INVESTIGATING STATIC COMPRESSION PRELOADS ON THE IMPACT BEHAVIOUR OF HONEYCOMB SANDWICH STRUCTURES

Chris Fischer[1], Falk Hähnel[2], Klaus Wolf[3] and Johannes Markmiller[4]

[1]Institute of Aerospace Engineering, Technische Universität Dresden,
Helmholtzstraße 10, 01062 Dresden, Germany
Email: [1]chris.fischer@tu-dresden.de, [2]falk.haehnel@tu-dresden.de, [3]klaus.wolf@tu-dresden.de, [4]johannes.markmiller@tu-dresden.de
Web Page: https://www.tu-dresden.de/ing/mw/ilr/lft

1. INTRODUCTION

Sandwich is often used as a lightweight design solution for load-carrying components of airplanes and helicopters due to their excellent mechanical properties such as high strength-to-weight and stiffness-to-weight ratios. This is particularly true for sandwich with face sheets made of carbon fibre reinforced plastics (CFRP) and non-metallic honeycomb cores [1]. Owing to the rather weak core material, this kind of structure is prone to a range of damages resulting from impact loading that may accidentally occur during aircraft assembly or operation. These damages and their effect on the load carrying capability of the structure have to be considered in the damage tolerant design of airframes. Currently, the standard design procedure is based on experiments carried out on unloaded structures. However, in reality even on the ground aircraft structures are not completely stress free because at least the structural weight will cause a permanent static preload. Structural preloads will be even higher during take-off and landing, where the probability of foreign object impacts is rather high.

Whereas the impact behaviour of unloaded sandwich has been investigated extensively [e.g. 2-5], up to now only few research papers have been published on the effect of impact events on loaded components. Most of these deal with experiments at higher impact velocities [e.g. 6-8]. In [9] an analytical dynamic model was presented, which provides the time dependent stress state in a preloaded composite sandwich resulting from low-velocity impacts. However, in this approach the core is assumed to be homogenous, which prevents the application to discrete cores such as honeycombs. Since no failure criteria are included in the model, also no information on the damage initiation and growth is gained. Therefore, the application on real honeycomb sandwich structures is rather limited.

The aim of the research presented in the current paper has been to reduce the knowledge gap regarding the influence of prestresses on the impact behaviour of honeycomb sandwich structures under low velocity impact conditions. For this purpose an experimental study was carried out, which was published in [10]. In this phase, uniaxial compressive preloads were applied to samples with different sandwich configurations, which were subsequently impacted in the stressed state at low velocities. After impact the damage size and intensity was determined using NDT methods. Based on this, the effect of various compressive preloads on the structural performance of different sandwich configruations was systematically investigated. Based on the experimental results, suitable simulation methods with highly detailed honeycomb sandwich models were developed. A sandwich modeling approach with detailed shell elements enables a realistic simulation of the impact damage behavior. Using a selected sandwich configuration, the results of the tests are compared with the simulation and the applicability of the simulation approach is demonstrated.

2. EXPERIMENTAL PROCEDURE FOR IMPACT TESTS ON PRELOADED SANDWICH STRUCTURES

Figure 1 shows the procedure steps for specimen preparation. In accordance with standard CAI test procedures, the square sandwich plates (1) were cutted to sandwich samples (2) with sizes of 100 mm in width and 150 mm in length, according to the ASTM specifications ASTM D7766/D7766M and ASTM D8287/D8287M. Additionally, the core of the specimens was partially removed in the area of the load introduction (3) and filled with epoxy resin (4). Afterwards, the edges were machined to achieve accurately parallel load introduction areas. Before testing, the sandwich specimens (5) were prepared for the use of the optical deformation measuring systems ARAMIS.

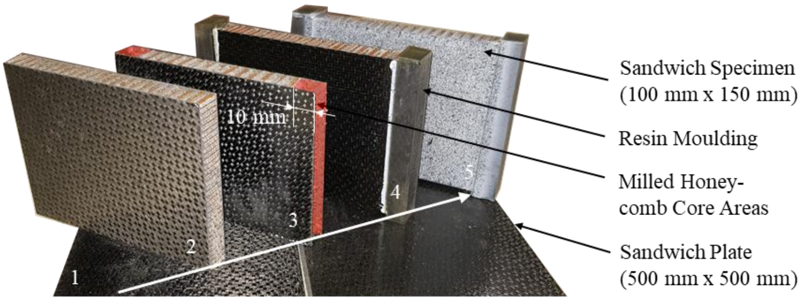

Figure 1. Procedure for specimen preparation

The test program included several sandwich configurations. In order to enable a comparison of the test data with the simulation results in this study, a sandwich configuration with a Nomex® honeycomb with 4.8 mm cell width and a density of 32 kg/m³ is selected. For the sandwich skin material a woven CFRP fabric plies Hexcel M18/1-G939 were considered. For the investigation, the skin shows a layered structure of [$\pm 45_F$ / 0_F / $\pm 45_F$] with a thickness of 0.795 mm. Skins in this thickness range are typical for sandwich applications in aircraft.

3. PRELOADED IMPACT TEST SETUP AND TEST PROCEDURE

The impact tests on the preloaded honeycomb sandwich specimens were performed using the test set-up shown in Figure 2. A drop tower was fitted on a steel framework in order to provide sufficient space below for the hydraulic loading rig. The used impactor had a semi-spherical head of 1-inch diameter and a weight of 1.25 kg.

The first step of the test sequence was to load the specimen up to the specified compressive strain level which was then kept constant. The sandwich samples were loaded up to the specified strain level and then impacted at several energy levels. Finally, the impact damage areas were analysed using an ultrasonic measuring method. Results gained were the contact-force-time histories depending on the prestrain level, the remaining impact dent depth and the in-plane and out-of-plane extent of the skin and core damage.

4. STEP-BY-STEP SIMULATION PROCESS

A multi-stage simulation process is developed to analyse the impact damage under compressive preloads (Figure 3). At the beginning, the sandwich structure is modelled with the load application areas in accordance with the test procedure. In a first simulation step, the compressive preload is applied along the longitudinal direction of the specimen using a nodal force. The compressive force corresponds to the compressive load selected in the test. In the third simulation step, the restart file is loaded into the simulation model to perform a full deck restart, where structural modifications can be carried out. In this case, the 1.25 kg impactor is inserted into the simulation model with a defined moving speed. The structural results can be used to carry out further simulation steps, for example in the form of compression-after-impact tests.

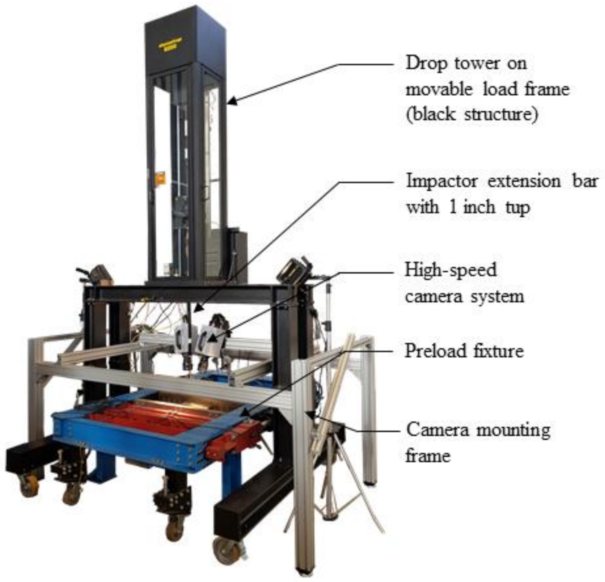

Figure 2. Preload and impact test set-up

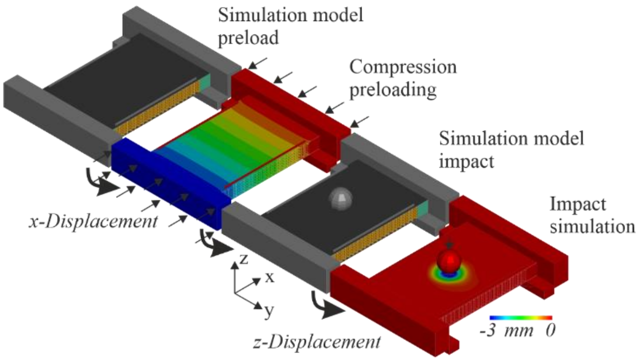

Figure 3. Step-by-step simulation process from compression preload to impact simulation

5. DAMAGE BEHAVIOUR AND COMPARISON TO TEST RESULTS

Figure 4 compares the real damage with the simulation results of the face sheet and the honeycomb core. Furthermore, the top view of the damage in Figure 4 allows a direct comparison of damage areas. In Figure 4 the damage areas were determined using ultrasonic scans. The legend shows the reduction of the ultrasonic signal from undisturbed (0 %) to completely absorbed (100 %) in grey scale. With increasing compressive preload, a continuous decrease in the face sheet layer damage can be seen up to a compressive preload of 1000 με. At an impact energy of 2 J, pressure pre-expansions of 1500 με and 2000 με result in a complete reduction of the damage area in the face sheet layers. In contrast, the core damage areas increase continuously with increasing compressive pre-strain.

At an impact energy of 3.5 J, the surface damage area also decreases with increasing compressive preload. At a compressive pre-strain of 1500 με, the face sheet damage area is reduced by 54 % compared to an unloaded sample. At compressive prestains of 1500 με and 2000 με, the specimens fail across the entire width, which significantly reduces the face sheet layer damage. It is very interesting that increasing compression preloads can lead to a reduction in the surface layer damage with a simultaneous increase in core damage. For the impact damage detection, this means that increasing pressure preloads can lead to damage that is more difficult to see from the outside.

In summary, with the selected configuration it can be shown that the developed simulation methodology is very well suited for modelling impact damage under static compression preloads. Both the face sheet layer and the core damage areas can be modelled realistically. It is obvious from Figure 4 that the core damage areas grow considerably with both the impact energy as well as the prestrain level. Nevertheless, the compressive prestrains are critical because an increasing core damage area affects the load carrying capability of sandwich structures significantly [3]. Also Figure 4 clearly shows that the results of the numerical analysis agree very well with the experimental data.

6. CONCLUSIONS

The experimental study performed in the presented research provided a comprehensive database on preload- and impact-force time relations for a range of impact energies and prestrain levels. The effect of static preloads on impact induced damages was evaluated for several compressive prestrain levels. The experiments revealed that even a low static preload has a considerable effect on the core damage of the investigated honeycomb sandwich configurations.

In this publication, a simulation methodology was developed and applied to the example of a sandwich configuration. The material properties were determined based on individual structural analyses of the sandwich components. A step-by-step simulation process was used to determine the impact damage of the sandwich structures under compression preloads. The results of the simulation steps are used as input parameters for the following simulation step by means of restart files.

Based on the simulations results, important findings can be made. Increasing pressure preloads increase the damage area of honeycomb core structures, whereby the influence on the surface layer damage can be different. With the test results, the simulations compare very well of both the face sheet layer and the core damage. The pressure load-dependent damage behaviour of all structural components is made possible with very good agreement.

ACKNOWLEDGMENTS

This research was part of the LuFo V-1 project SCHACH which was funded by the German Federal Ministry of Economic Affairs and Climate Action. The financial support provided is gratefully acknowledged.

The authors gratefully acknowledge the computing time made available to them on the high-performance computer at the NHR Center of TU Dresden. This center is jointly supported by the Federal Ministry of Education and Research and the state governments participating in the NHR (www.nhr-verein.de/unsere-partner).

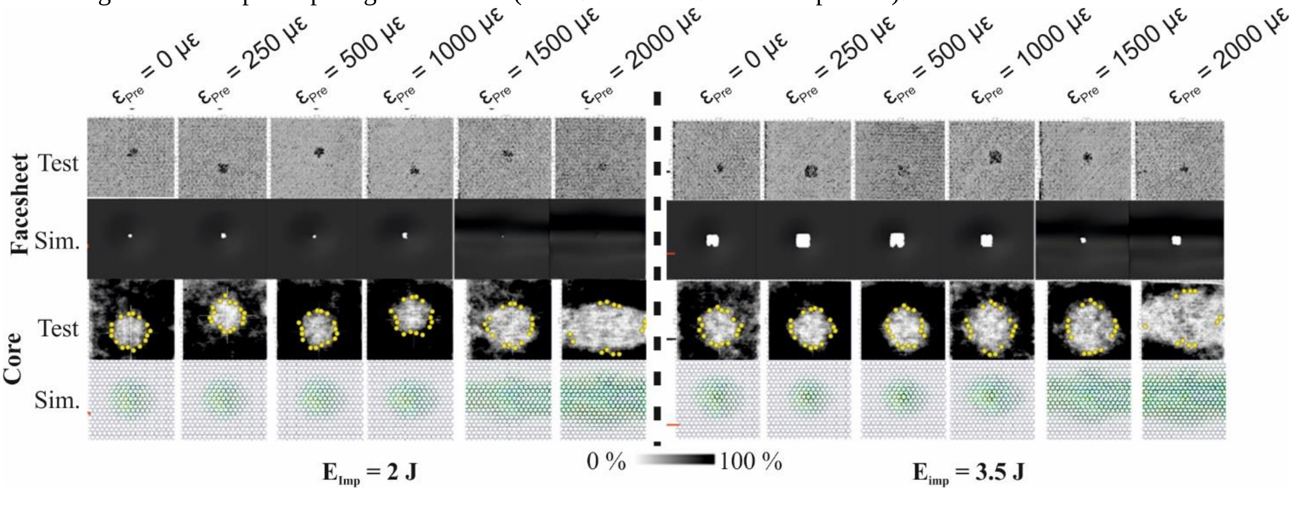

Figure 4. Comparison of the damage area of the surface layer and the honeycomb core measured in the tests with simulation results for different impact energies under different compression prestrain levels

REFERENCES

[1] A. S. Hermann et al., „Sandwich Structures Technology in Commerical Aviation", *Adv. Sand. Struct. and Mat.*, 2005, 7: 13-26.
[2] S. Abrate, "Soft impacts on aerospace structures", *Progr. in Aero. Sci.*, 2016, 81: 1-17.
[3] C. Fischer et al., "Strategies to investigate the residual strength of impact damaged honeycomb sandwich structures using detailed numerical models", *21th Int. Conf. on Comp. Mat.*, 2017, 7.
[4] M. Elamin et al., "Impact damage of composite sandwich structures in arctic condition", *Comp. Struct.*, 2018, 192: 422-433.
[5] M. J. Weber et al., "Nonlin. model. and characterisation of PMI-based foam core mat. for FRP sand. struc.", *Int. Conf. Mech. of Comp.*, 2017, 4.
[6] I. Kroeber, "Auswirkungen von Impacts auf CFK-Strukturen", *DGLR-Symposium Lightweight Struct.*, 1991, 8.
[7] M. D. Rhodes, "Impact Fracture of Composite Sandwich Structures", *Struct. Dyn. and Mat. Conf.*, 1975, 5.
[8] D. M. McGowan et al., "Struct. Response of Comp. Sand. Panels Impacted w/o Comp. Loading", *J. of Aircr.*, 1999, 36: 596-602.
[9] K. Malekzadeh et al. "Response of In-plane Linearly Prestressed Composite Sandwich Panels with transversely flexible Core to Low-velocity Impact", *J. of Sand. Struct. and Mat.*, 2006, 8: 157-181.
[10] C. Fischer et al., "Imp. analysis of compr. preloaded honeycomb sandwich structures", *J. Sand. Str. Mat.*, 2024; 26: 350–372.