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Application of Tailor Heat Treated Blanks technology in a joining by forming process

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ABSTRACT

The usage of modern materials in the automotive industry for the body in white construction leads to increasing requirements for the manufacturing process. Due to the limited formability of high-strength aluminium alloys and steels, joining by forming of these dissimilar materials is still a big challenge, which requires suitable and innovative manufacturing technologies. In sheet forming processes the Tailor Heat Treated Blank (THTB) technology allows enhancing the formability of high-strength aluminium alloys. Therefore, the applicability of the THTB technology for the shear-clinching technology is investigated in this paper. Up till now, this innovative joining by forming technology is only qualified to join ductile aluminium alloys and high-strength steels, but the combination of high-strength aluminium and high-strength steel has not been realized yet. In this research work, the limits of the shear-clinching process have been extended to successfully join the material combinations of AA7075 on the punch side and HCT780X, as well as press hardened 22MnB5 on the die side by using aluminium specimens with different heat treatment layouts. Further, this paper shows the possibility to adjust the material flow of the shear-clinching process by local and short-term heat treatment.

1. Introduction

Because of recent legislative developments concerningthe automotive industry, the reduction of CO_2 emissions has acquired new significance and urgency (European Parliament, 2009). The reduction of vehicle weight is one possibility to cope with this challenge. However, simultaneous demands for higher comfort and safety of car passengers counteract this approach. The implementation of an intelligent material mix of dissimilar materials in the car body structure is one way to make a compromise in this matter. Nevertheless, the combination of different lightweight materials causes the need for modern production processes.

On the one hand, forming limits of aluminium alloys are mostly lower in comparison to mild steels. Therefore, an approach was invented, in which precipitation hardenable aluminium alloys are locally heat treated to soften the blank in specific areas and create a tailored blank with an adapted material flow (Geiger et al., 2009). This modifies the forming process and enables the use of aluminium for complex geometry parts. On the other hand, due to the combination of dissimilar materials like aluminium and high-strength steel, new production requirements have to be met regarding the joining operation. One example for an innovative joining solution is the so-called “shear-clinching” technology (Busse et al., 2010), which combines a single stage cutting and joining process and allows joining of dissimilar materials, like ductile aluminium alloys and ultra-high strength steels, without any additional process steps or auxiliary elements. However, as soon as both materials are of high-strength nature, for example, if a high-strength aluminium alloy is used, necking occurs, because of insufficient formability of the punch-sided joining partner. To overcome these limitations, the applicability of the Tailor Heat Treated Blank (THTB) technology to improve the process limits of the shear-clinching operation is investigated in this paper. Therefore, an experimental setup with preceding short-term heat treatment will be used to successfully join punch-sided high-strength aluminium alloy and die-sided dual phase as well as press-hardened steel. The joints without and with heat treatment are compared by microscopic measurements and the influence of different heat treatment layouts on the joint formation as well as on the joint strength will be analysed. In the last step, the results will be summarized and an approach to adjust the material flow in the shear-clinching operation will be presented. But first, the state of the art of THTB and shear-clinching technology is given in the following.

2. State of the art

Due to the substitution of mild steel materials, the usage of aluminium alloys in the automotive industry has significantly risen in the

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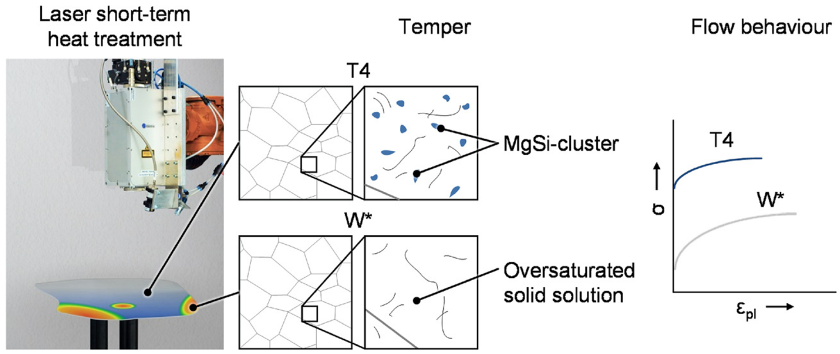

Fig. 1. Tailor heat treated blank technology.

past 30 years (Hirsch, 2011). However, this development was often complicated by the low formability of aluminium and resulting unstable production processes of complex car body parts. One approach extending the forming limits of aluminium alloys of the 6000 series is the application of Tailor Heat Treated Blanks (THTB) (Geiger et al., 2009). By a short-term heat treatment (retrogression heat treatment) the MgSi-precipitates are partially dissolved in the aluminium matrix (Fig. 1). This state will be called W* throughout the investigations. Thus, fewer obstacles hinder the dislocation movement and the strength of the material is reduced. If the heat treatment is applied locally, the result is a tailored blank with soft and hard zones, wherefore the material flow in forming operations can be controlled, stresses in the forming area are reduced and forming limits can be increased (Vollertsen et Lange, 1998). Subsequently, the blanks are formed after the heat treatment at room temperature. Therefore, conventional tools, handling systems and lubricants can be used.

The basis for this application was laid in 1953 by Siebel and Beisswänger (1953). They investigated the softening of pre-strained blanks by a short-term heat treatment. This effect was mainly associated with recrystallization and recovery effects. Nevertheless, results were hardly reproducible because of the used heating technology. However, the invention of laser technology and its use as industrial standard laid the foundation of THTB. Various investigations were performed regarding the local heat treatment of aluminium blanks to improve the formability in deep drawing processes. The gained results contain the material characterisation of different alloys in dependency of ageing processes and the numerical analysis and optimization of heat treatment layouts up to the design of near-series parts with THTBs of 6000 aluminium alloys (Vogt, 2009).

In recent years, aluminium alloys of the 7000 series, that combine high-strength and low weight, became more and more popular. Nevertheless, formability is even more limited in comparison to the 6000 series. As a logical consequence, investigations regarding the local softening of high-strength 7000 series aluminium alloys were established (Degner et al., 2015). After the heat treatment, hole expansion tests, as well as deep drawing test with a cross die tool, were conducted. A reduction of edge crack sensitivity, as well as an improvement of formability, was derived from the results.

A major trend in automotive construction is the use of different materials according to respective local requirements, a so-called intelligent material mix. Thus, joining technologies in general and mechanical joining operations in particular gain more importance due to the need to connect dissimilar and therefore limited weldable materials for achieving a significant reduction of car body weight without decreasing passenger safety and comfort (Groche et al., 2014). Nevertheless, the combination of aluminium and steel, as well as other materials with a high discrepancy in strength and low formability, is a big challenge. Therefore, various investigations are dealing with the improvement of mechanical joining operations (Mori et al., 2013). The usage of flow drill screws, for example, is one method to join dissimilar materials with or without pre-drilled holes. However, there are limitations regarding the minimum thickness of the joining materials as well as problems with galvanic corrosion (Martinsen et al., 2015). Self-pierce riveting is another possibility to join different types of materials (Hnrob, 1993), but is limited, when it comes to joining of ultra-high-strength materials. A solution to this problem was presented by Mori et al., who developed FE-optimized rivets (Mori et al., 2006). In addition, Hahn et al. introduced new rivet geometries as well as tool concepts to improve joint strength and adhesive layer distribution between the blanks (Hahn et al., 2014). In the field of clinching similar problems are encountered. With the increasing strength of the joining partners, for example, when ultra-high strength steel sheets are used, the interlock and in consequence the joint strength is decreasing (Abe et al., 2014). One method to improve the joining result is the use of modified die geometries to control the material flow during the clinching process (Abe et al., 2012).

Although methodologies and technologies regarding joining are advancing, the combination of dissimilar high-strength materials is still a big challenge for mechanical joining processes. For example materials like ultra-high strength steels as well as high-strength aluminium alloys are still declared as only conditionally joinable in clinching processes because of their high tensile strength of over 500 MPa and their low uniform elongation. (DVS/EFB, 2012) Because of this reason, another promising approach is the heat treatment of joining partners before or during the joining process to change the mechanical properties and achieve higher joint strength (Neugebauer et al., 2011). The research work of Lambiase (2015) deals with the improvement of clinch joints of precipitation hardenable AlMgSi-alloy EN AW-6082 by heating the blanks directly before the joining process. The heat treated blanks are transferred to the testing rig, where they are joined in a warm state. By this method, a significant increase of indentation, as well as a higher shear joint strength, was obtained. Similar results were acquired by Huang and Yanagimoto (2015) with inductive heating of thin blanks of EN AW-6061 T6 and X5CrNi18-10. Regarding semi-hollow riveting, Jäckel et al. (2016) investigated the possibility of reducing failure of 7000 and 6000 series aluminium blanks. By retrogression heat treatment at 225 °C for 3 s directly before the joining process, the onset of crack formation can be delayed. In investigations conducted by Reich and Osten, a short-term heat treatment was done by a laser, which was integrated into the clinch-punch. Therefore, the ductility of aluminium (Osten et al., 2015) and press hardened steel (Reich et al., 2014a) was increased to improve the joining process. In addition, this process was investigated in detail by thermo-mechanical simulations (Reich et al., 2014b). These studies increase the ability to join non-ductile materials, but until now the practicability is limited due to high requirements of warm forming processes as well as the complex process control and the joinable material combinations. Therefore, the development of innovative joining operations for the combination of aluminium alloys and high-strength steel sheets are an active field of investigation for the body in white production (Kleiner et al., 2003).