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Hybrid technologies for joining ultra-high-strength boron steels with aluminum alloys for lightweight car body structures

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Abstract

Lightweight design in car body engineering enables the reduction of energy consumption and greenhouse gas emissions of cars, which is crucial to fulfill the increasing legislative restrictions and market demand for eco-friendly mobility. The challenge is to realize more lightweight and at the same time still rigid and crash-stable car bodies, that are affordable for a large-scale production. For cars for high volume markets, an intelligent load-oriented multi-material design with intensive use of ultra-high-strength hot-stamped boron steels combined with modern aluminum alloy sheets and cast is often the optimal solution, as these materials offer a great weight reduction potential at reasonable costs. The lack of suitable cost-efficient joining technologies for these material combinations is one of the most important barriers for the realization of affordable cars in volume productions. This paper presents and overview about recent developments and research results for suitable joining technologies.

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1. Introduction

In recent years, the European automotive industry is focusing on the development and implementation of innovative technologies to reduce fuel or electric energy consumption of cars, e.g. by lightweight design. Measures often focus on the implementation of various lightweight materials like advanced high-strength steels, aluminum or magnesium alloys and fiber-reinforced plastics into the car body structure. Driven by the diverse and locally different requirements on a car body structure, multi-material design is the most common approach to weight reduction in the car body among car manufactures [1]. Not all of the mentioned materials are yet affordable for a large-scale production.

For cars for high volume markets, an intelligent load-oriented multi-material design with intensive use of ultra-high-strength hot-stamped boron steels (UHSS) with tensile strengths up to 1,650 MPa in structural parts combined with aluminum alloy sheets as skin or floor panels is often the optimal solution, as these materials offer a great weight reduction potential at reasonable costs. [2]

Due to the reduced solubility of Fe in Al at room temperature and the resulting formation of brittle intermetallic phases, standard automotive welding processes such as resistance spot welding are not applicable in series production environment [3]. Developments for a controlled formation of the intermetallic layer size by controlled heat input are not applicable in series production environment, when it comes to join boron steels with the typical Al-Si-coating [2].

Therefore, the focus is on adhesive bonding, combined with mechanical joining technologies. Established mechanical joining processes suitable for multi-material joints like self-pierce riveting (SPR) or clinching can reach their process limits due to the high strength and low ductility of UHSS. [4]

This requires further improvement of existing mechanical joining technologies or the development of new suitable

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methods with high productivity. High productivity especially includes short process times, none or inexpensive auxiliary joining elements as well as fast and simple positioning of the joining equipment. A prerequisite for fast positioning is that the parts to be joined require no previously punched or cut holes in the parts for the joining process. [2]

This paper presents four innovative productive methods for joining boron steel parts with aluminum sheet.

2. Introduction of innovative joining technologies

2.1. Self-pierce riveting with solid high-strength rivets

Self-pierce riveting with solid rivets allows joining punch-sided high-strength materials with die-sided ductile materials. Fig. 1 shows a process illustration. After a fixation of the parts to be joined by the blank holder, both parts are punched by the rivet. The following increase of the process force results in a penetration of the die-sided material by the emboss ring of the die. The die-sided material is plastically deformed and partially flows into the circumferential groove of the rivet, whereby a positive lock is formed (see image 3 in Fig. 1).

In contrast to classic self-pierce riveting with semi-hollow rivets (see Fig. 2), the process does not require to form the rivet plastically to create a positive lock. This allows utilizing rivet materials with very high tensile strengths and high hardness, which enable a process-capable punching of boron steels with the solid rivet. However, this requires relatively high process forces for punching the parts to be joined and forming the interlock.

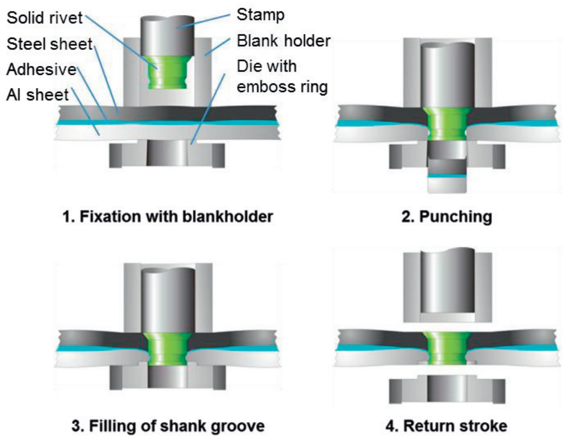

Fig. 1: Illustration of process steps for self-pierce riveting with solid rivet.

As already described above, it is mandatory to use adhesive together with a mechanical joining technology in order to exploit the lightweight potential of the materials.

Due to the high process forces of the SSPR process and the forming of the interlock by a relatively large plastic deformation of the die-sided material, adhesive is squeezed out of the joining zone, resulting in locally different adhesive layer thickness. In addition, spring-back effects of the die-sided sheet can occur, when the joint is released from the joining equipment during return stroke (see Fig. 2, left image). This spring-back results in gaps in the adhesive layer. These effects drastically decrease the strength of the hybrid joint due to a reduction of the effective adhesive area. Furthermore the vulnerability of the joint against corrosive media increases, due to less isolation of the materials by the gaps in the adhesive layer. Several recent research projects performed by the LWF focussed on the optimization of the hybrid joint. The development of a new rivet geometry in combination with a modification of the setting tools (blank holder and die) lead to a large improvement of the quality of the adhesive layer and therewith to significantly higher strengths of the hybrid joints, see Fig. 2. The developments also work for multi-layer joints with boron steels. [5]

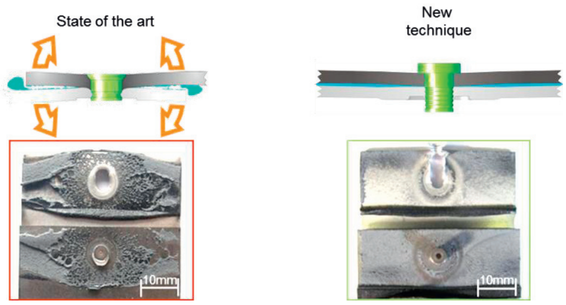

Fig. 2: Optimization of the self-pierce riveting process with solid rivets for improved adhesive layer structure

2.2. Local conditioning of the joining zone

Established and mature joining processes such as self-pierce riveting with semi-hollow rivets (SPR) or classic non-cutting clinching processes fail to join boron steel in fully martensitic condition due to its brittleness, high tensile strength and hardness.

For typical boron steel parts, such as b-pillars or rockers, are already several technologies available, which enable to realize in the same part areas with different mechanical properties (soft/hard) for an improvement of the crash performance of the part. This is done by a modified heat treatment during or after the hot-stamping of the boron steels, resulting in different metallic structures with different mechanical properties.

This principle can be transferred to the requirements of established mechanical joining technologies. The so-called local conditioning is a separate process step after hot-stamping. It was developed in a recent public-funded research project [6]. During the process, a short-cycle heat treatment, e.g. by robot-based induction or laser equipment, is applied locally limited to the areas, where mechanical joining is necessary in the subsequent assembly process. The controlled energy input allows various temperature profiles and therewith to transform the martensitic structure partially or fully into annealed martensite, bainite or ferrite-perlite. [2; 6] This permanently transformation is only locally, while the global part properties are not affected. The mechanical properties of the joining zone can be adjusted to the specific requirements of the various mechanical joining technologies