Development of Hot Stamping Technology for High Strength Steel Parts with Tailored Properties

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Abstract. In the context of lightweight vehicles, tailored properties high-strength steel parts play a vital role in improving safety under car collisions. Hot stamping technology provides good formability for manufacturing high-strength steel parts with tailored properties, and the hot stamping parts have high strength, small springback and good industrial promotion prospect. This paper summarizes the current state-of-the-art processes for the implementation of hot stamped parts with tailored properties, through intrinsic strategy and tailored welded / rolled blanks.

1. Introduction
With environmental issues and energy issues becoming increasingly prominent, automotive lightweighting has emerged as a result of industrialization based on energy conservation and emission reduction. The data shows that the use of high-strength or ultra-high-strength steel plates, the original thickness of 1.0 ~ 1.2 mm body panels can be reduced to 0.7 ~ 0.8 mm, the overall quality of the body can be reduced by 15% to 20%, fuel economy 8 ~ 15%\cite{1-2}. Although some alloy materials or other carbon fiber materials can be used for lightweight production of automobiles, their cost is too high, which is not conducive to cost control. Therefore, the use of high-strength or ultra-high-strength steel sheets for the manufacture of automotive body-in-white parts is one of the important ways to achieve lightweight vehicles. However, due to the poor mold ability of high-strength steel sheets at room temperature, many of the process problems such as large deformation resistance, cracking, and large rebound are common under the traditional cold stamping process. Therefore, the hot stamping process can solve the above problems and obtain industrial applications. The hot stamping process is a process for forming a martensitic structure by heating a high-strength steel sheet material to a temperature above 900°C, allowing it to be completely austenitized and then rapidly cooled and quenched. Although the traditional hot stamping process can achieve the formation of high-strength steel, only obtaining a uniform martensite phase does not meet the needs of many tailored properties automotive parts, such as automotive B-pillar parts. The upper part of the B-pillar requires high strength to support and ensure that the occupant has enough space to resist external casing intrusion during collision to ensure vehicle integrity and occupant safety; the lower part of the B-pillar requires lower strength and high plasticity to absorb the impact energy of the car, thus maximizing the safety of the occupants. Therefore, the molding process of such parts requiring custom mechanical properties
has become the focus of many scholars. According to the analysis of advanced processes in the existing literature, the hot stamping process of tailored properties automotive parts is divided into intrinsic strategies and tailored welded / rolled blanks.

2. Intrinsic Strategy
Intrinsic strategy is composed of differential temperature heating, differential cooling rate method and secondary annealing.

2.1. Differential Temperature Heating
The differential temperature heating method controls the heating temperature of different parts of the sheet. Bernd-Arno Behrens[3] regulates the performance of stamping parts by means of selective heating. In the traditional heating furnace, the appropriate shielding device is added to achieve different heating temperatures at different positions of the blank, and the hot stamping parts with gradient properties are obtained after quenching in the mold. The method of spray cooling is also adopted, and the performance quenching of the hot stamping parts and the performance gradient of the stamping parts are also realized. K. Mori[4-5] uses a grooved gradient quenching die and a shunt resistor heating method to prepare hot stamped parts with a gradient of strength distribution. The high-strength region is heated and in-mold quenched by means of bypass resistance heating, and the copper electrode is in contact with the blank for the low-strength region. And the current is introduced into the bypass by the high conductivity of copper, and the corresponding region of the billet is not heated. The U-shaped part using the bypass resistance heating method was subjected to a bending test, and the strength of the rounded corner reached 1.5 GPa, and the energy consumption and the maximum punching pressure were smaller than those of the uniform heating process. Wilsius J etc.[6] heats different areas of the sheet to different temperatures in the furnace, and the tensile strength of the final sheet temperature is 700 MPa, and the tensile strength of the higher temperature zone is 1600 MPa, which is customized for the performance of the formed parts. H. Hoffmann et al.[7] studied the cooling system of hot stamping dies. They point out that when the steel plate is heated above the austenitizing temperature and rapidly cooled to ensure a martensitic transformation, the cooling system is not set in the original production process. They used quenched alloy steel 22MnB5 as the stamping sheet, integrated the cooling system with the stamping die. And the simulation and experimental study on the distance between the cooling pipe and the mold profile show that the cooling effect is best when the cooling pipe of the cooling system is close to the mold profile. Bardelek A et al.[8] studied samples of boron steel hot stamping at five different cooling rates for maximum tensile strength analysis at different tensile rates. The difference in volume fraction of martensite and bainite in each sample and the relationship between hardness and martensite and bainite volume fraction were obtained. The experimental data was compared with the constitutive model data with specific performance, and the principle of tensile fracture was also explained.

2.2. Differential Cooling Method
The differential cooling method is a method of realizing the distribution of the tailored properties of the molded part by changing the cooling rate of the mold to the sheet material. There are three methods for achieving differential cooling.

2.2.1. Differential Temperature Mold. The method controls the temperature difference of the sheet material by the local mold temperature. R. George et al. [9-10] of the University of Waterloo, Canada, designed a segmented thermoforming mold with local heating and cooling. Through the control of the cooling rate of the sheet during the sheet forming process, the hot-formed parts with high-strength and low-strength areas were obtained. Finally, the Vickers hardness after forming was predicted by LS-DYNA and compared with the experimental results. The comparison results show that in the fully cooled region, the predictions are similar to the actual measurements, and the prediction results in the transition zone are significantly different from the actual measurements. Feuser et al.[11] developed a
full-size B-pillar with low strength and high intermediate strength at both ends. The part of the mold heated independently at both ends has a heating temperature of 550°C and a dwell time of 15s. The final Vickers hardness is 250-270 HV, and the tensile strength is also reduced to 50% of the martensitic structure strength. Graff S et al.[12] controlled the temperature of the hot zone of the mold at 500°C and the cold zone to room temperature, and the tensile strength of the final hot zone formed part was reduced by 50% compared with the cold zone. Changing the mold temperature can more accurately control the cooling rate of the sheet, making the final microstructure of the formed part more controllable and the performance transition more gradual.

2.2.2. Differential Thermal Conductivity Mold. The method is to change the mold material to have different thermal conductivity. D. M. Karbasian and A.E. Tekkaya of Germany[13] have changed the thermoforming control strategy and proposed three new methods of different thermal conductivity of different parts of the mold, different surface contact surface roughness, and the use of tailor welded steel sheets to realize the hot-formed parts with variable gradient characteristics. Casas et al.[14] using different thermal conductivity control the heat exchange rate between the sheet and the mold during forming and quenching. The thermal conductivity of the new material area of the mold is reduced by 90% compared with the thermal conductivity of the new material area, and the maximum and minimum tensile strengths of different parts of the final formed parts are 1500 MPa and 600 MPa respectively, indicating that this method can customize the performance of parts. But it is difficult to accurately control the cooling rate, and changing the cooling rate requires changing the mold material, which has high production cost and is not suitable for actual production. Kolleck and Veit[15] use ceramic insulation materials to make the heat transfer coefficient of different parts of the mold different, and the tensile strength of the sheet is changed from 1600 MPa to 650 MPa.

2.2.3. Differential Contact Area Regulation. The method is by controlling the contact area of the mold with the sheet. Maeno et al.[16] proposed a measure to improve the formability of hot stamped parts by increasing the stamping rate and appropriately increasing the local die gap by affecting the stamping rate and die gap on hot stamping. K. Mori and Y. Okuda[17] designed a thermoforming mold based on contact area control. The local contact area between the sheet and the mold is different. During the quenching and cooling process of the sheet, the part in contact with the sheet has a better cooling effect, and the non-contact area has a lower cooling rate, thereby realizing the custom attribute characteristics of the sheet.

3. Tailored Welded / Rolled Blanks
The method of changing the partial thickness of the sheet is to use a differential plate and a tailor welded plate. Choi J W et al.[18] simulated and experimentally analyzed stampings with different custom performances. The parts obtained by laser tailor welding and the hot stamping parts obtained by local quenching were studied and analyzed according to the phase transition characteristics and deformation behavior, and the performance was also analyzed through experimental tests. Bührl and Fritz[19] In order to ensure the mechanical properties of the hot-formed blank welded joints, it is proposed to use the laser ablation method to clean the Al-Si coating at the weld before welding. Tang Bingtao[20] of Shandong University of Architecture established a multi-field coupling numerical model for hot stamping of laser tailor welded blanks, and verified the reliability of the model by using the thickness and microstructure test results of B-pillar stiffeners after thermoforming. Lei Chengxi[21] of Harbin Institute of Technology established the constitutive relationship of TRB at high temperature by using the single tensile test results of different thickness and strain rate of B1500HS steel plates. However, there is a problem with this method. Due to the presence of weld seams in the tailor welded blank, the weld seam is easily cracked during the collision. And differential plates and patch plates increase their own weight when achieving component gradient strength.
4. Conclusions
Although there are many methods to achieve hot stamping parts with tailored properties, the first method - intrinsic strategy is more suitable for industrial production to realize, because this method will completed to obtain the parts in the process of molding and quenching integration in once hot stamping process. However, the second method requires more process steps. Moreover, in terms of achieving differential temperature heating, it can be realized by means of rapid heating such as induction heating, which can not only obtain the parts with tailored properties, but also realize grain refinement, furthermore, the research will be focus on it.

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