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CREEP RESISTANCE OF LOAD APPLICATION INSERTS FOR HYBRID THERMOPLASTIC SANDWICH STRUCTURES

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1. INTRODUCTION

Structural sandwich panels are nowadays employed in a wide range of technological fields where extreme lightweight solutions are required. In addition to the classical fields of the aerospace industry or the wind energy sector, sandwich structures become increasingly popular in transport applications of both the rail and road sector (Kim et al. [1], Ning et al. [2]. In contrast to aerospace components or wind turbine blades with limited numbers of components to be manufactured, especially the automotive sector is characterized by industrial scale mass production with large numbers of components to be manufactured with an extreme demand for short cycle times. Furthermore, automotive applications usually involve a large number of fixtures for secondary parts, seats, safety belts, etc. For this purpose, polymeric composite and sandwich components consisting of thermoplastic base materials are promising candidates for future composite automotive designs. One of the major shortcomings of thermoplastic composites is the distinct tendency of thermoplastic polymers towards creep due to the limited crosslinking of their macromolecules. Due to local stress concentrations, creep deformation is an issue especially at loading spots. Aim of the present contribution is the design and evaluation of load application inserts for thermoplastic sandwich structures for an enhanced creep resistance.

2. DESIGN

Regarding general design options, a wide range survey has been provided in a previous contribution (Fliegener et al. [3]). In the multiple-step optimization procedure employed in this study, the design options “C” and “E” according to Fig. 1 had been identified as the most promising options under static loading conditions. In addition, option “A” has been considered further due to its more economic manufacturing properties. Fig. 1 shows the sketches of the initial design identified in a preliminary design study on the left hand side as well as the optimized versions on the right hand side.

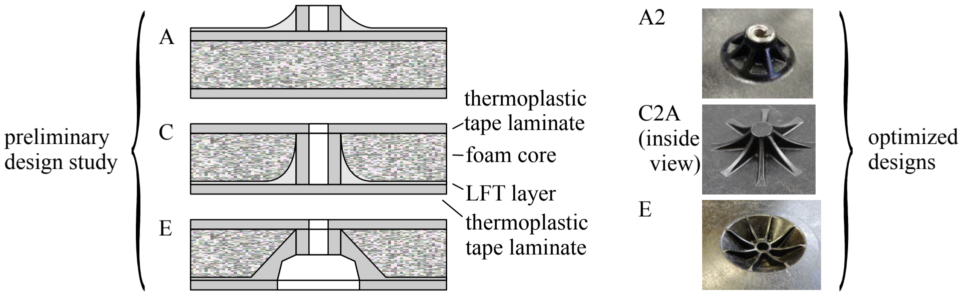

Fig. 1: Load application inserts considered in the present study.

In all three cases, the sandwich structures consist of laminated face sheets made from thermoplastic PA6 based tape with unidirectional carbon fiber reinforcement. The plies are arranged in a quasi-isotropic stacking sequence. The sandwich core consists of a polyurethane foam. For integration of the loading inserts (as well as for further functionalizations such as local stiffening ribs etc.), the face sheets were supplied with a thin layer of PA6-GF40 discontinuous long glass fiber reinforced thermoplastic (LFT), applied in a press molding process (Henning et al. [4]). By this means, a hybrid face sheet design consisting of plies with continuous fiber reinforcement (tape laminates) as well as plies with discontinuous fiber reinforcement (LFT) with integrated loading inserts are obtained.

3. MATERIAL MODEL

In a preliminary experimental investigation, the creep response of the individual tape plies as well as the LFT plies has been characterized. For this purpose, creep experiments under constant uniaxial loading conditions were performed, using standard plane ISO 3167 specimens. The creep load was applied at different load levels considering two different temperatures (23°C and 80°C). The overall creep time was 166.7 h (approximately one week). During the creep experiments, the axial strain in the gauge section of the specimens was recorded continuously using clip gauges. For the numerical simulation, an anisotropic creep model is defined. The model assumes linear elasticity in the fiber direction which is superimposed by an isotropic generalized 3-element Kelvin-Voigt approach representing the thermoplastic matrix response. The material model is implemented as a user-defined material model into the commercial finite element program ABAQUS. For the LFT material ranges, a similar approach is used. The material parameters are determined by simulation of the creep experiments in conjunction with a reverse engineering approach. In Fig. 2, selected results are presented. In all cases, the experimental observation and the numerical prediction for the creep curves are found in a good agreement. Both, the spatial anisotropy of the material as well as the stress dependence of the creep curves are properly reproduced by the proposed material model. Full details on the model can be found in an oncoming contribution.

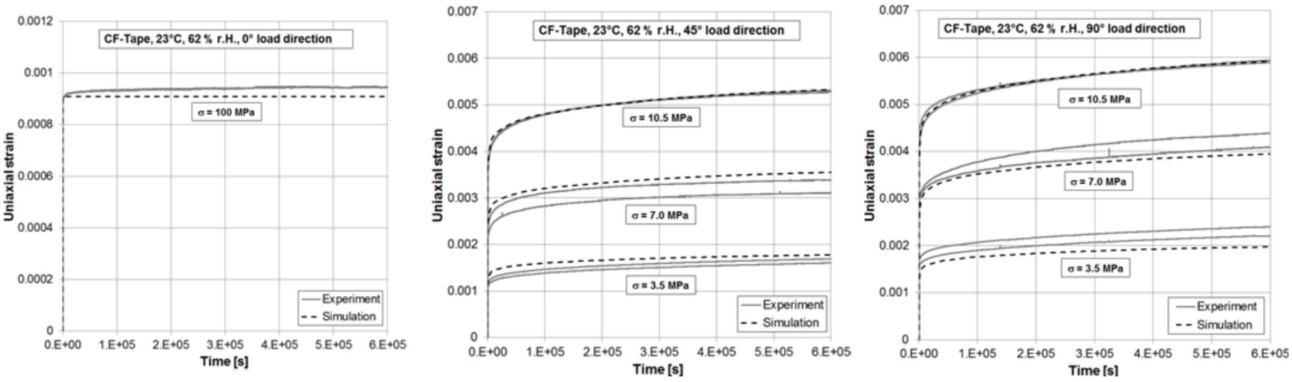

Fig. 2: Anisotropic creep material model.

4. FINITE ELEMENT PREDICTION

The material models defined and implemented in Sec. 3 are employed for a numerical simulation of the creep response of the loading inserts proposed in Fig. 1. For this purpose, circular three-dimensional finite element models with the respective loading insert located in the center according to Fig. 3 are employed. The finite element model is clamped around the external boundary and loaded by a constant force applied to the metal insert in the center. Using these models, the creep response for a creep time of approximately one week is computed.

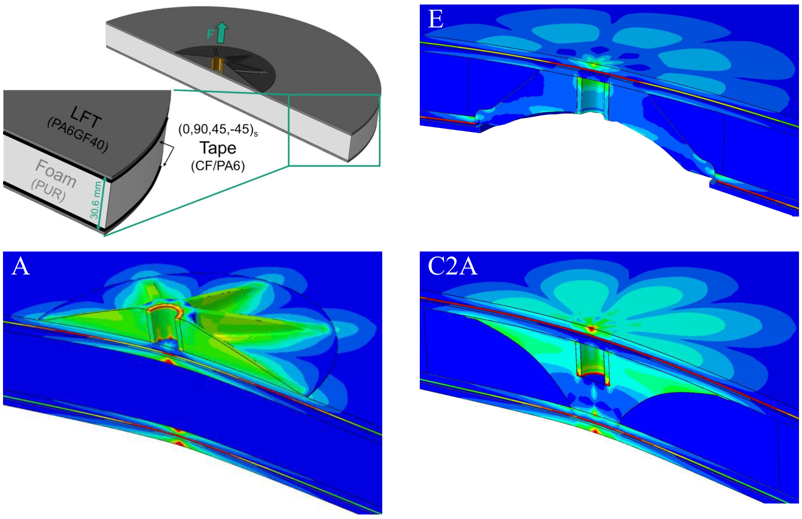

Fig. 3: Finite element model, schematic principle and details of loading inserts.

5. EXPERIMENTAL INVESTIGATION

In an experimental investigation, the three most promising design options have been examined experimentally. Using a fixture with a circular cutout, corresponding to the outer edge modelled in the finite element study, rectangular samples were loaded by a constant vertical force over a prescribed time. The samples for each design option were tested at three different load levels. Each of the three design options was tested at load levels of 2.5 kN and 5 kN applied over creep time intervals of 160 h and 80 h, respectively. In addition, a constant load close to the static strength was applied over an interval of 80 h. For options “A” and “C2A”, the corresponding load level was fixed at 6 kN whereas the statically much stronger design option E was loaded at 14 kN.

6. RESULTS

The numerical predictions for the creep curves are presented in Fig. 4 where the total displacement (i.e. elastic and creep displacement is plotted versus the loading time. As in the previous static investigations (Fliegener et al. [3]), design option “E” proves to be the design option with the highest stiffness and strength due to the contemporary distributed load transmission to both face sheets. Compared to the two other design options, option “E” also features the highest creep resistance with the lowest creep deformation developing during the one week creep interval. Qualitatively similar results are obtained at 23°C and 80°C with higher creep rates and creep deformations developing at 80°C.

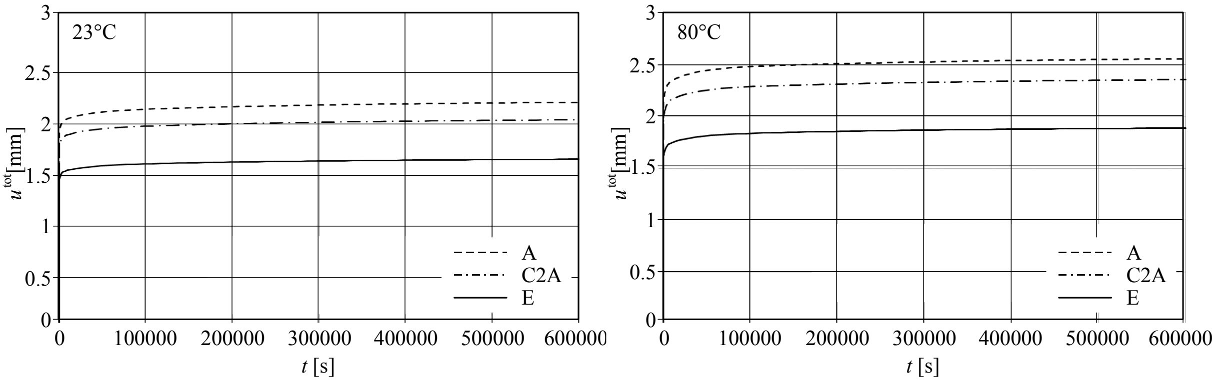

Fig. 4: Numerical prediction of the creep curves.

In Fig. 5, the creep curves for design options "C2A" and "E" at different applied load levels are presented in terms of the creep deformation (without initial elastic parts) plotted versus the creep time. Again, option "E" provides the highest creep resistance. The fact that at its highest load level of 14 kN, the specimen for design option "E" experienced larger amounts of creep deformation than option "C2A" derives from the higher applied load. The experimental findings are found in good agreement with the numerical predictions.

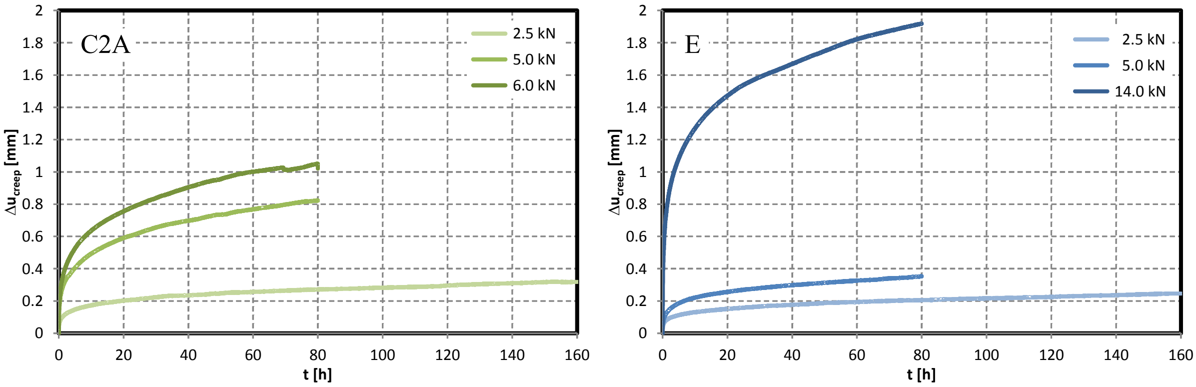

Fig. 5: Experimental results.

7. CONCLUSION

Different design options for loading inserts for thermoplastic sandwich structures have been examined with respect to their creep response, using a combined experimental and numerical approach. It is observed that substantial creep deformation might develop in the vicinity of the loading insert due to local stress concentrations. This creep deformation can be minimized by an appropriate design of the local geometry of the insert. Hence, in thermoplastic sandwich structures creep deformation forms an important design driver for such loading inserts.

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