Research and application of experimental analysis method for formability assessment of hot stamped parts with laser welded blanks

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This paper investigates the MPI hot stamping technology for body lightweighting, focusing on the formability of hot stamping materials and processes for laser welded plates of high-strength steel. This technology plays a key role in car body manufacturing, especially in the production of body-in-white, and is of great significance for the material selection and the combination of specification of spliced plates for components such as door rings, as well as for the stable manufacturing process. The study investigates the mechanical properties of laser welded plates in the hot stamping process, and determines the formability of welded plates through the study of the mechanical properties of different types of welded plates. Taking the testing and analysis of the hot stamping properties of double door rings of laser welded plates integrated with multiple components as an example, the method of sampling weld seams of welded plates and the adaptability of this method to be used as an assessment of the formability of welded plates are described. The in-depth testing and study of the mechanical properties of the laser welded plate to assess the formability of the welded plate is intended to provide guidance and reference for the optimization of the hot stamping process and the improvement of production quality and efficiency.

Keywords: Hot stamping; Laser welded blanks; Multi-parts integration; BIW; Double door ring.

1. Introduction

Body lightweighting is an important technological measure to improve body safety and to reduce energy consumption [1]. Hot stamping and forming of laser welded plates of high-strength steels is a key technology in the field of car body manufacturing, and important progress has been made [2]. Laser spliced plates have important applications in body manufacturing, especially playing a key role in the production of components such as door rings in the body-in-white manufacturing process. The aim of this study is to investigate how to evaluate the formability of hot stamped formed parts with laser spliced plates using a simple experimental method, and to develop its engineering application specifications for material selection and process design of large, complex multi-component integrated body parts. The in-depth testing and research on the mechanical properties of hot stamping of laser-welded plates will provide important references and guidance for optimizing the hot stamping process and improving production quality and efficiency.

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2. Key technology of MPI hot stamping - laser tailor-welded blank

2.1. *Development and application of multi-part integration (MPI)*

With the rapid development of modern industrial technology, the automotive industry in the field of lightweight body design and manufacturing, the concept of multi-part integration (MPI) came into being, and has gradually become a highly efficient organization and production mode [3]. This concept aims to integrate multiple components or assemblies in order to realize the improvement of product functions and performance. Its core idea lies in the combination of single components with different functions into a multifunctional 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.

The technological advancements in laser tailor welding of high-strength steel have facilitated the utilization of blanks created from multiple steel plates in stamped parts or components. Through the utilization of various materials and the adjustment of thicknesses, strengths, and coatings, Tailor-Welded Blanks (TWB) can achieve cost savings, enhance product quality, reduce blank sizes (by efficiently nesting blanks), integrate parts, and apply corrosion-resistant coatings more accurately.

2.2. *Laser-welded plate technology*

Since 2009, the global automotive industry has seen a rapid increase in demand for hot stamped laser-welded blanks, mainly in response to global emissions regulations. In the area of ablation technology, ArcelorMittal's patented ablation technology has succeeded in removing the AlSi coating while retaining the intermetallic layer between the coating and the underlying steel. In-depth research on this technology has further clarified the factors affecting laser ablation welding and has led to its widespread application.

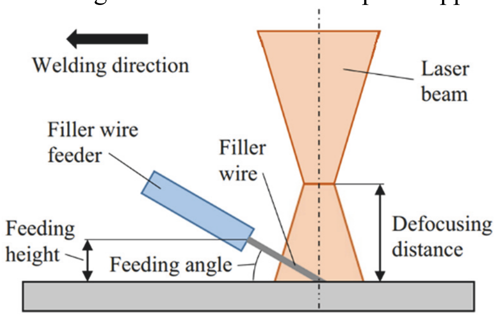

Fig. 1 Technical schematic diagram of the new generation of laser filler weld splicing plate [4]

For the laser ablation welding of aluminum-silicon coated panels, Baosteel developed a new laser welding method for aluminum-silicon coatings [4] with filler wire and variable energy distribution laser optics. This technique simplifies the entire production process of laser welded panels and avoids additional aluminum-silicon coating removal steps [5], making it particularly suitable for large-scale industrial applications and has emerged as an effective alternative to the laser ablation welding technique, as shown in Figure 1.

In the specific application of multi-component integration, the automotive industry, with its extremely demanding product performance requirements, has become a pioneering application area for multi-material high-performance integration (MPI). For example, in modern automotive structural design, designers are constantly striving to integrate multiple 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. Mechanical properties testing of laser welding plates

The mechanical property test of laser welding plate mainly includes tensile property, impact property, hardness and other aspects. Through the tensile test on the laser welding plate, we can understand its mechanical properties under different strain rates. The impact test is used to evaluate the rupture resistance of the welded plate under impact load. In addition, the hardness test can reflect the hardness distribution on the surface of the laser welded plate, especially the mechanical properties of the heat-affected zone of the weld.

Tensile test is an important means to measure the mechanical properties of laser welding plate. Through the tensile test, the tensile strength, yield strength, productivity and other mechanical property parameters of the laser welding plate can be obtained. It is possible to measure the mechanical properties of unequal thickness plate welded specimens, as well as the mechanical properties of welded plates after hot stamping and molding enhancement. The focus of this paper is on the testing of mechanical properties of weld seams and weld heat-affected zones after hot press forming-reinforcement.

The formability of Laser Welded Blanks (LWB) is significantly influenced by: 1) the base metal material condition - thickness ratio and strength ratio, 2) welding conditions - weld direction, position, soft zone, heat-affected zone (HAZ), and hardness variations. The design and application of spliced-welded plate parts should address the prediction of formability degradation and distinctive behavior of LWBs during the forming process.***Uniaxial Tensile Tests of Spliced Welded Plates***

The seams of a spliced welded plate, under load, have different stress states for the plate material, which can be considered as plane stress states. As a standard plate tensile specimen, the tensile direction may be perpendicular to the weld or parallel to the weld direction. See Figure 2 for an illustration. Theoretically, one could choose to perform 2 different tensile tests (see Fig. 2(a) and Fig. 2(b)) to characterize the performance of the LWB weld in different stress directions as a way of characterizing the formability of the LWB plate under uniaxial tension [6]. Considering the more extreme case, the solution with the weld perpendicular to the tensile direction should be adopted (see Fig. 2(a)), and the ultimate cracking condition should be based on the maximum stress state of the weld.

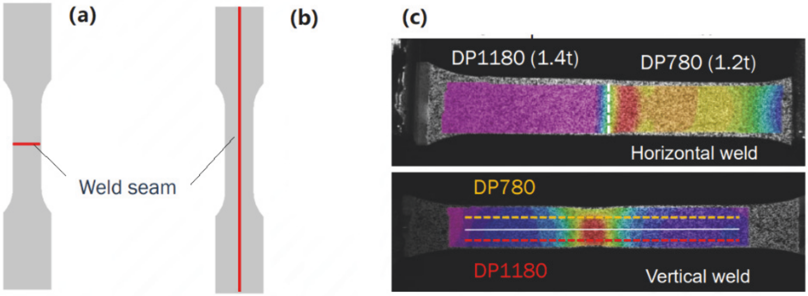

Fig. 2 Tensile specimens of spliced plates: (a) weld perpendicular to the tensile direction; (b) weld parallel to the tensile direction; (c) strain states of two tensile specimens shown by DIC testing [6].

3.2. *Effect of welds of different strengths and plate thicknesses on formability*

3.2.1. *Formability of laser welded boards (LWB) of the same strength class and different plate thicknesses*

When evaluating the formability of laser welded plates (LWB) with the same strength level but different plate thicknesses (see Figure 3 (a)), several key factors need to be considered. First, the blank should be homogeneous except for the weld seam to ensure stability and consistency of the forming properties. Secondly, there is a thickness variation between the base material and the weld seam, and this variation may have an impact on the forming process, especially the deformation problem that may result when forming complex curves or angles. According to data from the literature [6], the hardness of the material in the weld zone is about 60% to about 100% higher compared to the hardness of the base high-strength material, and this difference in hardness may affect the forming properties and the selection of the forming process. However, these experimental data were obtained from direct post-weld strength testing of the spliced welds and not from the strength state after hot stamping. Comprehensive consideration of the homogeneity, thickness variation, hardness difference and necking phenomenon of the blanks will help to formulate effective forming strategies and process control measures for the hot stamped parts of the spliced welded plates to ensure the production of high-quality laser spliced welded plate products.

3.2.2. *Formability of laser welded boards (LWB) of different strength grades and same plate thicknesses*

When evaluating the formability of laser welded boards (LWB) with different strength classes but the same plate thickness (see Figure 3 (b)), the inhomogeneity of the blank is an important consideration, especially the inhomogeneity in the weld seam area that may have an impact on the forming performance. When the molten pool shrinks within the weld seam it may lead to the formation of weld depressions, which may affect the form and quality of the weld area. The hardness of the material in the weld zone is approximately 60% to 150% higher compared to the hardness of the base high-strength metal, and this difference in hardness needs to be taken into account during the forming process in order to select the appropriate forming process and parameters. Finally, necking should occur in the lower strength base metal, so special attention needs to be paid to the strength characteristics of the base metal during the forming process to avoid necking from adversely affecting product quality.

The application of multi-material laser-welded blanks (LWBs) in automotive bodies has become a useful strategy to improve the crashworthiness of vehicles [7]. This combination of laser welded plates with different thicknesses and strengths is formed through hot stamping to achieve the integrated formation of multiple materials for body structural components, which has performance and cost advantages.

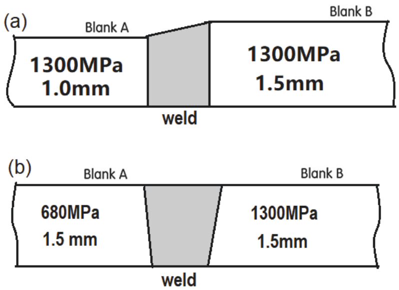

Fig. 3 Weld cross section of spliced welds: (a) blank A (1300MPa@1.5mm) spliced with blank B (1300MPa@1.5mm); (b) blank A (680MPa@1.5mm) spliced with blank B (1300MPa@1.5mm).

4. Splicing and welding plate application

In this paper, the actual mechanical properties of automobile door rings produced by the process of laser welding of high-strength steel plates were tested. The material selection of high-strength steel plate laser welding plate, welding process and hot stamping process, as well as the mechanical properties of the weld region of the test, a comprehensive design.***Material and mechanical property testing standards for laser welding blanks***

The high-strength steel grades used in the application case are CR950/1300HS-AS75/75 and HC370/550HS+AS75/75, and their compositions are shown in Tables 1 and 2. The dimensional specifications of uniaxial tensile samples for the testing of hot stamped formed parts of the weld plate are shown in Figure 4.

Table 1 Chemical composition of Baosteel CR950/1300HS-AS75/75 (w%, typical)

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 2 Chemical composition of Baosteel HC370/550HS+AS75/75 (w%, typical)

C	Si	Mn	P	S	Al	N	Cr	Ti

0.10	0.25	1.25	<0.025	<0.010	0.03	<0.008	0.25	0.05

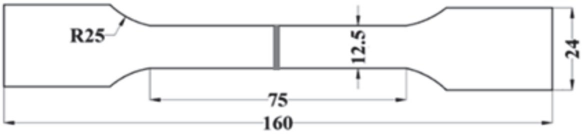

Fig. 4 Dimensional specification of uniaxial stretching sample of spliced welded plate

4.2. *Mechanical properties testing of hot stamping formed door ring*

The door ring is welded with different plate thicknesses of CR950/1300HS+AS high-strength steel plate spliced welding spliced welding (Class A weld, equal strength and not equal plate thickness), as well as CR950/1300HS+AS and HC370/550HS+AS (elongation of better medium strength) materials, as shown in Figure 5. The types of welds in each part of the double door ring, as well as samples taken from each part of the hot stamped formed door ring (shown in Fig. 6), and the results of the tensile test inspection are shown in Table 3.

Among them, the weld of A1-B3 is the weld of equal strength + equal thickness plate (Class C), and all other welds are Class A and B welds, i.e., equal strength, unequal thickness plate weld or unequal strength, unequal thickness plate weld. These combinations and strength and plate thicknesses are matched to meet the customized needs of the mechanical properties of the body structure.

In order to meet the energy absorption requirements of the body collision, the B2 part of the HC370/550HS + AS high strength steel (550MPa@1.4mm), has a good elongation.

Sampling tensile specimen test showed that all the fracture occurred in the base material part of the specimen, but not in the weld part, see Table 3. Weld No. 7 and No. 9 are the same weld seam, but the strength and elongation of this weld are different in different forming parts due to the difference in cooling factors of the hot stamping die. Mechanical properties of weld No. 7 are 1359 MPa/5.5%. Mechanical properties of weld No. 9 are 1431MPa/6.5%. It can be seen that the hot stamping mold, the precision of closing the mold, and process parameters such as cooling rate have an effect on the fracture data of the spliced weld plate, even though the mechanical properties of both weld areas meet the requirements of the product design.

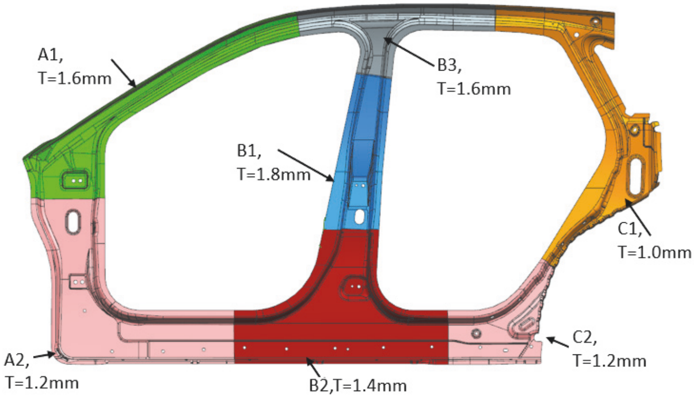

Fig. 5 Structure of the double door ring of the body and the plate thickness arrangement of the welded plate

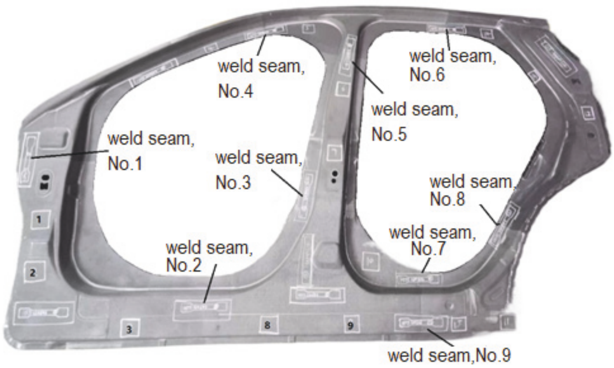

Fig. 6 Weld sampling locations and numbers of hot stamped door ring components (photo)

Table 3 Sampling and testing results of body door ring welding parts

No.	Weld	Type	Blank A	Blank B	Tensile Strength MPa / Elongation %
1	A1-A2	A	1500MPa@1.6mm	1500MPa@1.2mm	1382/6.0
2	A2-B2	B	1500MPa@1.2mm	550MPa@1.4mm	1302/6.0
3	B1-B2	B	1500MPa@1.8mm	550MPa@1.4mm	1373/5.0
4	A1-B3	C	1500MPa@1.6mm	1500MPa@1.6mm	1342/6.0
5	A1-B1	A	1500MPa@1.6mm	1500MPa@1.8mm	1416/6.0
6	B3-C1	A	1500MPa@1.6mm	1500MPa@1.0mm	1343/5.0
7	B2-C2	B	550MPa@1.4mm	1500MPa@1.2mm	1359/5.5
8	C2-C1	A	1500MPa@1.2mm	1500MPa@1.0mm	1316/5.5
9	B2-C2	B	550MPa@1.4mm	1500MPa@1.2mm	1431/6.5

Note: Type A- equal strength, unequal thickness; Type B- unequal strength, unequal thickness; Type C- equal strength, equal thickness.

5. Conclusion and outlook

Laser spliced plate technology demonstrates an important role in integrated hot stamping of multiple components. By developing a robust laser welding process, multiple material applications and adjustments can be realized, saving costs and improving product quality. For the mechanical property testing of laser welded plates, the study of applying tensile properties to evaluate the formability of welded plates provides a reliable and easy analysis method for optimizing the forming process, which can be used as an important basis for the formability of components. In practical application cases, the laser welding technology of high-strength steel has been verified in the production of automobile door rings, demonstrating a wide range of application prospects. In the future, continuing in-depth research on laser welded plate technology and exploring its wider application in car body manufacturing will provide more possibilities for car body lightweighting and product performance enhancement.

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