INNOVATIVE APPROACHES FOR INTEGRATION OF FUNCTIONS IN COMPOSITE SANDWICH STRUCTURES BY THE EXAMPLE OF CABIN INTERIOR

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OVERVIEW

Reducing the weight in aircraft (A/C) cabin is one of the challenging tasks in modern aircraft design. An innovative approach for integration of functions in sandwich composites is described, using energy attenuating supports for overhead stowage compartments as an example. Possibilities and procedures for integration of functions in A/C galleys are shown, taking the integration of lighting as an instance.

1. INTRODUCTION

During the joint research project between Airbus, EADS and the Hamburg University of Technology different options for optimising the passive safety were analysed. One option is the use of force-limiters to prevent an overload of support structures. The integration of this new function in cabin is one of the main responsibilities of the Institute for Product Development and Mechanical Engineering Design (PKT) of Prof. Dr.-Ing. D. Krause. Before the integration is shown, the motivation of research is further discussed.

The aim of the development of lightweight energy-absorbing support structures for A/C cabins is to limit the loads acting on the cabin components (force limiters) and to maintain a safe area for passengers during dynamic load cases. For example, the overhead stowage compartments (OHSC, hatracks, FIG 1) inside the A/C cabin are subjected to high loads during turbulences or hard landings. To prevent the detachment of the hatracks from the primary A/C structure force-limiting support structures were investigated to ensure the structural integrity of the hatrack and the A/C structure up to a certain level, depending on the energies involved.

Because commercially available solutions for force-limiters do not fulfil the specific A/C requirements with respect to weight and installation space, a joint research project between Airbus Germany, EADS Innovation Works and PKT of the Hamburg University of Technology was conducted in order to develop innovative energy absorbers for A/C cabin components.

Today the applicable design rules of OHSC refer to static decelerations which are used to calculate the forces inside the connecting support structures. Due to the short duration of a crash, these design rules do not necessarily represent the transient nature of the acting forces and decelerations. Therefore, an approach towards dynamic load cases, as used for the certification of A/C seats, was investigated. Since the load varies with time, force-limiters can be used to keep the maximum stress in the composite sandwich structures of the hatracks under a defined level. The aim is to develop force-limiting supports, which are capable of absorbing high amounts of energy but have low weight, thus leading inevitably to the design of innovative supports/attachments, which involve new energy-absorbing materials.

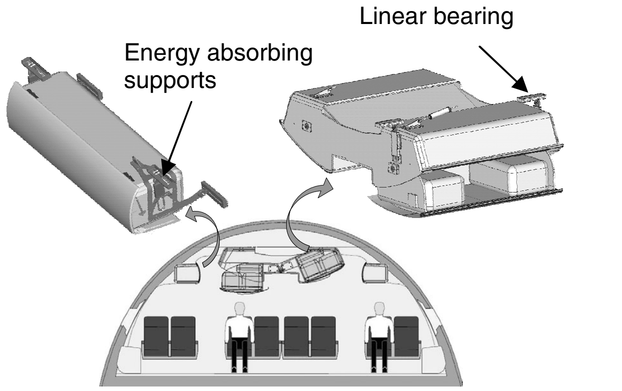

FIG 1. Showcase hatracks of common aircraft cabin interior

2. DEVELOPMENT OF AN INNOVATIVE ENERGY-ABSORBING CONCEPT FOR INTEGRATION IN OVERHEAD STOWAGE COMPARTMENTS

The utilisation of force-limiters has two main advantages:

- Firstly, the supported OHSC has to be designed only up to the triggering force of the force-limiter, including a fitting factor.
- Secondly, the primary A/C structure does not have to be designed up to the forces with fixed supports, but only to the triggering force of the force-limiters.

Both effects allow a decrease of structural weight due to lower forces.

In the project, more than 10 different energy-absorbing materials with different support concepts were analysed according to the defined boundary conditions, showing promising results but requiring a bigger design space than conventional supports [1],[2],[3]. Based on patent application publication DE 199 26 085 [4], one concept was found showing a high potential for implementation as a z-axis hatrack support (FIG 2).

The main principle for energy-absorption of this pin/plate-absorber is the destruction of the fibre-reinforced plastic (FRP) plate integrated in the hatrack's sidewall by tearing a pin in-plane through the plate. The pin and tension rod are guided by a guidance bolted to the hatrack's structure. To prevent damage of the OHSC or absorber during rebound loading, i.e. the spring-back of the hatrack as a result of elastically stored energy, a linear sprag clutch is integrated in the upper part of the guidance, which prevents the backward movement of the tension rod.

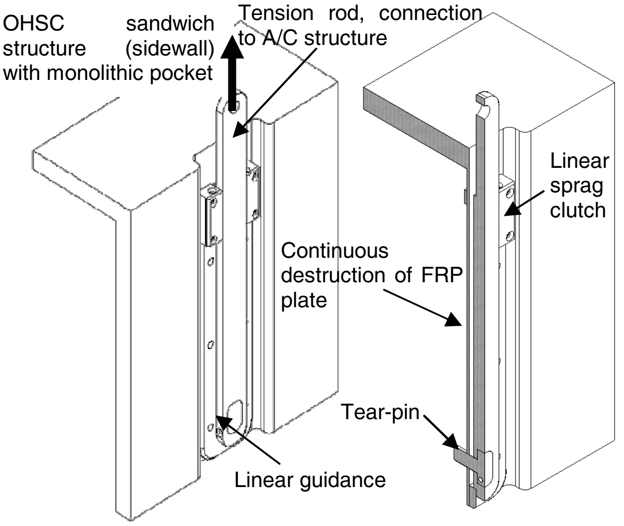

FIG 2. Pin/plate-absorber concept with part of an OHSC sandwich structure (patent pending)

A lot of information about energy absorption of FRP tubes is available [5]-[8] but virtually nothing can be found about the energy-absorbing capabilities of a pin torn in-plane through a composite plate (except for pin-bearing strength, which does not represent the whole deformation process).

Therefore, extensive material testing was conducted on composite plates, investigating the influence of fibre orientation as well as fibre- and matrix-material to understand the predominant failure modes and to analyse the potentials for optimisation.

3. MATERIAL TESTING

In order to investigate the influence of different fibre orientations on the energy absorption potential, carbon fibre/epoxy (CF/EP) plate specimens with four different orientations were manufactured from unidirectional (UD) and fabric prepregs:

a) Fabric (satin-weave): 0°/90°
b) Fabric (satin-weave): ±45°
c) UD: ±45°
d) UD: quasi-isotropic lay-up

Each lay-up was tested with two specimens with a thickness of 2 mm using a tensional test rig with a crosshead speed of 200 mm/min and an 8 mm pin bore and pin. The specimens were clamped by six bolts on the outer perimeter of the specimen.

As can be seen in Fig. 3, the crushing behaviour depends on the fibre orientation of the laminate, showing high fragmentation with little fronds and narrow damage band in FIG 3a to growing size of fragments in FIG 3b and FIG 3c, up to catastrophic failure with large fragments and broad damage area for the quasi-isotropic lay-up (FIG 3d).

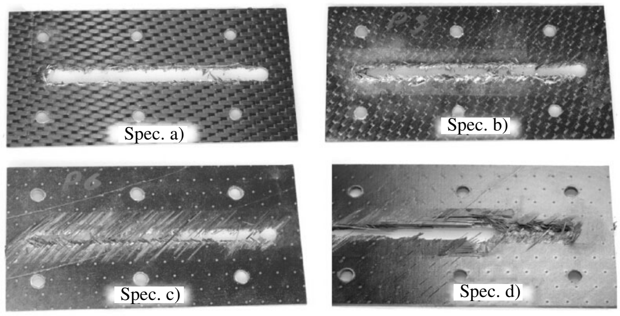

FIG 3. CF/EP composite plates with different fibre orientations after

The force-deflection curves of a 0°/90° fabric specimen and a quasi-isotropic UD specimen are presented in FIG 4. The 0°/90° fabric specimen shows a typical spread of the force level due to fibre cracking and crack initiation. In comparison, the quasi-isotropic UD specimen shows an increased spread due to larger fragments and extended damage progress in lateral direction. Apart from the greater spread of the force level, which is undesirable, the occurrence of large fragments inhibits the utilisation of this lay-up because these fragments may block the pin in the linear guidance.

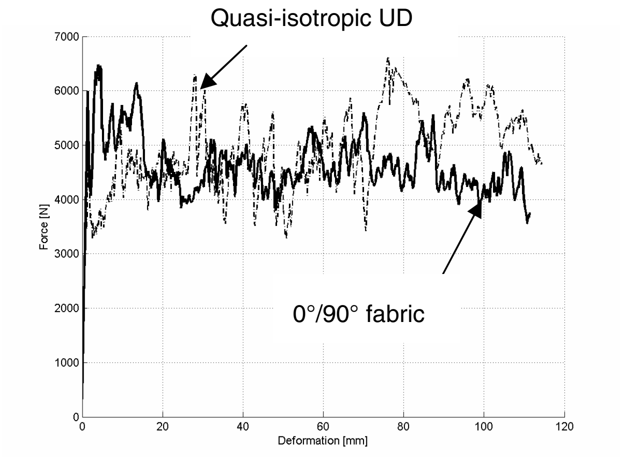

FIG 4. Force-deflection curves of 0°/90° fabric (solid) and quasi-isotropic UD specimens (dash-dot)

In order to prove the presumption that a debris wedge exists in front of the tear pin similar to those observed in the crush front of FRP tubes, micrographs of the crush front were prepared.

As can be seen in FIG 5a, delamination cracks are protruding from the top of the debris wedge, which consists of fragmented fibres and matrix. These cracks precede the wedge, pre-damage the laminate and propagate easily. To reduce this crack propagation, the influence of 3D-reinforcements by means of stitching aramid yarns in thickness direction was investigated (FIG 5b). The reinforcement increased the toughness of the laminate and led to an increase of the mean force of approximately 20%. The specific energy absorption, which is the ratio of absorbed energy to destroyed mass, increased about 20% as well. Because of the reduced crack propagation, smaller fragments were generated, reducing the risk of blockage by fragments inside the absorber. Furthermore, the yarn entangles the fragments and keeps them on the side of the slot, leading to a cleaner process compared to the other specimens.

As a result, it can be stated that firstly the implementation of fibre reinforcements in thickness direction increases the force level of the absorber, and secondly the global performance is enhanced due to smaller fragmentation and cleaner destruction of the material.

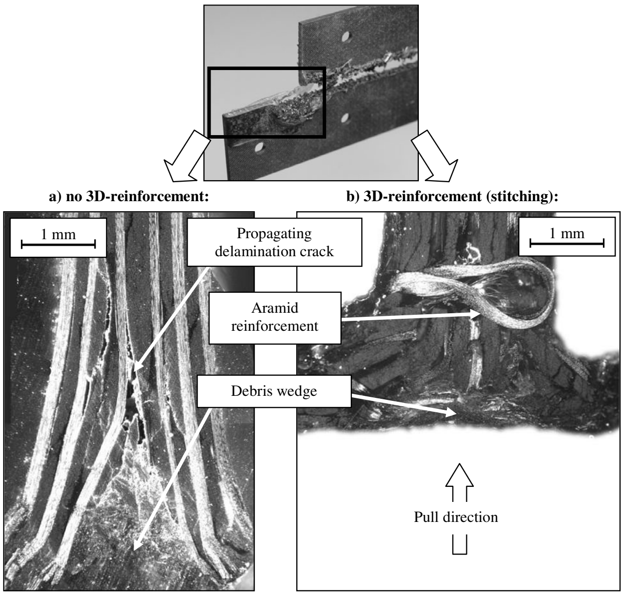

FIG 5. Micrographs of CF/EP specimens: a) 0°/90° fabric, b) 0°/90° fabric 3D-reinforced

In addition to the aforementioned specimens, further investigations with regard to different materials and different weave structures were conducted to provide a design-database for the integration of pin/plate energy absorbers in cabin components (FIG 6). Due to the fact that hatracks inside A/C cabins are typically made of glass fibre/phenolic (GF/PF) (FIG 6, b), these test specimens were tested in different thicknesses (2, 3 and 4.4 mm) and were used for simulation with LS-Dyna due to extensive knowledge about material properties. The outcome of the comparison between test and simulation can be seen in [3].

a) GF/PF fabric (satin-weave 0°/90°),
b) GF/EP fabric (plain-weave 0°/90°),
c) CF/EP fabric (satin-weave 0/90),
d) CF/EP fabric (satin-weave ±45°),
e) CF/EP unidirectional (±45°),
f) CF/EP unidirectional (quasi-isotropic),
g) CF/EP fabric (satin-weave 0°/90°, autoklav),
h) CF/EP fabric (satin-weave 0°/90°, autoklav),
i) CF/EP fabric 3D-reinforced,
j) CF/EP-GF/PF hybrid plate

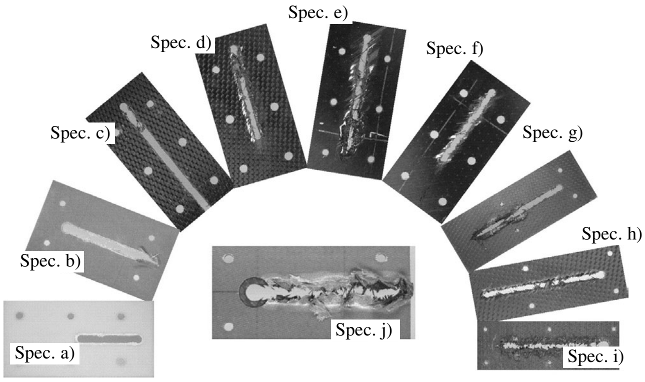

FIG 6. Analysed materials

Based on the concept in FIG 2 an integrated prototype of the pin/plate absorber was manufactured, integrating a CF/EP plate in a sandwich panel with GF/PF as a face sheet representing a common hatrack design (FIG 7). The analysis of the prototype is currently under way.

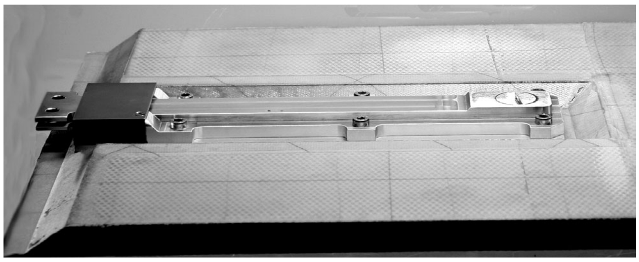

FIG 7. Integrated pin/plate absorber in a sandwich panel

Design Guidelines

Derived from the recent conducted experiments the following guidelines for design of a pin/plate absorber can be stated:

- A sufficient clearance between plate and tension rod has to be designed, leaving enough room for the fragments to clear the crush zone. At least 1.5 times the plate thickness shall be taken.
- Out of plane reinforcement of the plate is recommended. Heavily waved fibre orientation like plain weave is showing better performance. Unidirectional fibre orientations shall be avoided.
- The pin orientation and support is influencing the crush front, a stiff linear guidance is necessary for a one side supported pin to prevent the pin from being drawn out of the plate. Furthermore if the pin is deflected in an angle towards the plate, the crush front can be affected switching to an inefficient friction mode, producing less fibre fractions.
- If rebound is an issue, a linear sprag clutch has to be included.
- A mix of different materials (GF(0/90)/CF(±45)) in different fibre orientations showed undesired behaviour, but other combinations have to be analysed. To avoid interaction between the face sheets, the pin track has to be cleared of the (GF) top layer.
- Care has to be taken for design of the mean crush force, since recent experiments suggested a strong dependence of the force of the strain rate. This will be object to further investigations.

4. STRATEGIC FIELDS OF RESEARCH FOR INTEGRATION OF FUNCTIONS IN A/C GALLEYS

FIG 8 shows the influences on the integration of functions in sandwich panels. Apart from the airworthiness regulations, requirements concerning the thermal, mechanical, medium, durability and production as well as cost aspects have to be considered.

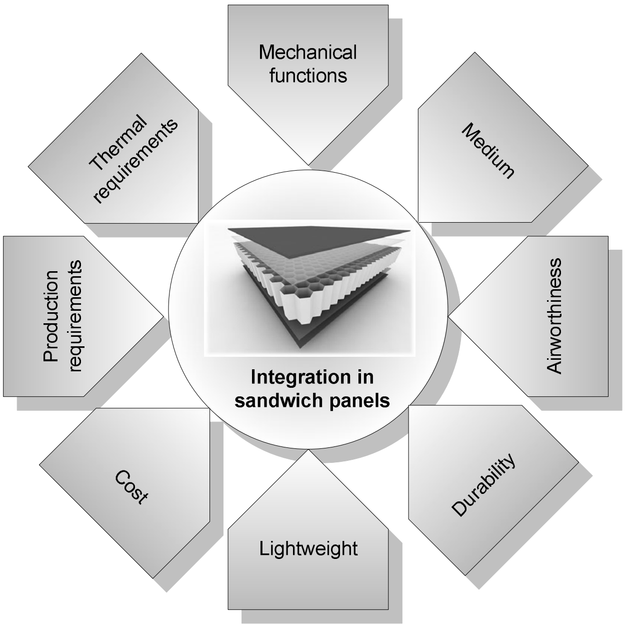

FIG 8. Influences on the integration of medium and functions in sandwich panels.

To analyse which of the influences lead to a reduction in cost and time-to-market[1], manufacturer specific information about the development and manufacturing process is necessary. With this information a ranking of the different influences can be established, providing the means to pinpoint the influence with the highest optimization potential (primary field of integration, FIG 8, FIG 9).

To ensure an efficient and faultless development an adapted development process is presented, derived from the VDI 2221, FIG 9. Beside the well known development process a new basic integration process is triggered, running parallel and providing the necessary information for the development of the product.

Inside the basic integration process the strategic fields of research are compared to analyse the primary field of integration, which is the base for integrating concepts. These concepts are fed back inside the basic integration process, triggering an iterative improvement circle consisting of test specimens of the integration concept, the verification with simulation and experiments, as well as the feedback of the information in the primary field of research, guiding further research, and the return of knowledge as design guidelines. Due to the iterative procedure a profound knowledge can be achieved, adding further ideas for integration possibilities.

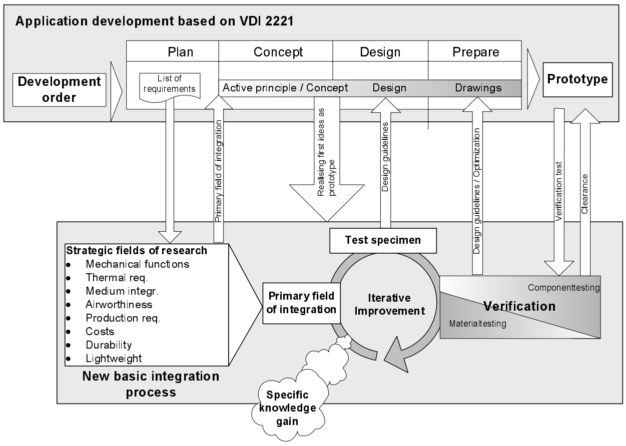

FIG 9. Development process to integration of functions.

Because of the necessity of verification inside of the basic integration process, test rigs and test procedures for experimental verification of prototypes exist, shortening the time until clearance of the prototype.

To prove the efficiency of the presented process exemplarily the medium, in particular ambient lighting, was chosen for integration inside the panel. One reason for this choice is the possibility to create new design concepts for ambient lighting of A/C galley during night flights.

FIG 10 shows a prototype for ambient lighting, using electro-luminescent foils for lighting. Because this foil is integrated inside the sandwich, beneath the glass/epoxy-face sheet the foil is safe against environmental hazards.

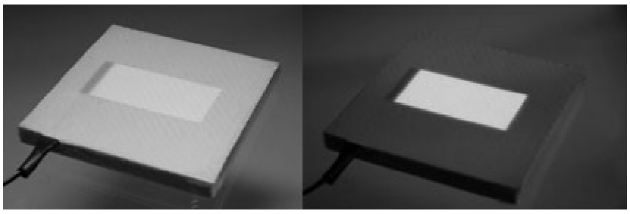

FIG 10. Ambient lighting integrated in a sandwich-panel (switched on under ambient and dark conditions)

Since the prototype has not been fully analysed yet, further information are not available. But first tests showed promising results.

Investigations will show if this integration concept is suitable for the manufacturing process. Additionally a business case will be evaluated, if this concept leads to cost reductions.

5. CONCLUSION

A new integrated prototype of an energy absorbing support structure was presented, together with material information concerning the fibre- and matrixmaterial as well as fibre orientations and possibilities for reinforcement of the FRP-plate. Design guidelines are shown, suggesting that an integration of the function

[1] Since most of the galleys are custom build for the airlines, the wording seems appropriate.

inside a hatrack wall provide advantages in weight and design space. To ensure an efficient integration of functions inside A/C components and sub-systems a development process was presented adapting the VDI 2221 to the specific boundary conditions. An ambient lighting for A/C galley was shown as another example for function integration. The amount of weight and cost savings will be further investigated, using the presented approach.

Acknowledgements

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6. LITERATURE

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