Research on material and process optimization for hot stamping of large dimensional parts in commercial vehicles

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Currently, commercial vehicles in China are facing severe pressure in terms of lightweighting. Hot stamping is one of the advanced process technologies that achieve the ultimate lightweighting of commercial vehicles and have the highest cost-effectiveness. Cargo box is currently one of the key lightweight objects of concern in the commercial vehicle industry. The size of the cargo box is generally large, and the development of hot stamped cargo box has raised new technical issues in various aspects such as materials, equipment, and technology. This article designs a kind of steel plate material suitable for hot stamping large-sized and high thickness parts based on thermodynamic analysis. Based on innovative press machines, heating furnaces, transfer devices, and mold designs, a series of key cargo box components with ultra large dimensions and a maximum thickness of 5 millimeters have been manufactured, and their quality meets the technical requirements of product development.

Keywords: Commercial vehicle; Cargo box; Alloy design; Thermodynamic analysis; Hot stamping process.

1. Introduction

In China, the proportion of commercial vehicles in the automotive market is only about 20%, but the fuel consumption of the commercial vehicle market is about 50% of the total consumption of the automotive market in China, and the carbon emission of the commercial vehicle market is about 60% of the total emissions of the automotive market in China. Based on this, in recent years, China has been continuously promoting the lightweight development of the commercial vehicle industry, promoting energy conservation and emission reduction of commercial vehicle products, and thus promoting the "dual carbon" process of the entire automotive industry in China[1-3]. The cargo box is one of the largest and heaviest components on commercial vehicles, accounting for 20% to 30% of the total weight of the vehicle. Heavy cargo box are not only detrimental to the safety performance (collision and braking, etc.) of commercial vehicles, but also to the energy conservation and emission reduction of the entire vehicle, ultimately causing damage to the interests of commercial vehicle users. Therefore, major domestic commercial vehicle enterprises are highly concerned about the light weighting of cargo

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box. Lightweight cargo box is of great significance for enhancing the market competitiveness and user profitability of commercial vehicle enterprises. Hot stamping technology can effectively solve the contradiction between multiple factors such as ultra-high strength, lightweight, complex shape forming, and production cost of parts. In recent years, it has become one of the hottest and most widely used advanced manufacturing technologies in the global automotive industry. At present, China has become the world's largest producer of automotive hot stamped parts, with over 300 production lines [4]. For commercial vehicle enterprises, based on comprehensive considerations of product quality and cost, hot stamping is also a cost-effective manufacturing solution for increasing efficiency and reducing costs.

However, for many years, the vast majority of hot stamping production lines in China have been aimed at the passenger car industry, which can only produce parts with smaller dimensions and lighter weight (less than 30 kilograms). However, a large number of parts on commercial vehicles often have larger dimensions, thicker specifications, and heavier weight. Existing hot stamping production lines in China are almost unable to meet production requirements. The hot stamping of large-sized components in commercial vehicles requires solving a series of problems such as material strength, toughness, hardenability, part heating, transfer, and pressure quenching and cooling [4-5]. This article focuses on the development needs of a commercial vehicle cargo box product, starting from the alloying design of steel, hot stamping equipment, and process innovation, breaking through the key technology of hot stamping manufacturing of large-sized components, and successfully developing a lightweight, high-performance, and low-cost cargo box product for integrated application of hot stamped parts, meeting the requirements of automotive enterprises.

2. Steel composition design based on product application scenarios

Based on the analysis of the service scenarios and working conditions of cargo box in commercial vehicles, it is required that the steel used for cargo box manufacturing should have excellent performance levels such as strength and toughness, wear resistance, corrosion resistance, hydrogen embrittlement resistance, welding performance, and hardenability, etc. In this regard, microalloying design of press hardening steel required for container manufacturing was carried out. Based on the design strategy of niobium vanadium composite microalloying, the technological advantages of improving the static and dynamic passive safety performance and hydrogen embrittlement resistance of hot stamped automotive parts have been recognized by the industry in recent years [6-7]. Therefore, it is still considered to add 0.02~0.06% niobium and vanadium to traditional 22MnB5. In addition, the biggest problem is that the dimensions of the front and rear panels, left and right panels, bottom plates, and other parts of the cargo box are large, and the tonnage of existing general hot stamping presses may not be able to meet the technical requirements of full quenching of parts (maximum thickness: 5 millimeters). Therefore, adding a certain amount of molybdenum further enhances the hardenability of the steel. In addition, the content of elements such as Cr and Mn has also been increased to the upper limit level to ensure that the hardenability of the steel meets the requirements of cargo box manufacturing. The composition of press hardening steel used in the manufacturing of cargo box is shown in Table 1.

Table 1 Composition and preparation process of press hardening steel（wt%）

Element	C	Si	Mn	P	S	Cr	Nb	V	Ti	Mo	B
wt%	0.20 ~ 0.25	0.20~ 0.40	1.50~ 2.00	≤ 0.015	≤ 0.003	0.15 ~ 1.0	0.02 ~ 0.06	0.02 ~ 0.06	≤ 0.03	≤ 0.20	≤ 0.005
Process parameters	Heating temperature of steel billet: above 1220 ℃; final rolling temperature: 870~920 ℃; curling temperature: 650~700 ℃.										

Figure 1 shows the CCT curve of the steel mentioned in Table 1 (calculated using JmatPRO software). The critical cooling rate for martensitic transformation of this steel is only 7 ℃/s, which is much lower than the traditional 22MnB5, indicating that the hardenability of this steel significantly exceeds the industry average level.

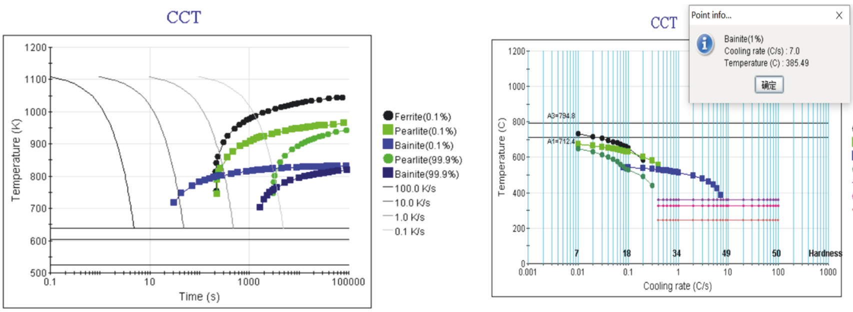

Fig. 1. The CCT curve of 22MnB5NbVMo

3. Production line

As shown in Figure 2, to meet the hot stamping manufacturing needs of large-sized commercial vehicle parts such as cargo box, a dedicated hot stamping production line has been customized and developed. The biggest advantages of this production line are three points: 1) super large tonnage press machines; 2) strong transfer device; 3) quickly and uniformly cool the mold. Based on this hot stamping production line, the maximum size of sheet metal parts that can be produced is 9500mm × 1600mm × 10mm, the maximum profile size is 330mm × 300mm × 10000mm, and the weight can up to 800kg.

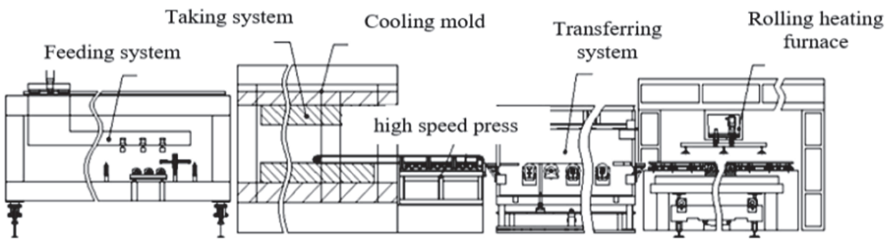

Fig. 2. Commercial vehicle hot stamping production line

3.1. *Heating furnace design*

Heating is the first process in hot stamping production. To meet the heating needs of large-sized components, a customized rolling large heating furnace has been developed. As shown in Figure 3, the heating furnace is 11.5 meters long, with a heating power of 600 kW. It can heat up parts with a maximum length of 9 meters, a width of 1.6 meters, a thickness of 0.25 meters, and a weight of nearly 1 ton. To prevent the overall large deformation of the steel skeleton of the long furnace body under continuous high-temperature operation conditions, a segmented furnace body design is adopted. The furnace is equipped with roller conveyor, ladder shaped plate positioning device, and plate movement device, enabling large-sized plates to enter and exit the heating furnace smoothly and stably. To address the issue of heating uniformity for large-sized components, dozens of heating and temperature monitoring devices have been installed in the furnace. To solve the surface oxidation problem of large-sized components during the heating process, multiple nitrogen gas devices have been uniformly installed in different parts of the furnace, ensuring that the nitrogen atmosphere in the furnace reaches over 95%. In addition, in the actual production process, to ensure sufficient heating of large-sized plates (achieving 100% austenitization of the substrate), the heating time is basically controlled within the range of 8~12 minutes. After the heating of the sheet metal is completed, it will be directly transferred to the press through the roller system for forming and quenching.

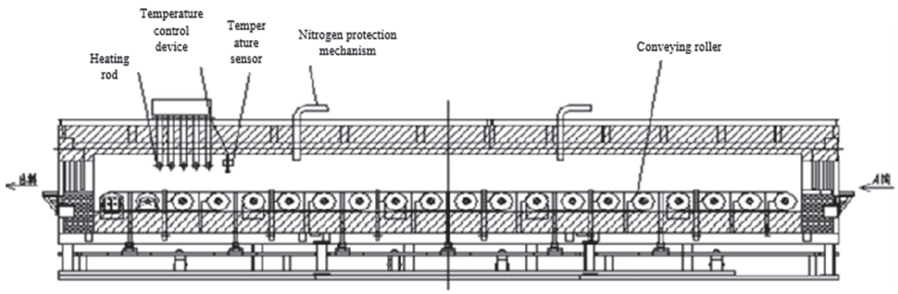

Fig. 3. Heating furnace

3.2. *The customized transfer system for large-sized parts*

The quality and length of commercial vehicle parts are generally much higher than those of passenger car parts. It is difficult to achieve efficient and stable transfer of such parts using a general mechanical arm, and production safety accidents are prone to occur. Based on this, a customized transfer system for large-sized parts has been developed. As shown in Figure 4, the overall length of the system is 12 meters and the travel distance is 10 meters. It consists of a feeding system, a transfer system, and a pickup system. This system can grab parts weighing up to 2 tons and achieve various functions such as automatic picking, feeding, collection, and stacking. Multiple suction cups are installed on the gripping device in the system, and in the actual production process, these suction cups are used to achieve stable gripping and transfer of various heavy weight sheets or parts.

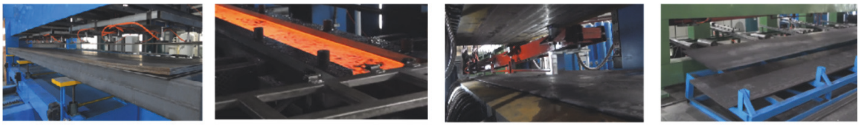

Fig. 4. Sheet material transfer system

3.3. *Hot stamping press*

As mentioned earlier, commercial vehicle parts are larger in size and thicker in thickness. To ensure that all parts of the parts can be quenched during the hot stamping process, in addition to requiring the steel itself to have high hardenability, higher requirements are also placed on the ability of the hot stamping press. The key to ensuring the quenching quality of large-sized and thick parts is that the press can provide ultra-high pressure and achieve high-speed pressure. Based on this, as shown in Figure 5, by improving the structure and oil circuit of the ordinary press machine, the free fall principle is used in the hot stamping process to significantly increase the downward working speed of the loading device, and it can generate a strong instantaneous impact force (up to 3000 tons), meeting the high pressure and high-speed quenching forming requirements of large-sized parts. For example, a certain steel plate has dimensions of 9.5 meters in length, 1.5 meters in width, and 2 millimeters in thickness. Under the condition of flat plate quenching, a load of 3000 tons was applied to the steel plate. Through theoretical calculation, the pressure acting on the steel plate was found to be about 2.1 MPa, significantly exceeding the pressure requirement (≥1.0 MPa) required for a 2mm part to fully achieve 100% martensitic transformation [8].

Fig. 5. 30000KN Hot stamping press

3.4. *Hot stamping molds and cooling systems*

In addition, in order to achieve good quenching effects on large-sized and thick parts of commercial vehicles, in addition to materials and presses, it is also closely related to the quenching and cooling process. How to keep the cooling rate of various parts of the parts as consistent as possible during the quenching process is a crucial issue, which poses high technical requirements for the processing of molds. The traditional hot stamping mold processing process generally first uses drilling to process linear cooling channels on each insert block, and then splices a large number of insert blocks together to form a complete mold [9]. Due to the fact that most parts have a spatial curved structure, the mold surface based on block splicing must also be designed as a spatial curved structure. Due to the impossibility of machining curved cooling channels on the insert using drilling methods, the distance between the internal cooling channels at different parts of the mold obtained by this machining method and the mold surface at that part is mostly different, resulting in significant differences in the cooling rate of different parts during the hot stamping quenching cooling process. The larger the size of the part, the more significant the difference in cooling rate, ultimately leading to severe uneven quenching microstructure and properties in different parts of the part, affecting the overall performance of the part. Based on this, as shown in Figure 6, an innovative cooling mold suitable for the hot stamping of large-sized parts has been developed. This mold has low cost and better cooling effect compared to molds processed by traditional methods. The biggest technical advantage of this mold is that the cooling channels inside the various inserts that make up its entire body are processed using casting method instead of drilling method. As the casting method can process cooling channels with arbitrary spatial curve shapes, this ensures that the distance between the cooling channels inside each part of the mold surface and the mold surface of that part is basically the same. Ultimately, the cooling rate of each part of the part is basically the same during the quenching process, solving the technical problem of uneven quenching structure and performance of large-sized parts.

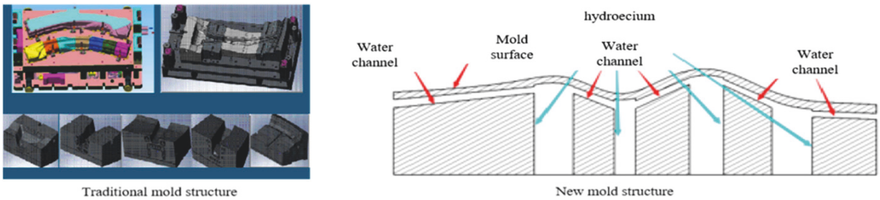

Fig. 6. Mold cooling water channel

4. Trial production and testing

4.1. *Trial production of hot stamped parts for cargo box*

In summary, by starting from various aspects such as the composition design of press hardening steel, hot stamping production lines, equipment, and process methods, the common key technical problems related to the hot stamping manufacturing of a large number of large-sized thick specification parts on commercial vehicles have been solved. The mold, production process, and sample of hot stamped parts used for cargo box manufacturing are shown in Figure 7. The microstructure and mechanical properties of the component matrix were tested, and the relevant results are shown in Figure 8 and Table 2.

It can be seen that the matrix of the part is nearly 100% martensitic structure, and the tensile mechanical properties, hardness and sharp cold bend angle indicators have reached the generally recognized performance level of hot stamped parts in the industry which verifies that the hot stamped material and process collaborative technology solution used in this article is reasonable.

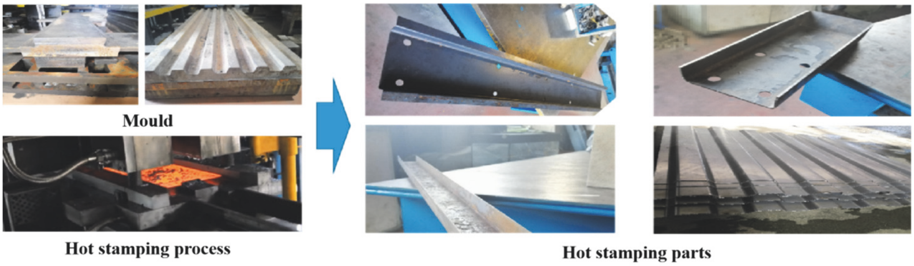

Fig. 7. The production process and samples of hot stamped parts for cargo box (thickness: 2~5mm)

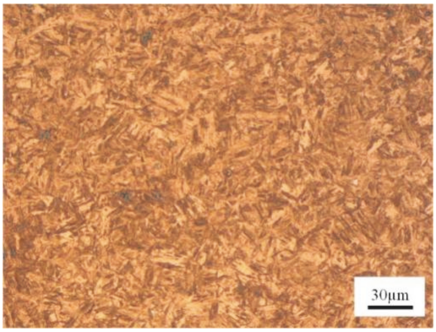

Fig. 8. Microstructure of hot stamped parts substrate

Table 2 Mechanical property testing results of one hot stamped part of cargo box

-	$R_{p0.2}$/MPa	R_m/MPa	$A_{50\ mm}$/%	HV10	Sharp cold bend angle/°
Results	1152	1502	6.3	466	65.4
Remarks	The above results are the average of the sampling test results at 5 different locations on the same part.				

4.2. *Trial production and performance verification of hot stamped cargo box*

As shown in Figure 9, based on the breakthrough in key technologies for hot stamping production of large-sized thick specification parts in commercial vehicles, a lightweight, high-performance, and cost-effective commercial vehicle cargo box has been successfully developed to meet the needs of automotive companies. This cargo box is based on the integrated application of hot stamped parts (the total weight of hot stamped parts is about 300 kilograms), achieving a weight reduction of about 20% compared to the prototype cargo box (from about 1.77 tons to about 1.39 tons), and the cost is basically the same as the prototype cargo box. As shown in Figure 8, relevant performance tests and evaluations were conducted on the hot stamped cargo box according to the requirements of the automotive company. The results showed that the rigidity, corrosion resistance, and other aspects of the cargo box met the requirements of the automotive company. Finally, the cargo box was placed on its corresponding vehicle product for road testing, and the results showed that after about 12000 kilometers of road testing, the cargo box body did not show any failure, further verifying its quality reliability.

Fig. 9. hot stamped cargo box and related performance testing

5. Conclusions

This article focuses on the common technical challenges faced by the hot stamping of large-sized thick specification parts in commercial vehicles, and conducts research on related materials and processes for commercial vehicle cargo box. Through research and breakthroughs in key technologies such as high strength, toughness, and high hardenability press hardening steel alloy design, uniform heating control of large-sized parts, efficient and stable transfer control, ultra high load rapid pressurization control, and cooling uniformity control, a lightweight, high reliability, and high cost-effectiveness commercial vehicle cargo box has been successfully developed. The relevant service performance level meets the requirements of automotive enterprises. The relevant technological achievements in this article have to some extent promoted the application of hot stamping technology in the domestic commercial vehicle manufacturing industry.

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