Research and application of laser welding process and automatic welding equipment for high strength steel plates

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This thesis explores the utilization of laser cutting and welding processes along with automatic welding equipment for high tensile steel plates in the realm of lightweight automotive body construction. As an important process in the field of automobile manufacturing, the laser welding technology realizes the lightweighting of the car body and improves the rigidity and safety of the car body through the hot press forming technology of laser welded plates.Laser welding technology, as a pivotal procedure in the domain of automobile production, facilitates the reduction of weight in car bodies and enhances their stiffness and safety by employing the hot press forming technique on laser-welded plates. Research has shown that laser welding technology has significant advantages in the welding of high-strength steel plates, especially in solving the welding problem of aluminum-silicon coated plates has made important progress. Studies have demonstrated that laser welding technology offers notable benefits in welding high-strength steel plates, particularly in addressing the welding challenges posed by aluminum-silicon coated plates, marking significant advancements. Through the optimization of process parameters and equipment improvement, high-quality welding effect is achieved, which provides new possibilities for body manufacturing. By fine-tuning process parameters and enhancing equipment, a superior welding outcome is attained, opening up innovative avenues in car body manufacturing.

Keywords: Lightweight body; High-strength steel; Hot stamping; Tailed welded blanks; Automatic TWB welding production line.

1. Introduction

With the increasing emphasis on environmental protection and energy efficiency, there is a rising demand for lightweighting in the automotive industry. Lightweighting not only reduces energy consumption and enhances driving safety but also minimizes exhaust emissions, thus contributing to environmental conservation. High-strength steel, as a lightweight material, possesses superior strength and toughness, making it a crucial option for automobile body fabrication. Laser welding technology enables the fusion of diverse materials to create a composite material with specific properties, presenting a novel approach to achieving lightweight vehicle bodies.

Laser welding technology originated in the 1960s and was initially integrated into automobile manufacturing in the 1970s, primarily utilized in the cold stamping process for body part production. During this phase, laser welding technology was primarily employed to address challenges such as material selection limitations, cost escalations, and molding complexities in the single plate forming process.

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The 1980s and 1990s witnessed significant advancements in research and application of laser welding technology. Its utilization in the automotive sector gradually expanded, with an increasing number of car manufacturers adopting this technology. During this period, laser welding plate hot press molding technology became prevalent in the construction of automobile body structures, further reducing body weight and enhancing rigidity and safety [1,2].

Currently, laser welding technology stands as a pivotal process in the realm of automobile manufacturing. As laser welding technology continues to progress, novel laser welding plate technologies like patch-type welding plates and engineering welding plates have emerged, offering enhanced possibilities for automobile production [3]. Particularly noteworthy is the advent of large-scale hot stamping technology for high-strength steel based on the MPI concept, which has spurred the development of fully automated and highly efficient laser splicing and welding equipment [4]. This study concentrates on investigating the laser welding process and equipment for high-tensile steel plates, providing technical backing for car body lightweighting.

2. High-strength steel plate laser welding process research

2.1. *Principle of Laser Beam Welding*

Laser Beam Welding (LBW) is a high-energy density welding method, in which the surface of the workpiece is heated by a laser beam so that it melts and combines with the substrate material. LBW is characterized by high seam quality, fast welding speed and concentrated energy, which makes it suitable for welding of high-strength steel plates. However, the surface coating (aluminum-silicon coating or zinc-based coating) of hot stamped high-strength steel plates affects the laser welding of high-strength steel plates, so a special welding process for aluminum-silicon coated plates has arisen.

2.1.1. *Laser ablation-welding technology*

The principle underlying the laser cleaning (ablation) and welding of aluminum-silicon coatings on aluminum-silicon coated plates hinges on the high energy density of the laser. When the laser beam interacts with the aluminum-silicon coated plate, its exceptionally high energy density induces rapid heating of the aluminum-silicon coating layer to the point of melting or vaporization, facilitating both cleaning and welding objectives.

Preceding laser cleaning, surface preparation of the aluminum-silicon plated plate is imperative, involving the removal of substances like oil and oxides to ensure optimal contact between the laser irradiation and the aluminum-silicon plating layer. By considering the properties and thickness of the aluminum-silicon plating layer, adjustments in laser power, beam diameter, scanning speed, and other parameters are made to achieve the desired cleaning outcome during irradiation. The laser beam is directed at the surface of the aluminum-silicon plating layer to melt and vaporize it, thereby effectuating the cleaning process. In this procedure, the laser beam must move at a specific scanning speed and trajectory to ensure uniformity in the cleaning results.

Tailoring the laser power, beam diameter, scanning speed, and other parameters in accordance with the characteristics of the aluminum-silicon plating layer and welding requisites is essential to achieve a high-quality welding outcome.

2.1.2. *Laser Fillet Welding Technology*

Laser filler wire welding is a welding technique that utilizes a laser beam as the heat source, where the workpiece's surface is heated by the high energy density laser beam to melt and seamlessly amalgamate with the filler wire, as illustrated in Figure 1. This welding method offers advantages such as low heat input, rapid welding speed, minimal heat-affected zone, and reduced thermal deformation. It finds extensive application in the customized splicing welding of high-strength steel plates for structural body components. The principle of laser filler welding can be delineated as follows:

(1) The laser beam impacts the workpiece's surface, inducing melting. Control over the laser beam's power and focusing intensity is achieved by regulating the laser's output power and the optical system.

(2) The filler wire interfaces with the molten surface of the workpiece, facilitating the thorough blending of wire components with the base metal constituents to generate a novel mixed molten pool.

(3) The elemental composition, ratio, and quality of the mixed molten pool vary between the wire and the base metal, enabling the selection of an appropriate wire to address performance deficiencies in the base metal itself. This, in turn, enhances crack resistance, fatigue resistance, corrosion resistance, abrasion resistance, and other microscopic aspects of the weld.

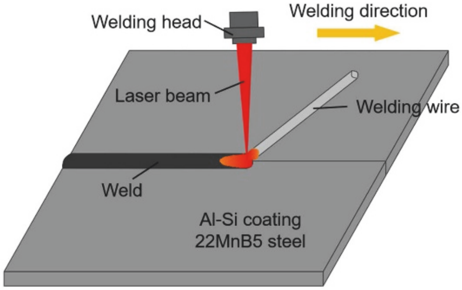

Fig.1. Schematic diagram of laser welding with filler wire[6].

Filler welding method abandons the plating ablation technology, which can effectively reduce the investment in equipment and increase production efficiency by 20-35%; Realize the double reduction of equipment investment and production and operation cost, strong market competitiveness; welding quality is stable, controllable, good reproducibility, the performance of the joint after hot stamping meets the requirements of the car factory, 100% broken outside the weld area. The sharp increase of Chinese patents on splicing welding has paved the way for the diversification of the application market.

2.2. *Influence of process parameters on weld quality*

The key process parameters in laser welding encompass laser power, welding speed, laser beam diameter, defocusing amount, among others. By optimizing these parameters, superior-quality welds can be achieved. The impact of various process parameters on weld seam quality was explored through material and wire process combination trials. Findings indicate that laser power and welding speed significantly affect weld quality, with improved weld shaping achievable by judiciously increasing laser power and decreasing welding speed.

2.3. *Influence of process parameters on forming properties*

Post laser welding of high-strength steel plates, the material properties and forming characteristics at the weld are altered. The impact of process parameters on forming properties is scrutinized through mechanical properties testing data of laser-welded seams on plates of varying thicknesses. Findings reveal that appropriate adjustment of laser power and welding speed can enhance the forming properties at the weld, mitigating issues like rupture and weld displacement during hot stamping and forming. Following optimization, the tensile strength of the welded CR950/1300HS-AS75/75 plate exceeds 1350 MPa, with an elongation exceeding 8%, surpassing the stipulated requirements of ≥1300 MPa and A50≥5% as outlined in Q/JLY J7110072D-2020.

3. High-strength steel laser welding automation equipment system

3.1. *Structure and functional parameters of automated equipment*

Considering the increasing demand for laser welding of high-strength steel plates, enhancements have been made to the laser welding equipment. These improvements primarily involve: opting for a high-power laser to boost welding speed; integrating an optical tracking system for precise laser beam control; incorporating a cooling system to ensure weld seam quality. To achieve top-notch weld quality and stability, the welding head in this system utilizes the TruDisk D70 fiber laser welding head, capable of withstanding up to 8 kW of laser power. The welding head is equipped with both a protective gas circuit and a cooling water circuit, ensuring prolonged stable and reliable operation.

The fully automated laser welding board production line is depicted in Figure 2, showcasing the equipment's key functional parameters detailed in Table 1.

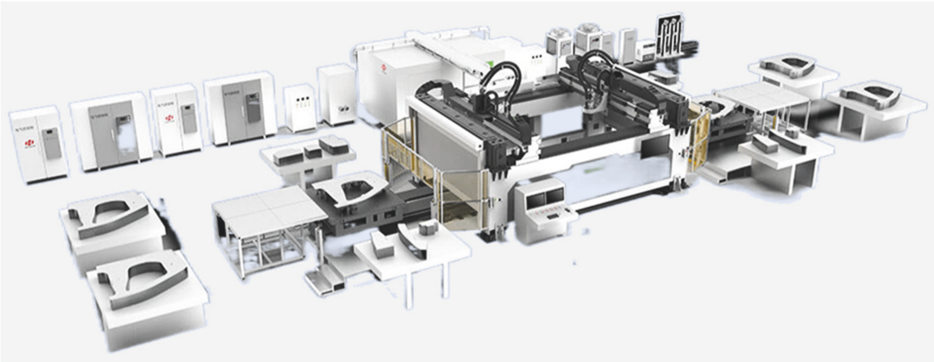

Fig. 2 Automatic laser welding plate door ring production line

Table 1 Main parameters of laser welding equipment

Item	Main technical parameters
Equipment model	JKH series
Processing materials	Uncoated high-strength steel, Aluminum silicon coated high-strength steel
Processing thickness	≤ 3mm (for other thicknesses, please call for consultation)
Processing shape	rectangular or door knocker shapes, etc
Maximum processing length (weld length)	≤ 2200mm (expandable)
Maximum machining width ≤ 3200mm (expandable)	positioning accuracy of each axis is 0.08mm/1000mm
Repetitive positioning accuracy of each axis	0.05mm
Rapid movement speed of each axis:	60m/min
Focal length:	300mm
Number of workstations	Double workstations
Machine tool appearance dimensions	25000 x 22000 x 3500mm
CNC system	SIEMENS from Germany
Total installed capacity	≤ 200KVA

3.2. *Design and manufacture of automation equipment*

The design and fabrication of automated equipment for laser welding of high-strength steel in body structural components primarily entail the following aspects:

(1) Laser splicing welding process optimization: Delving into the material properties of high-strength steel to investigate suitable laser welding process parameters, such as welding speed, laser power, and defocusing amount, to achieve impeccable weld quality and high-strength weld seams.

(2) System structure design: The automation equipment for laser welding high-strength steel comprises welding machinery, robots, jigs, and fixtures. This equipment necessitates high precision, stability, and efficiency to cater to mass production requirements.

(3) Control system design: Developing a tailored control system for laser welding automation equipment to enable automatic regulation of the welding process. The control system should feature real-time monitoring capabilities and the ability to adjust parameters on-the-fly during welding to uphold welding quality.

(4) Detection and monitoring: Crafting a detection and monitoring system for high-strength steel laser welding processes, enabling real-time monitoring of weld quality, welding speed, laser power, and other pertinent parameters. Prompt adjustment of equipment parameters ensures welding quality. Figure 3 illustrates the utilization of SERVOROBOT AUTO-TRAC weld seam tracking for rapid response compensation. The weld seam detection system incorporates a tracking laser emission module for verifying welding quality and defect detection during welding operations. Additionally, the three-dimensional joint tracking with a laser UISION module facilitates precise joint position measurement for joint tracking with external actuators.

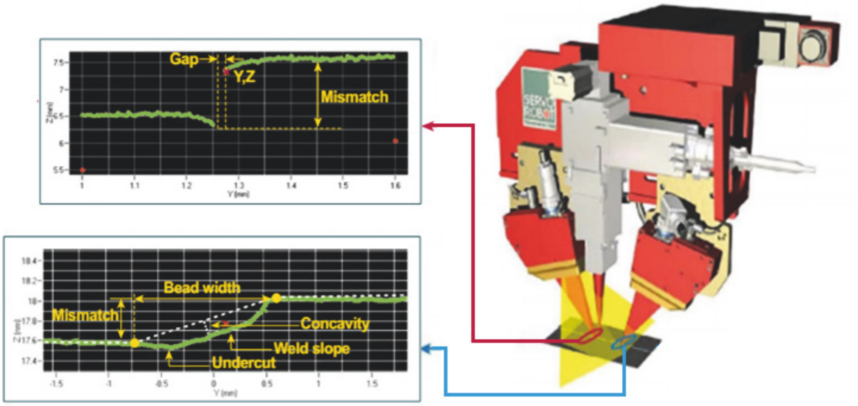

Fig. 3 High-response laser three-dimensional weld tracking system

(5) Planar motion control system: the robot is used to realize the automated welding of high-tensile steel laser welding, and the welding path and welding parameters of the robot are controlled by programming to improve the welding precision and efficiency. Figure 4 shows one of the splicing welding plate positioning fixtures, which is equipped with workpiece flip positioning pin assembly, lateral positioning pin assembly, electromagnet adsorption assembly and workpiece in-position detection system.

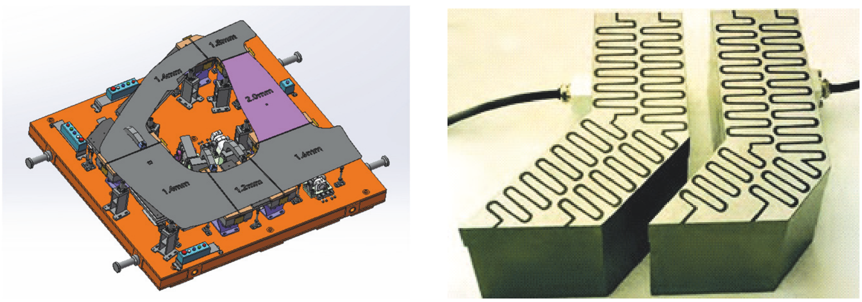

Fig. 4 Semi-automatic fixture and strong magnetic suction cup for spot welding

(6) Tooling and fixture design: for the characteristics of high-tensile steel laser welding, design tooling and fixtures suitable for various body structure parts to ensure the stability and accuracy of the parts in the welding process.

4. Application case analysis

This paper takes an automobile door ring as an example, and adopts the laser splicing welding process of high-strength steel plate for actual production. Through the optimization of process parameters and equipment improvement, cracking, weld movement and weld unevenness, rebound and other problems were successfully solved. Practical application shows that high-strength steel plate laser welding technology has a wide range of application prospects in the body manufacturing.

4.1. *Material and testing method of laser welding plate*

Splicing welding case using the typical material grade CR950/1300HS-AS75/75, is a low-alloy high-strength hot-forming steel, its composition is shown in Table 2. the main parameters of the hot stamping of the welded plate forming parts testing and standard parts shown in Table 3. Laser weld sampling method and experimental size specification pieces shown in Figure 5.

Table 2 Chemical composition of CR950/1300HS-AS75/75

C	Mn	P	S	Si	Al	Ti	B
0.2-0.25	1.1-1.4	<0.25	<0.008	0.15-0.35	>0.015	0.02-0.05	0.002-0.005

Table 3 Testing parameters and criteria

Test item	Test standard	Determine requirements
Tensile strength	GB/T228.1-2021	Q/JLY J7110072D-2020 ≥1300Mpa
Yield strength RP0.2	GB/T228.1-2021	Q/JLY J7110072D-2020 ≥950Mpa
Breaking elongation A%	GB/T228.1-2021	Q/JLY J7110072D-2020 A50≥5%

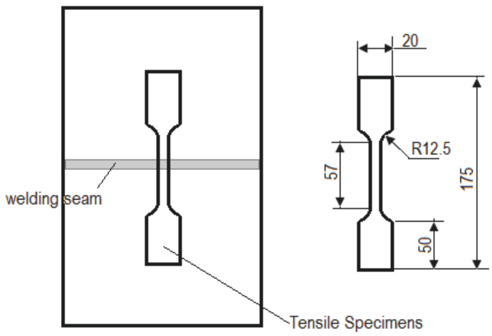

Fig.5 Schematic diagram of tensile sample location and tensile sample size

4.2. *Door ring hot stamping molding inspection*

The material grade of each part on the door ring is the same, all are CR950/1300HS-AS75/75, but the thickness is different. According to the sampling method in Fig. 5, samples were taken from each part of the hot stamped formed door ring parts (see Fig. 6), and the tested results are shown in Table 4. The results show that the fracture of the specimen was outside the weld region, in the base metal or close to the heat affected zone location. The elongation is above 8.5% and the tensile strength is above 1350 MPa.

Table 4 Sampling and testing results of body door ring spliced weld parts

Test area	Sheet thickness, a0（mm）	Test strip width, b0（mm）	Tensile strength, RM（Mpa）	Yield strength, RP0.2（MPa）	Breaking elongation A50 mm（%）	Determine (OK/NG)
T1-A50-1	1.35	12.41	1424	1054	8.9	OK
T1-A50-2	1.41	12.40	1419	958	9.0	OK
T1-A50-3	1.80	12.36	1505	976	8.5	Ok
T2-A50-1	1.36	12.41	1429	1079	8.9	OK
T2-A50-2	1.41	12.45	1418	936	9.0	OK
T2-A50-3	1.80	12.37	1507	1002	8.5	OK
T3-A50-1	1.37	12.45	1397	1077	9.5	OK
T3-A50-2	1.41	12.44	1427	977	9.5	OK
T3-A50-3	1.80	12.36	1517	1029	9.0	OK

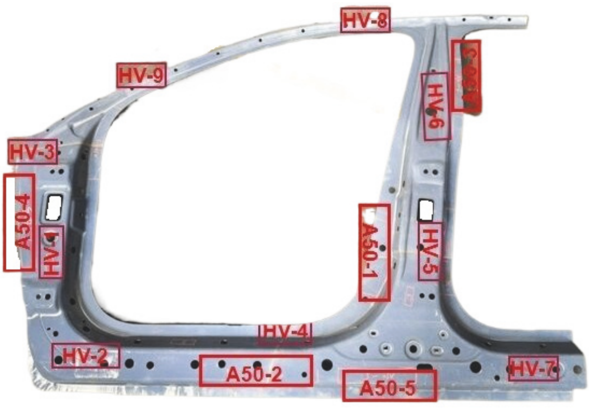

Fig.6 Sampling locations photo

5. Conclusion

The research underscores the pivotal role of laser welding technology in the realm of automobile manufacturing, particularly in the welding of high-strength steel plates, showcasing significant advantages. By optimizing process parameters and enhancing equipment, laser welding technology attains a high-quality welding effect, paving the way for novel possibilities in car body lightweighting and safety enhancement. The design and deployment of automated laser welding equipment further bolster productivity and welding quality, presenting sustainable development opportunities for the automobile manufacturing sector. Practical implementation cases have validated the reliability and extensive application potential of laser welding technology for high-strength steel plates, furnishing the industry with technical support and solutions. Through real-world production scenarios involving an automobile door frame, the efficacy and broad application prospects of high-strength steel plate laser welding technology are affirmed, offering dependable technical backing for body manufacturing endeavors.

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