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Metastable material conditions for forming of sheet metal parts combined with thermomechanical treatment

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ABSTRACT

Developments of new forming processes become increasingly complex due to the combination of thermomechanical treatment and advanced forming technologies in manufacturing sheet metal parts. The development of this technology is coupled with better understanding of the thermomechanical behaviour of the implemented alloys in this process such as hardenable low carbon steels alloyed with austenite-stabilizing elements. Complex process conditions such as high heating rates in combination with plastic deformation, as well as cooling processes are investigated for boron-manganese steel 22MnB5. Contrary to conventional hot stamping processes, metastable material conditions are considered and subsequently implemented. Advantages are found such as increasing formability, lowered forming forces and enhanced material properties in formed components. The obtained results are successfully implemented in innovative forming processes, for example roll forming with integrated heat treatment and cushion-ram-pulsation (CRP) hot stamping processes.

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1. Introduction and state-of-the-art

Increasing demands regarding product properties such as design, weight and strength require the use of advanced steels which may be difficult to form, and associated complex forming processes for part manufacturing.

Thus hot sheet metal forming increasingly gains importance due to advantages in forming technology and materials. Particularly, the combination of rapid heating strategies and quenching strategies, combined with forming processes, enables the exploitation of material states which do not occur when forming and thermal treatment are considered separately. The phase composition of the material is significantly influenced by rapid heating and quenching. The occurring phases can be thermodynamically unstable and have a considerable influence on the forming behaviour [1–3].

In the case of press hardening, numerous research activities are known regarding forming in combination with heat treatment [4]. Components with high strengths can be manufactured by direct or indirect (with pre-forming) press hardening. Current research focuses on rapid heating [5] and the generation of parts with tailored properties using various heating or cooling strategies [6]. According to new research approaches, it is possible to combine hot forming processes with cushion-ram-pulsation (CRP) [7]. Here a superposition takes place of rapid sheet metal quenching and a deep drawing process with low-frequency oscillatory motion (10–50 Hz) when using the servo-press technology [8]. Wrinkling in the component can be avoided, and significantly greater drawing depths can be achieved compared to conventional hot forming.

Another considerable focus of development is roll forming with integrated heat treatment [9,10]. Due to integrated heating and cooling units positive effects can be achieved regarding the attainable formability and component strengths [11,12].

This paper is focused on the influence of metastable material conditions on the forming behaviour of sheet metal materials.

Based on these findings, hot forming processes can be controlled in a defined way, and component properties can be adjusted.

2. Methodology of thermomechanical treatment

In order to determine the forming behaviour under metastable material conditions, the rapid heating process and the quenching process are investigated. Deformation dilatometer experiments are expedient, analysing the occurring phase transformations and the forming behaviour in specific temperature ranges. The following method has been established:

- FE calculation of the temporal temperature change, forming temperature and strain rate [13]
- Performing of the deformation dilatometer experiments
- Comparison of the phase transformation points with calculated thermophysical variables, based on the CALPHAD method
- Development of flow curves from the force–path curves of the deformation dilatometer experiments

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- Evaluation of the flow curves regarding significant forming parameters to derive the characteristics of the sheet metal material during the forming process
- Implementation of the obtained findings into novel forming processes

The process control of the thermomechanical experiments is similar to the real process of thermally assisted roll forming and CRP under rapid cooling. The thermally assisted CRP process follows the known direct press hardening process (Fig. 1, curve a), but differs by specifically defined forming temperatures during the cooling process (Fig. 1, curves c_1 and c_2). In roll forming at high temperatures there is a basic classification of rapid heating with subsequent hot forming (Fig. 1, curve b_1) and cold forming with subsequent rapid heating (Fig. 1, curve b_2).

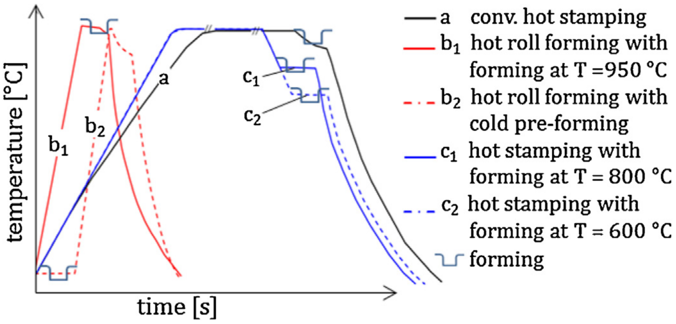

Fig. 1. Schematic presentation of the investigated process routes compared to conventional press hardening.

3. Investigations on thermomechanical treatment

3.1. Experimental setup for material properties

The tested material 1.5528 (22MnB5) is used for the experiments. It is a boron-manganese alloyed low-carbon steel (Table 1) which has become established for structural parts as a cost-efficient sheet metal material.

The experimental investigations were conducted on the deformation dilatometer BÄHR 805 T. In addition to dilatation due to thermal influences and allotropic transformations, tensile loads can also be applied using the same specimen. Fig. 2a shows the experimental setup with a hydraulic load unit and an inductor for heating the specimen. The schematic specimen shape is presented in Fig. 2b.

The investigated process window is defined according to the corresponding preliminary investigations [12,13]. Table 2 presents the relevant parameters according to which the process control is performed during the investigation as illustrated in Fig. 1.

The evaluation of the deformation dilatometer experiments is carried out regarding the phase transformation points which are presented in the CCT diagrams. Furthermore, flow curves are calculated based on the force–path curves of the deformation processes. These flow curves are investigated in terms of their onset of yielding k_{f0} and the strain hardening exponent n. The software Mathematica is used to calculate the n-value from a curve adjustment, considering the flow curve model by Hollomon [14]. Based on the chemical composition, the calculated phase transformation points are generated by using the software JMatPro.

Table 1
Chemical composition of the material 1.5528 [wt%].

C	Si	Mn	P	S	Cr	Ti	B	N
0.24	0.23	1.24	0.014	0.004	0.14	0.023	0.001	0.006

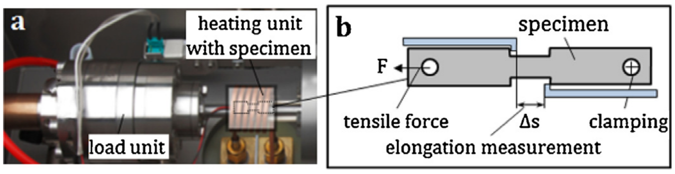

Fig. 2. Experimental setup and specimen shape at BÄHR DIL 805 T.

Table 2
Parameters for experimental investigations at BÄHR DIL 805 T.

	Rapid heating	Cooling
T_{initial} [°C]	Room temperature	900
dT/dt [K/s]	75, 110, 150	1–30
T_{forming} [°C]	900, 950, 1000	600, 800
φ [−]	To fracture	0.2

3.2. Experimental procedure for distinctive applications

The results of the fundamental investigation show that the forming characteristics of the investigated material strongly depend on various heat treatment parameters and forming parameters. In order to demonstrate the verified effects of metastable material conditions, two industrially established forming processes are modified and investigated.

3.2.1. Roll forming with integrated heat treatment

Roll forming integrates an inductive heating section and a cooling section (cooling by compressed air). A meander-shaped inductor is arranged at a distance of 6 mm above the sheet metal. Using a 25 kW high frequency generator, maximum feed rates of 1.2 m/min can be realized. First investigations comprise heating of a U-shaped profile in the last roll stands of the 9-stand roll forming system, so that a type of calibrating step takes place. Pre-formed areas of the part are heat treated. Moreover, the flexibility of the heating system allows for tempering of unformed areas at all forming stages.

3.2.2. CRP in combination with hot stamping

In the modified CRP process a blank heated up to 950 °C is formed by pulsation of ram and cushion during the ram stroke. Using a servo-driven spindle press by Dunkes and a deep drawing tool for manufacturing cups with a diameter of 100 mm, 1.5 mm thick circular blanks are formed with a diameter of 170 mm. In order to determine the maximum drawing depth, the die is designed as a drawing ring. The blank (22MnB5) is heated up in the furnace and subsequently transferred to the die. The ram with the attached die moves to a defined flange gap (sheet metal distancing). At a sheet metal temperature of approx. 900 °C forming starts with distanced drawing over a fixed punch. Then the die is stopped and the blank holder attached to the drawing cushion forms back the wrinkles and is then moved back to the predefined distance. This process is repeated until the maximum drawing depth is reached. In order to demonstrate how this type of forming is influenced when combined with rapid cooling, reference tests are performed with the conventional press hardening process. Ram speeds and distancing are varied for both process variants. When the maximum drawing depth is reached, the process ends for all tests with a holding time of 7 s.

4. Material properties under metastable conditions

4.1. Influence of rapid heating

In contrast to conventional heating with furnace technology [12], the following statements can be derived. Essential statements on the forming behaviour are investigated regarding the rapid heating processes with immediately subsequent forming processes. Thus the material tends to have a lower onset of yielding with increasing forming temperature (Fig. 3). However, the heating rate also has a significant influence on the forming behaviour in the area between A_3-temperature – at which transformation of ferrite into austenite is completed – and the homogenized austenite, as presented in the related TTA diagram (Fig. 4). The value k_{f0}

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