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SHAPE OPTIMIZATION OF A SANDWICH PLATE WITH A NOVEL CORE DESIGN

Coskun Yalkilic, Fazil O. Sonmez, Fatih E. Oz and Nuri Ersoy
Department of Mechanical Engineering, Bogazici University, Email: sonmezfa@boun.edu.tr

1. INTRODUCTION

The objective of this study is to optimize the shape of a sandwich composite plate with a novel core design under three-point bending. The core has an egg-crate shape. The initially chosen geometric design is shown in Fig. 1. The material is epoxy reinforced with non-crimp E-glass fabric and the layup configuration is quasi isotropic for both the core and the face sheets.

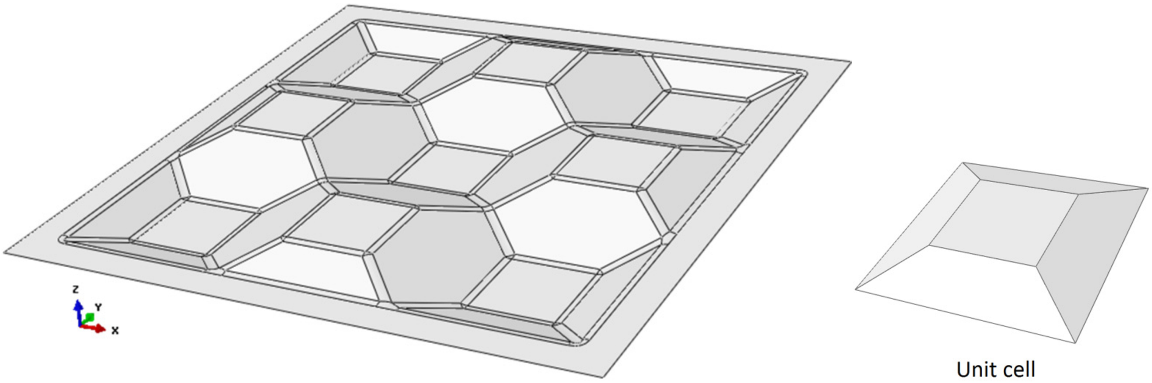

Fig. 1: The schematic representation of the initial core geometry and its unit cell [1].

2. TENSION TESTS

In the first stage of the study, the mechanical properties of the composite material are determined. A procedure is proposed to determine these properties using tension test and acoustic emission (AE) results for specimens with $[0/45/-45/90]_s$ and $[0/90]_{2s}$ layup sequences and a progressive failure model. Using this procedure, longitudinal and transverse tensile strengths, X_t and Y_t, shear strength, S, together with the stiffness properties can be obtained. Tension tests are conducted according to ASTM D3039 standard testing procedure. The strain of the specimen is measured by a video extensometer. Fig. 2 shows the peak frequency distribution as well as the energy levels of AE hits for a quasi-isotropic specimen, $[0/45/-45/90]_s$, together with the load-strain curve. Ply-failure load levels, which are indicated on the graph, are determined considering the changes in the load-displacement diagram as well as the AE signals. Fig. 3 shows a comparison between the experimental load-strain curves of cross-ply and quasi-isotropic tension test specimens and the curves predicted by the progressive model.

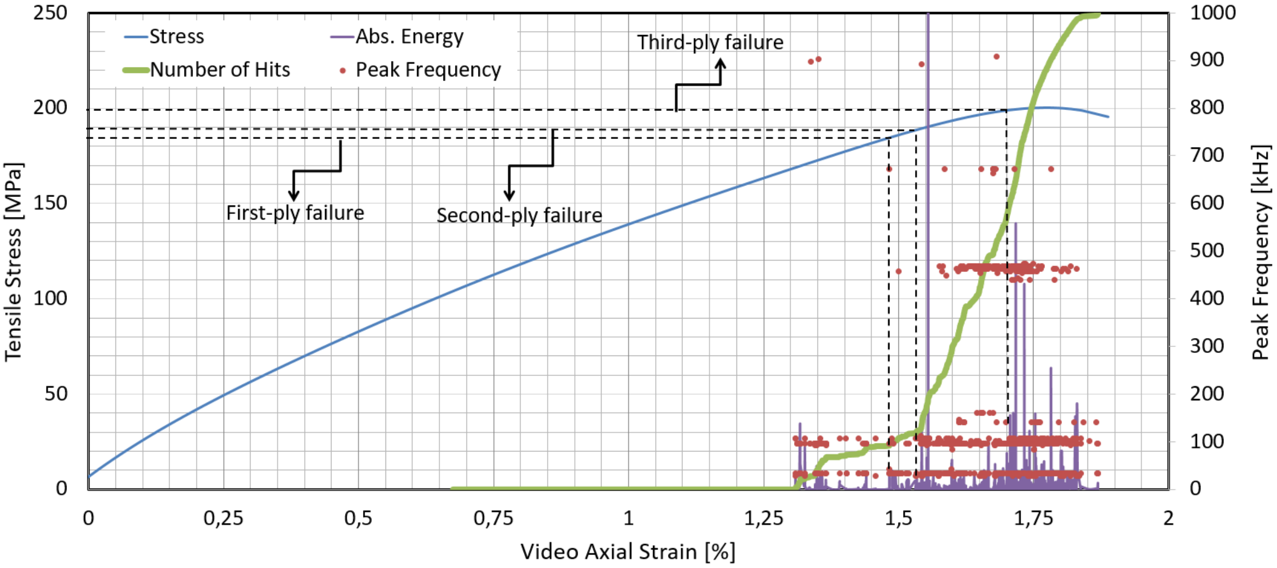

Fig. 2: The peak frequency distribution, the energy levels, and the cumulative counts of the AE hits and the stress vs. strain curve for quasi-isotropic tension test specimens with layup configuration $[0/45/-45/90]_s$.

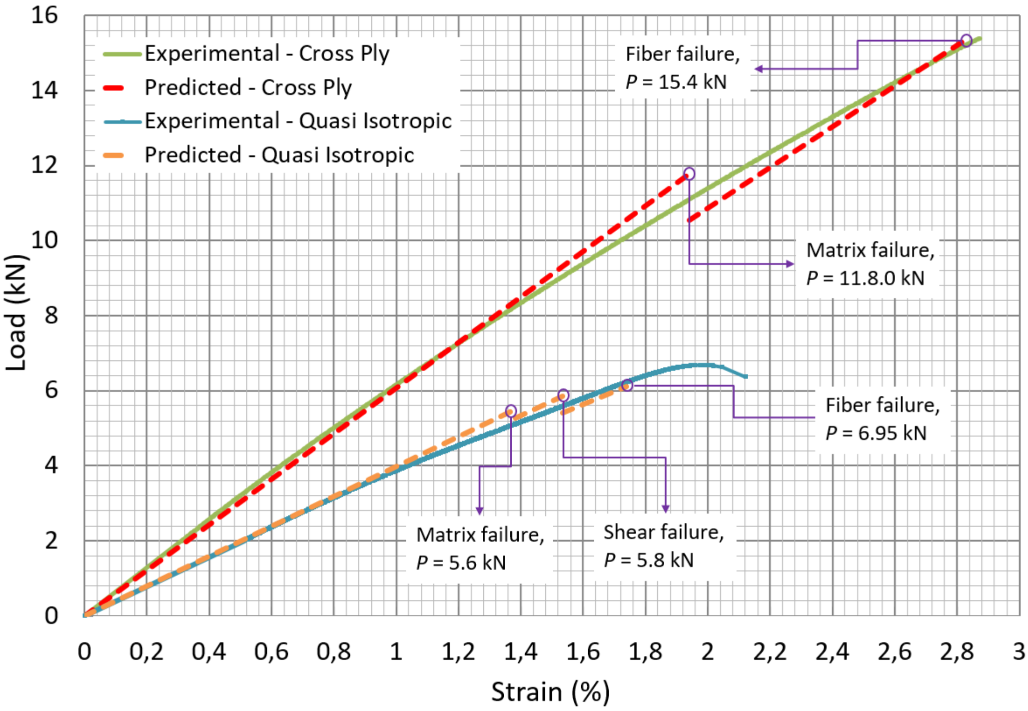

Fig. 3: Experimental load-strain curves of a tension test specimen with cross-ply, $[0/90]_{2s}$, and quasi-isotropic, $[0/45/-45/90]_s$, layup configurations and the curves predicted by the progressive damage model.

3. THREE-POINT BENDING OF SANDWICH SPECIMENS

In the second stage of the study, the failure behavior of the sandwich specimens is investigated via three-point bending tests. Acoustic emission (AE) monitoring is used to detect the progression of damage and identify the failure modes and failure load levels. A finite element model of the sandwich structure is also developed to predict the structural response and the failure behavior of the specimens under the loading conditions in the tests. A promising agreement between the results of the FE model and the experiments is observed. The force-deflection relation as well as the failure load level are accurately predicted.

4. DESIGN OPTIMIZATION

In the third stage of the study, the shape of the core is optimized using the experimentally validated FE model. Fig. 4 shows the geometry of a unit cell. There are basically three geometric parameters for the trapezoidal prism; the height of the prism, h, the angle between the base and side faces, θ, and the length of the top face, L_c, which is in contact with the face plates. The base length of the prism, L_b, is a dependent variable, which is a function of the other three independent parameters.

$$L_b = L_c + 2h/tan\theta \tag{1}$$

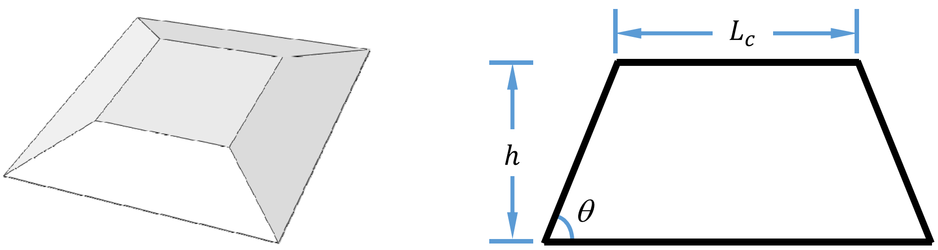

Fig. 4: The geometry of a unit cell.

Although fiber orientations are considered to be important design variables in composite optimization studies, for the structure considered in this study quasi isotropic layup configuration, $[(0/45/-45/90)_n]_s$, is considered to be preferable, because this structure is designed for applications in which high stiffness and high strength are desired in all directions. For this reason, only layer thickness or the number of plies in the layers, n, can be considered as design variable besides geometric parameters. The specimen tested previously is used as a benchmark in order to see the improvements in the performance of the optimized plate. For this reason, the thickness of the sandwich plate is taken to be constant and equal to the thickness of the benchmark specimen. For comparison purposes, the layer thicknesses are also taken to be the same. Accordingly, two of the design variables, contact length, L_c, and the inclination angle, θ, are used as optimization variables.

Because the dimensions of the unit cells are changed during optimization, strength of the plate is normalized to compare different designs. Besides, it should also be normalized for the amount of composite material used as the following:

$$F_n = F_{all}\left(\frac{t_0}{t}\right)\left(\frac{L}{L_0}\right)^2\left(\frac{m_0}{m}\right) \tag{2}$$

where t_0, L_0, and m_0 are thickness of the core, length of the plate between the supports, and mass of the composite material for the reference configuration. t, L, and m are the respective parameters for the configurations generated during design optimization. F_{all} is the first-ply failure load level calculated for the generated configuration. F_n is the normalized value for the first-ply failure load. The thickness is taken as constant and the same as that of the initial geometry, which is 2.0 cm. Then, a parametric study is conducted to investigate the effects of the design parameters on the strength and the stiffness of the sandwich plate. After that, optimum values of the parameters are found using Nelder-Mead search algorithm. The objective function is chosen as the normalized failure load, F_n, given by Eq. 2. Table 1 presents optimum values of the design variables and the normalized failure load level and the respective values for the reference configuration shown in Fig. 1. As seen in the table, significant improvement is obtained in strength by optimization compared to the reference configuration.

Table 1: Comparison of the optimum configuration and the reference configuration.

	Angle, θ	Contact Length, L_c	Failure Load
Reference Design	21.8°	6.20	4.2 kN
Optimum design	47.7°	15 mm	9.7 kN

In order to manufacture and test the optimized core geometry, a mold is produced by 3D printing. The mold and the fiber forms on the mold are shown in Fig. 5. Soon experiments will be conducted on composite specimens with the optimum core shape and the strengths of the plates with the optimum core structure and the foam-core sandwich plates will be compared.

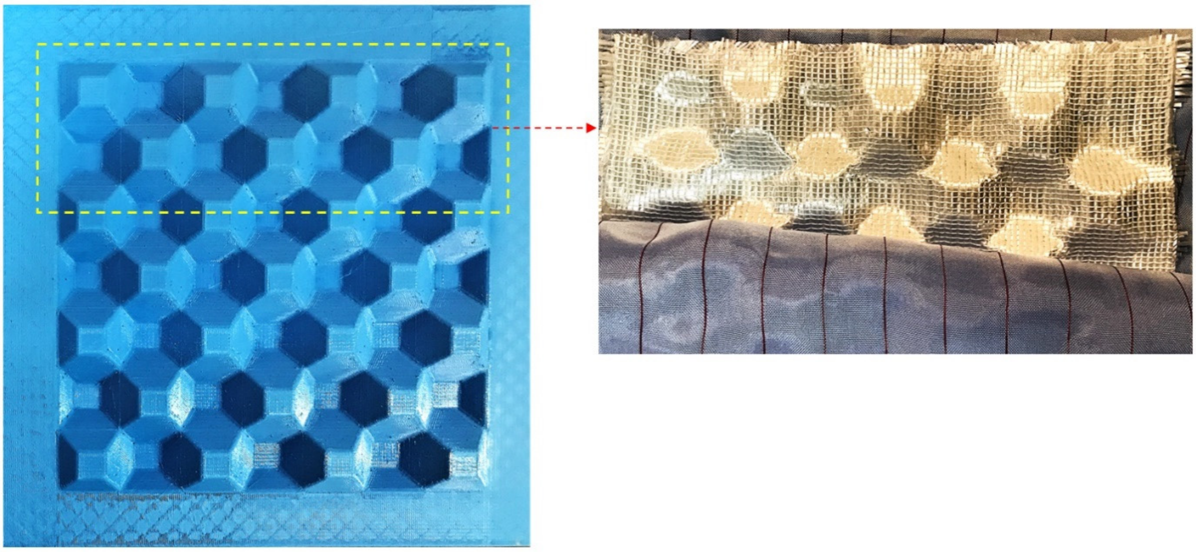

Fig. 5: 3D printed mold and the form of the fibers on it.

ACKNOWLEDGMENT

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[1] A. Uzal, F.O. Sönmez, F.E. Oz, N. Ersoy, K. Cinar, "A composite sandwich plate with a novel core design," *Composite Structures*, 2018; 193: 198-211.