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Effect of filler wire on laser welded blanks of Al-Si-coated 22MnB5 steel

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ABSTRACT

Carbon-steel filler wire was used to solve the coating problem in laser welded blanks of Al-Si-coated 22MnB5 without a decoating procedure. The effect of the filler wire on the fusion-zone microstructure and mechanical properties was investigated. The Al content was diluted by the filler wire. The δ-ferrite phase was also reduced after the reduction in Al and homogenization. The joint strength was ~1210 MPa, and the elongation was 1.1% without filler wire. When filler wire was used, the joint strength increased to ~1550 MPa, and the elongation was greater than 3%. The fracture surface of the joint with the filler wire was ductile. The effects of welding speed and feeding speed were also studied. A reduction in the Al content at the higher feeding speed or the use of a slower welding speed was found to be most effective because either approach enabled more filler material to be added to lower the ratio of the Al-Si coating in the fusion zone. In the absence of the filler wire, the δ-ferrite phases were large and long, connecting to a bulk zone. When the filler wire was used, the δ-ferrite phases were broken up and became narrow and small with a uniform distribution in the martensite matrix.

1. Introduction

Hot stamping steels are one class of the ultra-high-strength steels, which are widely used in crashworthy structural components such as A-pillars and B-pillars. Karbasian and Tekkaya (2010) have reported that these steels attain their ultimate tensile strength of more than 1500 MPa after hot stamping, for example, heating at 900 °C for 5 min and subsequently press-forming in a cooling machine. The cooling rate should be greater than 30 °C/s. The hot stamping technique brings high forming accuracy and reduces springback. Fan and De Cooman (2012) have reviewed the mechanisms of different coating systems to reduce high-temperature oxidation and decarburization during the hot stamping process. In general, Al-Si coatings are more common in production.

Large amounts of components with these steels are welded in a hot-stamped condition. Kim et al. (2011) welded the Al-Si-coated hot-formed steel in a lap configuration. They observed a softening zone in the heat-affected zone (HAZ) of the joint; however, the failure position in the tensile shear test was propagated along the fusion line. The stress concentration and brittle intermetallic compounds were considered to be responsible for this propagation behavior. Saha et al. (2015) reported the coating effect on joints formed by resistance spot welding. The nugget was more uniform, and the nugget size was large when the Al-Si coating was present.

Tailor-welded blanks (TWB) or laser-welded blanks (LWB) can further reduce the weight and improve the design flexibility. Sheets with different thicknesses or composed of different materials can be welded together. The procedures differ when the TWB of hot-stamped steels are applied in that the sheets are laser-welded and then hot stamped. Saha et al. (2016) investigated the Al-Si coating effect on the microstructure and mechanical properties of these TWBs. The mixing of the Al-Si coating substantially modified the fusion-zone compositions and microstructure. The δ-ferrite was found in the as-welded and hot-stamped conditions. The strength and ductility of the joint containing this ferrite phase was deteriorated. Kang et al. (2015) have shown that the ferrite could be reduced by raising the heating duration and temperature. However, they reported no corresponding results for mechanical properties.

Mechanical degradation indeed exists in the TWBs of Al-Si-coated steel after hot stamping. To reduce the influence of the coating, it is recommended that the coating be removed. This process can ensure that the fusion zone is not affected by the coating. Many ablation methods have been developed. Vierstraete et al. (2010) have demonstrated that laser ablation prior to welding is an efficient technique to form the TWBs of Al-Si-coated steel. This method is patented by ArcelorMittal, as reported by Canourgues et al. (2016). In this approach, a

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Q-switch pulse laser with a nominal energy of 450 W is used for laser cleaning. The pulse energy is 42 mJ, and the pulse duration is 70 ns. The speed of the laser ablation head is 20 m/min. In this same patent, the mechanical ablation method is also proposed. A “Spiraband” wire brush with a diameter of 80 mm is mounted onto a counterweight bench. During the ablation, the brushing force is approximately 35 N and the linear speed is 10 m/min. In addition, Flehmig et al. (2014) and Flehmig et al. (2015) have applied for several patents regarding other mechanical ablation methods to remove the Al-Si coating, such as a tool combined with a press machine and scraping knife, or scraping roller. In the ablation process, the Al-Si alloy layer must be clearly removed, with only the intermetallic compound layer remaining within the decoated area. To ensure the ablation is stable and reliable, the laser sources must operate at femtosecond or picosecond pulses. In addition, the detection of traces of the coating is necessary. Anabitarte et al. (2012) introduced an algorithm to deal with the data from laser-induced breakdown spectroscopy to detect Al residues. Mirapeix et al. (2016) performed on-line quantification of the Al contribution to the laser-welding process of Usibor® blanks. They analyzed and compared different welding specimens and analyses of the associated tensile properties, fracture locations and seam macrographs.

The previous discussions are focused on the decoating strategy, which has a high investment cost and requires additional time for the preparation process. Other methods that do not involve a decoating procedure have been reported. Francis and Dubet (2013) have considered that adding nitrogen or oxygen in the shielding gas is useful for welding the aluminized steel. The patents describe some gas mixture combinations, although they do not include description of the relative mechanical properties. Kovtunov et al. (2011) have expressed the same opinion that the oxidizing gas can adjust the Al content of the weld metal. The filler wire is also a simple addition in the laser-welding process. Francis and Dubet (2013) have mentioned that the filler wire should contain at least 3 wt.% of the gammagenic elements C, Mn, Ni and N. They give an example in which the 1.2 mm-diameter filler wire contains, in addition to Fe, 20 wt.% Mn. This filler wire is used in the hybrid laser-MIG welding of Al-Si coated steel, for which the tensile strength 1000 MPa or less after post-quenching.

The use of filler wire in the TWBs of Al-Si coated hot stamping steel has still not been extensively discussed. In this paper, carbon-steel filler wire is used to investigate the dilution effect. By adjusting both the feeding speed and welding speed, the weld bead formation and dilution ratio will be changed. The chemical compositions and δ-ferrite fraction are presented. The mechanical properties of butt joints with and without filler wire are also compared in the hot-stamped condition.

2. Experimental procedure

2.1. Materials

In the experiments, 1.5 mm-thick Al-Si-coated 22MnB5 steel sheets and 1.2 mm-diameter filler wire were used. The chemical compositions (wt.%) of the base material (BM) and filler wire ER70S were listed in Table 1. The Al-10%Si coating was applied to both sides by hot dipping. The coating thickness was 28 μm in the as-received condition. After filler-wire welding, the joints were treated using a hot stamping process, which consisted of heating the joints in a furnace at 950 °C for 5 min and then water quenching them. Fig. 1 showed the coating and base material microstructures in the as-received and hot-stamped conditions. The Al-Si layer with the Fe_2Al_5 layer was transformed into FeAl, Fe_2Al_5 and α-Fe(Al,Si) layers after the heat treatment. The mechanical properties of the Al-Si-coated 22MnB5 steel in the as-received and hot-stamped conditions were listed in Table 2.

Four conditions were used for the specimens: as-received welded joints with filler wire (ARW), as-received welded and then hot-stamped joints with filler wire (ARWHS), as-received welded joints without filler wire (N-ARW), and as-received welded and then hot-stamped joints without filler wire (N-ARWHS). The hot-stamped base materials are referred to as HSBM in this paper.

2.2. Laser welding with filler wire

The laser-welding system included a high-power fiber laser system (IPG-YLS 10,000) and a KUKA robot. The Fronius CMT wire feeder was used. The laser wavelength was 1064 nm. The focal length was 300 mm. The focus spot diameter was 0.7 mm. The laser power was fixed at 3 kW. A schematic of the setup was shown in Fig. 2. In laser welding with filler wire, the defocusing distance was 8 mm above the top surface. The feeding angle α was 40°. A copper tube guided the filler wire out to improve the feeding stability. The filler wire was positioned in front of the laser beam. The wire tip pointed at the front edge of weld pool. The values S1 and S3 were the square area increased by the filler wires. S2 was the square area of the base material in the fusion zone. $S_{(t)Al\text{-}Si}$ and $S_{(b)Al\text{-}Si}$ were the square area of the melted Al-Si coating. W_t and W_b were the width of the fusion zone at the top and bottom surfaces, respectively. W_m was the middle width of the fusion zone. Table 3 listed all welding parameters used in the bead-on-plate (BOP) experiments. The shielding gas was pure Ar gas (99.9%) with a flow rate of 20 L/min. Another group without filler wire was prepared at a laser power of 3 kW and a welding speed of 5.8 m/min for comparison. The defocusing distance was zero in this case. The mechanical properties of the butt joints were subsequently tested.

2.3. Characterization

The cross-sections for metallography were cut perpendicular to the weld seam. The specimens were ground, polished and then etched with 4% nital reagent for 10 s. The microstructures were observed by optical microscopy (OM, Zeiss Image A2m) and a scanning electron microscopy (SEM, JSM 7600 F). The chemical compositions were measured by energy-dispersive X-ray spectroscopy (EDS, Oxford Instruments). Fig. 2(c) described the weld profile parameters and the EDS spot positions in the centerline of the fusion zone. The Al content in the fusion zone was defined as $R_{Al\text{-}Si}$. The coatings on both sides would melt into the weld pool. The penetration ratio was defined as R. This value indicated that the ratio of base material in the fusion zone. The value was higher when the dilution effect of the filler wire was weakened. The coating thickness t_c was 30 μm. The equations for $R_{Al\text{-}Si}$ and R are expressed as

$$R = \frac{S_2}{S_1 + S_2 + S_3} \tag{1}$$

$$R_{Al-Si} = \frac{S_{(t)Al-Si} + S_{(b)Al-Si}}{S_1 + S_2 + S_3} \times \frac{2.7}{7.8} = \frac{(W_t + W_b) \times t_c}{S_1 + S_2 + S_3} \times \frac{2.7}{7.8} \tag{2}$$

The transverse tensile specimens of the butt joints were tested on a Zwick Z100 universal testing machine. The gauge length was 20 mm, and the tensile speed was 1 mm/min. The fracture surfaces were

Table 1
The chemical compositions of the base material and filler wire ER70S (wt.%).

	C	Mn	Si	S	P	Cu	Ni	Cr	Ti	Al	B	Fe
Base material	0.22	1.12	0.22	0.007	–	–	0.01	0.19	0.026	0.029	0.0047	Bal.
ER70S	0.07	1.48	0.83	0.015	0.015	0.12	–	–	–			Bal.