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Study of Laser-Welded Al-9%Si-Coated and Zinc-Coated Hot Forming Steel

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Abstract

The features of mechanical properties and microstructural evolution of laser-welded joints in Al-9wt%Si-coated and pure zinc-coated boron steel were studied before and after hot stamping heat treatment. Al segregation in the fusion zone (FZ) of Al-9wt%Si-coated sheet is divided into two types before hot stamping. The first type is unevenly distributed in the fusion zone (FZ), with a microstructure comprising martensite (in Al-deficient zones) and bainite/ferrite (in Al-rich zones). And the microstructure type were identical before and after hot stamping heat treatment. But Al content in FZ decreases because Al diffuses toward the base metal during hot stamping heat treatment. The second type is formed along the fusion boundary (FB) in a long comet shape with a high Al concentration. The microstructure of this zone comprises Fe-(Al,Si) alloy with a single phase before hot stamping. After the hot stamping process, phase transformations can occur at the fusion boundary. Such transformations lead to microstructural changes from the Fe-(Al,Si) phase to the polygonal ferrite phase. Zn segregation is not found in either the fusion zone (FZ) or the heat-affected zone (HAZ). The results indicate that the fusion zone (FZ) is composed of blocky-lath martensite before hot stamping, whereas the heat affected zone (HAZ) is characterized by the lath microstructure containing bainite (B) and ferrite (F). After hot stamping, the FZ and HAZ regions both exhibit martensite structures. The strength of the laser welded PHS is dependent on the fraction of ferrite phase formation, decreased as a result of coating mixing and leading to failure across fusion boundary and the FZ in the Al-9wt%Si-coated sample, whereas the zinc-coated specimen failed at the FZ as a result of thickness decrement without decrement of strength. The as-received base material (BM) hardness in the literature has been measured to be around 250 HV, the hardness of Al-9%Si-coated and zinc-coated fusion zone has been measured to be around 450-550 HV before hot stamping. The micro hardness was homogeneous between the FZ and base material (BM) after hot stamping in the zinc-coated sample. The Al-Si coating affects the hardness of the fusion zone (FZ) and heat-affected zone (HAZ), the lowest hardness was observed at fusion zone.

1 Introduction

The current demand for weight reduction and improved passive safety in vehicles body has driven the automotive industry to develop new materials and manufacturing processes. Hot stamping is an innovative and effective method to produce ultra-high-strength components, such as A and B pillars, roof rails, and bumpers, which combines forming and quenching in one step [1].

In current manufacturing processes, tailored properties of hot stamped automotive parts are obtained using tailor welded blanks (TWB), tailor rolled blanks (TRB), partial heating, differential cooling and other methods. Application of TWB is beneficial in that the mechanical properties can be locally adjusted by a proper choice of the joining partner. A blank can consist of different strength grades and sheet thickness, a feature that cannot be used with other methods to tailor properties. The most commonly used coating is the Al-9% Si alloy coating, which provides excellent barrier protection. However, the cathodic protection of AS coating is limited. When the steel substrate is exposed to air by chipping or flaking, the coating cannot protect the steel substrate. A Zn-based coating has been developed to provide cathodic protection for hot-stamped steel [2-4].

In this study, we examine the distribution of Al in the fusion zone, and the influence of Al before-and-after hot stamping on phase transformations in the segregation zone. At the same time, distribution changes of zinc-coated welded joint are studied. This paper examines previous studies on the characteristics and major impacts of Al-9%Si (AS) and a galvanized (GI) coated hot-stamped boron steel during laser welding, and aims to provide data necessary related to weldability improvement from various perspectives including material and process aspects.

2 Experimental Procedures

The cold rolled sheet were coated separately with two different hot-dip coating methods which are an Al-9%Si (AS) coating and a galvanized (GI) coating. The initial microstructures of the Al-9% Si coating and GI coating are shown in Fig. 1. The thickness of the Al-9% Si coating was about 28 μm and that of the GI coating was about 10 μm. The chemical composition (mass contents in %) of the tested steel is as follows: C, 0.20-0.23; Si, 0.25; Mn, 1.10-1.60; Cr, 0.15-0.55; S, 0.0017; P, 0.006; B, 0.0010-0.0040; and Fe balance, with a thickness of 1.4 mm was used in this study.

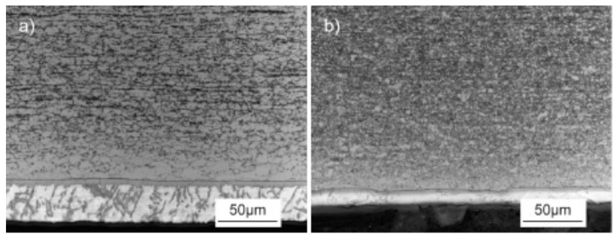

Figure 1: *microstructures of the Al-10% Si coating and GI coating*

A Soutec LPQ 3600 solid state laser beam facility was used in this study and the laser operates at 4 kW and 5 m/min. And the welding gap is 0.2mm. In the hot stamping process, the boron steel was heated to 930 °C in a furnace and austenitized for 5 min, then transferred to a forming die and quenched by the die surfaces to room temperature. Tensile shear tests were conducted three times on rectangular specimens with specimens of gage length of 50 mm and width of 12.5 mm at room temperature. The tensile test measured on an INSTRON 5985 tensile testing machine with a crosshead displacement of 2 mm/min. The micro-Vickers hardness of the samples was measured on 2% nital-etched weldments under a load of 200gf, which was held for 10s. In addition, 4% nital-etched weldments were observed using optical microscopy (OM) and electron probe micro analysis (EPMA) for microstructure observation and elemental distribution.

3 Results and Discussion

3.1 Microstructure and Element Distribution Before and After Hot Stamping Process

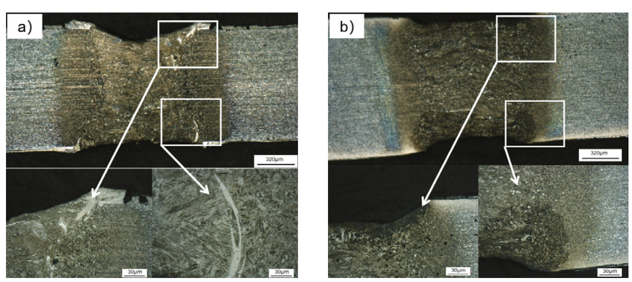

Figure 2 *Cross-section optical microstructure of the welded a) AS-coated and b) Zinc-coated joint before hot-stamped*

Weld section OM micrograph of laser-welded Al-10%Si-coated and Zinc-coated steel before hot stamping heat treatment are shown in Fig.2. The micrograph is clear in showing that ferrite is formed along the boundary between FZ and HAZ in laser-welded AS coated 22MnB5 steel due to the dissolution of aluminum into the joint during welding. For laser-welded zinc coated steel, a typical full martensitic microstructure was obtained in the FZ. And as noted previously in Fig 1, the BM comprised of ferrite grains decorated with pearlite colonies.

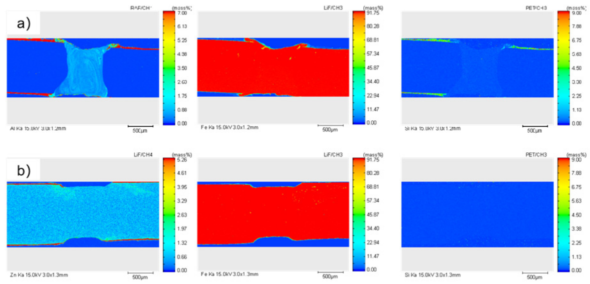

Figure 3 *Cross sections EPMA of the laser weld joint before hot-stamped. a) AS-coated and b) Zinc-coated*

Fig.3 shows the cross-section EPMA of the welded AS-coated and Zinc-coated joint. Before heat treatment, the AS coating penetrated along the boundary between the fusion zone and HAZ. As shown in Fig. 3(a), Al element induced segregation was clearly observed at the fusion line. Al element had a higher ability to stabilize ferrite than Si element, and Si element was more evenly distributed in the weld. While the zinc coating did not affect the welded microstructure, no segregation and enrichment of zinc was found in fusion zone.

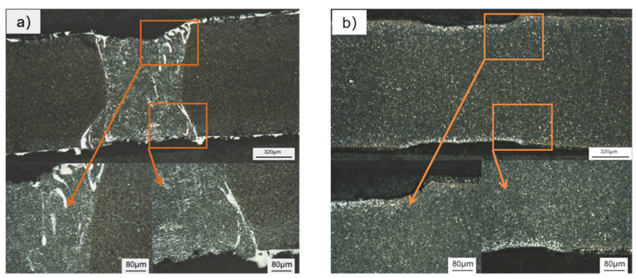

Figure 4 *Cross-section optical microstructure of the welded a)AS-coated and b)Zinc-coated joint after hot-stamped*

As shown in Fig. 4, the area had many white δ-ferrite phase near the fusion line. The reason for the formation of the white phase was Al segregation. The white δ-ferrite phase content in the middle area of the FZ increased after hot stamping, for Al liquidized and penetrated into the center of fusion zone, as shown in Fig.4(a). The microstructure of the FZ was δ-ferrite and lath martensite (LM), and the δ-ferrite layer at the fusion center was irregular. The δ-ferrite at the fusion boundary was long strip shape which can lead to stress concentration and crack initiation under loading. Zinc is also a strong ferrite stabilizer; however, the boiling temperature of Zn is 907°C. Therefore, Zn vaporized completely during laser welding lead to a surface decarburization after hot stamped, so full martensite microstructure were obtained both at FZ and HAZ [2, 5].

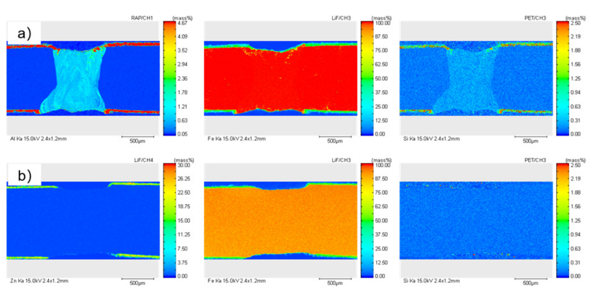

Figure 5 *Cross sections EPMA of the laser weld joint after hot-stamped. a)AS-coated and b)Zinc-coated*

After heat treatment, Al containing phases were universally distributed in the fusion zone. But Al content in FZ decreases because Al diffuses toward the base metal during after hot stamping heat treatment, as shown in Fig. 5(a). Due to the much lower boiling point of Zn, Zn mainly evaporates during the process. The EPMA proves very low content of Zn in the FZ.

The microhardness distributions of laser weld joints are shown in Fig. 6. The microhardness of the base material is about 200-250HV, while the FZ region of the joints exhibited a uniform hardness value in the range of 500±50 HV due to the martensite transformation during laser welding before hot stamping. The hardness of galvanized plate is evenly distributed in different areas, while the FZ hardness of AS-coated plate reduced to 300 HV due to more Al was distributed after hot stamping.

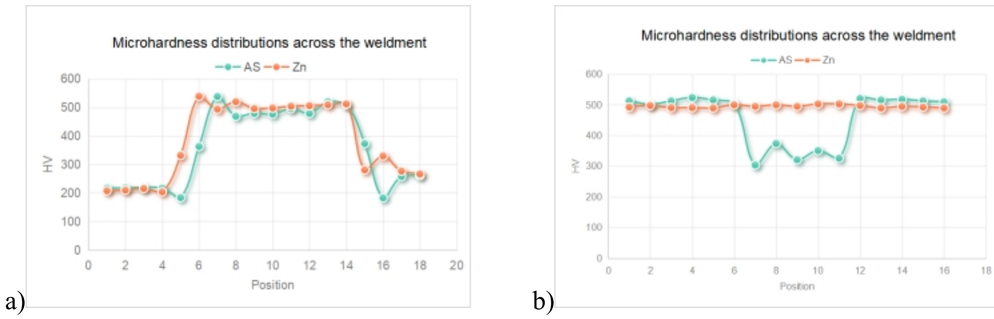

Figure 6 *Microhardness distributions across the weldment a) AS-coated; b) zinc-coated*

3.2 Mechanical Properties and Fracture Mode

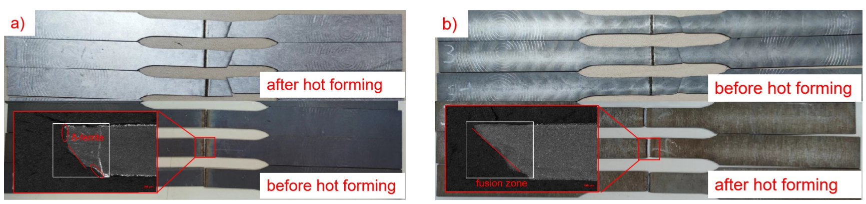

Figure 7 *Specimens and fracture location after tensile test a) AS-coated; b) zinc-coated*

As shown in Fig.6, all the fracture positions are in the base material for both AS-coated and zinc coated welded steel before hot stamping. After hot-stamping, failure occurred directly at the fusion boundary in the AS coated condition, but took place at the center of fusion zone in zinc-coated condition. The fracture of hot-stamped AS-coated steel is caused by δ-ferrite phase formation due to Al content at the boundary fusion zone and base material. In the case of zinc coated steel, the weld depression led the stress concentrated on a narrow FZ with a width that is relatively small as compared to the thickness of the base material, thus the fracture occurred at the narrow FZ.

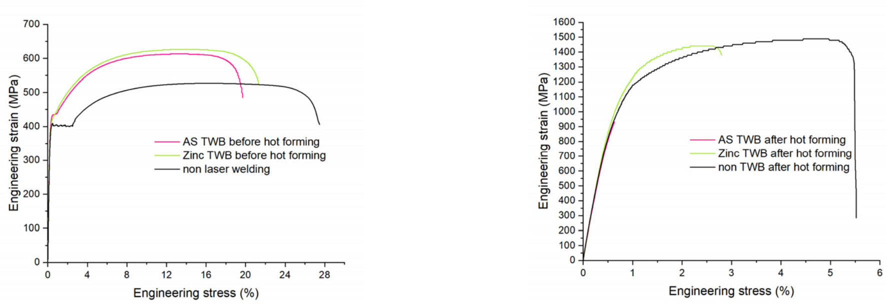

Figure 8 *Engineering stress-strain curves before and after hot stamping*

The engineering stress vs. strain curves of the different coated samples are presented in Fig.8. All the samples have very good ductility before hot tamping. While the tensile strength and total elongation of no welded blank reached 1501 MPa and 5.5% without any brittle failure during tensile testing after hot stamping. For the zinc coated laser-welded specimen made from blanks of the same thickness, tensile strength and total elongation reached 1446 MPa and 2.7%. In the case of the AS-coated welded steel, which the ferrite fraction in FZ was higher, the tensile strength was approximately 940 MPa and the elongation was the lowest, at an average of approximately 0.9 %.

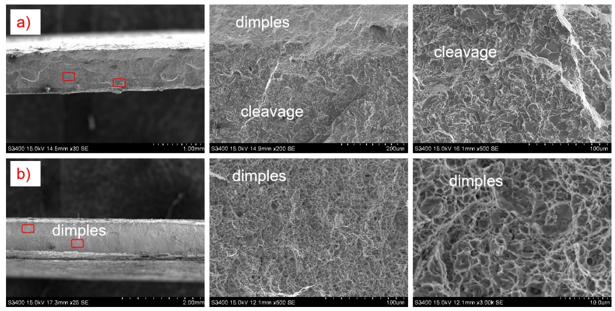

Figure 9 *Tensile fracture surface of the welded joint a) AS-coated; b) zinc-coated*

Figure.9 shows the fracture surface of laser-welded steel after tensile testing. Different failure patterns were exhibited. The fracture mode consisted of cleavage fracture and ductile fracture for AS-coated. From the stress-strain curve, sudden fracture during plastic deformation occurred before the UTS was reached. Moreover, a mixed brittle and ductile fracture surface was observed (Fig. 9a). Before and after hot stamping, the microstructure of the fusion zone did not contain any ferrite phases for zinc-coated welded steel. So zinc-coated improved the failure mode of the welding plate by the brittle fracture at the weld convert into a toughness fracture [6].

4 Conclusions

The following conclusions can be drawn from the present study:

1) Th δ-ferrite phase content in the middle area of the FZ increased after hot stamping, for Al liquidized and penetrated into the center of fusion zone of AS-coated plate. Due to the much lower boiling point of Zn, Zn mainly evaporates during the laser welding and hot stamping process. So full martensite microstructure were obtained both at FZ and HAZ after hot stamping.
2) The mechanical properties of laser-welded AS-coated steel did not achieve the target properties due to ferrite formation in the fusion zone caused by Al diffusion after hot stamping. In the case of zinc coated steel, the weld depression led the stress concentrated on a narrow FZ with a width that is relatively small as compared to the thickness of the base material, thus the fracture occurred at the narrow FZ without brittle fracture.

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