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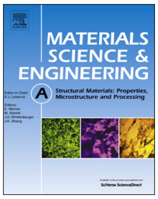

Experimental verification of tailor welded joining partners for hot stamping and analytical modeling of TWBs rheological constitutive in austenitic state

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ABSTRACT

Hot stamping of quenchable ultra high strength steels currently represents a standard forming technology in the automotive industry for the manufacture of safety and crash relevant components. Recently, hot stamping of Tailor-Welded Blanks (TWBs) is proposed to meet the environmental and safety requirements by supplying car structural body components with functionally optimized and tailored mechanical properties. In this paper, an appropriate partner material for the quenchenable boron steel B1500HS based on the phase transformation and deformation behavior under process relevant conditions is determined. It is generally accepted that the mechanical properties for joint partner after quenching process should meet the following requirements. The value of yield strength (YS) should be between 350 and 500 MPa. The ultimate tensile strength (UTS) should be within the limits of 500–650 MPa, and the total elongation (TEL) until rupture should be higher than 13%. Two kinds of High Strength Low Alloy (HSLA) cold rolled steels B340LA and B410LA are chosen for verification of which one is appropriate as joint partner. Microhardness is measured and metallographic is investigated on different base materials and corresponding weld seams. It is pointed out that the B340LA steel is an appropriate joint partner with ideal thermal and mechanical properties. An optimized Arrhenius constitutive law is implemented to improve the characterization and description of the mechanical properties of the base and joint partner, as well as the weld seam in austenitic state. The comparisons with simplified Hensel–Spittel constitutive model show the optimized Arrhenius constitutive law describes the experimental data fairly well.

1. Introduction

It is an important and consistently pursued goal of the automobile industry to reduce global CO_2 emissions by reducing vehicle weight while guaranteeing passenger safety. Neugebauer et al. [1] have pointed out that the controversial claim regarding a weight reduction while increasing passenger safety can be met by the use of high strength steel in the body. Naderi et al. [2] have stressed that the structural components can be made by high-strength steels with reduced thickness, resulting in a significant reduction in total vehicle weight.

However, there are some disadvantages of using high-strength steels, such as decreased formability and increased springback tendency as has been stated by Turetta et al. [3]. Karbasian and Tekkaya [4] have reviewed the hot stamping process in detail and demonstrated that the use of hot stamping process of boron steels has steadily increased in recent years and has been widely accepted by the automotive industry. Mori and Okuda [5] have shown that heating the sheets reduces the forming load, prevents springback, and greatly improves formability. Hot stamped components are composed of safety and crash-relevant structural components of the car body, including the bumpers, the B-pillar, the tunnel and the roof frame. These parts are shown in a typical middle class car by Karbasian and Tekkaya [4].

However, finished components used for energy absorption during a crash do not require high strength (greater than 1500 MPa). The B-pillar, for example, is a vertical structural member extending from the door sill to the roof frame that has to be able to yield in the lower part to absorb crash energy. The upper part has to stabilize the passenger cell and protect the occupants in a side impact. Maikranz-Valentin et al. [6] have proposed a new type of thermo-mechanical tailored processing based on the application of differential heating and cooling

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strategies. Bardelcik et al. [7] have examined the strength and strain-rate sensitivity of Usibor® 1500P subjected to various cooling rates ranging from 14 K/s to 50 K/s, which result in as-quenched microstructures ranging from bainite to martensite respectively. They have given a linear relationship between the Vickers hardness and percent area fraction of martensite and bainite present in the quenched specimens. Some researchers use tempering process to tailor the mechanical properties after final deformation. Labudde and Bleck [8] have post tempered the hot-formed workpiece, significantly reducing the hardness of the material from 550 HV to 290 HV. Induction tempering operation has been used by Hedegaard [9] to prevent cracking of boron steel before spot welding. They conclude that this tempering procedure results in reduced material strength, strain-hardening ratio and increased ductility. Their experiments study the resistance to material failure in 3-point drop tower test of B-pillars with tempered flanges increases as compared to fully hardened B-pillars. Tempered B-pillars can absorb approximately 30% additional kinetic energy as compared to fully hardened B-pillars at the same extent of crack initiation. Some other researchers use heating strategies to obtain functional distributed microstructure. Stöhr et al. [10] have examined differential heating within the furnace and have achieved tensile strength in the tailored region of 1100 MPa, which is much lower than the fully hardened region. Naderi et al. [2] have proposed semi-hot stamping, i.e. the blank is heated to about 650 °C and then formed and quenched in the die simultaneously. Microstructure and mechanical properties of semi and fully hot stamped blanks demonstrate that the semi-hot stamping process could be considered as an improved thermo-mechanical process resulting in a high formability and ultra high strength values. Mori et al. [11] have developed a tailored die quenching process using bypass resistance heating in hot stamping. In the process, a sheet is partially heated by bypass resistance heating and is subsequently hot stamped. Only the heated zones in the sheet are fully hardened.

In order to control the cooling rate of formed components, some other researches try to find novel tooling materials to supply variable thermal resistance. For example, Casas et al. [12] have examined new tool materials with varying levels of thermal conductivity. Compared to the traditional tooling steel which can supply the fully hardened component with final tensile strength of 1500 MPa, the lower thermal conductivity tool steel in the tailored region can produce partially hardened component with final tensile strength of 600 MPa. A lot of researchers focus on in-die heating techniques, which can prevent heat transfer from heated blank to the heated die. Hein and Wilsius [13] have partially prevented quenching in hot stamping by decreasing the cooling rate with partially heated tools. Mori and Okuda [5] have used grooved tools at the bottom dead center during the stamping. The heat transfer in the blank regions contacting with grooves will be less and lead to lower tensile strength. Svec and Merklein [14] have heated the die up to 500 °C and have achieved hardness value of 240 HV in the heated region and 420 HV in the cooled region. Banik et al. [15] have produced a laboratory-scale hot-formed B-pillar using segmented die with local heating and cooling zones such that the cooling rate of the blank is controlled locally during the hot forming process. Thus, it is possible to form regions of very high strength and regions of reduced strength but increased ductility, resulting in a part with tailored mechanical properties.

TWBs which are laser-welded with different thicknesses, have been reported in the cold forming to further reduce vehicle weight and obtain a variable distributed strength. Kinsey et al. [16] have proposed a newly contrived clamping method along the weld line in order to reduce the maximum strain. Tang et al. [17] have introduced an inverse analysis method to predict the weld line movement during forming process. If the technology of TWBs is combined with hot stamping technology, it is possible to realize specific locally adapted mechanical properties within a single component, avoiding changing the die structure and using expensive heating devices. Therefore, a 1-component solution meets the same requirements as the 2-component, providing both weight and structure optimized components. Stopp et al. [18] and Lamprecht [19] have conducted numerous experimental trials with different steel grades to select steels as complementary materials to the boron–manganese steel 22MnB5. Lechler et al. [20] have investigated the appropriate joining partner materials for the 22MnB5 and pointed out that the combination of boron–manganese steel 22MnB5 and micro-alloyed steel HX340LAD can supply lightweight components with functionally optimized mechanical properties. Lamprecht et al. [21] have carried out basic analysis related to the selection of steel grades. In addition to the characterization of the basic materials, special emphasis has been placed on the description of the weld seam properties. Therefore, it is vital to choose a suitable partner material for the boron–manganese steels to be tailor-welded. Furthermore, in hot stamping process the mechanical parameters, as e.g. friction and yield stress are temperature dependent. The definition of the flow stress as a function of strain, strain rate and temperature is essential in order to achieve reliable simulation results.

In the paper, the quenchable boron steel B1500HS made by Baosteel is selected as the safety related material. The determination of joint partner is carried out mechanically and thermally. Two kinds of high strength low alloy steels B340LA and B410LA produced by Baosteel are verified by micro/macro methods. The analytical procedure for the determination of the strain, strain rate and temperature dependent Arrhenius constitutive law is presented. Furthermore, different mathematical models are fitted to the experimental results and capabilities of the models to reproduce the test data are compared.

2. Selection of the partner material

In the paper, the Baosteel manufactured cold rolled boron steel B1500HS is used for hot stamping. In order to implement the forming process of laser-welded blanks with different locally distributed mechanical properties by hot stamping, it is necessary to identify a suitable partner material for press hardened boron steel in the automotive industry. The partner material should meet several mechanical and thermal properties after forming and quenching process, as have been described by Lamprecht et al. [21].

The ductile partner materials, which are tailor welded with high strength boron steel, should satisfy the following requirements in order to get lower hardening. The critical cooling rate for martensitic phase transformation should be much larger than that of boron steel B1500HS. Secondly, there should be small property gradients due to different cooling rates. Thirdly, there can be no abnormal grain growth during austenitizing. Finally, the joint partner should have comparably good formability at elevated temperatures to boron steel B1500HS. Besides the satisfactory thermal properties, there are also some mechanical requirements the partner material should meet. The desired yield strength (YS) is between 350 and 500 MPa, with the ultimate tensile strength (TS) ranging from 500 to 650 MPa, as well as Vickers hardness (HV0.1) ranging from 160 to 190 and with respect to a 10% total elongation (TEL).

Different potential partner materials have been chosen to impose a comprehensive material characterization. Within the scope of this study two potential complementary materials for the boron steel B1500HS are considered: cold rolled micro-alloyed steel B340LA and cold rolled micro-alloyed steel B410LA.