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Sensitivity of the final properties of tailored hot stamping components to the process and material parameters

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ABSTRACT

The final mechanical properties of hot stamped components are affected by many process and material parameters due to the multidisciplinary nature of this thermal–mechanical–metallurgical process. The phase transformation, which depends on the temperature field and history, determines the final microstructure and consequently the final mechanical properties. Tailored hot stamping parts – where the cooling rates are locally chosen to achieve structures with graded properties – has been increasingly adopted in the automotive industry. In this case, the robustness of final part properties is more critical than in the conventional hot stamping parts, where the part is fully quenched. In this study, a wide range of input parameters in a generalized hot stamping model have been investigated, examining the effect on the temperature history and resulting final material properties. A generic thermo-mechanical finite element model of hot stamping was created and a modified phase transformation model, based on Scheil's additive principle, has been applied. The comparison between modeling and experiments shows that the modified phase transformation model coupled with the incubation time provides higher accuracy on the simulation of transformation kinetics history. The robustness of four conditions relevant to tailored hot stamping was investigated: heated tooling (with low and high tool conductance), air cooling, and conventional hot stamping. The results show the high robustness of the conventional hot stamping compared to tailored hot stamping, with respect to the stamped component's final material properties (i.e. phase fraction and hardness). Furthermore, tailored hot stamping showed higher robustness when low conductivity tools are used relative to high conductivity tools.

1. Introduction

Hot stamping has been used for many years to produce high strength structural automotive components. The high tensile strength achievable by hot stamping is beneficial where the intrusion during a vehicle crash is not desirable – e.g. for the vehicle occupant compartment. On the other hand, there is a need for high ductility in the crumple zones to absorb crash energy via plastic work. Fig. 1 shows an example of a B-Pillar component, where both requirements should be satisfied. To achieve increased ductility in the local zones of the final part, the cooling rate during hot stamping should be slower than the critical value of 20 °C/s–30 °C/s (depending on the steel grade) to produce softer steel phases such as bainite, ferrite and pearlite in these zones. The local adjustment of the final properties within different areas in a single part using hot stamping is commonly referred to as tailored hot stamping. In tailored hot stamping, the accurate prediction of the temperature history is critical to determine the final phase fractions and the hardness values. Unlike the conventional hot stamping process, which has been well established in production for a number of years, the tailored hot stamping process is new and still needs more attention in terms of specification of the final mechanical properties as functions of the input (process and material) parameters.

The main challenge in the accurate prediction of the final mechanical properties in the hot stamped components is the accurate prediction of the temperature history and the phase transformation kinetics. As shown in Fig. 2, there are a large number of interacting thermal–mechanical–metallurgical parameters that must be considered. When designing the tailored hot stamping process, each of these parameters must be carefully considered so that the desired cooling rates (and resulting microstructure/properties)

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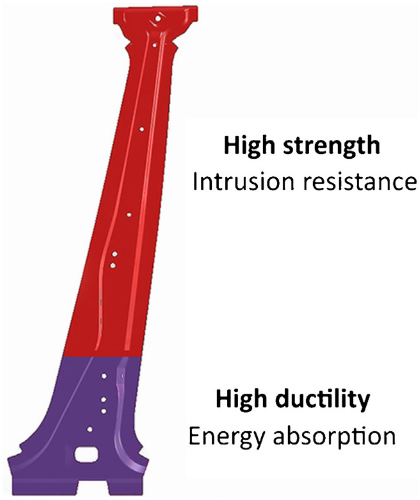

Fig. 1. A sample B-Pillar with tailored mechanical properties.

are achieved precisely during production. Therefore, a sound understanding of the influence of each of the parameters on the temperature history and final phase fractions is necessary. Some researchers have investigated the effects of some of the input parameters on the phase fraction and/or the final mechanical properties, with tool temperature being the most common parameter examined. Feuser et al. (2011) showed that increasing the tool temperature from 200 °C to 400 °C decreases the tensile strength by about 32%. The same decrease in the Vickers hardness has been reported by George et al. (2011) for the same change in the tool temperature. The effects of the tool temperature and the heat contact conductance between the blank and tool material on the temperature history have been shown by Oldenburg and Lindkvist (2011). It was shown that the most important parameter is the tool temperature, while the process sensitivity to the heat contact conductance is low. The effects of tool temperature, contact pressure, transfer time, die closure time and the blank thickness on the tensile strength and bending angle have been investigated by Feuser et al. (2011), which seems to be the most comprehensive parametric study in this field to the authors' knowledge. The fully martensitic microstructure in the final component was achieved at tool temperatures below 200 °C and the tool temperatures higher than 400 °C was necessary to obtain other phases. At tool temperature of 500 °C, other parameters had less significant effects due to the cooling down and keeping the specimens at a temperature higher than martensitic start temperature. No clear dependency of the material properties to the process parameters was observed in this case. This implies the necessity of more investigations to obtain a better understanding of the process sensitivity with respect to even more input parameters at different process conditions.

In this study, a thermal–mechanical–metallurgical model of a simple hot stamping process is created. The model includes internal dependencies of many parameters and a modified phase transformation model – based on JMAK-type equations and Scheil's additive rule with the inclusion of incubation time for the austenite decomposition into ferrite, pearlite and bainite – which increases the accuracy of the results. The paper provides detailed explanation of the mechanical–thermal–metallurgical model used, and validation of selected results with experimentation and the literature, which will be of benefit to future studies in this area.

Based on the developed and validated model, a series of parametric studies have been performed under four different process conditions. The significance of this study is the consideration of a large number of input parameters which is the first comprehensive parametric study in this field. In this study, the sensitivity of the phase fractions and the final mechanical properties to an arbitrary variation of ±10% in the input parameters have been investigated for four process scenarios. These scenarios were chosen to simulate a conventional hot-stamping process, and three possible methods in which tailored hot stamping can be achieved. The purpose is to understand the sensitivity of the hot stamping process to small variations of the input parameters under a number of operating condition scenarios.

2. Methodology

2.1. Thermal–mechanical model

The finite element software ABAQUS Standard V6.12 was used to simulate the hot stamping of a simple hat-shaped component (Fig. 3), including transfer from furnace to the tool, forming, quenching and air cooling processes. The model does not include a blank holder, representing the crash-forming-type process often used when hot stamping long structural members. The flange region of the part, which is typically formed by the blank holder in traditional stamping processes, is formed by the action of the top tool (punch) at the end of the forming stroke (as shown in Fig. 3). Symmetry boundary conditions were applied to the blank and tool which allows just one quarter of the geometry to be modelled.

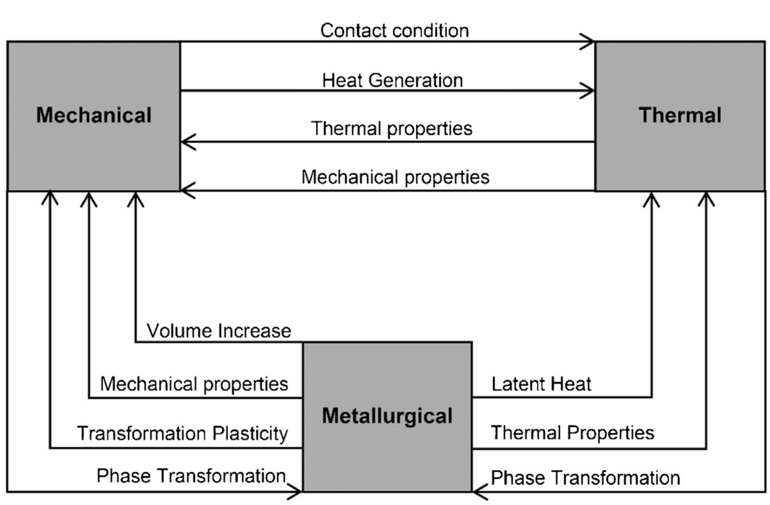

Fig. 2. Interaction of thermal–mechanical–metallurgical parameters in hot stamping modelling (Karbasian and Tekkaya, 2010).