Research of laser tailor welding technology for zinc-based coated hot stamping steel

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It is not necessary to remove the coating in advance for laser welding of zinc-based coating hot-forming steel. Under the condition of good quality of shearing edge, laser spot defocusing welding without wire filling can ensure the quality of welding seam, and achieve the tensile strength ≥ 1500MPa and elongation ≥ 5% after hot stamping. The zinc-based coated hot stamping steel have advantages of good forming quality and high corrosion resistance, because zinc has the function of cathodic protection, the zinc-based coated hot stamping steel can protect the substrate and the weld through the sacrificial anode.

Keywords: Zinc-based coated steel; Laser welding; Weld strength testing; Corrosion resistance.

1. Introduction

Hot stamping steel is widely used in anti-collision beams, bumpers, A-pillar, B-pillar, C-pillar and reinforcing plate, which is an important part of automotive lightweight. Coating on the surface of hot stamping steel can effectively improve the corrosion resistance of steel plate. At present, the main application is aluminum-silicon coating, but it is easy to crack in the hot stamping process, resulting in poor corrosion resistance at the position without coating protection. Due to the lack of cathodic protection, the corrosion resistance of the plate incision of aluminum-silicon coated hot stamping steel is low. Liquid metal embrittlement (LME) occurs in the hot stamping process of zinc-based coated hot-forming steel, which significantly reduces its tensile strength and elongation, so it has been used only in a small number of post-preforming heating processes [1-3]. With the development of forming technology, the problem of LME in zinc-based hot-forming steel has been effectively solved. And because of its stronger anti-corrosion ability for welds, openings and trimmings [4], it will be more widely used in the future.

In this paper, 1.5mm zinc-coated hot stamping steel was selected as the welding material, the defocusing amount, laser power and welding speed were controlled in the process of laser welding, and the quality of the weld was judged by tensile test, so as to obtain the process parameters to meet the quality of the weld without wire filling. In addition, a neutral salt spray test was carried out to compare the corrosion resistance of zinc-based and aluminum-silicon coated hot stamping steel in laser tailor-welded weld after

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electrophoretic painting, to verify whether zinc-based hot-forming steels have superior corrosion resistance in weld seams, holes, and cutting edges.

2. Laser welding of zinc-based coated hot stamping steel

During welding, the coating on the aluminum-silicon coated hot stamping steel will be melted into liquid, which is easy to invade into the weld pool and form iron-aluminum brittle phase with iron [5-6], which will reduce the toughness at the weld seam, and then reduce the structural strength of the steel. It poses a safety risk. Therefore, aluminum-silicon coated hot stamping steel generally needs to remove the coating before welding [7], or use special laser welding wire [8] to improve the weld strength.

In the process of laser welding of zinc-based coated hot stamping steel, because of the low melting point and boiling point of zinc, the zinc layer is easy to volatilize and discharge under the high heat of laser and the purging action of shielding gas, so there is no need for special welding wire, and in theory, welding without wire filling can be realized.

The zinc-based coated hot-forming steel HBF1500GI with 1.5mm thick was selected in the test, and the thickness of the zinc coating on the surface was (85/85) G/m^2, which belonged to the thick coating. The alloy contents are shown in Table 1. The A50 tensile test is carried out on the material before and after hot stamping, and the mechanical parameters (the average value of 3 tensile samples in each group) are shown in Table 2 below.

Table 1. Alloy contents in weight percent.

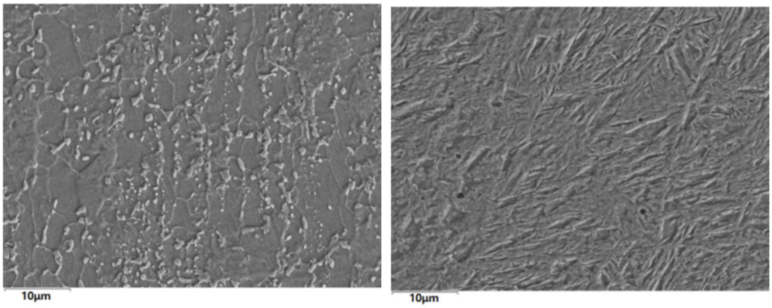
C	Si	Mn	Cr	Ti	B
0.19-0.21	0.17-0.27	1.60-2.00	0.25-0.35	0.025-0.040	0.0020-0.0030

Table 2. Mechanical property of the zinc-based coating hot stamping steel.

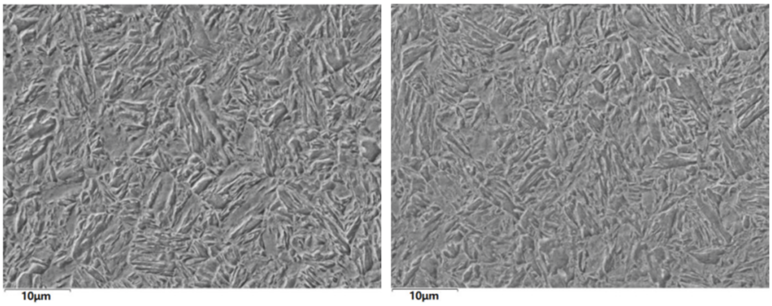
	Yield strength Rp0.2/MPa	Tensile strength Rm/MPa	Elongation A50/%
Before hot stamping	436	621	19.8
After hot stamping	1146	1551	6.05

2.1. *Changes in microstructure and hardness before and after hot stamping*

A TRUMPF TruDisk4001 disk laser was used for laser welding, with a beam quality of 4 mm/mrad. The microstructure and microhardness of the base metal and the weld seam before and after the hot stamping of the laser tailor-welded steel plate were tested respectively, in which the microhardness test is centered on the weld and perpendicular to the weld, the test length is 4mm and the interval between single points is 0.2mm.

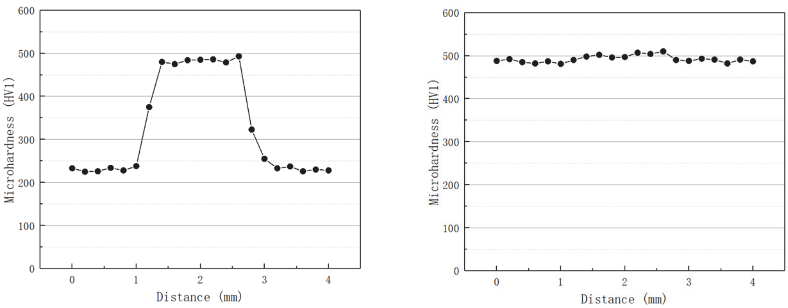


(a) Base metal before hot stamping (b) Weld seam before hot stamping



(c) Base metal after hot stamping (d) Weld seam after hot stamping

Fig. 1. Microstructure of weld seam and base metal under different conditions.



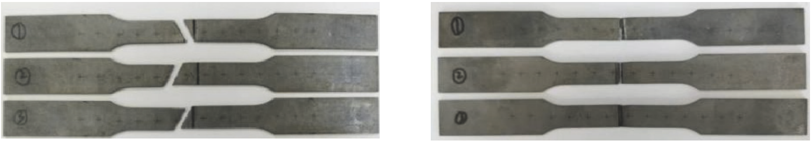
(a) Before hot stamping (b) After hot stamping

Fig. 2. Microhardness under different conditions.

Before hot stamping, the microstructure of the weld is ferrite and pearlite, containing a small amount of martensite and bainite, and the microstructure of the weld seam is coarse martensite. Through the microhardness test, the average value of HV1 at the weld seam is 482, which is much higher than the average value of 240 at the base metal. When the laser tailor-welded steel is heated to 890℃, the base metal, the weld and the heat affected zone are austenitized, and then cooled again to transform into a martensite-based structure. After hot stamping, the average value of hardness HV1 at the weld seam is 502, which is slightly higher than the average value 487 at the base metal. This is because the weld seam is subject to two heat treatments of welding and hot stamping, and the microstructure is refined.

2.2. *Mechanical property test of weld seam*

Mechanical property test of weld seam is an important means to evaluate the quality of laser tailor-welded steel. In this test, A50 tensile test is used to inspect the weld quality. Three A50 tensile samples are taken from each group, and the weld is vertically placed in the middle of the tensile sample. If the fracture position after the test is the base metal, the weld is judged to be qualified. If the fracture position is the weld seam/heat affected zone, the weld is judged to be the weak part and the quality is unqualified.



(a) Fracture of base metal (b) Fracture of weld seam/heat affected zone

Fig. 3. Fracture location of tensile specimen

In the welding process, the inclination angle of the lase beam is 2 degrees, and the tailor-made welding is completed by adjust the defocusing amount, laser power and welding speed. After welding, the material was hot formed at 890 ℃ for 5 min.

Table 3. Stretch results of different test parameters.

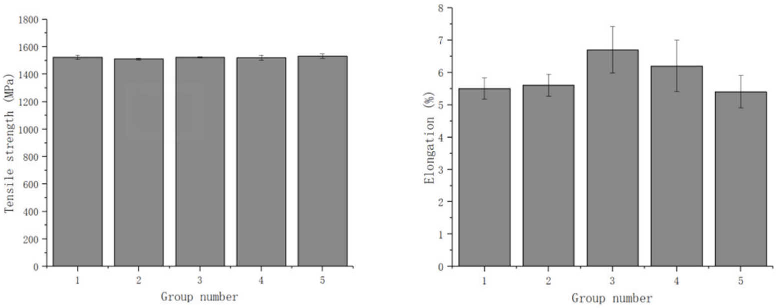
Welding speed m/s	Laser power W	Defocusing amount mm	Yield strength Rp0.2/MPa	Tensile strength Rm/MPa	Elongation A50/%	Fracture location
0.05	2500	0	1216	1534	5.40%	B[b]
		3	1190	1439	4.58%	B
		5	1169	1524	5.78%	A[a]
		7	1199	1500	5.60%	A
0.03	2500	5	1164	1516	4.86%	B
0.05			1169	1524	5.78%	A
0.07			1172	1522	6.42%	A
0.09			1186	1499	5.32%	B
0.05	2800	5	1160	1492	4.30%	A, B
	2500		1169	1524	5.78%	A
	2200		1180	1498	5.38%	A
	1900		1171	1506	4.66%	A, B
	1600		1176	1504	5.62%	B

Note: [a]the fracture position is the base metal; [b]the fracture position is the weld seam/heat affected.

In the welding process, in addition to the zinc layer will volatilize, a small amount of steel substrates will also be lost, so the weld will be slightly thinner than the base metal, and the hardness of the weld seam is only slightly higher than the base metal after hot stamping. Therefore, the quality of the weld seam is extremely important. The experiments show that the welding quality can be ensured without wire filling by increasing the defocusing amount [9], properly increasing the width of the weld seam, and selecting the appropriate laser power and welding speed to ensure the smoothness of the weld.

2.3. *Tensile test stability*

The parameters of defocusing amount of 0.05m/s, laser power of 2500W and welding speed of 0.05m/s were selected, and five groups of tailor-made welding were repeated and tensile tests were carried out to achieve fracture of the base metal. The key mechanical properties of tensile strength and elongation after fracture are shown in Figure 4.



(a) Tensile strength (b) Elongation

Fig. 4. Mechanical property.

3. Study on corrosion resistance of hot-forming steel with zinc-based coating

3.1. *Analysis of anti-corrosion mechanism of zinc-based coating*

Based on the principle of electrochemistry: the more negative the electrode potential of the coating layer, the more it can provide anode protection for the steel substrate. For zinc-based coating materials, when the corrosion occurs, GI coating can avoid the steel substrate from corrosion through physical shielding effect and cathodic protection, which due to the zinc's lower electrode potential (-0.96V) than the iron's electrode potential (-0.47V).

The coating potential of zinc based coated hot stamping steel decreases with the Zn content in the coating. After hot-stamped, because the potential of the Γ phase and α-Fe（Zn）phase are -0.75V and -0.6 V respectively, which are much lower than that of the iron substrate (-0.47V), so the coating still has good cathodic protection against corrosion [10]. The hot-stamped coating shows more superior quality of resistance to pitting corrosion than GI coating, due to the higher potential of its corrosion products. Zn content in Γ phase layer and α-Fe（Zn）phase should be in range of 70-95wt% and 17-44wt% to ensure adequate cathodic protection [11].

3.2. *Corrosion resistance test of Hot stamping steel with different coatings*

A 1.5mm thick zinc based coated hot stamping steel HBF 1500GI tailor-welded sheet and a 1.6mm thick aluminum-silicon coated hot stamping steel tailor-welded sheet are selected, and the laser tailor-welded sheet are made into a test sheet after hot stamping.

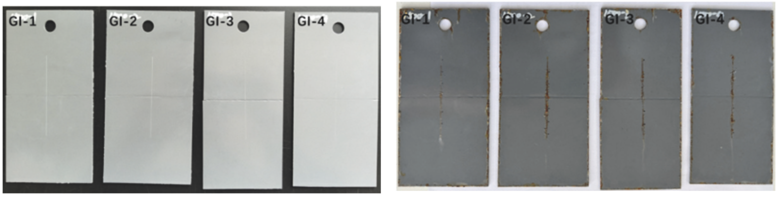
The test sheets are coated with phosphitylation (Parkerizing) and cathodic electrophoresis paint film (BASf) according to automobile body coating process, then scribe with a knife on the surface of the paint film perpendicular to the weld. The Ascott CC1000iP cyclic corrosion test chamber was used to carry out the 1000h neutral salt spray test according to GB/T 10125 2021. After corrosion, the cleaning water rinses the surface rust of the sheet, and use tape to remove the film that loses adhesion, The corrosion width at the intersection of the scribe line and the weld was measured.

It can be seen from Fig. 5 that obvious red rust appears around scribes of the test sheet of two materials, and a small amount of white rust appears at the weld of zinc-based coated Hot stamping steel. This is due to the fact that in the high temperature environment of laser welding, the coating evaporates and the weld position is actually iron substate without coating protection, so it is easy to rust when the film is damaged. For hot-forming steel with zinc-based coating, the weld periphery is alloyed with Zn-Fe, and the lower electrode potential of Γ phase and α -Fe (Zn) phase can provide cathodic protection for the iron substrates, the coating corrodes priority over the substrate in the corrosion process. The red rust appears due to the high Fe content in the coating [12], and the appearance of white rust is due to the high content of Zn in the Γ phase to product $Zn(OH)_2$. As Hot stamping steel with aluminum-silicon coating, because the aluminum-silicon coating has no sacrificial anode protection of the iron substrates after hot stamping, the coating around the weld cannot replace the substrate to be corroded. In the same corrosive environment, the corrosion of the substrate can occur directly, to appear red rust.

The corrosion width at the weld is shown in the following table. It can be seen that the welds are corroded and expanded to the surrounding corrosion in neutral salt spray environment, and the corrosion width of the two materials is close. This is due to the potential difference between the zinc-based coating and the iron substrates, so the coating is preferentially corroded with faster corrosion, which is mainly concentrated on the surface of the coating and gradually extends along the surface; while the electrode potential of the aluminum-silicon coating is close to that of the substrate, so there is little difference in the corrosion width of the two materials. However, comparing holes and cutting edges position of the two materials, aluminum-silicon coated hot stamping steel shows more severe corrosion on the edges and holes when both the substrate and the coating are exposed, and the zinc-based coated hot stamping steel shows better corrosion resistance. In addition, the hot stamping steel with aluminum-silicon coating has the probability of 100% corrosion of the weld.

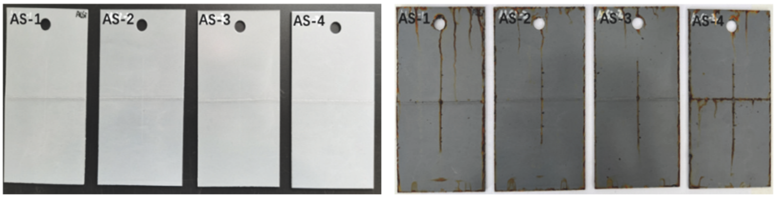
Table4. Aluminum-silicon hot stamping laser tailor-welded coating sheet material

Materials	Zinc based coated hot stamping steel				Aluminum-silicon coated hot stamping steel			
Sample No.	GI-1	GI-2	GI-3	GI-4	AS-1	AS-2	AS-3	AS-4
Initial scribing width / mm	0.2	0.2	0.18	0.2	0.2	0.18	0.2	0.18
The expansion width at the weld junction / mm	1.79	2.08	1.51	1.86	2.33	1.16	2.12	2.26



(a) Pre-test (b) After test

Fig. 5. Zinc based coated hot stamping steel.



(a) Pre-test (b) After test

Fig. 6. Aluminum-silicon coated hot stamping steel.

4. Conclusion

During the laser welding of zinc-based coated hot stamping steel, the appropriate laser power and welding speed can be selected under the condition of a certain amount of defocusing, so as to obtain a good weld without filling wire. Taking 1. 5mm HBF1500GI as an example, under the parameters of 0. 05m/s defocus, 2500W laser power and 0. 05m/s welding speed, the weld quality can be maintained in a stable and good state.

Under the condition of neutral salt spray corrosion, the coating of zinc-based coated hot stamping steel can provide cathodic protection for the substrate instead of the substrate corrosion, and the weld, holes and cutting all show better corrosion resistance.

Acknowledgments

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