INTEGRATION OF CONNECTING ELEMENTS IN HYBRID-COMPOSITE COMPONENTS

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ABSTRACT

The design and structure of lightweight components in automotive applications is nowadays a major challenge for engineers. To implement aspects of lightweight, it is an approach to substitute massive metal components by sandwich elements composed of an aluminum foam core between two carbon-fibre-reinforced plates. Technically, it does not appear to be reasonable to cut mounting-threads in that kind of sandwich elements. To enable the mountability of these parts, assembly elements are desired to allow an integration of screws or other standard components. In order to avoid a destruction of the resilient aluminum foam design, the insert-geometry must ensure that the stress is being transitioned to the carbon-fibre layers. This paper deals with the design of different component geometries, strength calculations, an FEM analysis, the preparation of the production and examination of test specimen.

Index Terms – aluminum foam, carbon fibre, fibre-reinforced plastics, hybrid-composite, insert, sandwich

1. INTRODUCTION

1.1 General context

The present research object is a vibration-test-plate which allows an examination of varying technical components. These parts have to be mounted on a shaker plate. In the already existing test fence the shaker plate is made of a magnesium alloy with a screwing grid with 100 mm gap (figure 1). The purpose of the actual research is to decrease the weight of the plate. This is particularly interesting because a decreasing weight leads to a higher resonance frequency. As a result the maximum frequency which can be tested rises too. A weight reduction can be realized by replacing the magnesium plate with a hybrid-composite component. The component is made of two carbon-fibre-reinforced plates with a core of aluminum foam.

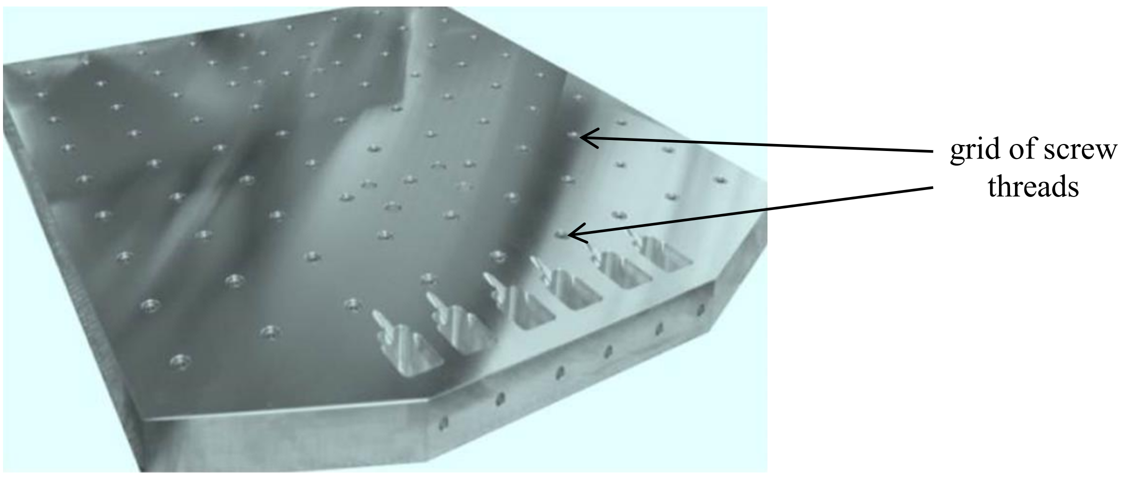

Figure 1 – shaker plate made of magnesium alloy

1.2 Motivation for research

Technically, it is not reasonable to cut mounting-threads in that kind of sandwich element. The loading capacity of threads in carbon-fibre-reinforced plates and aluminum foam is slightly. To enable the mountability of these parts, assembling elements have to provide an opportunity to integrate screws or other standard components. In order to avoid a destruction of the low resilient aluminum foam, the insert geometry has to ensure that the stress is being transitioned to the carbon-fibre layers.

1.3 State of the art

1.3.1 Lightweight-topic hybrid-composite component

To decrease the weight of different parts, it is an approach to substitute massive metal components by a sandwich element composed of a thick-walled core made of a low-density material between two thin-walled solid surface layers [1]. The connection between surface layers and core transfers shear and tensile loads [1] and is currently realized through sticking, welding or cladding [2]. Usable core-materials are for example honeycomb structures, corrugated sheet metal and polymer- or metal-foams. The surface layers consist of metal-plates, grid-structures or composite-materials. [2] A general method is to implement surface layers with a high tensile stiffness and a core with tender shear property [3]. Compared with conventional design the sandwich-construction enables a weight reduction up to 50 percent [2].

1.3.2 Applied materials

Carbon fibre-reinforced plates are used as surface layers in current research. This material is a composite of carbon fibres and an epoxy resin matrix. The carbon fibres initiate loads and show high strengths and stiffnesses. They are furthermore adjustable in a wide range during fabrication. An epoxy resin matrix is used to fix the fibres in the requested geometrical disposal as well as to keep a distance between them to prevent rubbing. Another task of the matrix is to transfer loads from one fibre to another and to absorb loads in lateral-fibre direction. Furthermore the matrix material protects the fibres from compressive stress and negative environmental influences. Nearly all properties for example density, stiffness, strength, thermal conductivity or chemical resistance of the prepared composite are crucial attributable to the matrix material. The current matrix system consists of a thermoset. It is a resin hardener composite with a low viscosity before the chemical reaction occurs. This allows a well flow into the cavity and a good saturation of the fibres. [4]

Decisive for the mechanical properties of a fibre-reinforced composite is the orientation of the fibres in the matrix system. A general classification of fibre orientation is fabrics and clutches. Fabrics consist of two orthogonal fibre directions (figure 2, left) which were joined with various overlaps. The disadvantage compared with unidirectional layers is a strength reduction of 5 till 20 percent depending on the ondulation of the fibres. To manufacture clutches unidirectional layers were ripple-free connected with knitted meshes. This generates a good drapability and enables several angles (22-90°) of fibre direction. Another possibility are unidirectional layers where all fibres have the same orientation (figure 2, right). This is beneficial for adaption on applied forces because it is possible to drape the fibres exactly in load direction. [4]

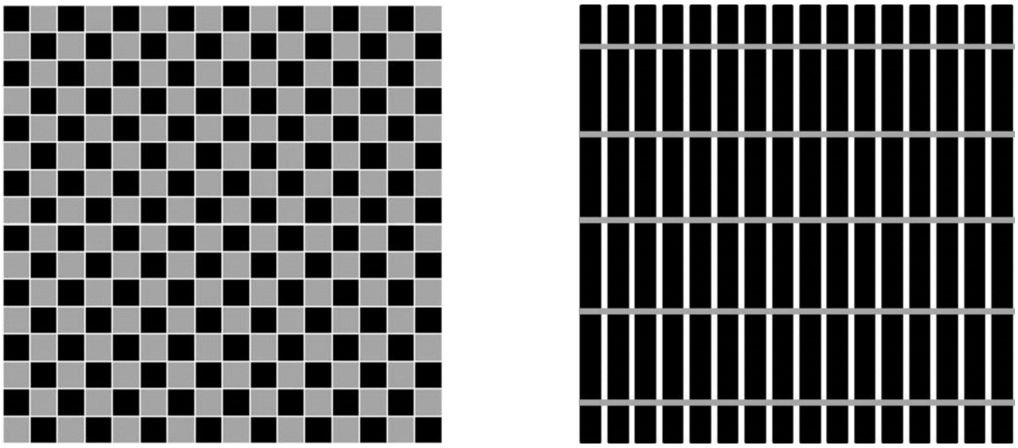

Figure 2 –Bidirectional carbon fibre fabric and unidirectional clutch

The core structure of the sandwich-component consists of aluminum foam. Aluminum foam has a cellular structure with a large volume of gas-filled pores. This structure offers high weight reduction rates because of its low density. Despite this low density aluminum foam has a high specific shear and fracture strength. Besides the assignment as filler material in sandwich-components aluminum foam supplies significant performance gains in light stiff structures as well as for the efficient absorption of energy, for thermal management and acoustic control. The cell topology can be used to describe aluminum foam. Two kinds of foam are common. Open cell-foams (figure 3, left) offer higher lightweight potentials because of the viable lower density. For these kinds of sandwich-elements the open cell structure has a negative effect. During the infusion of matrix material the cell structure is filled with resin. This has an adverse influence to the weight of the sandwich-element. In this case it is useful to apply aluminum foam with a closed cell structure (figure 3, right) to minimalize or prevent a flow of resin in the foam structure. [5]

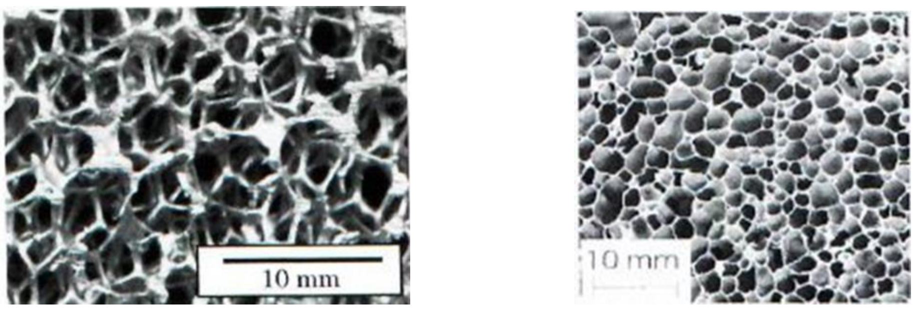

Figure 3 – aluminum foam with open [6] and closed [7] cell-structure

1.3.3 Possibilities of force transmission into sandwich-components

In previous studies two possibilities of force transmission in sandwich-components has been investigated. One option is to apply the connection element on the surface of the component. To realize this gluing or welding, for metallic layer material, is suitable. Another opportunity is to integrate the fasteners into the sandwich-component. To do so, a blind hole is drilled through the top layer and the aluminum foam core. The fixation of the fasteners is possible by gluing in the foam or riveting in the top layer. [2] The crucial disadvantage of these solutions is the support of the fasteners only on the top layer of the sandwich-component. Because of this the second layer is not used for force absorption and the maximum bearable strain is limited.

1.4 Purpose

The current investigation deals with the development of an connecting element for an aluminum foam – carbon-fibre composite. This fastener is supported by both layers to reach the maximum tolerable thread strength. It is necessary to maintain the weight of the whole unit on a preferably low level.

2. INITIAL DATA AND METHODS

2.1 Basic data

The applied hybrid-composite component has a total thickness of 40 mm consisting of a 20 mm aluminum foam core between two 10 mm carbon-fibre-reinforced plates (figure 4). This material combination is used for a shaker-plate analogous to figure 1. On this plate it is possible to test various components under practice-oriented oscillation-cycles. The tested part can have a weight up to 1,000 kilogram. To fix the specimens a fastener with mounting thread is necessary. The size of this thread is given to screw M10 bolts. The number of inserts in the whole plate is 62.

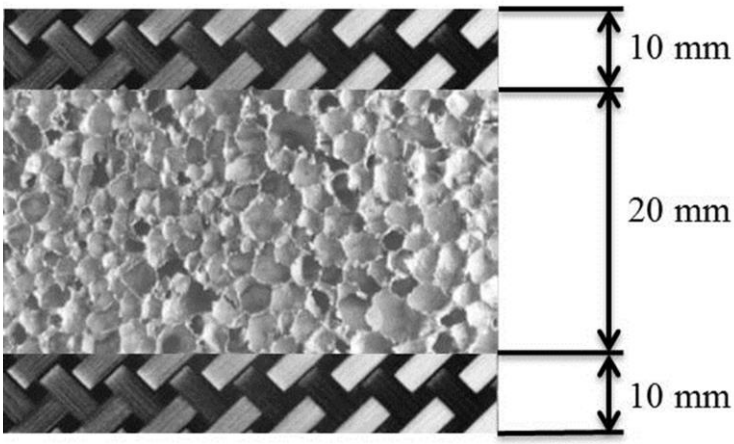

Figure 4 – schematic structure of hybrid-composite component

The proceeding is influenced by different predefined loads which are represented in table 1. These values descends from the former applied shaker-plate made of magnesium. As a result of the given temperature range and the possible accretion of water a stainless material for the inserts is demanded. Another target is a non-destructive release of attrited fasteners.

Table 1 – predefined loads

predefined loads		unit	value
pull-out strength		kN	54.85
appropriate torque		Nm	84
operating temperature	above the plate	°C	- 40 till + 40
	among the plate	°C	- 20 till + 20

2.2 Methodical approach

The first step is to construct a connecting element by designing different insert-structures to consider several varieties of force application. The next pace is to analyze the relevant stresses caused by the given loads. These are tensile loads and pressure-loads within the insert-material as well as surface pressure at the contact surface between insert and carbon-fibre-reinforced plate. The precise component design occurs with implication of those ascertained stresses. To define the insert geometry the fundamental calculations for shearing, tensile load and surface pressure are applied. Based on this the material can be selected. With knowledge of the required material the former calculations are reviewed with FEM simulations. Thereby the general procedure of a FEM simulation as illustrated in figure 5 is considered.

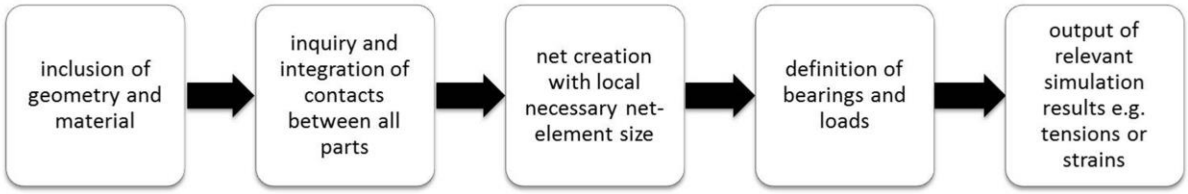

Figure 5 – steps of a FEM simulation

At this point of methodical approach the current research is completed. In further studies the inserts were produced and verified by suitable testing methods. With the resulting bearable forces and torques the most promising concept is selected.

3. RESULTS

3.1 General design and strength calculations

The results of the design process for two different insert geometries are illustrated in figure 6. The main differences between these inserts are the contact surfaces between insert and carbon-fibre-reinforced plates (figure 6, red lines). On the left side, this contact surface is conducted as circular ring and on the right side as a cone. The major benefit of the cone is the exactly defined position of the insert and the possibility to adjust it if the surface is minimal altered. Considering on lightweight-aspects the diameter of the insert is reduced in the section of the aluminum foam. The rotation prevention is realized by a cubic retaining element which braces in a recess in the upper carbon-fibre-reinforced plate.

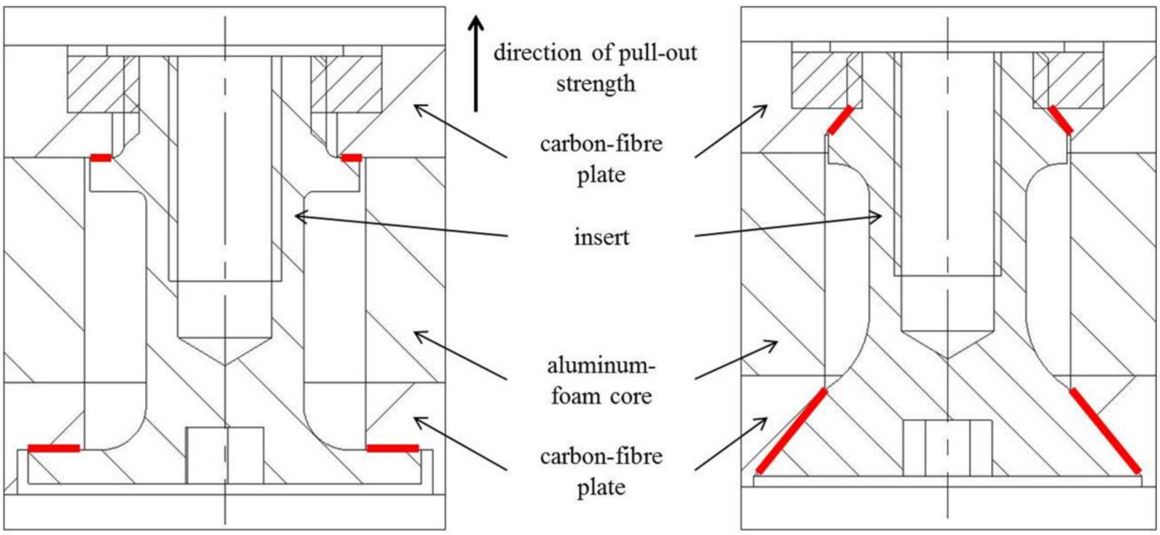

Figure 6 – selected insert geometries

The main item in the designing and dimensioning process is the contact pressure between the insert and the carbon-fibre-reinforced plate. The limit of compressive stress is given by the material datasheet of carbon-fibre-reinforced plate as 68 N/mm². The size of contact surface (A) is determined by the general equation for contact pressure which depends on the force (F), the existing pressure (p_{ex}) and the acceptable pressure (p_{acc}).

$$p_{ex} = \frac{F}{A} \leq p_{acc}$$

The rotation prevention is dimensioned by the same relationship with inclusion of appropriate torque. The material selection involving the calculation of tension in the area with the smallest bearing profile results in a minimum tensile strength of 730 N/mm². Therefore the stainless steel 1.4021 with an average tensile strength of 830 N/mm² is selected. For comparison the often applied stainless steel 1.4301 is selected. The average tensile strength of 660 N/mm² is lower than the demanded tensile strength. Nevertheless the possibility of working is given because of safety factors in the limit of compressive stress of carbon-fibre-reinforced material.

3.2 FEM simulations

The size of test specimens is oriented on the grid dimensions of the shaker plate and exceeds 100 mm between insert and corner. Fixed bearings on the outer edges (figure 7, orange lines A-D) are used. The pull-out strength (figure 7, E) acts on the connection thread of the insert. An element size of 1 mm is chosen for the net which represents a good compromise of accuracy and calculating time.

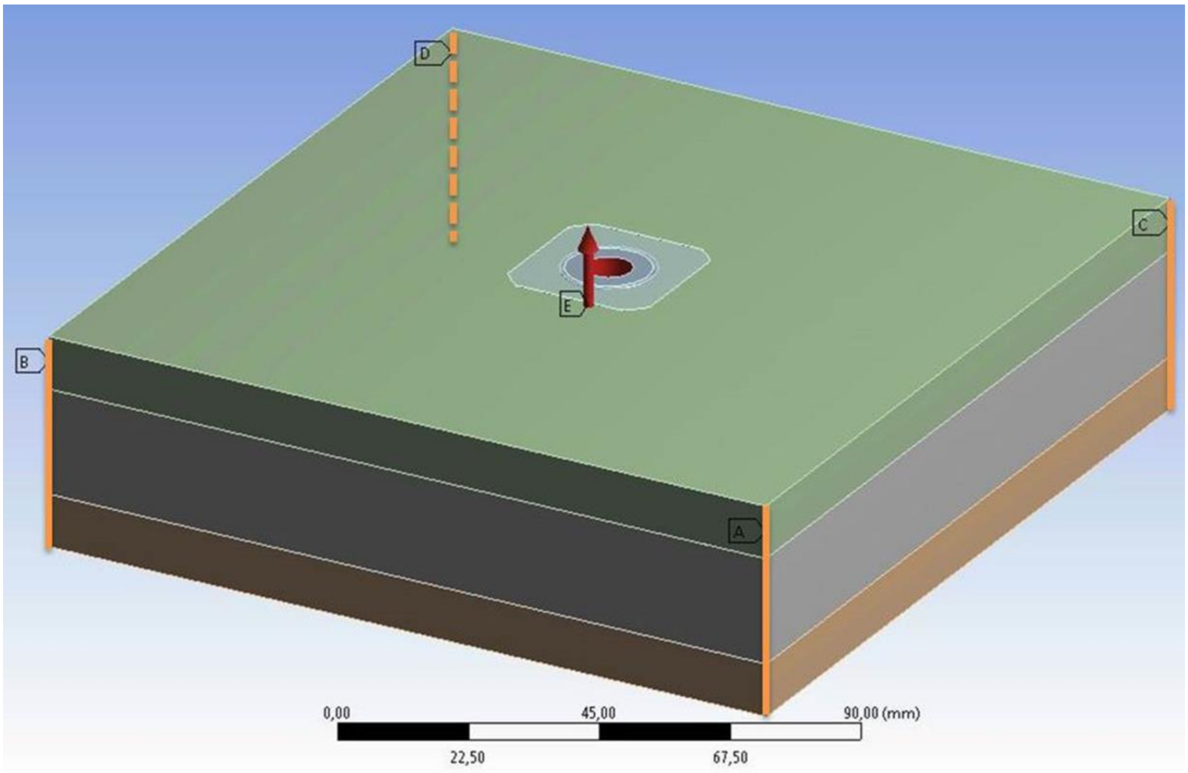

Figure 7 – bearings and strength in simulation model

The results of the FEM simulations are illustrated in figure 8. The unit of scale is N/mm². It is obvious that the right insert geometry realizes a better tension course than the left one. The radii are larger and so the notch effect is smaller. The size of the displayed tension has to be considered critically. The FEM software does not work reliable in areas of tension exaltation like sharp edges or short radii. Accordingly FEM simulations should never be the only element of component design and strength calculations. Structural tests e.g. pull-out test are also important to get reliable results.

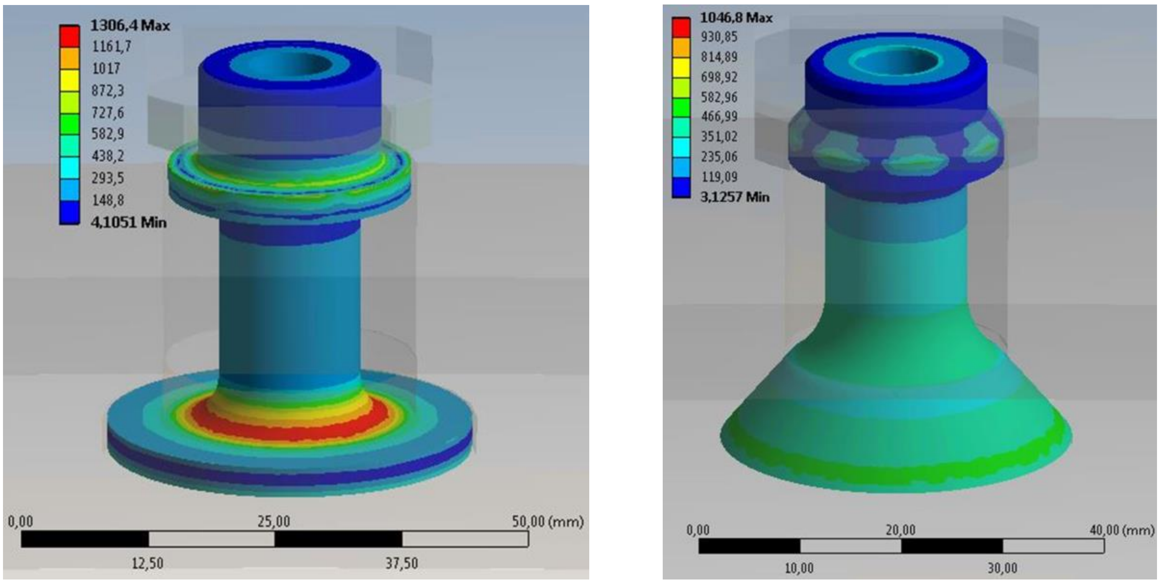

Figure 8 – stress diagram as result of FEM simulation

4. CONCLUSION AND PROSPECTS

During the research it is succeeded to design two insert geometries which accomplish the given requirements like the bearing on both carbon-fibre-reinforced plates, the resolvability and the regard on lightweight aspects. Involving strength calculations and FEM simulations the two inserts seems to be inherently qualified.

The simulation results show oversized tensions for the chosen material. Because of that pull-out tests should be conducted to prove the qualification of the chosen insert geometries finally.

It can be expected that the results of the insert with conical contact surface are preferable to the one with circular-ring interaction area.

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