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Investigation of a new hot stamping process with improved formability and productivity

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Abstract

In order to improve the drawability of boron steel and also to increase the productivity of hot stamping process, a new hot stamping process with pre-cooling has been proposed. Stress-strain behavior at various temperatures was investigated and compared with that in traditional hot stamping processes. Detailed studies were carried out on the strain hardening parameter, *n*, at different temperatures and deformation rates. To evaluate this concept, hot stamping experiments were performed with both conventional (without pre-cooling) and new process (with pre-cooling) for a scaled down B-Pillar automotive component. The new hot stamping process with pre-cooling was able to produce the B-Pillar at low temperature (500 °C) with less thinning than the hot stamping carried out without precooling at high temperature (765 °C). Also the in-die quenching time was reduced by about 60%, by adopting the new hot stamping process with pre-cooling, which would increase the productivity significantly for automotive mass production without compromising the part quality.

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Keywords: *Hot stamping;Improved hot stamping;Boron steel;strain hardening.*

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1. Introduction

A typical hot stamping process of a press hardening steel is described in Fig. 1(a). The process begins with steel containing ferrite and pearlite microstructure with tensile strength of approximately 600 MPa. The material is heated to above austenite temperature, usually about 900 °C and kept in furnace for a few minutes to get complete austenite phase. The austenized material blank is quickly transferred from the furnace to the stamping tool and deformed into the required shape with simultaneous rapid cooling within pressurized-closed-dies. It is necessary to achieve a faster cooling rate during cold-die quenching to ensure martensitic formation for post-form ultra-high strength product of approximately 1500 MPa [1].

Currently the stamping temperature in conventional process is about 800 °C. At this temperature, the material is softer and more ductile. However, high temperature also results in materials with low strain hardening exponent (*n*-value). Materials with a lower *n* value have less drawability than those with high *n* values. Moreover, during hot stamping, it is necessary to achieve a faster cooling rate (> 27 °C/s) during in-die quenching. It takes about 6-15 seconds to quench the material from 800 °C to 250 °C within a pressurized die depending on die pressure and the thickness of material blanks, which decreases the productivity. Also the tooling cost is increased because of die cooling arrangements. The die temperature increases due to high stamping temperature of boron steel [2, 3], which results in a longer waiting period between the stamping strokes. The employed elevated temperature and relative movement between tool and blank lead to an increased wear rate of the tool reducing its lifetime [4].

To overcome the above limitations, a new hot stamping process with intermediate cooling has been proposed [5, 6] as shown in Fig. 1(b). However, detailed investigation on the above proposed patent was not carried out. Therefore, in this study an experimental analysis was performed with both conventional and new process. In the new hot stamping process a pre-cooling stage is incorporated between furnace and stamping press. The austenized boron steel is quickly transferred to pre-cooling stage for rapid cooling to desired stamping temperature. Pre-cooling is done at a cooling rate of > 60 °C/s with the help of high pressure air. The austenized and pre-cooled boron steel is then positioned onto the die for stamping. Even though, the material is pre-cooled, it needs to be in the austenitic condition before and during stamping. The stamping has to be completed before the boron steel drops to martensitic starting temperature of around 425 °C.

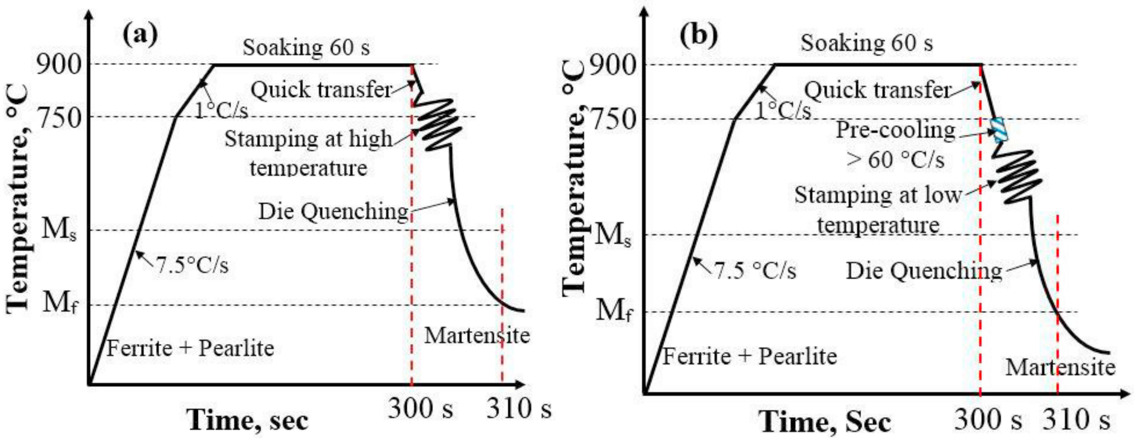

Fig. 1. (a) Typical stamping process; (b) Modified stamping process.

In the present work, the material response under the new hot stamping process conditions with intermediate cooling was investigated. Uni-axial tensile tests were performed with various temperatures and strain rates to cover the new process range. To validate this concept, hot stamping experiments were performed using both conventional and the proposed hot stamping processes, with various forming temperatures and forming speeds. The hot stamped B-pillar final product was analysed in terms of maximum thinning and quenching time. The benefit of the new hot stamping process was also investigated in terms of productivity improvement due to in-die quenching time reduction compared to conventional hot stamping processes.

2. Experimental details

2.1. Hot uni-axial tensile tests

The hot uni-axial tensile tests were conducted using a Gleeble 3800 with a set of new grips for an improved temperature uniformity within the specimen gauge length as proposed earlier by Ganapathy et al. [7]. Uncoated 22MnB5 boron steel with 1.5 mm thickness was used as test material for this study. Isothermal tensile test at various temperatures and strain rates were performed for test conditions. The true stress versus true-strain curves obtained from hot uni-axial tests were used to determine the strain hardening exponent over the range of 2 to 15% true strain as per ASTM standard E646 – 16.

2.2. Hot Stamping

The schematic experimental illustrations of conventional and the new/proposed hot stamping process with pre-cooling step are shown in Fig.2. The processes consist of electrical heated roller hearth furnace for heating a blanks, feeder to transfer the blank and stamping press with a B-pillar tool assembly. The pre-cooling device was installed in between the furnace and the stamping press for the process with pre-cooling step (Fig. 2b). High pressure compressed air (10 bar) was supplied by the device for cooling the material. The cooling plate contains multiple nozzles for uniform cooling. All the stages were computer controlled with closed loop feedback control system to ensure the heating temperature, pre-cooling time (or completion temperature of pre-cooling), transfer time and the starting of forming temperature to be accurately controlled. The feeder was able to pick, transfer and position the blank on the stamping tool within 8 seconds. Monitoring and control of temperature during transfer and pre-cooling was done by a non-contact infrared pyrometer which was attached on the feeder as shown in Fig. 2a. The pyrometer was calibrated before the test with contact k-type thermocouples. The material was heated to 900° C and held for about 60 Seconds for homogenization and then transferred with the help of feeder to pre-cooling stage. To prevent the decarburization and scale formation, the heating was performed in nitrogen atmosphere. The material was cooled to slightly above the required stamping temperature in 3 seconds, and then the austenized boron steel was quickly placed on the B-Pillar die. Stamping was done at a range of start temperatures (765 - 440 °C) and at three different forming speeds (60, 150, and 350 mm/s). The variability of the process depends on the transfer time, pre-cooling rate and blank temperature at the beginning of stamping, hence the experiments were conducted with three samples for each of the process conditions to ensure repeatability of hot stamping process condition.

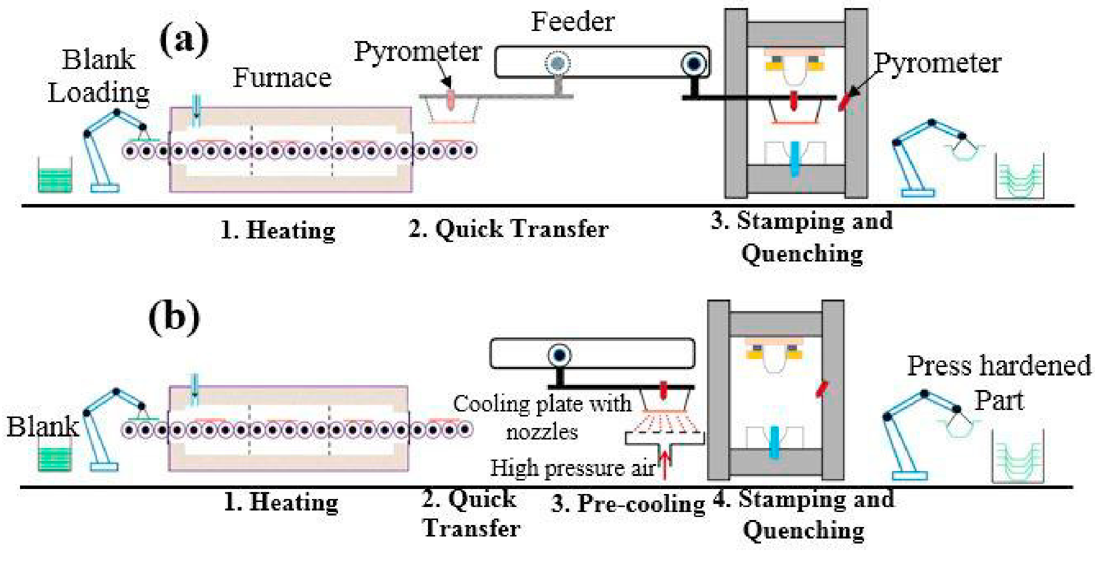

Fig. 2. (a) Conventional stamping process; (b) Proposed stamping process with pre-cooling.

2.3. Quenching tests

Quenching tests were done to evaluate quenching time during hot stamping operations. The quenching temperature was recorded for press hardening the boron steel at various temperatures with different die temperatures and contact pressure. A circular boron steel blank with the diameter of 80 mm and the thickness of 1.5 mm was used as the test-piece. K-type thermocouples were embedded in the tool setup and work-piece at the locations as shown in Fig. 3. The dies were made from AISI H13 steel and were fixed on a hydraulic press machine with a maximum load capability of 25 tonne as shown in Fig. 3(a). Top and bottom die were heated using a band heater placed around the die periphery as shown in Fig. 3(b), which ensures uniform heating compared to other heating techniques [8]. In the quenching tests, the dies were pre-heated to different temperatures namely 70 °C, 100 °C and 150 °C; the test-piece was heated to 900 °C, and was air-cooled to different target temperatures during transfer, and compressed between the dies to a predetermined maximum load, which was set by two gas springs from the bottom of tool setup. The temperature histories of the test-piece and die were recorded during the quenching process using TC-08 thermocouple data logger.

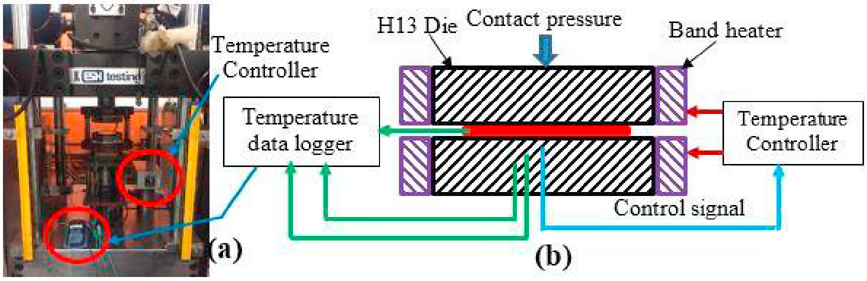

Fig. 3. (a) Heat transfer experiment; (b) Schematic tool setup.

3. Results and Discussion

3.1. Strain hardening exponent (n-value)

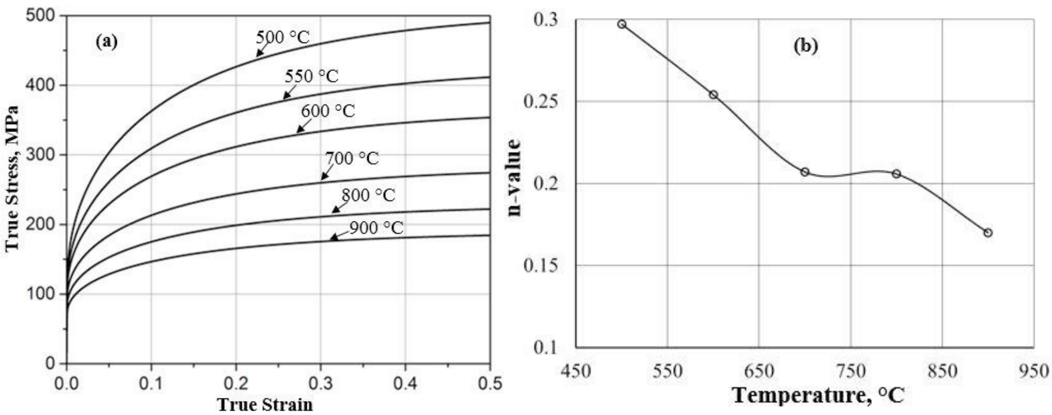

Fig. 4. (a) Flow curve fitted from experiment data; (b) Strain hardening exponent (n-value) versus deformation temperature

The strain hardening exponent determined from the true stress versus true-strain curves over the range of 2 to 15% true strain as shown in Fig. 4(a). Fig. 4(b) shows that the strain hardening exponent (*n*-value) decreased with increasing deformation temperature obtained from hot tensile tests. This is due to temperature dependency, the level of strain hardening gradient is lower and the variation of strain hardening is less apparent at a higher temperature.

High strain hardening exponent, n can restrain localized thinning and enhance uniformity of deformation, so as to improve the drawability of the material in hot stamping processes [9].

3.2. Thickness distribution at critical region of B-Pillar product

B-pillars formed without pre-cooling (765 °C, 150 mm/s) and with pre-cooling (500 °C, 150 mm/s) processes were analyzed through thickness measurements. The thickness variation at the wall region of the B-pillar formed with a product height of 64mm is shown in Fig. 5(a) and its critical section (*A-B*) is shown in Fig.5(c). The maximum thinning by without pre-cooling is 35% and the new process with pre-cooling produced a maximum thinning of 30%. Thickness reduction decreases by 16% in new process, the reason could be at lower temperature boron steel blank might have a better temperature uniformity during forming, and also high value of strain hardening is another factor to restrain localised deformation. Fig. 5(b) shows the effect of forming speed on thickness variation for product formed with product height of 50mm. The thinning is less for lower forming speeds (60 mm/s and 150 mm/s) compared to the higher forming speed (350mm/s) for same stamping temperature (440 °C). A possible reason is that a lower forming speed leads to more heat transfer to die and resulted into higher strength material during forming. Also, when the part is stamped at low temperature (500°C), it is easier to get the strained area compensated from its surrounding area and thinning is less compared to conventional hot stamping at high temperature (765 °C).

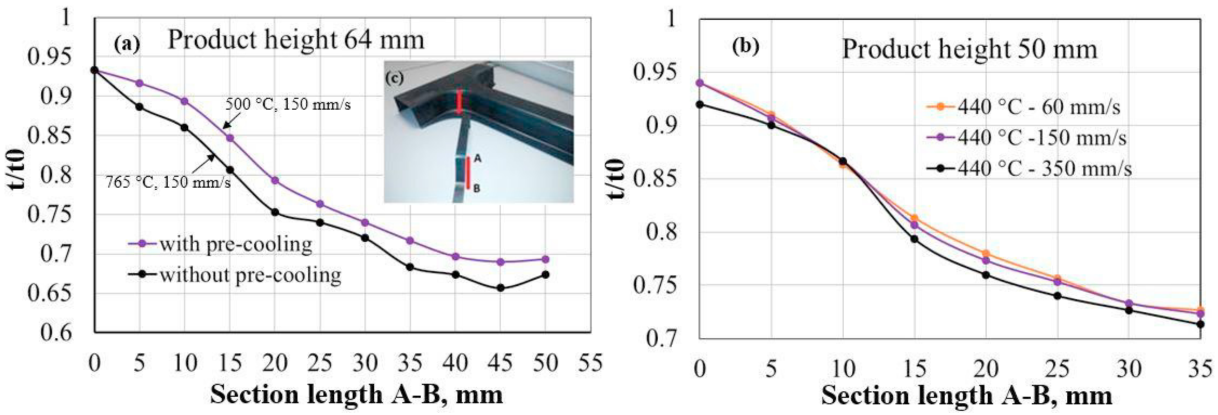

Fig. 5. Comparison of typical and new process on (a) Thinning versus Stamping Temperatures; (b) Thinning versus Strain rates; and (c) B-Pillar with critical section *A-B*

3.3. Quenching time

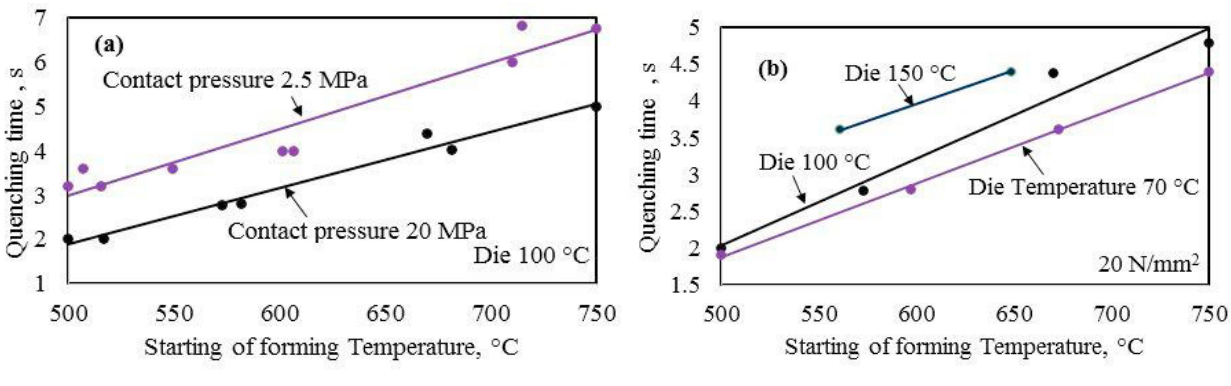

Fig. 6. Quenching time for different starting of forming temperature to 250 °C at (a) various contact pressure; (b) various die temperatures.

The effect of stamping temperatures on die quenching time at both low (2.5 MPa) and high (20 MPa) contact pressure with initial die temperature of 100 °C is shown in Fig. 6(a). In a conventional hot stamping process (starting of forming temperature =750 °C), the in-die quenching time required to cool down the product to 250 °C is 7 s for low (2.5 MPa) and 5 s for high (20 MPa) contact pressure. However, in the new hot stamping process with pre-cooling (starting of forming temperature of 500 °C), in-die quenching time required is 3 s and 2 s for both low and high contact pressure respectively. Hence the Pre-cooled-hot stamping process reduced the in-die quenching time which would benefit to increase productivity. Fig. 6(b) shows the effect of stamping temperature on quenching time at various die temperatures [70 °C, 100 °C and 150 °C] with contact pressure of 20 MPa. The die quenching time decreased with lower die temperature, hence maintaining the die at lower temperature would benefit to reduce the in-die quenching time, which is easier to realize in the new hot stamping process since there is less heat to be extracted from the boron steel blank. It should be noted that additional pre-cooling time (3 sec) would not affect the productivity, because pre-cooling is preceding operation which can be done simultaneously during the part discharge from die in mass production. However, there are some disadvantage in new hot stamping process like complicated experimental setup with additional stage, and essential to have sophisticated feedback system to control the time and temperature during pre-cooling in order to achieve required final properties. The possibilities of contact cooling methods within stamping stage could be considered to overcome the above drawbacks of air cooling.

4. Conclusions

In the present study, a new hot stamping process with pre-cooling was proposed and its advantages in terms of the in-die press hardening time and material drawability have been experimentally investigated. Hot stamping of a scaled down B-Pillar was carried out with both the conventional (without pre-cooling) and the newly proposed (with pre-cooling) processes. The maximum thinning at critical wall region was 35% for conventional hot stamping process, but in the case of new process the maximum thinning was 30%. The new hot stamping process with pre-cooling was able to produce the B-Pillar component successfully at low temperature (500 °C) without compromising the part quality. Moreover the die quenching time was reduced by 60 % in the new process than that in the conventional process, which would result into an increased productivity.

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