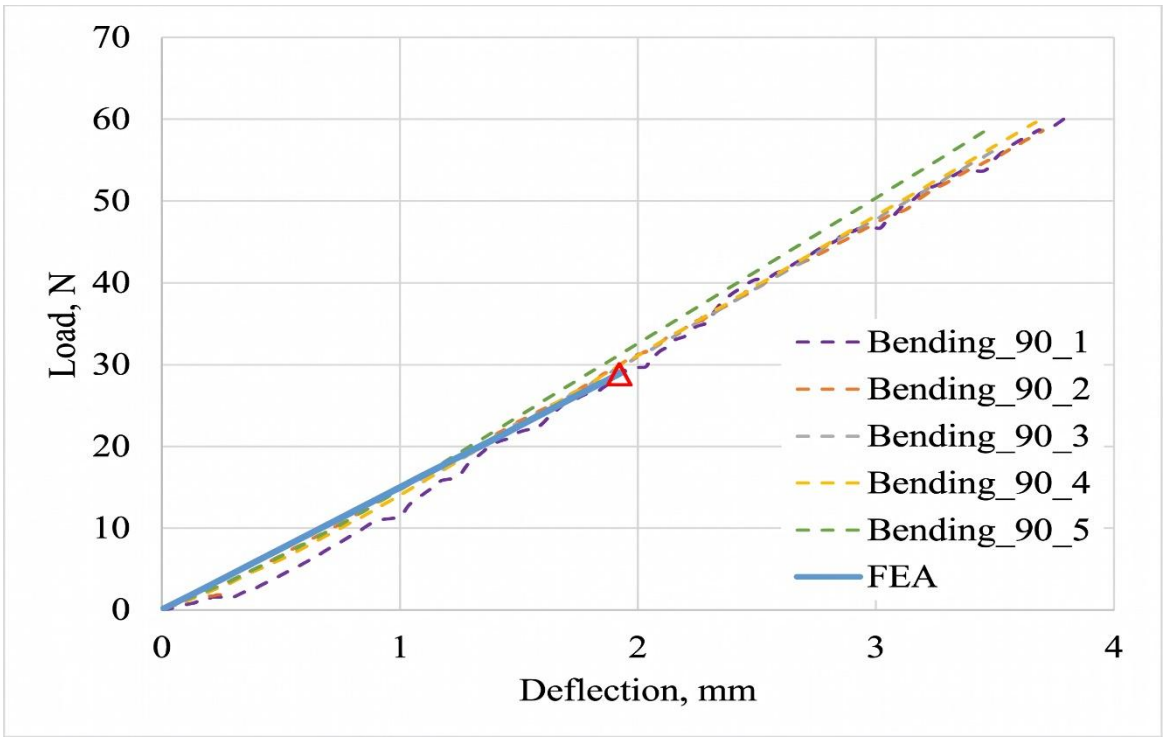


Fig.

4. "Load-deflection" diagrams during bending of unidirectional PCM reinforced at an angle of 45° to the axis of the specimen



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Fig. 5. Diagrams of the "load-deflection" relationship during bending of a unidirectional PCM reinforced in the transverse direction

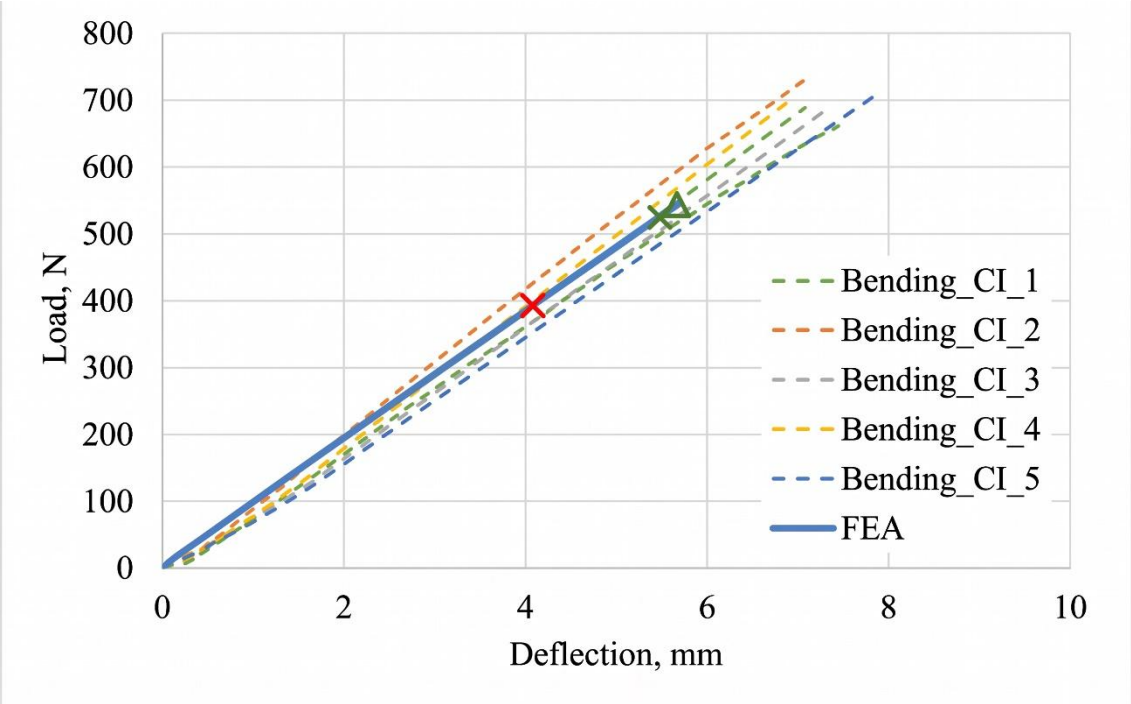


Fig. 6. "Load-deflection" diagrams under bending PCM with quasi-isotropic layup

The calculation diagrams shown indicate the point at which the strength indicators reach a value of 1. The red cross indicates the fibre tensile strength indicator tensile strength Ft; red triangle – indicator of of the matrix in tension Ft; a green cross indicates the strength indicator fibre compressive strength Fc; a green triangle indicates the matrix compressive strength indicator Fc.

Conclusion. Based on the analysis and discussion of the experimental findings, a comprehensive evaluation method for the stress-strain state of polymer matrix composite (PMC) structures was developed. The minimum required volume of experimental data ensuring reliable identification and calibration of the constitutive deformation model and failure criteria was established.

A methodology for identifying the PMC monolayer properties was developed and substantiated using mechanical test data from tensile, compressive, and interlaminar shear experiments on unidirectional specimens oriented at 0°, 45°, and 90° to the reinforcement direction.

A thorough verification of the proposed PMC constitutive model, failure criteria, and monolayer parameter identification algorithm was performed by correlating numerical (finite element) and experimental load–deflection curves in bending for both unidirectional laminates and specimens with a quasi-isotropic stacking sequence. A high degree of qualitative and quantitative agreement between the calculated and experimental results was achieved across the entire loading range up to the onset of failure.

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