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Hot formability of DIN 27MnCrB5 steel sheets under controlled thinning

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A B S T R A C T

Hot stamping has been widely studied and increasingly applied in the automotive industry. This process is characterized by its ability to stamp high strength steels, yielding products with high mechanical strength, thus reducing the weight of stamped components and therefore the vehicles weight. It also demands less energy because steel sheets can be heated by induction, more efficient than electric furnaces. With controlled thinning, it is possible to manufacture thinner stamped parts with high mechanical strength, therefore it is necessary to know the formability limits to prevent failure and achieve the largest possible thickness reduction. In this work the hot formability of DIN 27MnCrB5 steel sheets 4 mm thick, under thinning conditions was evaluated by numerical simulation with the finite element (FEM) software Forge2008. Tensile tests were carried out at 500, 600, 700, and 800 °C and with strain rates from 0.1 to 4 s^{-1}. With the results of tensile tests, it was possible to calculate Hensel–Spittel coefficients to model the steel sheet and simulate the hot Nakazima test to evaluate the highest dome which could be formed without failure risks caused by sheet thinning. Simulation results obtained with specimens 200 mm long and 125, 150 or 200 mm wide that were stamped at 930 °C, showed the radial position and dome height associated to plastic instability as well provided the thickness distribution along the specimen. The numerical results were compared to experimental tests and showed a good agreement in terms of failure initiation and localization. As a result, a new numerical and experimental strategy was elaborated to define the hot formability based on the plastic instability and necking localization as a function of stamping temperature and blank dimensions. This strategy proved to be useful to define the safe formability region and therefore the larger thickness reduction that can be done during hot stamping to reduce vehicular components weight and to avoid cracks and failures usually observed in components like clutch covers.

1. Introduction

Hot stamping presents a wide application in the automotive industry from external components that define the vehicle body-in-white to internal structural components which require durability, rigidity and impact resistance that conventional cold stamping cannot match without subsequent heat treatment (Karbasian and Tekkaya, 2010).

Many recent researches have been published analyzing important aspects of hot formability, focusing on materials behavior and products quality. Turetta et al. (2006) states that the restricted application of hot stamping in industry is due to the lack of basic knowledge on mechanical and microstructural characteristics of sheets at elevated temperature, boundary conditions, sensitivity of the formed component geometrical and mechanical characteristics to all process parameters. To overcome part of those restrictions, they present a novel test based on the Nakazima's which allows the determination of sheet formability, reproducing the hot stamping conditions in terms of cooling rates and phases distribution during and after deformation.

Bariani et al. (2008) present an innovative experimental procedure, based on Nakazima test, for evaluating the formability limits in hot stamping a high strength steel (22MnB5) which is capable of generating formability data suitable for simulating the process by numerical methods. They concluded that the thermal, mechanical and microstructural parameters determining the onset of localized necking and fracture could be individually controlled during the tests which results can provide the formability data in the form of combinations of strains that cause the onset of necking and fracture

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Table 1
DIN 27MnCrB5 steel – chemical composition (weight %).

C	Si	Mn	P	S	Cr	B
0.24–0.30	<0.40	1.10–1.40	<0.035	<0.040	0.30–0.60	0.0008–0.0050

for given temperatures and average strain rates in the metastable austenitic phase.

Naderi et al. (2011) characterized the behavior of the steel grade MSW1200 blanks under semi and fully hot stamping processes. They concluded that the highest ductility and consequently, the best formability were achieved for the blanks which had been semi-hot stamped. They also stated that semi-hot stamping process could be considered as an improved thermo-mechanical process that not only guaranteed a high formability, but also led to ultra-high strength values.

Mohamed et al. (2012) shows a set of coupled viscoplastic constitutive equations for deformation and damage in hot stamping and cold die quenching of AA6082 panel parts. The equations can be used to predict viscoplastic flow and plasticity-induced damage of AA6082 under hot forming conditions. They found a good agreement between the process simulation and the experimental results has been achieved, confirming that the physical dependencies in the constitutive equations are correctly formed, and that the equations and finite element model can be calibrated and used for hot stamping of AA6082 panel parts.

Li et al. (2013) described the material yield and flow behavior of 22MnB5 steel during hot stamping by an advanced anisotropic yield criterion combined with two different hardening laws. They also constructed an elevated temperature forming limit based on the Marciniak–Kuczynski model.

Maeno et al. (2014) succeed to improve the formability in hot stamping DIN 22MnB5 steel sheets 1.2 mm thick by reducing the temperature drop by using a high speed servo press and spacers to reduce the contact of the sheet with the die and blankholder.

To understand the fracture mechanisms and determine the hot ductility of high-strength boron steel, Güler et al. (2014) evaluated the mechanical properties of Al–Si-coated 22MnB5 boron steel via hot tensile tests performed at temperatures ranging from 400 to 900 °C at a strain rate of 0.083 s^{-1}. They also examined the corresponding fracture-surfaces via scanning electronic microscopy, and concluded that the material presented a low hot ductility at 700 °C with a brittle fracture.

With controlled thinning, it is possible to manufacture thinner hot stamped parts with high mechanical strength like clutch covers which could present thicker regions to support the clutching loads, as well as thinner regions to reduce the component weight. Therefore, it is necessary to know the formability limits to prevent failure and achieve the largest possible thickness reduction. Despite the many researches recently published on hot stamping, few results were shown in respect to forming limits, more specifically for thicker sheets and for the boron hardenable steel DIN 27MnCrB5. In this work the hot formability of DIN 27MnCrB5 steel sheets under thinning conditions was evaluated by numerical simulation with the finite element software Forge2008. The numerical results were compared to experimental results obtained in tensile and Nakazima tests, both at temperatures and strain rates similar to those found in the actual hot stamping process.

2. Numerical and experimental procedures

To evaluate the hot formability this work was divided into two parts: numerical simulation with the Finite Element Method (FEM) software Forge 2008 and experimental tests. First, hot isothermal tensile tests were carried out to calculate the coefficients of the Hensel–Spittel constitutive equation to be used as input in the FEM software to simulate Nakazima tests which were evaluated both numerically and experimentally to obtain the Forming Limit Diagram and to define the largest possible thinning.

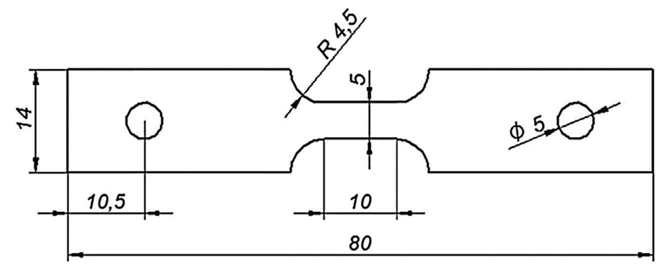

Fig. 1. Gleeble tensile tests – specimen dimensions (in mm).

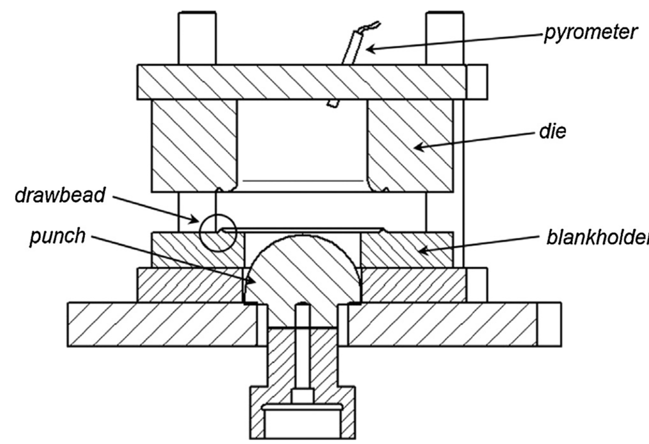

Fig. 2. Tooling setup for Nakazima test.

2.1. Hot isothermal tensile tests

Hot tensile tests were carried out in a Gleeble 3800 thermo-mechanical testing system to obtain flow curves at different temperatures and strain rates and to calculate the coefficients of the Hensel–Spittel constitutive equation used to model the DIN27MnCrB5 steel (Table 1). Specimens of 4 mm thick were cut-off by water jet according to standards ASTM E8 M-03 (tensile tests) and ASTM E 21-05 (complementary hot tensile tests) with some dimensions modified to fit to the Gleeble grips (Fig. 1). Three specimens were tested for each strain rate–temperature combination.

At first, each specimen was heated to 900 °C with a heating rate of 10 °C/s, then kept for 8 min for complete austenization, cooled to the test temperature (500, 600, 700 and 800 °C), deformed with three strain rates (0.1, 1.0 and 4.0 s^{-1}) defined in premilinary simulation of Nakazima tests, and finally cooled with a cooling rate of 60 °C/s, which is above the minimum cooling rate (37 °C/s) to form martensite in the DIN 27MnCrB5 steel (Naderi, 2007).

2.2. Numerical simulation of hot Nakazima tests

The blanks, the punch, the die and the blankholder with the drawbead were modeled and dimensioned as shown in Fig. 2 and Table 2. The blanks were modeled with a constant length (200 mm),

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