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Effects of phase transformation in hot stamping of 22MnB5 high strength steel

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Abstract

In automotive industry, hot forming of high strength steels offers the possibility to obtain significant reduction of weight without affecting the structural performances of the car-body-in-white. The sheets used in the hot stamping process are heated above the austenitization temperature, and, then, formed and quenched in cooled dies by using a minimum cooling rate of 27°C/s in order to obtain the direct martensitic transformation from the initial austenite. However, improper transfer times from the furnaces to the dies may be unacceptable with regard to the phase changes to be realized during the quenching. Furthermore, strain induced effects influence the phase transformations, so making the process difficult to design and control in case of new part shapes: variations of the applied strains determine changes in the Continuous Cooling Transformation (CCT) curves and, consequently, the cooling rate becomes fundamental to control the material phase transformations, in order to obtain the desired mechanical properties. The paper investigates the effects of the soaking time and cooling rate in the nose area of the CCT curves, where the time represents a critical aspect to control the phase changes in the microstructure. It was found that the phase transformations at the critical temperature of 550°C determine an increase of the flow stress that depends on the specific cooling rate during the dies quenching and on the percentage of bainitic transformation.

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Keywords: hot stamping, 22MnB5, phase transformation, martensite, austenite.

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1. Introduction

Due to the increasing demand of vehicle weight reduction, safety improvement, as well as improved crashworthiness, high strength steels (HSS) and ultra-high strength steels (UHSS) as well as new forming processes at elevated temperatures have become more and more popular to manufacture automobile structural components [1]. The hot stamping of HSSs is a non-isothermal sheet metal forming process where the blank is formed in a single step that combines forming at high temperature with fast quenching using cooled dies [2,3]. The blank, which initially has a ferritic-pearlitic microstructure and low mechanical properties, is heated in a furnace above the austenitization temperature and maintained long enough to lead to the formation of a homogenous austenitic microstructure. Then, it is transferred to the press where it is simultaneously formed and quenched at a minimum cooling rate of 27°C/s by means of continuously cooled dies. At the end of the cycle, the part reaches a fully martensitic microstructure, with strength levels above 1500 MPa [4]. Thanks to the final martensitic microstructure, the reduced springback and the adequate formability that HSSs exhibit at elevated temperatures, thinner and more complex sheet metal parts can be produced with a high or very high strength-to-mass ratio and high geometrical accuracy as well, such as A-pillars, B-pillars, bumpers, roof rails, rocker rails and tunnels [5-9]. Despite its advantages, hot stamping is a complex manufacturing process where the properties and quality of the final part are strongly affected by the material and the numerous parameters in the thermo-mechanical cycle, such as strain- and strain rate-paths, temperature and microstructure evolution that mutually interact during the forming and the cooling stages. The investigations on ultra-high strength steels have shown that boron alloys are the only steel grades which produce a fully martensitic microstructure after hot stamping when a water-cooled tool is used [10]. 22MnB5 is the most commonly used steel grade in hot stamping processes, both direct, when coated with AlSi coating, and indirect, with other type of coatings [11]. If the cooling rate exceeds a minimum cooling rate of approximately 27 K/s, at a temperature of around 400 °C, a diffusionless martensitic transformation will be induced, which finally is responsible for the resulting high strength of the part (Fig. 1) [12]. The martensite transformation begins at 425 ◦C (martensite start point M_s) and ends at 280 °C (martensite finish point M_f) [13]. The mechanical properties of steel after quenching change in dependence on its carbon content and consequently, the strength after quenching can be controlled by a proper adjustment of the carbon content. The alloying elements, such as Mn and Cr, are known to have only a small influence on the strength after quenching. However, since these elements have an influence on hardenability, they are essential for shifting of existence fields. Thus, the desired phase transformation and hardenability is achieved by technically feasible cooling rates [14]. Boron is the element that influences the hardenability the most, whereas boron slows down the conversion into softer microstructures and leads to a martensitic microstructure over the cross-section of the part.

The paper aims to investigate the influence of austenitization temperature, testing temperature and strain rate on the final properties of the 22MnB5 steel sheet, analyzing the true stress-true strain curves along with the microstructures of the tested samples.

2. Experimental procedure

The 22MnB5 sheets, 1.5 mm thick, were tested by hot tensile tests in order to obtain the true stress – true strain plots. The specimens were cut following the 0° orientation of the sheets and have standard dimensions. Fig. 1 shows the apparatus used for the tensile tests: it consists on a MTS hydraulic dynamometer having a maximum load of 50 kN and a FELMI frontal inductor with a maximum power of 30 kW and a frequency of 100-250 Hz, which allows heating the specimen up to 950°C. The temperature of the gauge length of each temperature was measured through a thermocouple spot welded on the gauge length of each specimen, in order to monitor and control the temperature during the heating cycle.