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Effect of Zn Vaporization on Wetting of Al-galvanized Steel in Cold Metal Transfer Process

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Abstract: The wetting of galvanized steel by molten Al alloys was studied in the cold metal transfer process by the sessile drop method using a high speed video camera. The wetting behavior can be divided into two typical cases, trending of non-wetting by using small wire feeding speed and wetting by using large wire feeding speed. The Leidenfrost effect is caused by the volatilization of Zn, which is responsible for the former case. The enhanced wettability of steel by Al and the weakening of the Leidenfrost effect are responsible for the latter case. Zn is the destabilizing factor for Al-steel joining that needs to be avoided by a reasonable design of process.

Key words: capillarity; wetting; interface; Zn vaporization; Al-galvanized steel; cold metal transfer

Galvanized steel is a common material used in the automobile industry with the consideration of anti-corrosion. Recent studies[1,2] have shown that this material is also necessary for Al-steel joining. The Zn coating plays an important role in Al-steel welding-brazing process[2], but reports on the wetting behavior and interfacial structures are unavailable.

Cold metal transfer (CMT) method is characterized as low heat input, which is very suitable for Al-steel joining. The role of Zn in such a process is still mysterious. Some studies[3-6] suggested that Zn played a role more like brazing flux which optimized the interfacial structures, and then the thin intermetallic layer and desirable mechanical performance could be obtained. Some scholars[7,8] considered the volatilization of Zn might induce defects and deteriorate the final mechanical performances. Therefore, it is necessary to probe the role of Zn in the joining process of Al-galvanized steel.

Wettability of iron or steel substrates by molten metals was studied by numerous studies. For example, Ebrill[9] studied the intrinsic wetting behavior in H_2 atmosphere by the dispensed drop method. In the practical application, due to the high oxygen partial pressure in the atmosphere, intrinsic wetting behavior always cannot be realized. Chapuis et al. [10] studied the wetting behavior in gas arc metal welding (GAMW) process and pulsed gas arc metal welding (P-GAMW) process with different atmospheres, and the spreading seemed no link to the capillary effect but being governed by mass, heat and energy transfers. Vollertsen and Thomy[11] developed a correlation between the temperature fields and wetting length in the laser-MIG hybrid welding of Al-steel. However, the temperature of over-heated melt pool was so high that was already over the melting temperature of steel. Koltsov et al. [12] studied the wetting of Zn-coated steel by Cu-Si alloys using dispensed drop technique, and the improvement of wetting with a Zn-rich zone near the triple line was observed; this phenomenon was also mentioned by Marder[13] and Agudo et al. [14] in the metallurgy between Zn-coated steel and Al-alloy melts.

The purpose of this study is to reveal the effect of Zn vaporization on the wetting and the mechanism of the improved wettability in CMT process. It is expected that such a study could provide guidance to Al-steel joining and coating process.

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1 Experimental

Al 4043 wire with diameter of 1.2 mm, galvanized steel sheets with dimensions of approximately 200 mm×100 mm×1 mm and about 5.3 μm thick Zn coating were used in the wetting experiments. The nominal chemical composition of Al wire is shown in Table 1. Galvanized steel was fabricated by using low carbon steel as the matrix material.

Table 1 Nominal chemical composition of Al 4043 alloy wire

mass%

Fe	Si	Cu	Mn	Mg	Zn	Ti	Al
0.80	5.00	0.30	0.05	0.05	0.10	0.20	Balance

Wetting experiments were carried out by the sessile drop method, that is, a high speed video camera (1200 frame/s) recorded CMT spot welding process with various parameters. Laser of 450 mW in power and 650 nm in wavelength was used as the backlight source, and a narrow-band filter was used before the camera to reduce the arc light. As known, low heat input to the interface is the typical characteristic by using the CMT method. The mechanism is the special mode of metal transfer, i. e., almost no electric current can go through during short circuit transition processes. In these experiments, although the surface roughness was uncontrollable after the vaporization of Zn coating and might influence the wetting results, the stable average roughness (about 4.3 μm in an area of 190 μm×250 μm) of the ablation zone with different wire feeding speeds (WFSs) could be obtained by a confocal scanning laser microscope (CSLM, LEXT OLS3000, Japan). In the whole process, high purity Ar (nearly 99.999%) with a flow rate of 15 L/min was adopted as shield gas and the frequencies of the metal transfer process was 50—70 Hz. A series of wetting quench experiments were carried out, and the cross-sectional microstructures were examined by using a scanning electron microscope (SEM, FEG 450, Netherlands) equipped with energy dispersive spectrometer (EDS).

2 Results

The WFS is a key parameter for CMT welding, which means the quantity of transferred melts from wire per unit time. The larger WFSs also mean the larger transferred heat to the substrate. The heat input ($\eta \cdot U \cdot I$, where η is the coefficient of efficient heat input (a constant), U is the welding voltage and I is the welding current) increased with the increase of WFS and was almost linear, as shown in Fig. 1. Therefore, two WFSs (1.2 and 6.0 m/min) were selected as typical parameters in this study; one tended to non-wetting and another to wetting finally. Fig. 2 shows the variation of contact angles and radius with time t. The contact angle increased with the proceeding of metal transfer process (i. e., with accumulated amount of molten drop) for WFS of 6.0 m/min until around 0.1 s, and then decreased to about 30° gradually. The contact radius increased almost monotonously. The contact angle decreased at the initial 10 ms, i. e., the spreading of the first drop transferred from the wire, as shown in Fig. 2(b). The dynamic behavior in this stage could be described as a hydrodynamic model, as reported in previous work[15]. There were nearly no data for WFS of 1.2 m/min before 0.24 s (Fig. 2(a)). As shown in Figs. 2(c)—2(h), the drop could not be transferred from wire to substrate; meanwhile, the welding spatter was observed. As a whole, the contact angles and radius all increased with time, and the wetting behavior tended to non-wetting for WFS of 1.2 m/min.

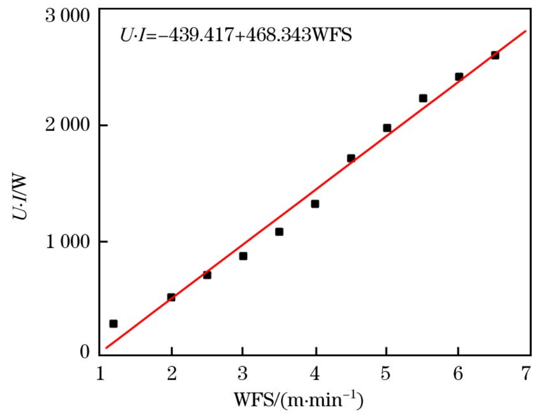

Fig. 1 Variation of input power with WFS

The top-view of the sample quenched at 0.1 s for WFS of 1.2 m/min is shown in Fig. 3. Only very small metal was transferred, and an obvious ablation zone could be observed. The line distribution of elements on the straight line for the corresponding position in Fig. 3(a) shows some Zn was retained in the interior and some accumulated at the edge after ablating by arc. The details of these two zones are given in Figs. 3(b) and 3(c). The macroscopic top-views of the samples quenched at 0.1 s and 0.8 s for WFS of 6.0 m/min are shown in Fig. 4(a). The ablation zone (the dashed circle in Fig. 4(a)) can also be observed. Furthermore, the triple line of the tran-