DESIGNING A METAL-CFRP-HYBRID BY USING A STRUCTURED POLYMERIC COMPONENT ON THE INTERFACE

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Abstract

A multi-material design comprising of aluminium and carbon fibre reinforced plastics (CFRP) is a common way to generate lightweight-structures. The interface between these different materials requires a closer consideration when a cost-efficient high-volume production with good mechanical properties should be obtained. In this contribute an additional polymeric component between the metal and the CFRP is introduced to produce this hybrid-structure. Due to these three materials there are two interfaces that have to be considered in the design process. This approach allows a direct (adhesive-free) adhesion between the join partners without the need of a special preparation to join the materials. The interface between the metal and the polymeric component as well as the interface between the polymeric component and the CFRP use a mechanical interlocking on different scale levels to transmit the forces from one material to the other.

1. Introduction

Lightweight optimized structures are developed to reduce costs and energy during the product life-cycle. Different materials that meet the local requirements in the structure are often used to achive this goal. This concept creates new challenges for the connection technology because most of the used materials cannot be joined by conventional methods like welding. The key to resolve this challenge in the context of large scale production processes is to develop an intrinsic joint. This means that the connection between the join is established during the production of the hybrid structure which usually requires a specifically designed adhesion mechanism.

An overview about the functional performance of engineered surfaces is given by Bruzzone et al. [1]. The authors list inter alia the mechanical adhesion which uses an interlocking between the connection partners. This method has been used to some extend by Möller et al. [2] who investigated the adhesion between CFRP and aluminium. To transfer their concept to a large scale production process additional approaches have to be considered which can be realized within a production process like the injection moulding. These approaches are mechanical interlockings on different scale levels. Luchetta et al. [3] investigated the effects of the surface roughness on the adhesion. Next to these stochastic microstructures different elements on the same scale level can be specifically generated [4, 5]. Possibilities to produce an interlocking on a millimeter-scale are shown in [6]. In addition to this mechanical adhesion the design of the contact area as a whole has to be considered. [7–9] show approaches to reduce stress concentrations and to distribute the load on a larger contact surface.

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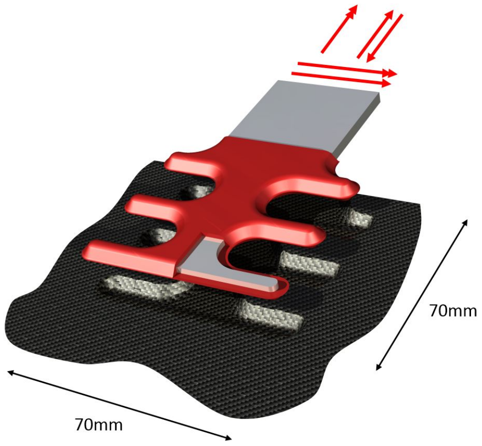

Figure 1. Schematic view on the hybrid structure and the considered load cases.

2. Developement of the Geometry

The intrinsic hybrid-structure is exemplarily developed for a defined two-dimensional area of 70mm x 70mm at the edge of a larger CFRP structure. The task is to form a connection between the CFRP and the metal with a metallic mounting bracket on the outside. The bracket is representative for any given metallic structure that has to be joined to fibre reinforced plastics. Figure 1 gives a schematic view of the hybrid-structure as well as the considered load cases. With regard to a large scale process the metal component is designed as a punched part that is overmoulded by a thermoplastic component in a following production step. Thus the produced insert has a reduced stiffness of the outer layer due to the material properties of the polymer but a high modulus as a whole part. The polymeric component reduces the difference in the stiffness jump to the later applied CFRP. Furthermore the polymer has an outer shell that directs the carbon fibres in larger radii to reduce stress concentrations at the edges. The development of these two interfaces is shown in more detail below.

2.1. The Metal Component

The basic idea is to use primarily a mechanical interlocking of the different materials. The metal component of the joint was developed by using a simplified FEA-model. It consists of a metal component with initially simple contour, a partly surrounding rectangular-shaped polymeric component and as third flat CFRP components on the front and the back side of the polymer (see Fig. 2 a)). The above introduced loads are applied on this structure by means of the metal bracket. At the first interface between the metal and the polymer, a contact behaviour that only allows normal and no tangential stresses is implemented to model a non adhesive joint following the concept of a pure mechanical interlock at the interface. Any possible additional adhesion that occurs in reality would then further increase the strength of the interface so that this simplification appears to be the worst case scenario. In contrast to that the polymer is ideally tied to the CFRP to model the second interface. Finally the CFRP has as boundary conditions all displacements and rotations fixed at the outer edges.

A multi-stage parametric study was performed on this model to modify the geometry of the metal component and to analyse its influence on the normal contact stresses at the metal-polymer-interface. A design of experiments was used to analyse the relation between geometry parameters like the radius and width of the arms and the corresponding contact stresses. Exemplarily two geometries of the first stage of the study as well as the related main effect chart for tensile load are shown in figure 3. It is obvious that the

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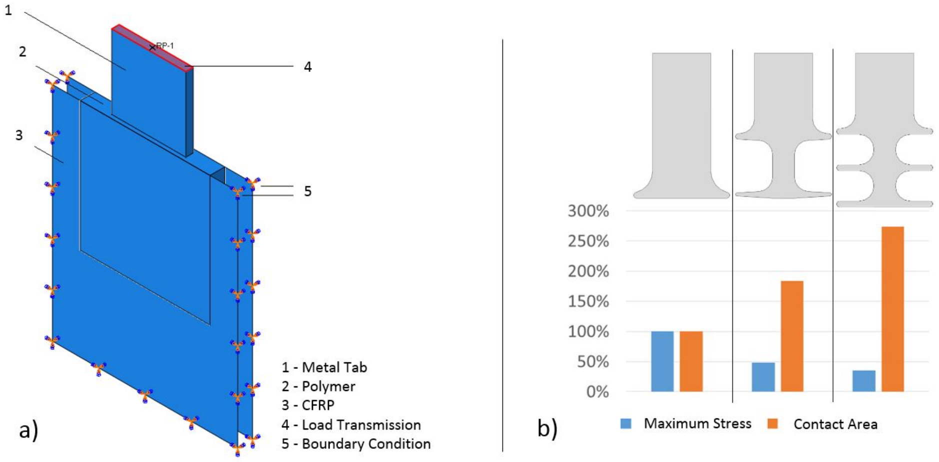

Figure 2. a) FEA-model for the development of the metal component. b) Stages of the parametric study.

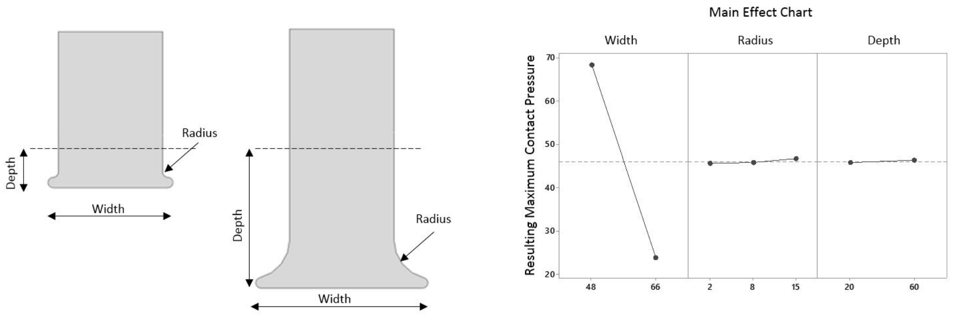

Figure 3. Selected metal geometry setups and their corresponding main effect chart for tensile load.

resulting stress is mainly influenced by the width of the structure than by its depth. For this load case the effect of the radius is found to be negligible. Next to the width, depth and radius the angle of the arms, their number, tapered arms and different lengths of the arms were considered geometry parameters. The range of the investigated geometric parameters was selected in such a manner that the resulting design fits inside the given design space of 70mm x 70mm. Selected randomized geometrical parameters violating the design space restrictions were investigated to account for possible boundary effects. There was no indication found for such effects. Figure 2 b) shows a comparison of three different metal geometries and their corresponding maximum contact pressure as well as the associated contact area. Both values, the maximum contact pressure and the contact area of the first metal geometry were set as 100%. With each stage of the parametric study the maximum contact pressure decreases whereas the contact area increases.

A multiple response optimisation was performed afterwards to take the different load cases at the metal bracket into account. Thus the final metal geometry shown in figure 2 b) on the right was systematically derived. It consists basically of a six-arm structure that shows a horizontal and vertical symmetry concerning the alignment of the arms. This is a consequence of the symmetry of the load cases, e.g. tension and compression and their same weighting factors within the multiple response optimisation process.

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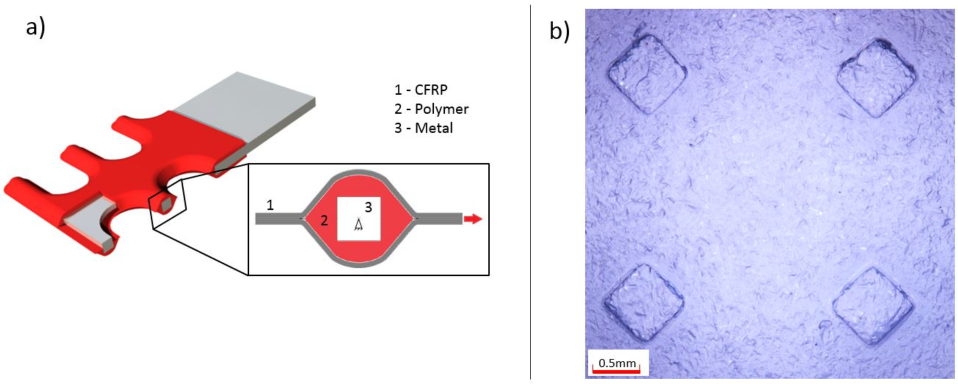

Figure 4. a) Geometry of the polymer component. b) Micrograph of the polymeric surface structure with structural elements and an increased surface roughness.

2.2. The Polymer Component

The second interface, the polymer-to-CFRP joint is realized by a mechanical interlocking as well. The polymer surrounds the metal component completely and builds a continuous shape of the insert. This shape redirects the carbon fibres smoothly around the sharp edges of the metal. Therefore stress concentrations and notch effects at the interface can be reduced. Additionally the adhesion is increased with an interlocking on different scales: a micro-scale such as the surface roughness and a macro-scale like structural elements on the surface (e.g. Fig. 4 b)). The before mentioned injection moulding process is suitable for this application because the surface structure is casted directly onto the insert. There is no need for a subsequent processing step to form the mechanical interlocking elements.

A simplified FEA-model was used to develop the geometry of the polymer component. This model consists of a cross section of only one of the six arms. Figure 4 a) shows this model. The pictured tensile force at the arm occurs locally due to a tensile, compression or shear load at the metal bracket. The main parts of this model are the metal component in the middle, the surrounding polymer and the CFRP layers on top and underneath the polymer. The interfaces between the three materials are implemented with a hard normal and a frictionless tangential behaviour (see chapter 2.1). A parametric study was performed on this model to examine the influence of the shape and the material properties of the polymer component. The approach was similar to the already described design of experiments of the metal structure but with different radii to direct the fibres around the metal, with different heights and widths of the polymer and with a variation of polymer material properties from ones with very low moduli and strengths like TPEs and high values like short fibre reinforced plastics. The target of this study was to reduce the stress within the polymer because this indicates a homogeneous distribution of the load at both interfaces. The resulting geometry is shown in figure 4 a) and figure 1 as an additional structure around the metal component.

3. Results

A FEA-model of the structure as a whole was developed to examine the effects of the individual parametric studies. Based on the previous results the model consists of a six-arm metal structure that is coated with a defined polymeric layer. Here the same assumptions of the interface behaviour as in the prior models were used. That means that only normal and no tangential loads can be transmitted at the interface. For the evaluation of the loads at the contact area the properties of each material can be simplified to a pure elastic behaviour. A consideration of the plastic or damage behaviour has to be taken

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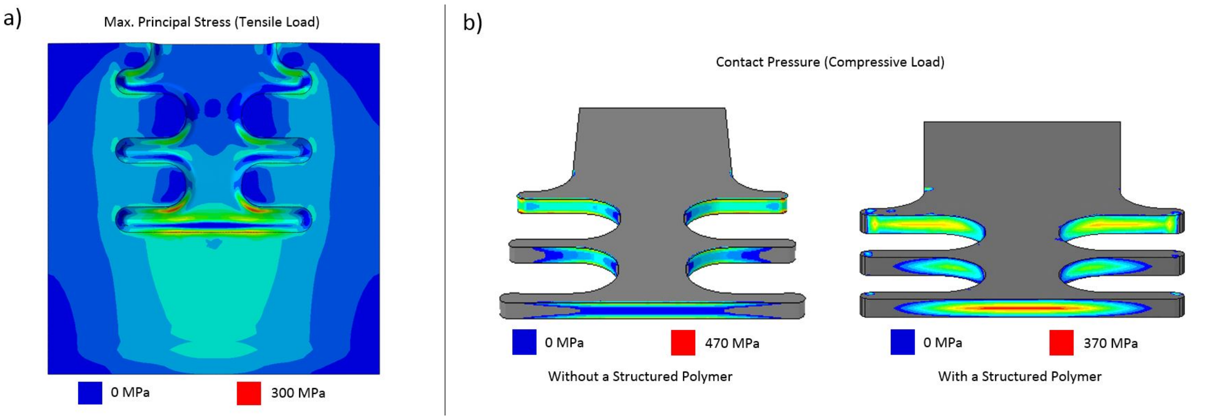

Figure 5. a) FEA Results of the CFRP component. b) Comparison between the contact pressure on the metal component with and without the surrounding polymer.

into account in subsequent development steps. Figure 5 a) shows the results of the simulations for the maximum principal stresses in the CFRP component under a tensile load. It is clearly visible that all six arms contribute to the load transmission. In proportion the upper pairs of arms transmit less load than the lower one but in total they ensure a better distribution of the load.

Figure 5 b) shows the contact pressure on the metallic surface under compressive load and compares the influence of the polymer component. The structure of the polymer causes a decline in the maximum stresses in the contact area. Furthermore it shifts the maximum stresses to the middle of the surface which reduces notch effects and reduces stress concentrations.

4. Conclusion

An additional polymeric component was used to develop an intrinsic metal-CFRP-hybrid structure. Its main purpose is to allow a large scale production that uses the benefits of the injection moulding process to cast a surface structure specifically designed for the connection to CFRP structures. The results of the design and simulation process point out that the developed structure is suitable for this application. Further research has to be done to investigate the influence of different surface structures as well as a local adjustment on the macroscopic polymer structure. The existing FEA models have to be extended to take a tangential load transmission at the interface and a plastic and damage behaviour of the materials into account.

Acknowledgments

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