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The interface of an intrinsic hybrid composite – development, production and characterisation

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Abstract

Due to a combination of different classes of materials, intrinsic hybrid composites are characterised by high strength and low weight. The mechanical properties of hybrid parts are mainly determined by the interface between the different materials. Consequently, this interface has to be considered in detail within the development of an intrinsic hybrid composite. The general approach of the considered composite is the combination of a mechanical form fit with adhesive bonding. This contribution focuses on the development, production and characterisation of the interface between aluminium and a fibre reinforced polymer as well as of the hybrid composite.

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Keywords: hybrid composite; interface; mechanical interlocking; cohesive bonding; crash performance

1. Introduction

The combination of fibre reinforced plastics (FRP) with metals to hybrid metal plastic composites offers the fusion of the mechanical properties from both material classes. Hence, these materials have a high potential in lightweight applications [1]. A drawback for the widely use of this material class is the sophisticated and expensive manufacturing process. To decrease the process cycle time and therefore the manufacturing costs, the concept of intrinsic hybrid composites has been developed [2]. According to the intrinsic approach, the part is manufactured in a one step process, in which the shaping of the part and the connecting of the different materials is carried out. The point of weakness in hybrid composites often is the interface between the different materials. This results from the joint as itself and the strong change of the material properties. In the scope of this paper, a novel approach for the interface design of an intrinsic hybrid composite is presented. The research work is focussed on the one step production process, the surface treatment of the metallic insert, the characterisation of the interface at high strain rates and the finite element simulation of a representative volume element of the resulting composite.

2. Concept of the intrinsic hybrid composite

The investigated intrinsic hybrid composite consists of a FRP with an integrated aluminium layer (AA 6082) to improve the crash performance [3]. The applied FRP is a continuous unidirectional carbon fibre sheet with 50% fibre volume content and a thermoplastic PA6 matrix (BASF Ultramid B40). The developed interface concept enables a continuous transition between the two material classes and, thus, a continuous change of the local properties, e.g. elastic modulus and thermal expansion coefficient. Due to a combination of adhesive bonding and mechanical interlock elements, the strength of the interface can be increased. Generally, the utilisation of different joining techniques has got high potential to enhance the ultimate load, the maximum deformation and the energy absorption capacity [4]. However, the realisation of these joining requires additional production steps. Contrary, a production process, which enables the generation of the part geometry, the creation of the mechanical interlock elements and the hybridisation of the hybrid composite within one production step, is developed. For this purpose, the forming is simultaneously applied on two geometric scales. On the macroscopic level, a conventional thermoforming process is carried out to generate the global shape. On the mesoscopic level, the mechanical interlock elements are formed (cf. Fig. 1a) [2]. The metallic insert is a plane structure during the global forming process and, thus, does not affect the thermoforming process. Despite this, the metallic insert has an

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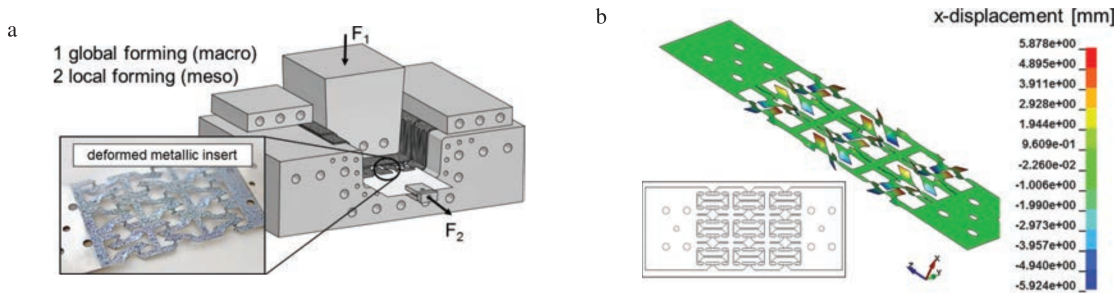

Fig. 1. Investigated production process: (a) Forming process; (b) Forming simulation of the metallic insert.

innovative geometry, which allows the generation of the form fit elements under a tensile force [5]. The developed geometry and the resulting out-of-plane deformations of the form fit elements are depicted in Fig. 1b. The tensile force is applied just before the lower dead centre of the global forming process. Consequently, the form fit elements are pressed in the molten matrix material of the FRP and a mechanical interlock between the fibre rovings and the matrix material is generated. For quantifying the resulting undercut, joining experiments are performed. To this end, hybrid composites are produced under varying the joining temperature and the joining pressure. The interface is analysed by metallographic cross sections. Figure 2 shows the cross sections from the manufactured intrinsic hybrid composite. According to Figure 2, no delaminations in the interface are observed as a consequence of the manufacturing process. However, the manufactured hybrid is not free from cavities. To decrease the amount of cavities, additional foils of pure matrix material are placed between the FRP and the metallic insert. The remaining undercut between the metallic insert and the fibres are measured along and perpendicular to the fibre direction. The measured values are in the dimension of 25% of the thickness of the hybrid part.

3. Generation of the interface based on a sol-gel coating

An important precondition is the generation of an appropriate interface for the material compatibility of the heterogeneous materials systems of the metal insert and the FRP. The aim of producing a suitable coating systems is to achieve a maximum adhesion by combining coating and functionalisation methods. Carbon fibre reinforced polymers are often seen as particularly critical. Contact corrosion between the noble fibre-reinforced polymer (redox potential of +0.35 V in 3% NaCl) and the less noble aluminium substrate (redox potential of −0.55 V in 3% NaCl) has to be avoided. The organically modified silicatic layers, produced by a sol-gel process, can be considered as isolators. Thus, one of the advantages of the sol-gel coatings is a high corrosion barrier. Another important advantage of the sol-gel coating is the optimisation of adhesive interactions between heterogeneous partners in the hybrid component to achieve the best possible connection. The aim of this work is the development of a formulation for a sol-gel coating on aluminium before the forming process. For this reason, the chemical surface composition of the coating is changed in order to produce higher interactions from the selected matrix out of PA 6. 3 samples (EN-AW 6082 T6, 25 mm × 100 mm × 3 mm) of each parameter set were ultrasonically degreased in ethanol, dried in air and subsequently pickled for 2 min in 3% NaOH solution. After rinsing in distilled water, the samples were treated in boiling distilled water for 30 min in order to produce a dense Böhmite layer (aluminium oxide hydroxide). After rinsing and cooling in distilled water, the samples were dipped in a 40 wt. – % sol-gel solution, dried in air at room temperature for 1 h and additionally dried for 2.5 h at 150 °C [6]. Subsequently, some samples were treated with a 4 wt. – % solution of a silane (chlorotrimethylsilane [CAS75-77-4], octadecyltrimethoxysilane [CAS3069-42-9], N-(2-aminoethyl)-3-amino-propyltrimethoxysilane [CAS1760-24-3]) in xylol for 30 min at 130 °C. The thermal joining with PA 6 stripes (BASF

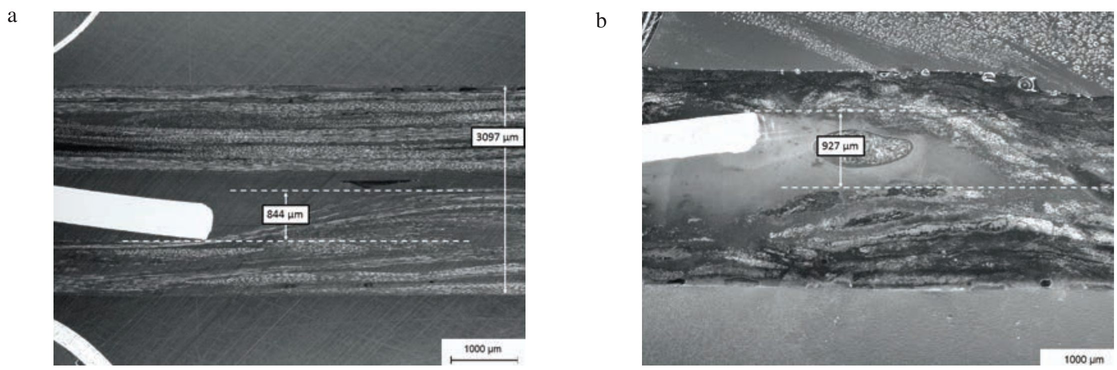

Fig. 2. Results of joining experiments: (a) Cross section in the fibre direction; (b) Cross section perpendicular to the fibre direction.