

Impact Testing of a Hot-Formed B-Pillar with Tailored Properties - Experiments and Simulation

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ABSTRACT

This paper presents the numerical validation of the impact response of a hot formed B-pillar component with tailored properties. A laboratory-scale B-pillar tool is considered with integral heating and cooling sections in an effort to locally control the cooling rate of an austenitized blank, thereby producing a part with tailored microstructures to potentially improve the impact response of these components. An instrumented falling-weight drop tower was used to impact the lab-scale B-pillars in a modified 3-point bend configuration to assess the difference between a component in the fully hardened (martensitic) state and a component with a tailored region (consisting of bainite and ferrite).

Numerical models were developed using LS-DYNA to simulate the forming and thermal history of the part to estimate the final thickness and strain distributions as well as the predicted microstructures. A strain-rate-sensitive constitutive model is used to model the as-quenched behavior of the hot-formed components with tailored microstructures.

With an impact mass of 300 kg and total energy of 1.7 kJ, the measured maximum impactor displacement of the tailored components was approximately 9% (7.6 mm) greater than the fully hardened components. The measured peak impact load of the tailored components was approximately 24% (9.3 kN) lower than the fully hardened components. The numerical impact models are able to capture the force-displacement and deformation trends observed in the experiments.

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INTRODUCTION

Hot forming of boron steels is an increasingly popular manufacturing process to produce ultra-high strength steel (UHSS) components for the purpose of decreasing a vehicle's mass and improving its crash performance. These hot formed components are generally used in body structure applications such as A/B-pillar reinforcements, door beams, roof rails, and other structural members [1]. The hot forming process involves the austenitization of a boron steel blank followed by simultaneous forming and quenching within a cooled tool. The rapid quenching due to the cooled tool ($>30^{\circ}\text{C/s}$) will cause a transformation of the austenite into martensite. A fully martensitic microstructure is generally desired due to its very high tensile strength to in excess of 1500 MPa.

As the tensile strength of these UHSS materials continues to increase, the ductility and elongation at fracture tends to

decrease, potentially reducing overall energy absorption capacity due to early fracture. It is due to this reduction in ductility that hot formed components are typically employed for intrusion-resistance rather than energy-absorbing structures. There is a potential to improve the energy-absorbing capability of these hot formed components by introducing regions of reduced strength and increased ductility, referred to here as "tailored properties". There are currently several methods of achieving these tailored properties, including: variable furnace heating zones, tailor-welded blanks, advanced tool materials with reduced thermal conductivity, in-die heating, and post heat-treatment [1]. The method used to create these tailored properties is through the "in-die heating technique" which is further described by George, *et al.* [2]. They have shown that by using this tool it is possible to create a part with a fully hardened region of 488

HV (1554 MPa UTS) and a tailored region of 234 HV (794 MPa UTS).

The affordability and competitiveness of future automotive vehicles is of paramount importance to manufacturers and consumers. Key factors of future products' success will depend on the application of light, smart, innovative materials. Consequently, the development of design criteria for weight reduction plays a major role for further improvements in efficiency and lower energy consumption. In the future, production vehicles will require significantly lighter structural solutions which offer the best balance in terms of performance, cost, and weight.

As a result, current industry and university collaborative research focuses on combining new materials into novel structures which includes functional integration, manufacturing, and design aspects. The development of advanced simulation tools is required to enable optimization of each structural part's performance while minimizing cost and weight.

EXPERIMENTAL PROCEDURE

Material Description

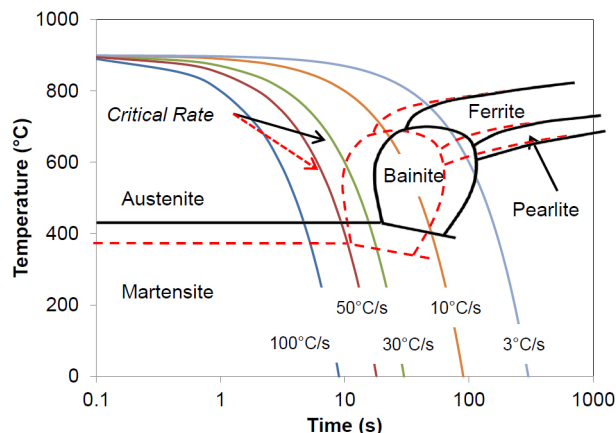


Figure 1. Continuous Cooling Transformation (CCT) diagram of Usibor® 1500P [3]. The black CCT lines represent a sample that is quenched without any imposed strain or deformation, with a critical cooling rate of approximately 30°C/s. The dotted red CCT lines show the effect of deformation on a sample that is strained during quenching, with a critical cooling rate of approximately 50°C/s.

The material used for these experiments was Usibor® 1500P; a hot-forming steel developed by ArcelorMittal. This steel is developed specifically for the hot-forming process and is very hardenable, requiring a cooling rate of 30°C/s to transform the austenite into martensite. The steel contains an aluminum-silicon (Al-Si) precoat which is in place to prevent oxidation of the steel during heating in the furnace. Figure 1 shows the Continuous Cooling Transformation (CCT) diagram of this material with the critical cooling rate

of 30°C/s highlighted. Cooling rates greater than this will cause the formation of 100% martensite, while lower cooling rates will produce a mixture of microstructural constituents such as bainite, ferrite, and pearlite. The nominal blank thickness of the material is 1.2 mm. The material was austenitized at a furnace temperature of 930°C for a total duration of 5 minutes.

Hot-Forming Tool

The lab-scale B-pillar assemblies were produced using a hot-forming tool with individually heated and cooled sections to induce various cooling rates in the austenitized blank during quenching [2]. A schematic of the tooling is shown in Figure 2, showing the location of the cartridge heaters and cooling channels. The purpose of the cartridge heaters is to raise the temperature of the tool in specific regions such that the cooling rate of the blank is reduced below the critical cooling rate. The heated and cooled sections of the tool are thermally isolated from each other by a 3 mm air gap.

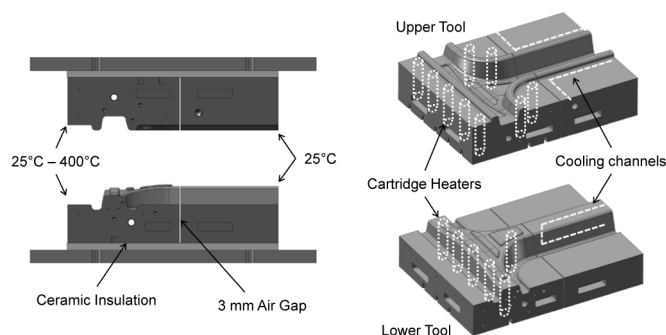


Figure 2. Schematic of the hot forming tool showing regions of heating and cooling to induce various cooling rates in the blank.

The components were produced in two configurations: fully hardened (fully cooled die) and tailored (heated tool at 400°C and cooled tool at ~25°C). Figure 3a shows a B-pillar in the tailored configuration with the location of the transition zone highlighted between the fully hardened and fully softened regions. Figure 3b shows the locations of the various hardness measurements including four point measurements (H1-H4) and two transition zone measurements (H5, H6). Figure 3c shows the Vickers microhardness distribution across the transition zone for both the fully hardened and tailored component. It can be seen that the width of the transition between the fully softened and fully hardened microstructure is approximately 45 mm at location H5 (top) and 35 mm at location H6 (sidewall).