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Hot Stamping a B-Pillar with Tailored Properties: Experiments and Preliminary Simulation Results

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Abstract

B-pillars are the key automotive components for side impact safety. The pillar must be strong enough to resist deformation during impact which can be achieved by using thick gage or high strength materials. Ultra high strength in formed sheet metal parts can reduce the weight of the vehicle and be achieved by hot stamping. However, low elongation in the hot stamping part reduces its energy absorption characteristics. To improve the crash performance and save weight, it is necessary to hot stamp components with tailored properties, i.e. variable strength and hardness throughout the part. For this purpose various techniques are used with blanks that are (a) tailored-tempered, (b) tailor welded with uniform or non-uniform thickness, and (c) tailored rolled.

The use of tailored-rolled blanks, with variable blank thickness, is a relatively new application in hot stamping for saving weight and obtaining desired local stiffness and crash performance. As shown in the experimental part of this work, tailored-rolled blanks may also cause variation in the final temperature and microstructure of a hot stamped part.

In this study, experiments and Finite Element (FE) simulations were used to investigate the hot stamping process for forming B-Pillars from (a) uniform thickness blanks and (b) tailor-rolled blanks with 2 different thicknesses. Simulations were conducted using LS-DYNA. The predicted temperature distributions are compared with data obtained from hot stamping tests. The experiments put forward the thickness transition of tailor-rolled blanks as one critical zone regarding final temperature and hardness. Preliminary simulation results cannot replicate this effect, suggesting that a refined approach is required to capture the experimental observations.

1 Introduction

1.1 Tailored Hot Stamped Parts – State of the Art

Tailored parts have been commonly used in the automotive industry to reduce the weight of components, simply by either: (1) eliminating the need for reinforcement and/or (2) to reduce the thickness in low-load areas. Use of Tailor Welded Blanks (TWB) and Tailor Rolled Blanks (TRB) in hot stamping has been studied since 2008 and 2006, respectively. In this paper, we will focus on hot stamping of Tailor Rolled Blanks (TRBs), as illustrated in Figure 1.

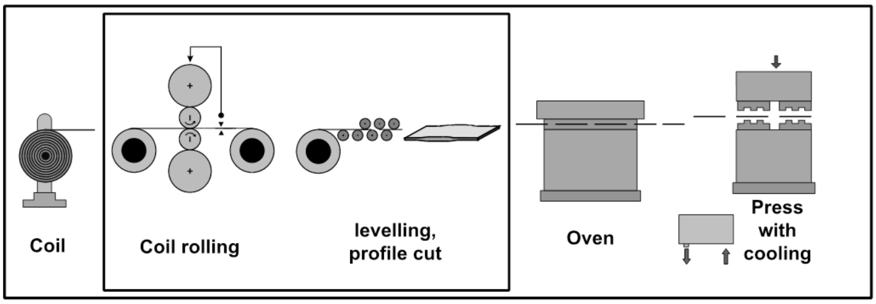


Figure 1: *Hot stamping process of tailor rolled blanks [1].*

Through a literature survey, it was found that hot stamped TRBs have been used in at least 12 recent vehicles as listed in Table 1, with respect to years when their production started (Start of Production, SOP).

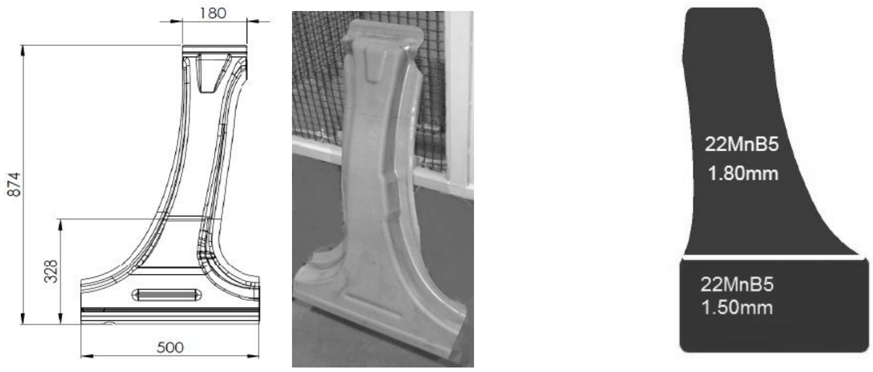
Table 1: *Hot stamped TRB application in various vehicles.*

SOP	Make / Model	Hot Stamped TRB Application	Ref
2006	BMW X5	B-Pillar, *5* thicknesses: *1.2 to 2.2 mm*, saved *4 kg*	[4]
2006	Dodge Caliber	B-Pillar, *4* thicknesses: *1.0 to 1.9 mm*	[5]
2006	Jeep Patriot & Compass	B-Pillar, 4 thicknesses: 1.09 to 1.95 mm	[5]
2007	Mercedes C	Rear bumper, *3* thicknesses, saved *2 kg*	[6]
2008	BMW X6	B-Pillar, *4* thicknesses: *1.2 to 2.2 mm*, saved *4 kg*	[7]
2010	Volvo S60	Cantrail, saved *3 kg*	[8]
2011	Audi A6	Cowl beam, *4* thicknesses: *1.0 to 1.75 mm*	[9]
2011	Ford Focus	B-Pillar, *8* thicknesses: *1.35 to 2.7 mm*, saved *1.4 kg*	[10]
2012	Audi A3	Heel piece, *7* thicknesses: *0.95 to 1.7 mm*	[11]
2012	BMW 3	B-Pillar, *3* thicknesses: *2.4 to 2.9 mm*, saved *1.3 kg*	[12]
2012	VW Golf	B-Pillar, *3* thicknesses: saved *4 kg*	[13]

1.2 Demonstrator Design

As shown elsewhere, the demand of hot stamped parts is continuously increasing in the automotive industry. This is the reason why Metalsa S.A de C.V. launched a project aimed to develop internal capabilities leading to the implementation of the hot-stamping process in the short term. Fast knowledge acquisition by using experimental and numerical resources is at the forefront of this initiative. For this matter, the design and manufacturing of a tool-set intended to form a prototype B-pillar was commissioned to a specialized hot-stamping tool maker. The shape and general dimensions of the B-pillar prototype can be observed in Figure 2a. As depicted, features of the studied prototype part are representative of a production component.

Besides conventional direct hot-stamping, the developed tool-set allows performing other variants of the process like tailored weld, tailored tempered or tailor rolled blanks. The focus of this paper is comparing the outcomes of two direct hot-stamping strategies: (i) Full tempered with constant thickness blank and (ii) full tempered with variable thickness blank (Figure 2b). The reduction of thickness at the foot of the studied B-pillar is mainly intended to investigate the implication of thickness variation on the final component.



(a) (b)

Figure 2: *(a) B-pillar design (dimensions in mm) and product; (b) Sketch of the tailor-rolled blanks.*

The final part of this document introduces preliminary simulations of the afore-mentioned experiments. As detailed in [14], the interaction between thermal, mechanical and micro-structural fields results in the much higher difficulty of hot-stamping simulations in comparison to the cold forming of a similar part. Nevertheless, feasibility studies based on process simplifications can give useful information about the formability and final temperature distribution of the formed components.

2 Experiments

2.1 Experimental Setup

Blanks of 22MnB5 steel (with AlSi coating) were procured in two different configurations:

I. Constant, 1.8 mm thick blanks, and

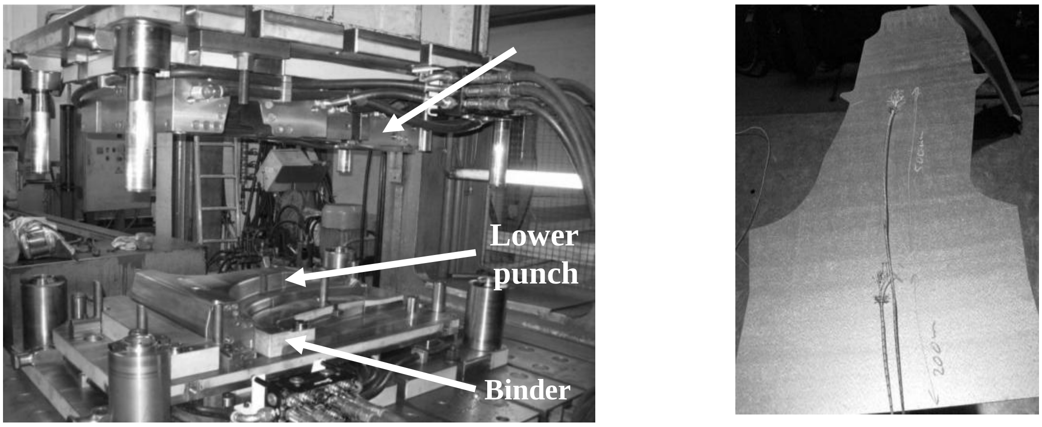
II. Variable 1.8 / 1.5 mm thick blanks; schematically shown in Figure 2b. In this case, the blank was cut from raw material generated by the tailor rolling process [1].

The B-pillars were manufactured on a prototype cell comprising an electrical chamber furnace and one hydraulic press with 6300 kN maximum press force. As shown in Figure 3a, the forming toolset comprises an upper die, lower punch and a binder (or blank holder). For Case II, an adjusted tool insert compensated for the thinner blank.

Typical of this technology, the forming tools are provisioned with cooling channels that keep their temperature close to room conditions. It is important to remark that only the die and punch were connected to the cooling system during the experiments. The binder is mounted over hydraulic cushions of the bed and moves down once the upper die overcomes its set-up force.

After austenization in the furnace at 940 °C, the blanks were transferred to the press within a time of 8 s. Before forming, one sample of each variant was instrumented with type K thermocouples at two different locations (Figure 2b). Press holding, forming and quenching times were respectively 3, 2 and 10 seconds. An example of a B-pillar manufactured with the described procedure can be observed in Figure 2a.

Post-forming characterization of temperature, thickness and hardness was taken for each sample. In order to investigate the tool temperature increase during process start-up, 12 samples per variant were formed. The results of the first formed part of each process variant will be summarized in the next sub-sections.



(a) (b)

Figure 3: *(a) Hot-stamping tools mounted on the hydraulic press, (b) Thermocouples installed in the blank.*

2.2 Experimental Results

2.2.1 Blank Temperature

Figure 4 compares the temperature behavior of one air-cooled blank of each investigated variant after being extracted from the furnace (up to 100 seconds). Important differences exist, especially at the end of each curve; however, cooling during the handling time was similar for the two cases. From this test, inlay blank temperatures were identified as 788 °C for the constant thickness blank and 773 °C, 785 °C respectively for the TC1,TC2 spots of the variable thickness sample.

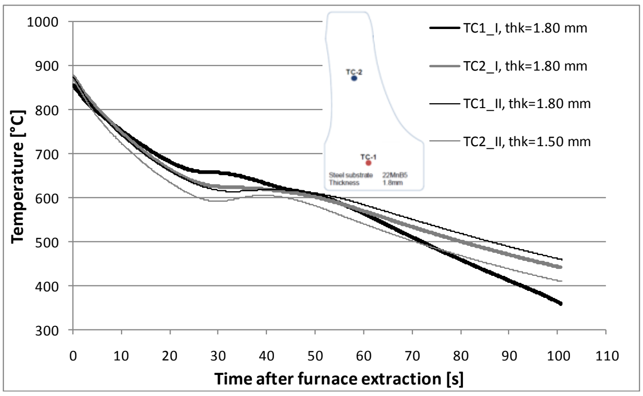
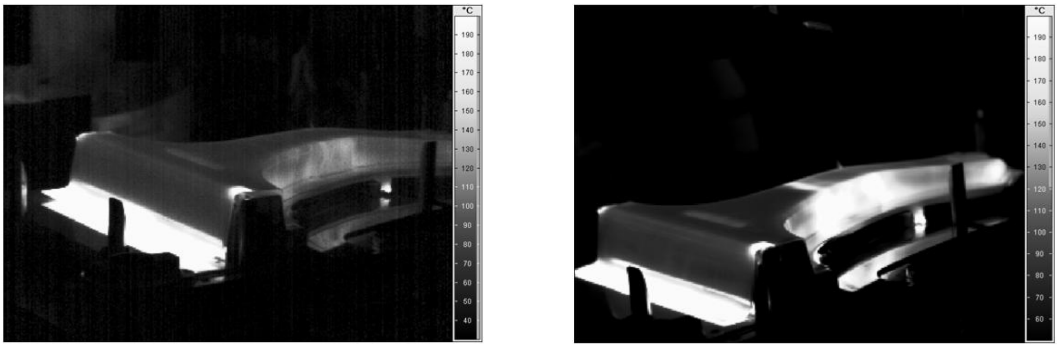


Figure 4: *Temperature evolution for one sample, of each studied case, air-cooled after austenization.*

On the other hand, thermal photographs taken at the end of the quenching process, shown in Figure 5, indicate that temperature distribution is affected by the variation in thickness. In fact, the higher temperatures observed in Case II seem to initiate right at the thickness transition zone.



(a) (b)

Figure 5: *After-quench temperature for (a) constant thickness and, (b) variable thickness blank.*

2.2.2 Vickers Hardness

Cross sections, 200 mm long, were cut at different locations of the product in order to allow Vickers hardness measurements. As shown in Figure 6, one section was taken at the boundary of the thickness variation for Case II.

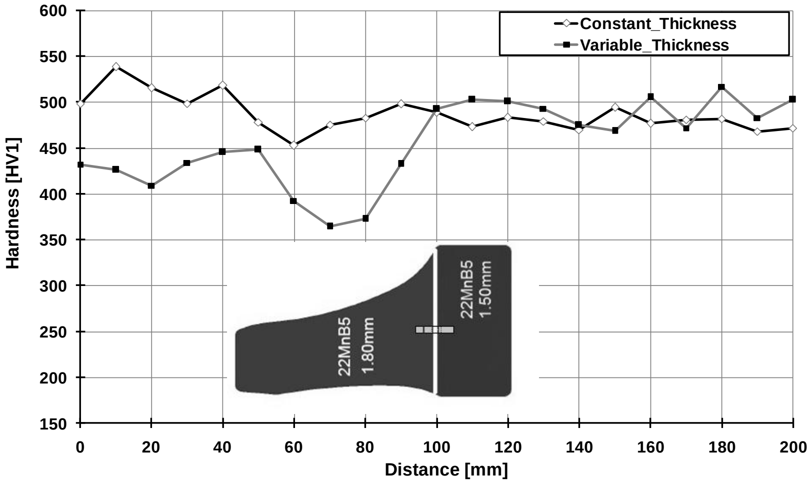


Figure 6: *Vickers hardness taken at the transition zone of the two studied variants.*

3 Finite Element Simulations

3.1 Numerical Procedure

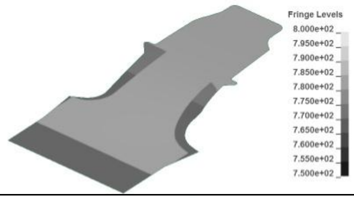
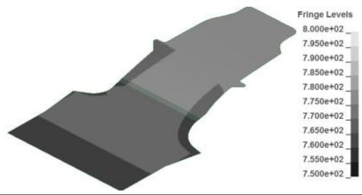
Aimed for better understanding the experimental results, the process was simulated with *LS-DYNA* version 971R6.1. Despite the availability of a Boron steel material model, a visco-plastic material approach is more amenable for initial trials. Furthermore, as presented in Section 2.2, microstructure derives from the temperature history during the different stages of the process.

Common inputs for the models were the inlay temperatures identified in Section 2.2.1 and the tool's mesh, excepting the adjusted lower punch insert. The total process was divided in three stages: (a) heating and gravity, (b) holding and forming, and (c) quenching. Flow-stress data for the visco-plastic model was taken from [15]. Tools and blank were modeled with shell elements. Frictional contact (μ=0.4) was established between blank and tools as well as thermal contact with variable heat conductance (up to 3500 W/m^2°K). Actual tooling velocity was applied without taking into account the force limits utilized in the press operation. Finally, temperatures of the tools were considered constant (50 °C) during the process.

3.2 Numerical Results

Table 2 compares the temperature evolution (in °C) of the two cases during different stages of the process. Numerical results point to both variants having after-quench temperatures above 200 °C at the upper part of the B-pillar.

Table 2: *Temperature [°C] predictions of hot stamped B-pillar after different process stages.*

<table>
<tr><th>Stage (time after furnace extraction)</th><th>Case I</th><th>Case II</th></tr>
<tr><td>Gravity (8 s)</td><td>
</td><td>
</td></tr>
<tr><td>Forming (13 s)</td><td>
</td><td>
</td></tr>
<tr><td>Quenching (23 s)</td><td>
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4 Conclusions

The higher temperatures observed at the top of the variable thickness product (Figure 5b) induced a decrease in hardness at the thickness transition, in comparison to the constant thickness case. Further measurements (not presented) confirmed that other regions of the part were effectively tempered.

Besides formability, the main target of hot-stamping simulations at the feasibility stage is estimation of the part temperature distribution during the process. In our case, the subtle differences between the two numerical models do not reflect the experimental results. Hence, further details have to be included, for example, the force set-up utilized during the forming operation.

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