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Combined hot stamping and Q&P processing with a hot air partitioning device

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ABSTRACT

Combining the hot stamping process and a Quench and Partition (Q&P) heat treatment can improve the mechanical properties of hot stamped automotive parts. This paper investigates using a new heating device to heat or cool a part to a given temperature. Instead of performing the partitioning heat treatment in a furnace, this work proposes using a new hot air process that performs the partitioning treatment. The new device obtains a fast heating rate and a uniform temperature distribution, necessary for Q&P. The effect of partitioning time and temperature on the mechanical properties of parts were analyzed by the new processing method, which is suitable for use in the area of industrial hot stamping. The results show that the hot air partitioning device provides more control over the partitioning temperature because convection is more efficient than radiation. Control over the quench temperature and partition is critical for the Q&P process to enable the carbon diffusion to stabilize the austenite. Furthermore, the highest product of strength and elongation (1380 MPa × 13%) using the hot air process under the authors' set-up condition is obtained when the partitioning time is 60 s and the temperature is 425 °C, thanks to the optimum ratio between martensite and austenite, which was observed through scanning electron microscopy.

1. Introduction

Currently the automotive sector is motivated to reduce the weight of each vehicle, while improving its safety performance during collisions (Fan et al., 2009). It is, therefore, urgent to produce ultra-high-strength energy-absorbing automotive structural parts, and thus hot stamping has become a popular technology (Karbasian and Tekkaya, 2010). The general process of direct hot stamping is where the blank is heated in a furnace above the austenitic transformation (AC3) temperature. Next, the uniformly austenitic blank is quickly transferred to the cold stamping tooling. Then, the blank is formed and quenched under the pressure of the press to create a fully martensitic part (Thomas et al., 2008). Hot stamping is an applicable technology with many advantages, and through this process, parts with more than 1500 MPa Ultimate Tensile Strength (UTS) can be produced (Merklein and Lechler, 2006). These parts satisfy the first objective of high strength and weight reduction, however, they do not necessarily provide higher energy absorption (Wang and Feng, 2011).

The increasing demand for safe vehicles requires automotive parts to not only have high strength, but also good ductility. Matlock et al. (2003) found that retained austenite can improve the ductility of steel after heat treatment. Therefore, hot stamping and carbon partitioning can be combined to form a new type of hot stamping quenching and partitioning process (HSQP), which is illustrated in Fig. 1 (Liu et al., 2015). Firstly, the blank is heated to the austenitizing temperature. Then, the blank is formed and quenched to the quenching temperature (between the start transformation temperature (M_S) and finish transformation temperature (M_F) of martensite) to form the microstructure of the initial martensite and retained austenite (Speer et al., 2003). Next, the blank is heated to a higher temperature to complete the carbon partitioning process, during which the carbon in the martensite is diffused into the austenite, and the final microstructure of the martensite and retained austenite is obtained (Edmonds et al., 2006). Jirková et al. (2012) concluded that the increase of the partitioning temperature influences the intensity of martensite tempering and causes the decrease of tensile strength, but the growth of ductility (Thomas and Speer, 2014). Clarke et al. (2009) studied the effect of partitioning time on the carbon diffusion process and found that partitioning time has a significant influence on the retained austenite content. The parts created through this method have good ductility at

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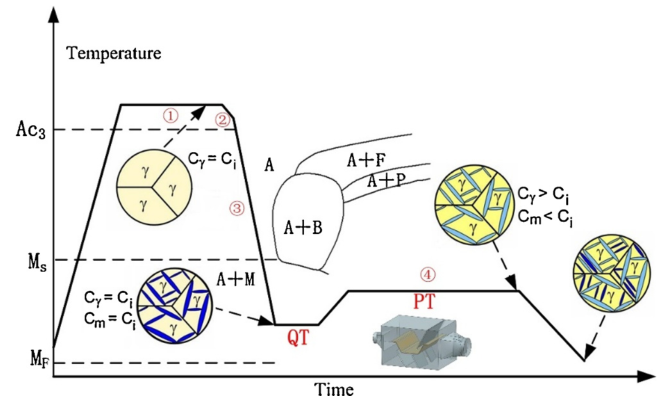

Fig. 1. Process chart of HSQP (Liu et al., 2015).

the expense of slight strength reduction, which has significantly improved product of strength and elongation (PSE) (Zhou et al., 2011). In the previous study (Liu et al., 2015), the samples was directly hot stamped and the tensile strength was 1812.92 MPa and the total elongation was 4.95%. In this study, 1380 MPa in tensile strength and 13% in elongation were obtained through the proposed process, which present good combination of strength and elongation together with relatively high PSE (near 17,940 MPa%) in comparison with conventional directly hot stamped parts (PSE near 8974 MPa%).

Currently, methods for carbon partitioning in the HSQP process for formed sheet parts are limited, and mostly exist at the laboratory scale for individual samples or parts. The most common approach is to perform carbon partitioning in a furnace (Zhang et al., 2015). This method heats the blank through radiation heat transfer, which has a slow heating rate and the partitioning effect is seriously affected, where the parts cannot reach the required temperature in a suitable time. Meanwhile, the salt bath method is also used for carbon partitioning. Although the temperature uniformity of this method is good, but it is expensive and not environmentally friendly, which consequently limits its applications. Furthermore, the salt bath approach is not suitable for large volume production. To address these issues and improve the partitioning effect in heated samples, this paper proposes a new method, hot air partitioning. Hot air partitioning is based on the principle of using heat convection, and temperature change is achieved through the convective heat transfer between the flowing air and the hot stamped part. The biggest advantage of this approach is the rapid heat transfer (Poozesh et al., 2013). This approach heats the parts within a short time, while obtaining a uniform temperature distribution. Therefore, the final performance of the part is improved and more robust. In summary, this paper will introduce the hot air partitioning device for the HSQP process. The heat characteristics of the hot air partitioning will be studied. Finally, the effect of partitioning time and temperature on the final performance of parts will be also investigated.

2. Design of the hot air partitioning system

Hot air partitioning has more advantages than conventional heating of a blank in a furnace. In this method, the thermal response is extremely fast and the parts can be quickly heated to partitioning temperature. The temperature distribution showed that the maximum difference in within 50 °C, which was detected by the infrared thermal imager. Moreover, after heating for 20 s, the temperature difference in the locations between flange, floor and sidewall is below 30 °C, which was measured by thermocouple. Most importantly, the target temperature can be reached quickly by initially overheating the air and changing the flow of hot air. As a result, partitioning can be performed steadily and the performance of the parts is improved effectively. This section will first outline the structure of the partitioning device, and then analyze the performance of the hot air partitioning device by a computational fluid dynamics simulation of the system.

2.1. Structure design of partitioning device

The hot air partitioning system is composed of two components: the hot air generating component (consisting of a heater and an air blower) and the partitioning box, where the parts are heated and kept at controlled temperature.

First, the hot air generating component is required to provide the partitioning box with continuous and stable hot air. The output air temperature must be adjustable within a range of 200 °C–500 °C. Currently, there is off-the-shelf equipment already available to heat the air. Therefore, we chose an industrial circulating hot air machine, which can recycle the hot air. When choosing the air heater, air-blast power and heating power, which are used to ensure temperature stability and speed, are the main parameters that should be considered. Given there is hot air leakage and heat loss, a larger hot air heater should be selected than that theoretically required to produce the results. In the authors' experience, there is approximately a 15% loss of heat. Therefore, the machine with an air-blast power of 370 kW, 11.5 m^3/min, and heating power of 15 kW was chosen.

Hence, the partitioning box to hold and heat the part must be designed. The most important factor for this design is to ensure uniform and effective heat convection between the part and the flowing hot air, which requires an optimization of the structure. The authors in this work only considered U-shaped parts. Therefore, the envelope of the partitioning box was designed according to the U-shaped die, and the main body of the partitioning box is a 340 mm × 240 mm × 220 mm box. To improve the heating efficiency and temperature uniformity, three structural models of the partitioning box were proposed, where the air guide plates were carefully arranged at positions and orientations around the part. A numerical analysis of the temperature field on the U-shaped part was conducted, and the optimum design was selected. Fig. 2 shows the three proposed structural box models (Model1, Model2, Model3).

2.2. Numerical analysis of the temperature field in the partitioning box

This section explains the computational fluid dynamics modelling conducted on the partitioning box. CFX software ANSYS 15.0 was used to simulate the coupled heat transfer between the air flow and the U-shaped part in the partitioning box model. The heating process of the part in the partitioning box is not only related to the heat convection with hot air, but also the heat conduction in the solid metal parts. In

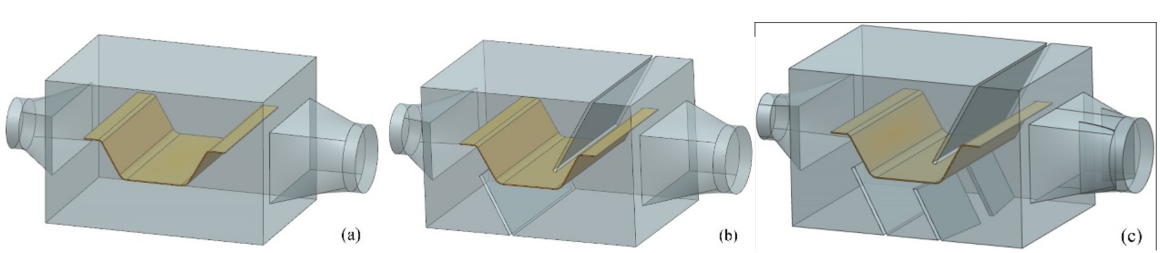

Fig. 2. Three proposed structural models: a) Model1; b) Model2; c) Model3.