Laser tailored welding blanks hot stamping technology based on multi component integration and digital transformation of workshop

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This paper describes the hot stamping of laser spliced plates based on multi-component integration and the digital transformation of the shop floor. As the global automotive industry faces energy and environmental challenges, automotive lightweighting has become an industry trend, in which high-strength steel replaces traditional materials to achieve lightweighting. Hot stamping technology combines material heat treatment and molding processing to improve the performance of automotive structural components, especially in terms of automotive safety. The concept of multi-component integration in the field of lightweight design and manufacturing as well as the development and application of laser welded panels were also elaborated. The laser ablation welding technology and its application for aluminum-silicon coated plates, the digital process and equipment in the hot stamping shop for high strength steel, and the digital transformation of hot stamping production are discussed and analyzed in depth, and the transformation roadmap of the digital hot stamping shop is put forward, which looks forward to the prospect of digital technology in hot stamping production.

Keywords: Body lightweighting; High-strength steel; Laser spliced plate; Hot stamping; Digital workshop.

1. Introduction

In the present era, the global automotive industry is facing energy and environmental challenges. In order to effectively address these challenges, automotive lightweighting has become a trend in the industry. Lightweighting not only reduces automobile energy consumption and improves fuel economy, but also helps to reduce exhaust emissions. The density of traditional materials of steel is gradually replaced by high-strength steel, which enables vehicles to maintain structural strength while effectively reducing total weight, improving the power performance and driving stability of the car, while reducing energy consumption and exhaust emissions. Lightweight materials have a wide range of applications, including body, chassis and engine and other key parts. A variety of factors need to be considered when selecting lightweight materials, such as light weight, mechanical properties, cost-effectiveness and sustainable development.

Hot stamping technology, as a high-efficiency forming technology that has been rapidly developed in the automotive manufacturing industry in recent years [1], combines the dual advantages of material heat treatment and forming and processing, and is able to overcome the problem of high strength materials that are difficult to be formed at room temperature. In the hot stamping process, the metal sheet is heated to the automatization

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temperature, then quickly transferred to the die for stamping and forming, and cooled rapidly in the die to enhance the strength of the material. The application of hot stamping technology has greatly enhanced the performance of automotive structural components, especially in improving the safety performance of automobiles. Components formed by hot stamping have higher strength and hardness, as well as good energy-absorbing properties, which can more effectively absorb and disperse collision energy and reduce injuries to occupants. With the continuous development and maturity of hot stamping technology, its application scope in the automotive industry is also expanding, and it has become an important means to improve the safety performance of automobiles

2. Multi-Part-Integration (MPI) Concepts and Laser Splicing Plate Forming Technology

With the rapid development of modern industrial technology, especially in the field of high technological requirements, such as the automotive industry's lightweight body design and manufacturing, the concept of multi-component integration (MPI) came into being, and gradually became a highly efficient organization and production mode [2]. This concept aims at integrating multiple components or assemblies in order to realize the improvement of product functionality and performance. Its core idea lies in combining single components with different functions into a multi-functional whole through precise design and manufacturing, so that the product not only gets a significant improvement in performance, but also realizes the optimization of the production process, reduces the waste of materials, and improves the utilization of resources.

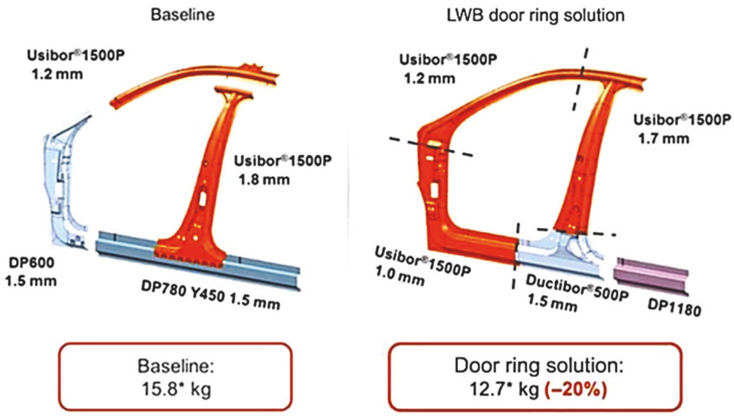

Fig. 1 Advantages of hot stamping and forming of butt-welded plates compared to conventional hot stamping techniques [3]

The development of a robust process for laser butt welding of steel plates has allowed blanks made from multiple plates to be applied to stamped parts. With the ability to use multiple materials and adjust thicknesses, strengths and coatings, cost savings can be realized and product quality can be improved through the use of multiple thicknesses in the part, reduction of blank sizes (through more efficient nesting of blanks), consolidation of the part, and more precise application of corrosion-resistant coatings. Customized blank technology has been successfully applied to door rings, as shown in Fig. 1 [3].

Since 2009, the demand for laser-welded blanks (LWBs) hot stamping and forming in the global automotive industry has started to grow rapidly, mainly in response to global emission regulations. In 2013, laser ablation spliced blanks were first applied to manufacture the first one-piece hot stamped door rings. The solution was first deployed on the 2014 Honda Acura MDX, which offered a 20% weight reduction compared to conventional door assemblies [4]. The first production vehicle to utilize the new inner and outer door ring blanks, it is also the world's first inner and outer door ring system designed to better balance strength and performance and reduce the additional weight of the vehicle. In terms of joining technology, ArcelorMittal's patented ablation technology successfully removes the AlSi coating while retaining the intermetallic layer between the coating and the underlying steel, as shown in Fig. 2. In-depth research on this technology has further clarified the factors affecting laser ablation welding [5], which has led to the widespread application of this technology.

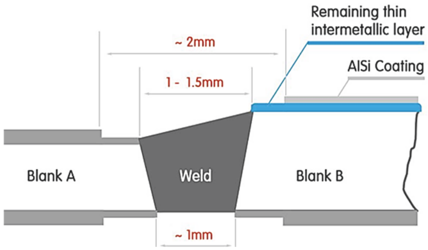

Fig. 2 Schematic diagram of the principle of laser ablation weld plate technology [4]

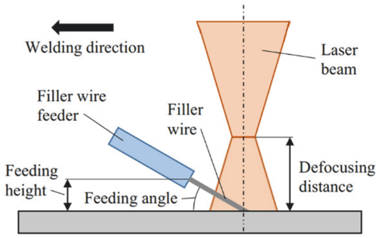

Fig. 3 Schematic diagram of the new-generation laser filler wire weld plate technology [6]

For the laser ablation welding of aluminum-silicon coated plates, BaoSteel has developed a new laser welding method for aluminum-silicon coatings [6], using filled wires and variable energy distribution laser optics. This technology simplifies the entire laser welded plate production process and avoids additional aluminum-silicon coating removal steps [7], making it particularly suitable for large-scale industrial applications, and has become an effective alternative to laser ablation welding, as shown in Fig. 3. As an innovative method for processing metallic materials, the laser butt-welded plate technology clearly offers advantages in terms of precision and speed. The precision splicing of different metal plates is accomplished by the rapid heating, melting and solidification of the metal material through the action of a high energy density laser beam on the material [8]. In this process, laser welding technology can effectively control heat input, reduce material deformation, and improve the quality of welded joints. This technology is not only suitable for welding between the same material, but also can realize the splicing of dissimilar materials, which greatly broadens its scope of application.

In the specific application of multi-component integration, the automotive industry, with its extremely stringent requirements for product performance, has become the pioneer application area of multi-material high-performance integration (MPI). For example, in the structural design of modern automobiles, designers are constantly striving to integrate a wide range of materials and components into a single body structure due to the need for higher safety standards and lower energy consumption targets. In this process, the performance characteristics of different materials are fully utilized to achieve the goal of reducing body weight while maintaining structural strength.

However, a series of challenges are faced in the process of advancing multi-component integration. These challenges center on how to ensure reliable and effective connections between different materials and components, and how to keep the functionality of each component intact during the integration process. In order to solve these problems, the research and application of laser weld plate forming technology has become an efficient and reliable technical support for multi-component integration.

3. Laser processing technology in the production process of hot stamping of high-strength steel

3.1. *Processes in the hot stamping plant of high-strength steel*

The digital workshop should fully consider the digital technology approach of the pre-process and post-process of hot stamping production, as well as the technical maturity and production flexibility of these equipment. A combined laser processing process is shown in Fig. 4.

With the emergence of multi-variety and low-volume models and the development of customization, large-scale die drop will receive considerable limitations. The laser dropout will have a larger proportion and will occupy a major position. Body structural parts of the multi-component integration of hot stamping the expansion of the application of laser welding will also become an important means of laser processing. After hot stamping forming parts strength up to 1300-2000Mpa, laser three-dimensional cutting is more effective technology and has become a mature technology. In order to meet the assembly welding of body structure parts, the spot welding of high strength hot stamped parts to adapt to the new requirements of the local spot welding parts "laser softening" has also become an optional laser processing procedures.

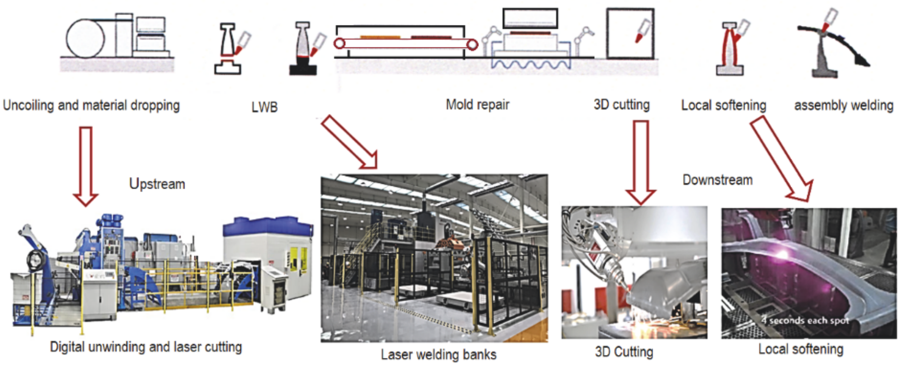

Fig. 4 Production flow and associated laser processing in a hot stamping production plant

3.2. *Equipment of digital hot stamping workshop*

3.2.1. *Synchronized laser cutting of falling material*

Laser cutting is crucial in the hot stamping production of high-tensile steel, and its high precision and efficiency directly affect the quality of the final product. Laser cutting technology is widely used in high-strength steel cutting processes because of its high degree of automation, high-quality cutting and excellent material adaptability. Its working principle is to locally heat the material through a focused laser beam, causing it to melt or vaporize rapidly, and then blow away the melted or vaporized material through an auxiliary gas to realize the cutting process.

In hot stamping production, laser cutting is not only used to cut and shape the finished product, but also for processes such as pre-cutting and hole processing. These processes are essential to ensure dimensional accuracy of the part, reduce material waste and optimize subsequent processes. The high precision of laser cutting ensures smooth cut edges, reduces subsequent trimming and greatly improves productivity.

In addition, laser cutting is highly flexible and can easily cope with cutting needs of various complex shapes and sizes, providing greater freedom for design and production. With the development of laser technology, the cutting speed and accuracy of laser cutting machines have been significantly improved, further broadening its application in the production of hot stamping of high-strength steel.

In the processing technology of laser drop material, it is conventional to have different support and motion control methods for two-dimensional laser cutting, and consequently, different production efficiency. Among them, the toothed peg plate support is usually used in laser static cutting technology, the use of advanced mobile toothed peg plate can also be realized automatically or without knowing the laser synchronous cutting. And the belt support as another support method, through the bearing mounted belt structure, it can meet the needs of sheet movement and laser synchronized cutting, see Fig. 5. belt support system can maintain the smooth transmission of the material during the cutting process, and has the characteristics of the belt to follow the light seam when the cutting head is moving, it can avoid the friction damage of the sheet and the toothed pegs in order to ensure the precision and quality of the cutting [9].

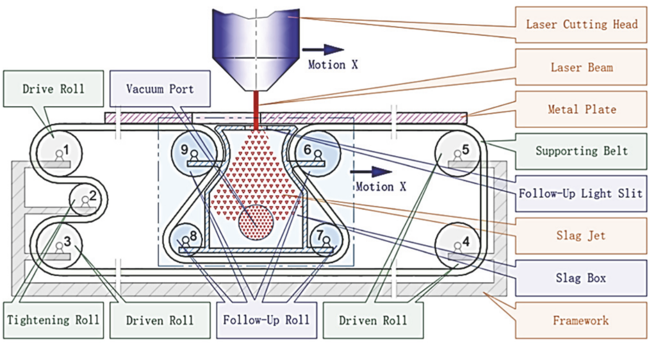

Fig. 5. Principle of belt support laser cutting.

3.2.2. *Three-dimensional five-axis laser cutting*

The application of thermoforming 3D 5-axis laser cutting in automotive body parts is now well established. From automotive OEMs to thermoformed component suppliers' demands for continuous cost reduction, the requirements of automotive thermoformed component providers for 3D laser cutting machines are changing. As the thermoforming market evolves, customers are asking for different directions for laser machines with lower investment costs and higher machine efficiency. The results of this study are based on the needs of different customers in the existing thermoforming market and develop new technological innovations for 3D laser cutting machines.

One is the latest application of 2-in-1 fiber lasers for 3D thermoforming material cutting. With the same laser power, it is possible to increase the cutting efficiency of the entire machine for a single part, reducing investment costs while meeting the needs of some customers.

The latest laser technology is the Bright Line Speed 2-in-1 fiber technology for thermoforming 3D cutting. The two-in-one fiber is rationally matched to use two diameters of laser beams (inner core laser beam and outer ring laser beam), and the combination of inner core and outer ring diameters of the laser beams can change the beam quality of the laser output laser from the laser source used for cutting [10]. After achieving the laser beam ratio that is most suitable for 3D laser cutting, the cutting speed of the machine system can be effectively increased to ensure the cutting quality of laser-machined parts with complex part shapes (Fig. 6).

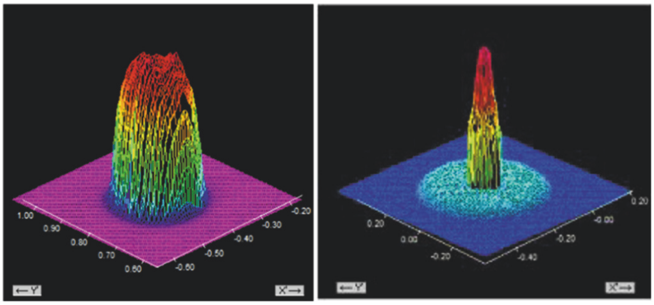

Fig. 6 Power distribution in the beam cross-section. On the right is a normal single-beam laser source with a diameter of ϕ100 μm, and on the left is the beam quality of the 2-in-1 laser.

3.2.3. *Automatic laser welding plate equipment*

Fully automatic gantry type continuous welding line can realize automatic loading of material, automatic joining and positioning of blanks, and automatic unloading of welding blanks, which requires 1 direct operator. The production efficiency of the specialized fully automatic line for gantry splicing and welding is much higher than that of the traditional semi-automatic splicing and welding line, as shown in Fig. 7 [11]. The new generation of Baosteel Laser Splicing & Welding International Co., Ltd. is 2 to 3 times more productive than the traditional splicing and welding plate production line, and a typical one-piece door ring splicing and welding plate is shown in Fig. 8.

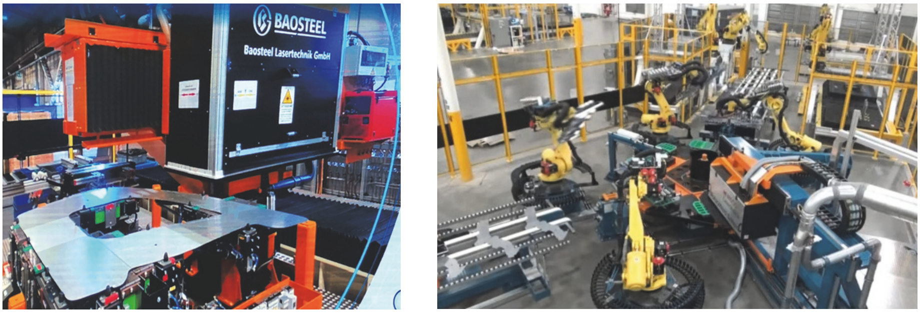

Fig. 7 High-performance door ring welding plate automatic production line

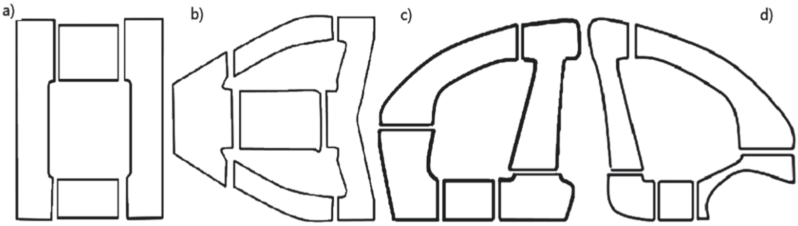

Fig. 8 Typical laser welded blanks for body parts: a) Sun roof; b) Hood inner; c) &d) Door rings a) Sun roof; b) Hood inner; c) &d) Door rings

4. Digital transformation of automotive hot stamping production

4.1. *Digital Mechanical Servo Hot Stamping Production Line*

With the in-depth promotion of Industry 4.0, digitalization and intelligence have become an inevitable trend in the development of machinery manufacturing. As the core equipment of the stamping process, the stamping press is also experiencing the transformation from the traditional hydraulic type to the digital mechanical servo type. The new generation hot stamping production line is an innovative production line based on digital mechanical servo presses, which adopts advanced hot stamping and forming technology and automated conveying system, and is capable of meeting the demand for hot stamping processing of high-strength steel materials for large and complex high-strength steel body parts, and improving the production efficiency and product quality. This innovative production line encompasses three key components: a digital mechanical servo press, a low-energy short-line roller-heating furnace, and a digital servo automated conveyor system. One of the key technologies is the use of digital mechanical servo presses, whose advanced control functions and responsiveness provide the basis for efficient and low-energy production of hot stamping of high-strength steels.

Compared with the traditional hydraulic stamping presses, the digital mechanical servo hot stamping press has significant advantages [12]. The digital-mechanical servo hot stamping press has higher stamping accuracy and more stable stamping results. Due to the digital servo technology, the motion control accuracy of the press can reach 0.01mm, which ensures the closing accuracy of the stamping mold and creates conditions for the uniform cooling of the hot stamping. The digital mechanical servo hot stamping press has higher productivity and lower energy consumption, and the total energy consumption is reduced by 25-30% compared with the hydraulic press of the same tonnage.

4.2. *Hot stamping digital workshop and production process*

In the past 10 years, the production process of hot stamping of high-strength steel has made great progress in meeting the safety and lightweight goals, especially in the hot stamping and forming technology of simple to complex body structure parts. With the in-depth research and application of safety and rational utilization of materials for bodywork, more refined bodywork design and efficient and low-cost technology research have begun to be widely applied.

Innovating the component units of production lines with a green starting point has become a trend that has been consistently applied in the last 10 years. With the concept of Industry 4.0, the research of hot stamping production line based on Industry 4.0 has received extensive attention from enterprises and research organizations. Since 2014, our research team has been studying and deploying hot stamping production lines with digital mechanical servo presses, and completed the manufacturing of prototypes and production line deployment in 2017. Combined with the proposal of multi-component integrated hot stamping technology for laser spliced panels, and with the previous research and application experience, we propose a transformation roadmap for the digital hot stamping production plant, as shown in Fig. 9.

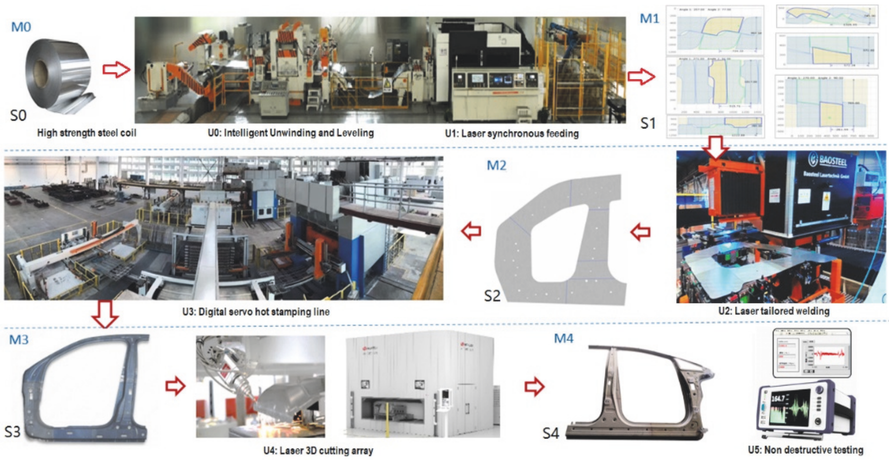

Fig. 9 Manufacturing unit and logistics of digitalized hot stamping plant

In the planning of the manufacturing unit and logistics of the digital hot stamping production plant (see Fig. 9), where M (Material) stands for material; U (Unite) stands for the digital manufacturing unit, which is the digital processing equipment based on the CPS specification; and S (Stock) is the stack or three-dimensional warehouse for raw materials, intermediate products, or final products, which is detailed in Table 1.

Table 1 Digitalized units and logistics nodes in hot stamping production plant

No.	1	2	3	4	5	6	7	8	9	10
Material	M0		M1		M2		M3		M4	
Units		U1		U2		U3		U4		U5
Stock	S0		S1		S2		S3		S4	

In Table 1, the meanings of the numbers in the first row are as follows: 1- Raw material; 2- laser cutting Blank; 3- Specification sheet; 4- laser welding ;5- LWB blank; 6- Hot Stamping; 7- Parts after hot stamping; 8- Laser 3D cutting; 9- Finished Parts; 10- Nondestructive testing of mechanical properties. stamping; 8- Laser 3D cutting; 9- Finished Parts; 10- Nondestructive testing of mechanical properties.

M represents the shape of the material in the production process, where M0 is the original material steel coil, M1 is the laser cut sheet of different sizes, thicknesses and strength grades, M2 is the sheet that meets the shape of the hot stamping blank after laser welding, M3 is the stamped part after hot stamping and forming, after the transformation of the material organization, and M4 is the final part after 3D laser cutting (perforation and trimming).

U represents the processing unit of the production line, which is generally a digital processing equipment. U1 is a digital leveling and laser plane cutting unit equipment, which functions as a plate drop; U2 is a laser welding unit equipment, which functions as a pre-designed plate thickness, strength level of the plane plate, welded into the blank needed for hot stamping; U3 is a digital servo hot stamping production line, which realizes hot stamping forming and strengthening of the blank; U4 is a 3D laser cutting unit equipment, which is for the production line to realize hot stamping forming and strengthening; M4 is the final part after 3D laser cutting (punching and trimming). U4 is a three-dimensional laser cutting unit equipment, in order to match the capacity of the production line, you can need more than one laser cutting machine to form a cutting unit; U5 is a non-destructive testing and recording unit for the mechanical properties of hot stamped parts.

S represents the storage or stack of materials and parts: S0 is the raw material warehouse; S1 is the stack or three-dimensional warehouse of the sheet after laser drop material; S2 is the stack or warehouse of the flat sheet after laser welding; S3 is the stack of hot stamping products; and S4 is the stack or three-dimensional warehouse of the final products after completing three-dimensional laser cutting. Hot stamped products are generally stored in stackable frames and transported to the U4 unit.

On the basis of the above digitization, combined with industrial Internet information technology, intelligent process and equipment management can be further developed by realizing system monitoring. The application of real-time monitoring sensors and intelligent control systems can greatly improve the automation level of production and the degree of intelligent operation, and even realize the intelligent control of long-cycle production [13]. The application of these digital systems not only reduces human intervention and production costs, but also ensures the consistency and high quality of the finished product by accurately controlling the production parameters, such as temperature, pressure and cooling rate.

5. Conclusions and outlook

In this thesis, we have deeply explored the digital transformation of hot stamping and workshop of laser splicing plate based on multi-component integration. By studying and analyzing the concept of multi-component integration and the development and application of laser splicing plate in body lightweight design and manufacturing, as well as the transformation process of the hot stamping digital workshop, we have drawn the following conclusions:

First, in terms of technology development and application, we emphasize the important application of laser spliced plate forming technology in the concept of multi-component integration. As a high-precision and high-efficiency metal material processing method, this technology provides strong support for lightweight automotive design and manufacturing. Especially for hot stamping technology for high-strength steels, the digital transformation process continues to drive the development and application of this technology, which brings more room for innovation in the automotive industry.

Second, in terms of digital transformation, we explore the positive role of digital technology in hot stamping production plants and production processes. The application of digital technology makes the hot stamping production process more intelligent and automated, improves the production efficiency and product quality, reduces the production cost, and injects a new impetus for the sustainable development of the automotive manufacturing industry.

Finally, looking into the future, we believe that with the deepening of the concept of Industry 4.0, the prospect of digitalized hot stamping production will be even broader. The transformation roadmap of digital hot stamping workshop will provide new technical support for the digital transformation of industrial manufacturing industry, which provides more possibilities and opportunities for automotive lightweight design and manufacturing.

In summary, this thesis thoroughly studies the automotive lightweighting, the digital transformation of hot stamping production, and the development and application of laser splicing plate. Facing the challenges and opportunities of the global automotive industry, the application of digital technology brings new vitality and development direction to the whole industry. We hope that the research results of this thesis can provide useful references and insights for professionals in related fields, promote the innovation and development of the automotive manufacturing industry, and facilitate the industry's continuous forward development.

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