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Towards Simulation of Geometrical Effects of Laser Tempering of Boron Steel before Self-Pierce Riveting

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Abstract

The automotive industry is continuously developing and finding new ways to respond to the incremental demands of higher safety standards and lower environmental impact. As an answer to weight reduction of vehicles, the combination of boron steel and composite material is being developed along with their joining process, self-pierce riveting. Boron steel is an ultra-high strength material that needs to be locally softened before the joining process. However, the joining process deforms the part. This paper investigates factors affecting the geometrical deformation during the tempering process and lists important phenomena that need to be included when simulating the tempering process.

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Keywords: boron steel, laser tempering, self-pierce riveting, distortion, hot stamping, residual stresses, geometry assurance, thermo-mechanical simulation.

1. Introduction

Sustainability requirements in the automotive industry are increasing when demands for lower energy consumption are getting significant. Likewise, the vehicles need to preserve and improve safety of the driver and in traffic.

The automotive industry is continuously pursuing innovative ways of creating lighter but safer vehicles. Most often, safety improvements in the vehicles come from the addition of active and passive safety systems, which represent a higher mass and thus higher CO2 emission. Additionally, the incursion of the electric and hybrid cars requires the car structures to be lighter in order to compensate the weight increase from the batteries. Consequently, new lightweight materials and combinations are being developed for the car body in order to fulfil prior requirements.

One classified lightweight material, used to meet the requirements of lightness, stringer safety regulations, emissions reduction and performance is Ultra High-Strength Steel (UHSS) and in that category boron steel belongs [1]. SAAB Automobile AB was the first automotive company who used boron steel for a component inside its SAAB 9000 [2]. Since then, the application of boron steel components has increased and today it is used in parts such as A-Pillars, B-Pillars, bumpers, roof rails, rocker rails and tunnels [3]. With increased variety of materials new challenges arise in the area of joining two materials with different properties.

One way of joining materials is mechanical joining; under this classification self-pierce riveting (SPR) can be found. One of the advantages of SPR, compared to more traditional methods of sheet material joining is the ability to join dissimilar materials [4]. In this paper, the aim is to contribute to the development of a robust process for mechanical joining of non-compatible materials based on SPR. The SPR allows weight reduction by extending the use of different materials which are hardly possible to join with steel by the use of conventional joining techniques, e.g., welding. The SPR process interlocks boron steel to composite material with the help of extra material. In order to pierce boron steel, it needs to be softened in advance. To do this, the boron steel part is locally tempered using a laser, which

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reduces the hardness of the material but also causes geometrical defects, such as distortion of the structure.

Geometrical variation in parts and in the assembly process is a problem that affects the size, shape and other requirements of subassemblies or final products. This may cause problems when assembling the parts or might result in final products not meeting the functional or aesthetical requirements [5]. Activities aiming to avoid this kind of problems are often referred to as geometry assurance. The geometry assurance activities comprise tasks such as finding robust locating schemes, variation simulation and tolerance allocation [6].

In order to predict the geometrical impact of the tempering process it is necessary to attain relevant information about the root causes of the deformation and then simulate the process to optimize important parameters and factors such as laser parameters and sequence of tempered points. This paper aims to find these root causes and gathers necessary phenomena that are important in order to conduct reliable simulation of the heat tempering process.

The part that will be studied in this paper is an A-Pillar of a newly released SUV from an automotive company. This part is made of Usibor 1500 steel, a 22MnB5 boron steel with an Al-Si layer, which is a special kind of steel intended for hot stamping processes. In the case study section of the simulation model, the variation simulation tool RD&T is used since it fulfilled the needs of the study. RD&T is a software for Robust Design and Tolerance Analysis that is used to analyse functions of different stages of a design process such as stability analysis for general robustness of the design, variation analysis for predicting variation in critical dimensions of the design and contribution analysis that presents ranked list of points and tolerances, contributing to measure variation [7]. RD&T does also provide functionality for non-rigid analysis and joining sequence analysis that are used in this study [8].

Simulation of laser tempering of UHSS with respect to geometrical deformations is a relatively new research area and the input to this paper was gathered through studies of research within the field of welding sequences and simulations, heat treatments, boron steel and manufacturing processes of boron steel parts.

1.1. Scope

This paper presents the root causes of geometrical defects after heat treatment of hot stamped, boron steel parts. The case study illustrates the simulation of the tempering process using RD&T software and theoretical support from existing literature.

In Section 2, literature studies are presented. The material characteristics of boron steel are introduced, along with the most significant production process steps of the A-pillar and their consequences. Section 3 covers the case study of the tempering process where different sequences are simulated and compared using RD&T. Section 4 covers the discussion of the work, how it was achieved, recommendations and next steps for further development. Finally, the paper is summarized with its important findings and conclusions in Section 5.

2. Theory

Boron steel offers the possibility of reducing the car body weight 30-50% compared to cold formed parts [9]. Adding boron to a steel alloy is a very cost effective way of increasing its hardness compared to using other elements; maximum hardness is achieved with small amounts of it, ranging from 0.0003 to 0.003% [10].

On the microstructure level, boron has the effect of delaying the transformation of martensite to bainite, ferrite and pearlite structures, which are softer. If boron were not present, these softer structures would be formed during the cooling process after austenitization, after annealing or hot working [10].

The manufacturing process of a part, made of boron steel, consists of several process steps. Every step affects the material characteristics and create changes in the part that may influence the geometrical behaviour in later steps of the manufacturing process. One characteristic step in manufacturing process of boron steel parts is hot stamping. UHSS materials have a very high hardness resulting in high impact on tools, reduced formability and a tendency to springback. Therefore, the part needs to be heated prior the stamping step, which decrease the strength and hardness of the material.

The material therefore needs to be locally softened by laser tempering to conduct the SPR. This heat treatment is effective for reducing its hardness, but causes geometrical deformation.

2.1. Hot Stamping

A new forming technology had to be developed to improve the formability of UHSS. Hot stamping was developed first by a Swedish company, Plannja, in 1977 which used the forming process to produce saw blades and lawn mowers [11]. Today the same manufacturing method is used in the automotive industry for UHSS. According to [12], hot stamping is defined as “a non-isothermal forming process for sheet metals, where forming and quenching takes place in one combined process step”.

When the boron steel sheet enters this stage of the process the microstructure of the material is ferritic-pearlitic with ultimate tensile strength of about 600 MPa and yield strength 450 MPa. With this method, the blanks are heated inside a continuous-feed furnace up to a temperature between 900 and 950°C for 4 to 10 minutes. At that temperature, the microstructure of the material transforms to austenite and has high formability, so that shapes that are more complex can be formed in a single stroke. It is transferred automatically to an internally cooled die within three seconds. During the cooling process the formed part is quenched in the closed die that is internally cooled by water circulation at cooling rate of 50 to 100 °C/s. A diffusionless martensitic transformation is induced, which results in higher strength of the part. The process of transferring, forming and quenching the part takes 15 to 25 seconds [13]. To reach fully martensitic structure the cooling rate must be higher than 50 °C/s [12]. The changes are summarized in Table 1.