Modelling of 22MnB5 hot stamping process coupling microstructural evolution

MODELLING OF 22MNB5 HOT STAMPING PROCESS COUPLING MICROSTRUCTURAL EVOLUTION

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Abstract

Recent trends in the automotive sector show a big interest in reducing CO_2 emissions, while demanding better vehicles safety by regulations. This represents new challenges for the body-in-white components lightweight design. Hot stamping of High Strength Steels (HSS) parts has proved in recent years to be one of the solutions. Due to the complexity of the process, the design of the production cycle requires the use of finite element techniques to evaluate how the microstructural changes can affect the formability of the material. The development of accurate numerical models is a key to improve the capabilities of the hot stamping process. Regarding HSS, this requires the calibration of a proper material model, which enables simulation of phase changes that occur during the hot-stamping process. In this context, the aim of the paper is to develop a numerical model of the hot stamping process being able to predict failure occurrence in 22MnB5 sheets characterized in different microstructural phases. The validation of the model is provided by the comparison between experimental and numerical outcomes of Nakajima tests.

1. Introduction

The hot stamping process of HSS sheets is one of the most successful manufacturing technologies developed in the last decade to achieve the goal of producing lightweight structural components for the automotive sector. The high formability of the HSS at elevated temperature allows complex safety component geometry. and it is possible to reduce the blank thickness in order to save weight and, reduce the fuel consumption, improving safety [1]. To fully exploit the capabilities of this process it is necessary to control both the thermal path undergone by the material and its deformation to achieve the final shape without failures. During the austenitization stage, it is mandatory to control the temperature and soaking time to control the initial austenitic gran size that influences the subsequent forming process [2]. Then, the blank is handled from the oven to the press and should be formed while still in the fully austenitic phase, being the latter the phase with the best formability. However, due to possible delays in the handling time as well as to the superimposed effects of stress and strain with the cooling process, phase transformations may start during deformation [3]. If this happens, the microstructural changes the material experiences while forming may provoke drastic variations in the mechanical properties of the stamped component [4]. Furthermore, cracks or defects may occur in the final components, as a consequence of the reduced formability of phases other than the austenitic one. With this regards, in order to enhance the design of the hot stamping process, it is necessary to take into account how the microstructural changes can affect the formability of the material. The aim of this paper is therefore to study the effects of microstructural changes during the forming process by means of a numerical model of the hot stamping process, which is able to predict the failure occurrence in 22MnB5 sheets under different microstructural conditions. The numerical model of the process was developed within the Ls-Dyna^{TM} environment, and made use of the material model 244_UHS_STEEL [5] to take into account the mechanical behaviour of the different phases that may form during the forming process. Nakajima tests were carried out under different thermal cycles in order to test the sheets formability under different microstructural conditions. The results of such tests were compared with the results of the developed numerical model to assess its capabilities in predicting the formability limits under the investigated conditions.

2. Nakajima testing and modelling

In order to study the formability of 1.2 mm 22MnB5 steel sheets with variable microstructure, a series of Nakajima tests were conducted and then numerically simulated. The experimental equipment, schematized in Figure 1a, consists of a punch (1) equipped with a series of heating cartridges, a blank (2) placed between a die (4) with its counter die (3), heated through an inductor head (5) and cooled with a series of air nozzles (6). Each test was filmed with two CCD cameras and then the images series were analysed with Aramis^{TM} in order to obtain the true major and minor strains needed to draw the FLD. In the numerical model, the tools, namely the punch, die and counter die, were represented as rigid bodies, while the blank was a deformable body. Boundary conditions between the tools and the blank, namely thermal exchange and friction coefficients, were set on the basis of [6]. The die and the counter die were set to 120°C according to the thermal camera measurements conducted during the tests.

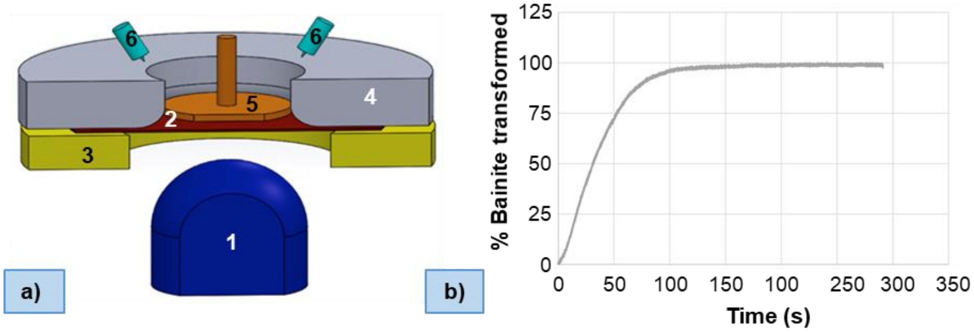


Figure 1: a) experimental equipment scheme, b) Saturation curve for 22MnB5 at 600°C.

The material model used for the blank was the 244_UHS_Steel, which allowed the introduction of the stress-strain curves of the pure phases: in this work, austenite and bainite were considered, whose flow curves were obtained through hot tensile tests at different temperatures and strain rates. The other parameters inserted were the chemical composition of the steel, given by ArcelorMittal [7], the thermal expansion coefficients [8], and the elastic moduli of the different phases at high temperature, obtained from tests with the extensometer.

Three different microstructures were obtained during the Nakajima tests following specific thermal cycles. The austenitization cycle was the same for the three conditions, namely heating up to 950°C, and then soaking at this constant temperature for 6 minutes. After cooling at 80°C/s to the testing temperature of 600°C, the specimen was kept at this temperature for different soaking times: 5 s for the pure austenite tests, 30 s for the 50%

austenite + 50% bainite tests, and 200 s for the pure bainite tests. The soaking times were obtained from the saturation curve in Figure 1a: this plot represents the percentage of austenite transformed into bainite at constant temperature with increasing time. After the soaking time, the specimen was stretched by the punch until fracture in nearly isothermal conditions, since the punch was kept at 600°C by conduction heating. The repeatability chosen for this experimental campaign was 5.

3. Results

The results of the experimental and numerical Nakajima tests are reported in Figure 2. It can be seen that there is a very good agreement in the cases of pure austenite and pure bainite, while the 50-50 case shows a less good fitting. This is probably due to the fact that, during the deformation of the specimen, the phase transformation went on, and, at the moment of fracture, the percentage of the two phases might not be 50% austenite-50% bainite, but it might be closer to 40% austenite-60% bainite. Since the numerical simulation was capable of modelling the phase transformation during cooling, and not at constant temperature, this might have caused the differences between experimental and numerical data. From the reported data it is worth noting that the phase transformation from austenite to bainite caused a shift to lower values of major strain, meaning that the a bainite-based material is less formable and a crack during deformation can easily occur when other phases than austenite are present in the blank.

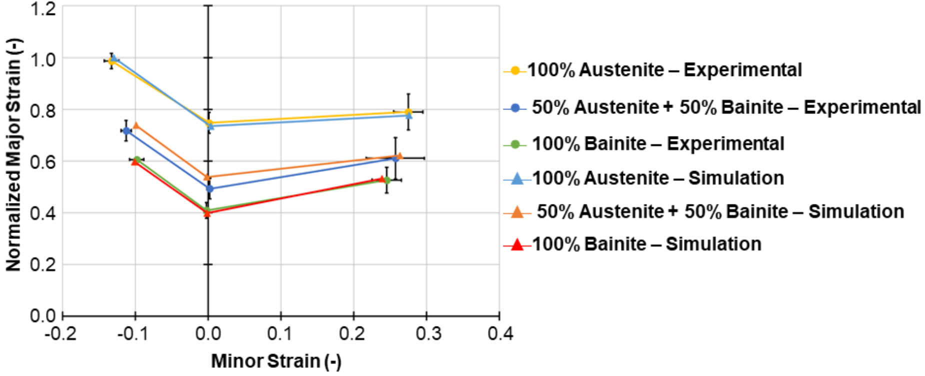


Figure 2: Experimental and numerical FLDs at varying microstructure.

Figure 3 shows the comparison between the measured and simulated thickness reduction of the different specimens. It can be seen that the percentage of reduction is lower in the case of pure bainite with respect to pure austenite. This means that the material can be stretched less during deformation, which may cause unwanted cracks in the most stretched areas of the blank.

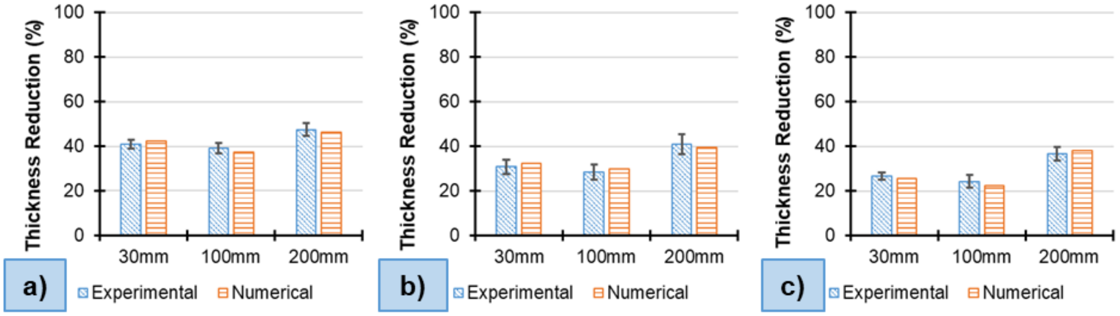
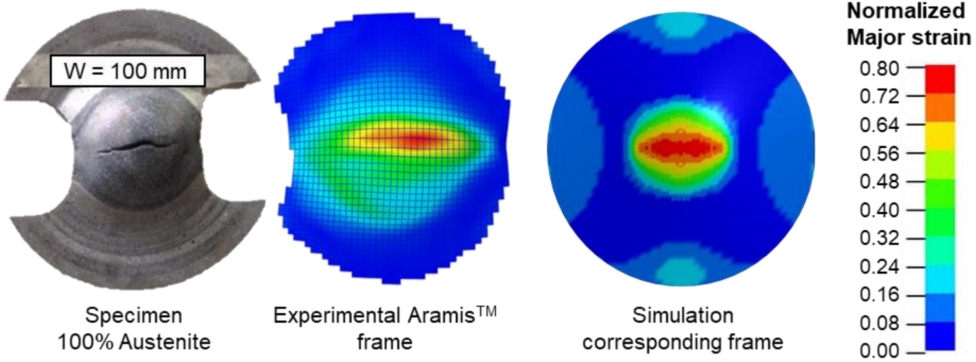


Figure 3: Experimental and numerical thickness reduction: a) 100% A; b) 50%A-50%B, c) 100% B.

Figure 4 shows a comparison between the experimental Aramis™ frame and the corresponding simulation frame of the 100mm geometry of the 100% austenite case. It can be seen that the distance of the fracture from the centre of the specimen is almost the same in the two cases, underlying the good accuracy of the numerical model. The numerical simulation cannot predict the localization in one specific region because there are no preferential areas with concentration of defects, which causes the concentration of the strain and subsequent fracture.



Specimen
100% Austenite

Experimental Aramis™
frame

Simulation
corresponding frame

Figure 4: Experimental and numerical normalized major strain, 100% bainite case.

4. Conclusions

Nakajima tests were conducted and simulated within the Ls-Dyna™ environment to study the formability of 22MnB5 characterized by different microstructures. The experimental results show a decrease of the material formability with increasing percentage of bainite in the specimen. The numerical simulation can predict the final FLDs, with a better agreement in the case of pure bainite and pure austenite. The thickness reduction is higher in the case of pure austenite and lower in the case of pure bainite, the latter indicating a lower stretching of the material before failure.

5. References

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