The arc characteristics and metal transfer behaviour of cold metal transfer and its use in joining aluminium to zinc-coated steel

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\textbf{A B S T R A C T}

Cold metal transfer (CMT) is a modified metal inert gas welding process based on short-circuiting the transfer process, characterised by low heat input and no-spatter welding. The arc characteristics and its droplet transfer process have been studied by high-speed video photography. The process was used to join aluminium to zinc-coated steel. The results show that no-spatter welding and low heat input during the welding process can be realized by CMT, and a dissimilar metal joint with good performance can be obtained by the CMT process.

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1. Introduction

In order to reduce pollution and save energy, it is attractive to make car bodies lighter through introducing some aluminium parts to substitute for the previous steel structures \cite{1–5}. So joining aluminium to steel becomes a key problem which should be resolved. Joining dissimilar metals such as aluminium and steel by fusion welding methods is known to be very difficult because of the formation of brittle intermetallic compounds which can deteriorate the mechanical properties of the joints. But Kreimeyer and Sepold \cite{6} have shown that, when joining aluminium to steel if the compound layer is less than 10 m thick, the joint will be mechanically sound. Furthermore, the author also deems that the existence of zinc coating can increase the fusion metal wettability to steel.

Fusion welding methods become the “hot direction” to solve the dissimilar metal joining problem because of their high efficiency. So a fusion welding method with low heat input and high efficiency may give a solution to realize the aluminium use in automobile. Short-circuiting metal transfer is a suitable method because of its low heat input characteristics \cite{7}. But the excessive spatter during the welding process also poses great problems to the producer. A recent development in welding technology is the cold metal transfer (CMT) process which is ideally suited to welding aluminium and dissimilar joint owing to the no-spatter welding process and low thermal input.

The CMT process is a modified metal inert gas welding process which was invented by Fronius company. The principal innovation is that the motions of the wire have been integrated into the welding process and into the overall control of the process. The wire retraction motion assists droplet detachment during the short circuit, thus the metal can transfer into the welding pool without the aid of the electromagnetic force. Then the heat input and spatter can be decreased greatly.

The major aim of this article is to examine the arc characteristics and the metal transfer of the CMT process and use it to join aluminium and zinc-coated steel with a lap geometry by a welding–brazing method. The microstructure of the joint and the tensile strength of the joint were investigated to evaluate the process applicability in dissimilar metal joining.

2. Experimental set-up and procedure

A high-speed camera (CA-D6-0256W) was used to acquire the images of the arc shapes and the droplet images. When collecting the metal transfer process a back light is projected by the left xenon lamp to travel towards the droplet/wire and then the image plane as a set of parallel lights. The filter system was used to diminish the intensity of the light and promote the image articulation. The current and voltage waveform were captured by the corresponding sensors and then written into the computer.
Deep drawing sheets of hot dip galvanized steel with thickness of 0.6 mm and sheets of pure aluminium 1060 with thickness of 1 mm were used in welding experiments. Al–Si alloy wire in 1.2 mm diameter were selected as the filler metal. In welding process, argon was adopted as shielding gas at a flow rate of 15 dm³/min. The surface of the samples was cleaned by acetone before welding.

3. Results and discussion

3.1. The arc characteristics and metal transfer of the CMT process

The arc shape variation of the CMT process as shown in Fig. 1. In one cycle, the brightness of the arc is low except two frames at the beginning of the cycle. These characteristics are consistent with the waveform features of the process.

A typical CMT welding electrical signal cycle is shown in Fig. 2. A cycle can be defined as the period required to deposit a droplet of molten electrode into the weld pool. From the figure, we can divide the cycle into three phases: (i) the peak current phase. This is represented by a constant arc voltage corresponding to a high pulse of current. The high pulse current make the ignition of the welding arc easily and then heats the wire electrode to form droplet. In this phase, the brightness of the arc is very high. (ii) The background current phase. The phase is represented by a lower current. Through the peak current phase, a little liquid droplet is formed on the wire tip. In order to inhibit the globular transfer, so the current decreases abruptly. This phase is the background current phase. Then the low current keeps constant until the short-circuiting process happens. (iii) The short-circuiting phase. In this phase, the wire contacts with the weld pool and the arc voltage changes into zero and the arc extinguishes. The back-drawing force becomes the main factor to urge the droplet break away from the wire into the weld pool.

Fig. 3 is the metal transfer process in one waveform period. The size of the liquid droplet attaching to the wire tip is very close to the wire diameter during arc-burning time. And the rupture of the liquid bridge is very stable. Because of the additional back-drawing force the droplet can transfer into the welding pool without the aid of the electromagnetic force.
The smooth welding seam was made and the zinc coating of the welding back seam can be retained to keep the corrosion resistance. Fig. 4 is the typical cross-section image of the joints. The scanning electron micrograph shows that a visible intermetallic compound layer between the steel and weld metal has been formed during the welding process as shown in Fig. 5.

The joint was disjoined at the interface between weld metal and steel. X-ray diffraction was used to determine the phase composition of the compound layer. The results are shown in Fig. 6. The compact layer near the steel side is Fe2Al5 phase and the needle-like compound growing into the weld metal is FeAl3 phase.

The maximum thickness of the compound layer in the aluminium–steel interface is about 4 μm. The tensile test results show that the bonding strength is about 83 MPa, equaled almost to 86% of that of the pure aluminium and the fracture all occurred in the heat-affected zone of the aluminium as shown in Fig. 7.

4. Conclusions

Based on the experimental results and discussions, conclusions were drawn as follows:

The metal transfer process of the CMT is very stable and the arc heating behaviour is changed based on the special wave control features and a assistant back-drawing force. Dissimilar metal joining of aluminium to zinc-coated steel sheet without cracking by the CMT process in a lap joint is possible. The compound layer at the interface between steel and weld metal mainly consists of Fe2Al5 and FeAl3 phase. The thickness of the intermetallic compound layer can be controlled under 5 μm, so the joint strength can be guaranteed. The tensile strength can arrive at 83 MPa.

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References