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# Investigation on Hot Stamping Process for Door Beam of Ultra-High Strength Steel

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*Abstract— Ultra-high strength steel is widely used for automobile parts to reduce the weight of automobile and enhance the safety performance. Compared with the traditional cold forming, hot stamping is more suitable for the manufacture of these parts. However, the imperfect technology restricts its application in the industry. To investigate the hot stamping process technology further, a numerical simulation and forming experiment were made in this paper with a door beam as an example. After process parameters analysis, the thickness, temperature and microstructure distribution of sheet during the whole hot stamping were predicted through the simulation, according which the microstructure of the part were full martensite and no fracture was produced. A door beam was well-formed in the experiment based on the results of simulation, and then a series of tests as metallographic observation, hardness test, tensile test and side impact test were carried out, studying its performance in practice.*

**Index Terms—** hot stamping, mechanical properties, numerical simulation, ultra-high strength steel.

## I. INTRODUCTION

Along with the development of automobile industry, more and ultra-high strength steel is used to produce automobile parts. Such may reduce the weight of automobiles, low down the fuel consumption, and improve the impact safety at the same time. However, in the forming process of the ultra-high strength steel, there are such problems as formability is poor, forming force is big, springback is serious, fracture is possible and service life of mold is low, etc [1]-[3]. In recent years, a new technology called hot stamping that combines stamping and quenching in one non-isothermal forming process is considered as a solution to overcome above-mentioned difficulties [4]. At the beginning of hot stamping process, the blank is heated in the furnace to get full austenite, then subsequently formed and quenched in the die simultaneously. During quenching, the austenite is transformed into martensite with a cooling rate higher than 27 °C/s, that causes an increased hardness and strength sharply. Moreover, due to the mold retaining pressure in this stage, accurate geometrical shape is assured without springback [5]-[7]. Hot stamping parts are widely applied as chassis components in automobile, like door beam, A-pillar, B-pillar, roof rail, rocker rail, bumper and tunnel [8].

The prospect of hot stamping technology is so attractive, that many researchers and automobile manufactures spend more attention on it [9]. The research was mainly focused on the numerical simulation and experiment of simple shape (for example: U-type) parts, and most of which is about theoretic exploration, lacking the overall awareness of the hot stamping process in practice and performance research of the actual formed parts. In this paper, a hot stamping chain was made, with the actual door beam (W-type) of a certain brand automobile (Fig. 1) taken as an example. After parameters analysis, the evolution of sheet and its possible defect during the process were predicted through the simulation. Then a door beam was formed in the experiment based on the results of simulation, and a series of tests were carried out, studying its performance. All the work in this paper will provide reference basis for the future hot stamping parts manufacture and its process development.

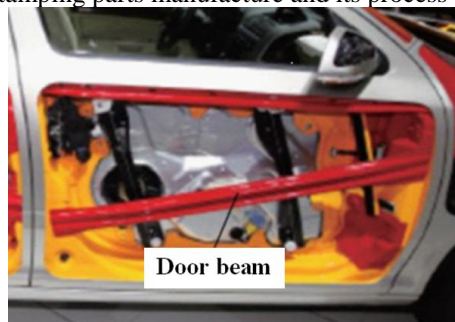
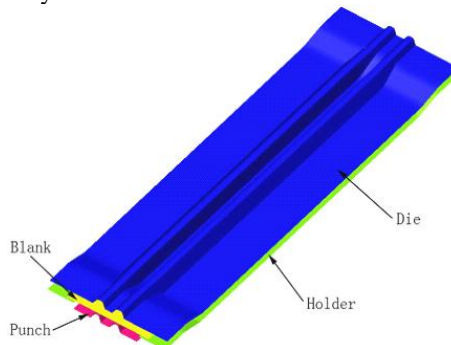


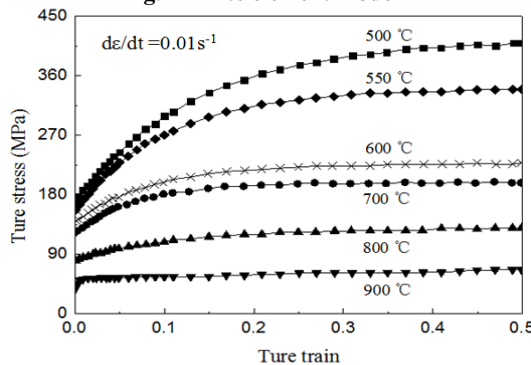
Fig.1 Door beam in automobile

**a. Finite element model**

The door beam is a complex medium-sized stamping part with length of 1071 mm, width of 100.8 mm and max depth of 35.4 mm. On the basis of acquired tests data, a finite element model was set up shown in Fig. 2. Wherein, the blank was ultra-high strength steel B1500HS, with dimension of 1190 mm× 180 mm× 2.0 mm. The initial temperature of the blank was set as 850 °C and metallurgical structure was 100% austenite, while the tools and ambient temperature were kept at room temperature of 20 °C. For the thermo-mechanical coupling process, the affection to the relationship between stress and strain by temperature should also be considered in the model shown in Fig. 3, which was estimated by hot test on Gleeble-3800 mechanical system.



**Fig. 2 Finite element model**



**Fig. 3 Stress-strain curves of B1500HS at different temperatures**

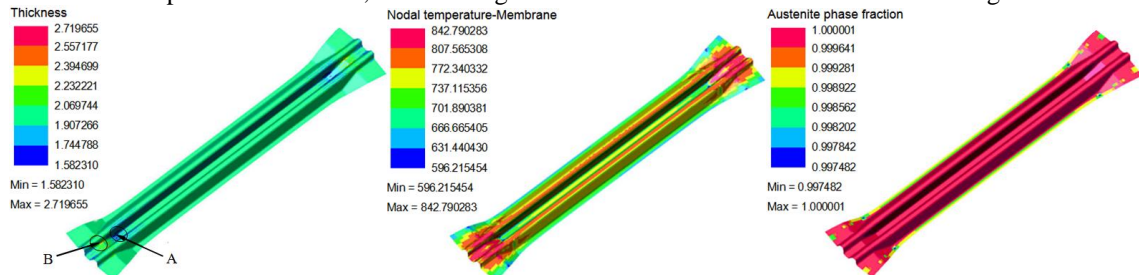
In the model, die is set at the top, punch is set at the bottom, and blank placed on the holder according to the mold structure in real stamping process. The whole process is divided into three stages as holding, stamping, and quenching. To begin with, the die moves down to the blank, making it be clamped by the holder, that is known as holding. Then they fall to the punch together at a speed of 90 mm/s. When the blank contact with the punch, the stamping stage starts. At the end of stamping, punch is closed to the die, finishing a 8 s pressure-retaining quenching.

**b. Process parameters analysis**

Process parameters play an important role in the hot stamping of the ultra-high strength steel, which determines the final part performance and quality [4]. The paper mainly focused on three main process parameters including BHF (blank holder force), friction coefficient and die clearance, and investigated their influence on the formability of the sheet, which is embodied in the change of minimum thickness after stamping stage. Since the deformation resistance of sheet is very small in hot, the influence of parameters is particularly sensitive.



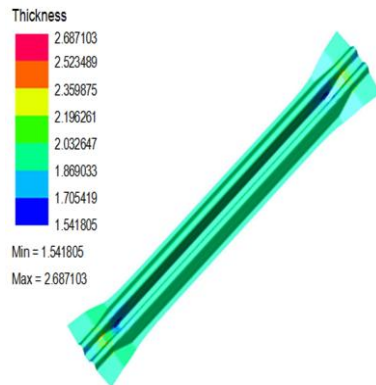
accumulation with the maximum thickness of 2.72 mm. As it not be stretched, most regions of the sheet has the fixed thickness of 2 mm. Seen from Fig. 6b, the sides has a lower temperature for contacting with the ambient directly through the gap and cooling more rapidly. The minimum temperature was 596 °C, which is above the martensite start temperatures. As such, the most regions of the sheet is still austenite shown in Fig. 6c.



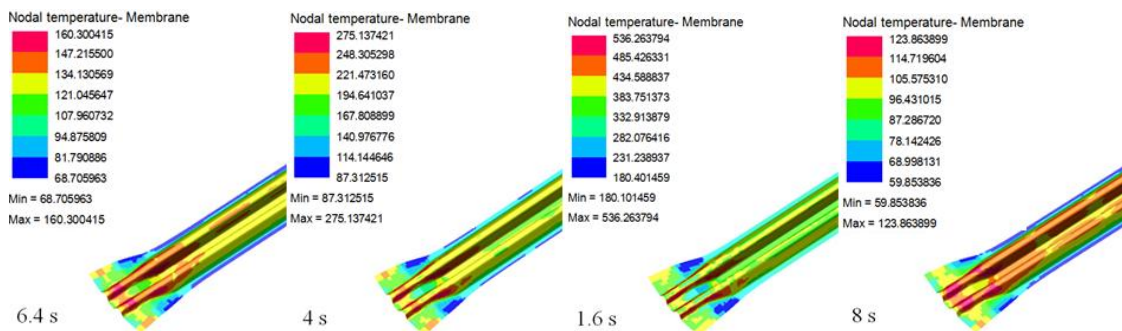
(a) Thickness distribution (b) Temperature distribution (c) Microstructure distribution

Fig. 6 Simulation result of stamping stage

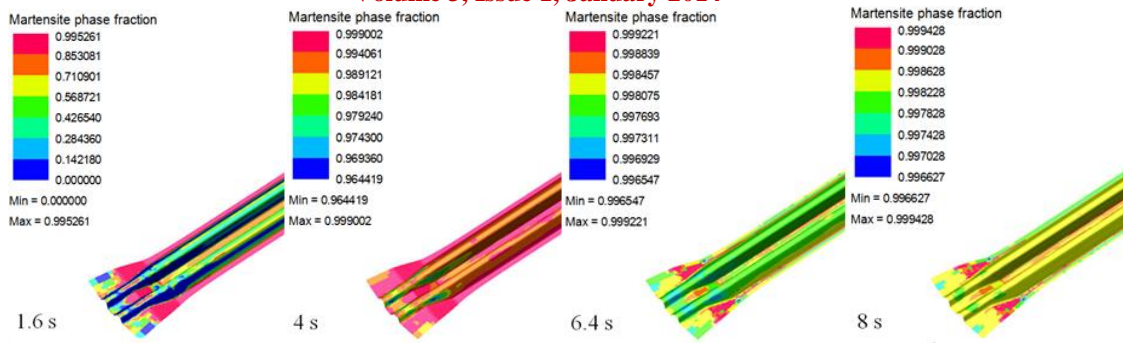
After quenching, the sheet obtains improved mechanical properties for the microstructure transformed from austenite to martensite. Meanwhile, the part is shaped further due to the mold retaining pressure, which makes it of higher precision and smaller springback. Results are shown in Fig. 7. Since there is no deformation in the quenching stage, the thickness distribution is roughly same as that in stamping stage, except the smaller value of maximum and minimum thickness that is due to the internal stress release caused by martensite transformation and temperature reduction (Fig. 7a). From the temperature distribution as Fig. 7b, it can be known the cooling rate is much greater than critical rate of 27 m/s, and the sheet cools down rapidly. After 1.6 s, the temperature of most regions drops to 410 °C and martensite transformation starts. A high amount of martensite appears after 4s with the temperature below 270 °C. When in the 8 s, all regions are at the temperature around 100 °C and with the microstructure of full martensite. Above all, pressure-retaining quenching is helpful for the martensite transformation and thickness distribution equilibrium of the formed sheet, which should be kept for 8 s or longer.



(a) Thickness distribution after quenching



(b) Temperature distribution at different time



(c) Microstructure distribution at different time  
 Fig. 7 Simulation results of quenching stage

**d. Defect analysis**

Hot stamping of the ultra-high strength steel is a complex thermo-mechanical coupled process. Not only does large plastic deformation the sheet have, but also experiences quenching hardening from high to low temperature. If the parameters or mold are not appropriate, the defects such as wrinkle and fracture will be easily produced. In stamping stage, the sheet has largest deformation and thus defects are more likely produced. Fig. 8 shows the equivalent stress and thickness distribution of the sheet after stamping. Stress concentration produced at the sharp corner zone A for its more complex shape, where the reduction is more serious according to the simulation above. Moreover, since zone A is the first region contacting with the tools during the hot stamping process, it cools down rapidly, while the other regions remain in hot. That results the uneven thermal distribution and transformation hardening produced here. When deformation exceeds its forming limit in the subsequent process, there will be necking, instability, and then fracture. Fig. 9 shows a door beam with fracture in actual production. Seen from the figure, the position of fracture is at the sharp corner, and that is completely consistent with the simulation prediction. It is demonstrated that the numerical simulation is reliable and applicable in guiding the production practice. In this simulation, the minimum thickness of sheet is 1.58 mm and the maximum reduction ratio is 21%, that meets the stamping thickness requirement, no fracture would be produced. The results indicate the process parameters adopted in the paper is feasible, and that will be verified further in experiment.

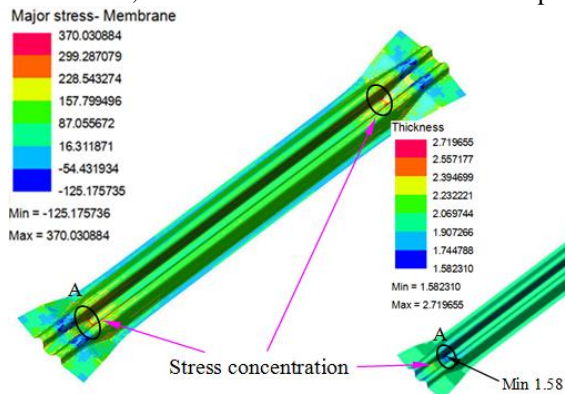


Fig. 8 Equivalent stress and thickness distribution of the sheet after stamping



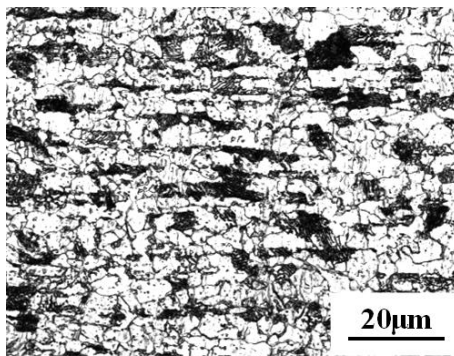
Fig. 9 Door beam with fracture in actual production

*a. Material characteristics and experiment procedure*

The chemical composition of the studied hot stamping steel manufactured by Baosteel which is known as B1500HS is shown in Table 1. The microstructure before hot stamping is pearlite and ferrite, wherein the pearlite is distributed along the rolling direction as shown in Fig. 10. The tensile strength of the original sheet is about 600MPa, the yield strength is about 400MPa and the hardness is between 170-200HV.

**Table 1 Chemical composition of B1500HS (in mass %)**

C	Mn	Si	Ti	Cr	B
0.22	1.20	0.20	0.03	0.2	0.035



**Fig. 10 Microstructure of the original sheet**

With the process parameters optimized in the simulation, the forming experiment was made and the main steps were as follows: heated the precut blank in furnace at a temperature of 950 °C, kept it for 5min to obtain homogeneous austenite; put the austenite blank into the mold with cooling system quickly (the transfer process should be as soon as possible within 3s to avoid the oxidation); underwent the hot forming and quenching; held the mold pressure for 8s to facilitate the transformation from austenite to martensite.

*b. Metallographic observation*

After the experiment, a door beam is well-formed, without any defects shown in Fig. 11, which verify the accuracy of the defect analysis through simulation.

Since the material has been heated to the temperature of austenite and then cooled down rapidly, the microstructure of the formed part is mainly lath martensite. The results of typical positions selected for metallographic observation are shown in Fig. 12. There is little difference among the microstructure in different positions, although the sheet is deformed in the process; different regions contact with the tools asynchronously; and the heat conduction along the geometric contours of the part is not the same. It shows a good agreement with the prediction through simulation, that all regions have the microstructure of full martensite after a 8-s pressure-retaining quenching.



**Fig. 11 Morphology of door beam after hot stamping**

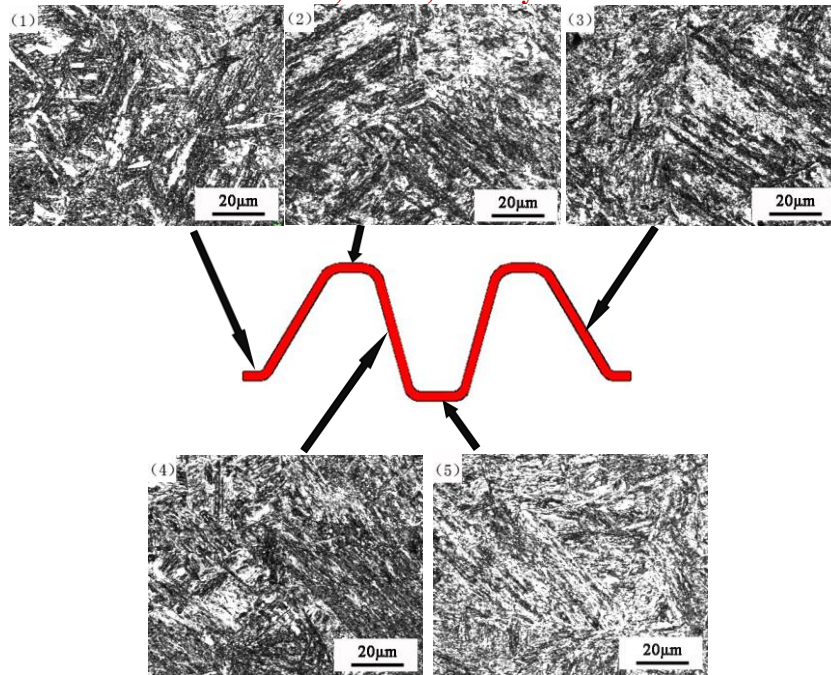


Fig. 12 Microstructure of the part in the five typical position

**c. Mechanical properties**

The micro hardness test on the five typical positions was measured with load of 2 N and holding pressure for 5s. From the results shown in Fig. 13, the part has a homogeneous hardness with average value of 491HV, wherein the maximum value is 503HV and the minimum is 481HV. The value meets the requirement on hot stamping parts hardness range of 400-520 HV, and is far more than that of the original sheet (170-200HV). Position 1, which first contacts with the die and has longer cooling time, thus owns a higher hardness. It is the difference between cool forming and hot stamping, that the part structure (sequence of the contact with tools in different position), as well as the cooling system design has a great influence on the mechanical properties of formed part, which should be considered seriously.

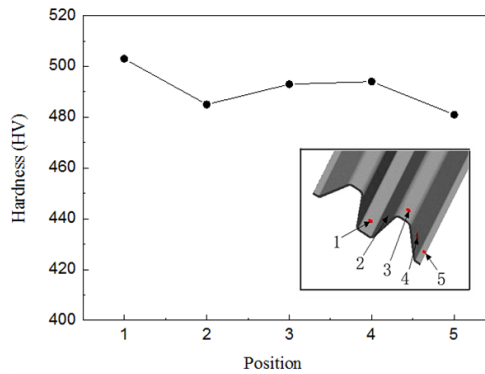


Fig. 13 Hardness distribution of the part

Original sheet and the part obtained through hot stamping were sampled respectively for the uniaxial tensile test, which was carried out on Zwick-Z100 testing machine, with the tensile rate of 4 mm/min. Sample dimension and tensile curves are shown in Fig. 14. Main mechanical properties data got from the curves is shown in Table 2. According the results, mechanical properties of the part are improved substantially through the hot stamping process. Wherein, the tensile strength with the value of 1558 MPa is increased to 2.7 times of the original one, and the elasticity modulus is increased to 16 times. Because of the strong impact resistance, it is difficult for the hot stamping parts to get plastic deformation when impacted or collided, and they are ideal for stress relevant components in the automobile.

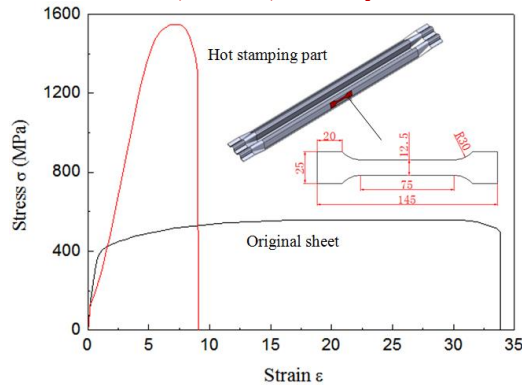


Fig 14. Tensile curve of the tow samples

Table 2 Main mechanical properties of tow samples

	Tensile strength in MPa	Yield stress in MPa	E-Module in MPa	Elongation
Original sheet	568	370	12803.4	33.4
Hot stamping part	1558	1012	204000	9.1

**d. Side impact test**

The door beam, as the additional energy absorption layer, can reduce the force from outside and offer protection to passengers. To examine its real effect, the side impact test was made in accordance with C-NCAP (China-New Car Assessment Program), which proposes a relative safety level for the automobile by scoring a series of security-related items. In the test, the moving barrier impacted with the automobile side at a speed of 50km/h, which was equipped with the door beam formed through hot stamping. Fig. 15 shows the automobile door after the test. Seen from the figure, the panel depresses inward with small amplitude and the beam clearly slants across the door without bending at all. The evaluation score is 16 points (full marks) under assessment, that shows the door beam formed through hot stamping can enhance the side impact safety significantly.



Fig 15. Automobile door after side impact test

**IV. CONCLUSION**

Through the numerical simulation and forming experiment made in this paper, the following main contribution and conclusions can be drawn.

- (1) Process parameters have a great influence on the formability of sheet. Minimum thickness increase with the BHF and friction coefficient decrease, but with the die clearance increase. BHF of 1 kN, friction coefficient of 0.12 and die clearance of 2.1 mm are optimal, with which no fracture produced.
- (2) The evolution of sheet during the whole hot stamping process is realized through the simulation. All regions are at a temperature around 100°C and with the microstructure of full martensite after the pressure-retaining quenching, which should be kept for 8s or longer.
- (3) Fracture is likely produced at the transitional sharp corner between flat and incline plane, which has the minimum thickness and is easy to generate stress concentration.
- (4) A door beam is well-formed based on the results of simulation, with microstructure of full lath martensite, average hardness of 491HV, and tensile strength of 1558 MPa.
- (5) Performance of the steel B1500HS is improved substantially through the hot stamping process, which can





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enhance the impact safety used for automobile parts. In Side impact test, the automobile equipped with the door beam gets an evaluation score of 16 points (full mark in C-NCAP).

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