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Modeling and design of corrugated laminates

Claudia Thurnherr[1], Gerald Kress[1], Paolo Ermanni[1]
[1]Laboratory of Composite Materials and Adaptive Structures, Department of Mechanical and Process Engineering, ETH Zurich

CMASLab

1 Introduction

Corrugated structures have been used in morphing wing design, since they provide deformation of the wing skin in chord direction while they behave very stiff in the span direction at low weight. Modeling of corrugated structures by use of commercial FEM software leads to enormous computational costs. Hence the development of new modeling techniques is needed. Further, we ask the question how corrugated structures can be designed to prevent delamination failure.

2 Numerical model

Our numerical model uses a unit-cell approach and a generalized plane strain state to reduce the computational costs (figure 1). By using a unit-cell, we assume that the corrugation pattern is periodic and we apply periodic boundary conditions on both ends. The generalized plane strain state assumes that the stresses and strains do not change in transverse direction to the corrugation. The model is derived from a simplified mechanical equilibrium leading to a 3D displacement solution consisting of an inner 2D FE solution and prescribed macro-strains. A special planar finite element is used that fulfills the generalized plane strain assumption. From the displacement solution the strain and stress fields are calculated. Thanks to the efficiency of the model it is very well suitable for large parameter studies.

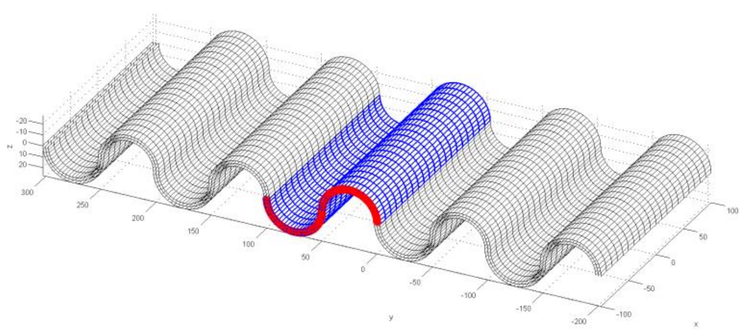

Fig. 1. Unit-cell (blue) and generalized-plane strain (red) approach for efficient modeling of corrugated laminates

3 Experimental validation

The numerical model was experimentally validated. Samples made from carbon fiber reinforced plastics were manufactured. The samples were tested in a tensile machine (see figure 2). With a Digital Image Correlation system (DIC) we measured both the 3D displacement field and the strain field on the surface of the samples. Different lay-ups were tested consisting of twill – and / or UD layers.

Fig. 2. Experimental testing

4 Results and discussion

Figure 3 shows a comparison between a) the experimentally measured and b) the numerically calculated strain field. The results show a very good agreement between experiments and simulation. Further the results show that both the unit-cell approach as well as the generalized-plane strain assumption are correct.

Further, a parameter study was performed investigating interlaminar stresses in corrugated laminates. We investigated both through-thickness and shear stresses and normalized the stresses with intralaminar bending stresses. We identified geometries consisting of circular sections with large amplitudes as favorable in order to minimize both the normalized trough-thickness and shear stresses (see figure 4).

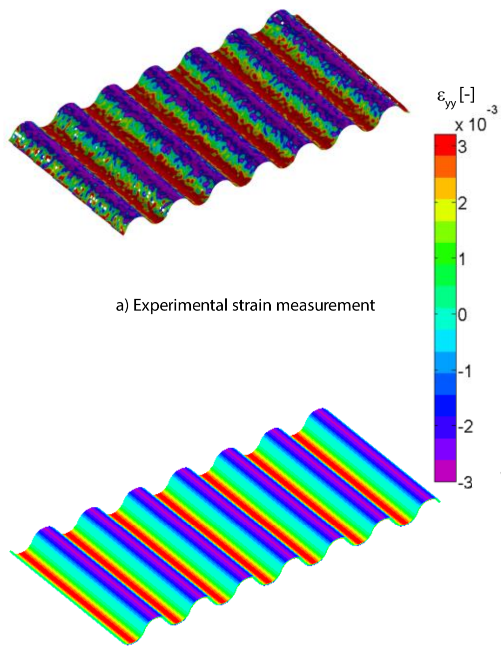

Fig. 3. Comparison between a) measured strain and b) calculated strain

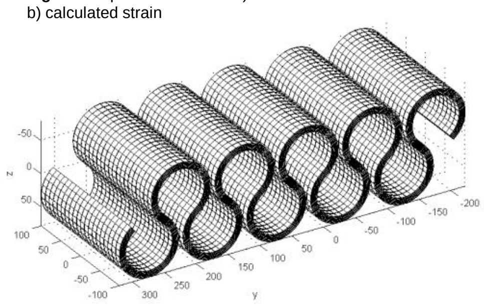

Fig. 4. Favorable configuration to minimize interlaminar stresses

5 Conclusion and outlook

Conclusions:

- A model to analyze stresses in corrugated structures was developed and experimentally validated
- Performing a parameter study we could identify favorable geometries in order to reduce interlaminar stresses and hence the risk of delamination

Outlook:

- Modeling of geometrical nonlinearities in corrugated laminates
- Failure analysis of corrugated laminates

6 References

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Fonds National Suisse
Schweizerischer Nationalfonds
Fondo Nazionale Svizzero
Swiss National Science Foundation