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# Development of novel form-locked joints for textile reinforced thermoplastices and metallic components

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ABSTRACT

Lightweight constructions in multi-material-design, especially the application of textile reinforced composites in combination with metallic components, gain increasing relevance, e.g., in automotive engineering. To ensure an optimal load bearing capability of the hybrid structure, it is essential to provide adapted joining technologies.

In this paper a new joining technology to produce hybrid structures with continuous fibre reinforced thermoplastics and metallic components is introduced, adapting the concept of classical clinching for thermoplastic composites. The technological concept of the thermoclinching process was successfully tested by manufacturing, testing and both non-destructive and destructive analyses of firstthermoclinched joints.

## 1. Introduction

In recent years, aspects like resource consumption and energy efficiency gain increasing relevance within the development of lightweight structures, e.g., for automotive applications. Currently, especially the multi-material design is focussed in many research and development activities, aiming to take advantage of the specific structural and functional properties of different materials. In this context, hybrid structures made of continuous fibre reinforced thermoplastics in combination with metallic materials have proven to be very efficient, due to their adjustable high-level mechanical properties and the ability of an effective and reproducible manufacture in short cycle times using the pressing technology. One of the main challenges during the development of such hybrid structures is to provide specific joining technologies, considering the load bearing capability, the specific properties of the combined materials and the associated manufacturing processes.

Classical joining technologies like bonding, riveting and joining via loop connections are established for manufacturing of continuous fibre reinforced composites with thermoset matrices. Hereby, bonding is known for its flexibility regarding the material combinations, but often requires an extensive surface pretreatment of the joining partners as Bishopp (2005) described for structural bonding applications used in the aerospace industry. Higashi and Lima (2012) and Wilson et al. (2012) have displayed that bolted and riveted connections are common and proven joining methods for aviation, according to their high reproducibility and fast joining processes. Since the holes which are needed for these connections are usually manufactured by drilling, the fibre reinforcement is locally interrupted and the component is structurally weakened in those areas (Thoppul et al., 2009). Beside this, Liu et al. (2012) have shown that drilling of composites can cause specific problems such as local delamination and high tool wear. Furthermore, the need of additional joining elements increases the weight of the joining area. To fasten continuous fibre reinforced composites without any pretreatments such as surface treatments or hole drilling, Ueda et al. (2012) tested a modified self-piercing riveting process. Although a significantly reduction of the process time was achieved, the process-related unpredictable interruption of the fibre reinforcement is inadequate to generate joints in structural components. The integration of special joining zones during processing of thermoset composites, like Hufenbach et al. (2006) have shown for loop connections or Rispler et al. (2000) for metallic inserts, is state of the art but very labour intensive.

In contrast, the manufacturing of such joining zones in fully automated process chains for thermoplastic composites is highly complex and often requires the adaption of the manufacturing technology and the process setup, as shown by Hufenbach et al. (2011) for producing bolted joints in textile thermoplastic composites or by Blaga et al. (2013) for joining thermoplastic composites and metallic parts with an adapted riveting process. Additionally, adhesive bonding of most thermoplastic composites is

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problematic due to low surface polarity and a lacking surface wettability as shown by Gotoh and Kikuchi (2005), resulting in an extensive surface pretreatment and therefore being not very efficient in the scope of high-volume applications.

A promising approach for the manufacturing of joining zones in thermoplastic composites is the use of its repeatable meltability to build form-locking joints by plastic deformation. Thereby, state of the art technologies to build short and long fibre reinforced hybrid joints are for example injection clinching joining, presented by Abibe et al. (2011), or ultrasonic staking, described by Troughton (2008). However, considering that continuous reinforced thermoplastic composites only provide a limited plastic deformation range, established joining technologies based on forming short and long fibre reinforced thermoplastics are only partly transferable.

In the presented investigations a novel joining technology for manufacturing hybrid components with continuous fibre reinforced thermoplastic composites and metallic joining partners was developed in accordance to the metallic clinching process and first laboratory scaled joining zones were produced. Furthermore, the joining zones were analysed by means of experimental and analytical methods.

## 2. Process development

The development of the new joining technology is based on process sequences from the metallic clinching process, which is an established method to join double- or multi-layered metallic structures. According to the aimed production of form-locking joints with thermoplastic and metallic components by plastic deformation, for this process no additional joining elements are required. During clinching, the metallic joining partners are partial interspersed by a punch and afterwards compressed using a die, whereby a non-detachably joint is created by cold forming alone (Grote and Antonsson, 2009). However, the increased application of high-strength steels combined with aluminium or magnesium materials has lead to developments such as single-staged clinching with a pre-punched pilot hole (Meschut, 2006), also known as CONFIX-clinching (Wöbner, 1998). For this technique the non-ductile material is pre-punched, arranged at the die side and interspersed from the ductile joining partner, as displayed in Fig. 1.

To join metallic components with fibre reinforced thermoplastic structures, the new joining technology “thermoclinching” intends a plastic deformation process similar to the CONFIX-clinching.

Thereby, the composite is pre-cut in the joining zone and locally heated to increase its plastic deformation ability, shifted through the pre-punched metal sheet and compressed from the backside to generate a form-locked joint. The principle procedure of the novel thermoclinching process is shown in Fig. 2.

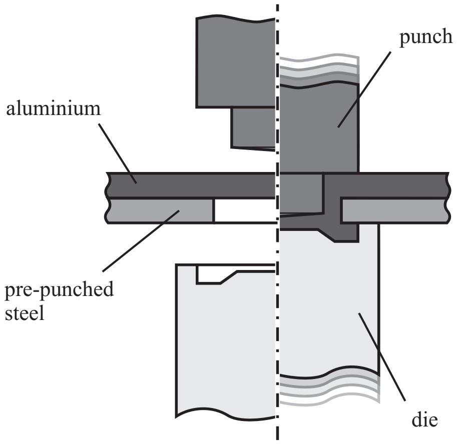

**Fig. 1.** Schematic illustration of the single-staged clinching process with a pre-punched pilot hole (CONFIX).

In particular, the process starts with the positioning of the aligned joining partners inside the mould. The following heating process (Fig. 2(a)) further increases the plastic deformation ability of the pre-cut thermoplastic composite and enables the tapered pin to permeate the joining zone. Subsequently, the mould is closed and the tapered pin is shifted forward into the composite, shifting thermoplastic matrix and parts of the textile structure through the pre-punched pilot hole of the metallic joining partner (Fig. 2(b)). Immediately after this step, the passed-through material is compressed by the ring shaped die, forming out the form-locked head of the joint (Fig. 2(c)). After cooling and solidification the mould is opened and the geometrical defined joint is removed (Fig. 2(d)).

Thereby, compiling a defined fibre orientation of the composite in the neck and head area and without the necessity to apply any additional or ancillary joining elements, a high lightweight potential of the thermoclinched joining zone can be achieved.

## 3. Manufacture and analysis of thermoclinched joints

In order to demonstrate the capability of this novel process, first thermoclinching joints were manufactured using a laboratory-scaled experimental joining installation with defined mould, pin and die geometry (Fig. 3).

As specified in Table 1, the general processing investigations were performed on exemplary materials using thermoplastic composite sheets made of glass fibre reinforced polypropylene (GF/PP) known as TWINTEX (N.N. (2008)) in combination with pre-punched steel sheets as joining partners. Though, alternative materials and reinforcement structures such as carbon fibres and thermoplastic laminates are expected to be also suitable for the thermoclinching process. Their adapted transmission into processing is intended for further investigations once the thermoclinching process is

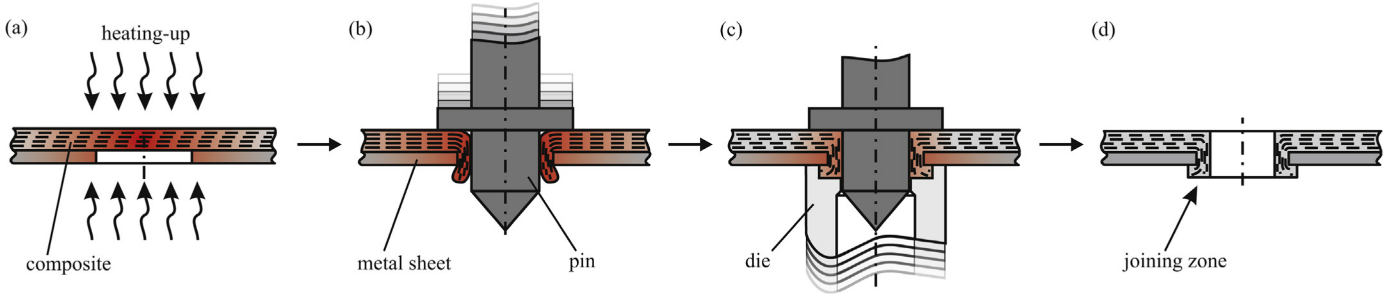

**Fig. 2.** Schematic illustration of the novel thermoclinching process: (a) positioning of the joining partners and heating-up of the 0.55,0,0 pre-cut joining zone, (b) permeating of the fibre reinforced structure with the tapered pin, (c) forming of the undercut with the die and (d) demoulding of the thermoclinched joint.