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Surface Modification of Resistance Welding Electrodes by Electro-Spark Deposited Coatings

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Abstract

To improve electrode life during resistance welding of Zn-coated steels, TiC_P/Ni coatings were deposited onto the surface of electrodes by electro-spark deposition. In addition, laser treatment was performed to eliminate cracks formed in the as-deposited TiC_P/Ni coating. Properties of the coatings were characterized by electro-microscopy, energy-dispersive X-ray analysis, X-ray diffraction and micro-hardness tests. The results showed that cracking occurred within the as-deposited TiC_P/Ni coating. The cracks of the coating could be eliminated with the use of a multi-layer deposition process using Ni and TiC_P/Ni layers. Although laser treatment of TiC_P/Ni coating could eliminate cracks, the softening of copper substrate after laser treatment was a problem that restricted welding performance. Welding tests showed that alloying between copper alloy and molten Zn as well as pitting (erosion) of electrode were significantly reduced due to the barrier action of the coatings, especially with multi-layer Ni/(TiC_P /Ni)/Ni coating on the electrode surface.

Introduction

Use of zinc-coated steels has attracted extensive attention over the past decade owing to their good corrosion resistance and relatively low cost. Resistance spot welding (RSW) is the primary method for joining sheet steel in the automotive industries. However, the zinc coating has resulted in the difficulty of welding due to its lower electrical resistance and melting temperature. This has led to a drastic reduction in the electrode life. A short electrode life limits the rate of production. Electrode degradation during RSW of coated steels has been the subject of many studies where developments in electrode materials and the design of electrode have been explored in an effort to improve weldability and increase electrode life. [1-5].

On the other hand, coating the electrode surface has been suggested as a method to extend electrode life. For example, Dong and Zhou [6] have shown that an electrode with electro-spark deposited TiC_P/Ni composite coating (TiCap™, a trademark of Huys Industries Limited, Ontario, Canada [6-7]) can extend the life of micro-resistance welding electrodes. More recently, the use of the TiC_P/Ni composite coating for electrode life improvement in RSW of hot-dip galvanized zinc coated steel has also been reported and it has been shown that TiC_P/Ni coating acts as a barrier against erosion and alloying of electrode by molten Zn [7]. TiC_P/Ni composite coating, however, could be further improved to present better performance by improving the barrier layer by reducing the cracks within the coating. In the present work, laser treatment of the as-coated TiC_P/Ni coating and a multi-deposition process has been suggested to eliminate cracks within the coating. The metallurgical phenomena of electrodes without and with monolithic TiC_P/Ni coating as well as multi-deposited Ni/(TiC_P/Ni)/Ni coating during RSW of Zn-coated steel are investigated.

Experimental

The RSW electrode used was a standard FB-25 domed electrode. The electrode base metal was a precipitation strengthened and cold worked Cu-0.84wt.%Cr-0.05wt.%Zr alloy. A sintered TiC_P/Ni composite rod and a pure Ni rod were used to deposit coatings on the electrodes. The volume percentage of TiC particles (~2 μm in diameter) was 36-48 in the composite rod. The chemical composition of TiC_P/Ni composite rod is as follows (wt.%): Ti:67, Ni:21, Co:2.5, Mo:3.0 and W:6.0. Deposition of TiCp/Ni and Ni coating were carried out using a self-developed electro-spark deposition (ESD) machine with a handheld gun in air and argon at room temperature, respectively. After deposition, some of the electrodes with TiC_P/Ni coating were further treated using a 4 kW diode laser with a scanning speed of 80 mm/min in argon. The welding test of the electrodes, with and without coating, was carried out using a 250 kVA single-phase AC spot welding machine. Hot dip galvanized (HDG60G) mild steel (0.7 mm thick with 0.01mm thick Zn-coating on both side) was employed as material to weld. Welding currents are 9200 A and 8500 A for uncoated and coated electrodes. The 'growing rate' of electrode tip diameter during welding was taken as an evaluation parameter of electrode performance, which was determined using a carbon imprint technique. Coating surface and cross-section of the electrodes before and after certain welds were examined using scanning electron microscope (SEM) equipped with an energy-dispersive spectrometer (EDS). Phase identification was conducted using an X-ray diffractometer (XRD).

Results and Discussion

The topographical and cross-section of as-coated TiC_P/Ni coating are shown in Fig. 1. The typical 'splash' appearance is a characteristic feature of the ESD technique, especially when air is used for shielding. The thickness of coating was not unique, usually varying from 30 μm to 40 μm. From cross-section images, it was observed that when TiC_P/Ni was directly deposited onto the copper alloy, there was significant cracking and delamination of the coating. When molten droplets were deposited onto the cold copper alloy substrate, they rapidly solidified to form a coating due to the much greater thermal sink of the substrate. As a result, tensile thermal stress developed during cooling and solidification of the droplets due to their constriction. The tensile thermal stress increased during deposition, causing cracking of the coating and delamination at weakly bonded interface. In addition, low toughness of the coating was responsible for cracking. After laser treatment, it was noted that a higher Cu content was detected within the TiC_P/Ni coating and that the coating became more dense and free of cracks both within the coating and at the interface (Fig.1). On the other hand, multi-coatings showed a higher Ni and a lower TiC content. A dense and crack-free Ni/(TiC_P/Ni)/Ni coating could be obtained by a multi-deposition of Ni, TiC_P/Ni and again Ni (Fig.1), owing to Ni as an excellent binder.

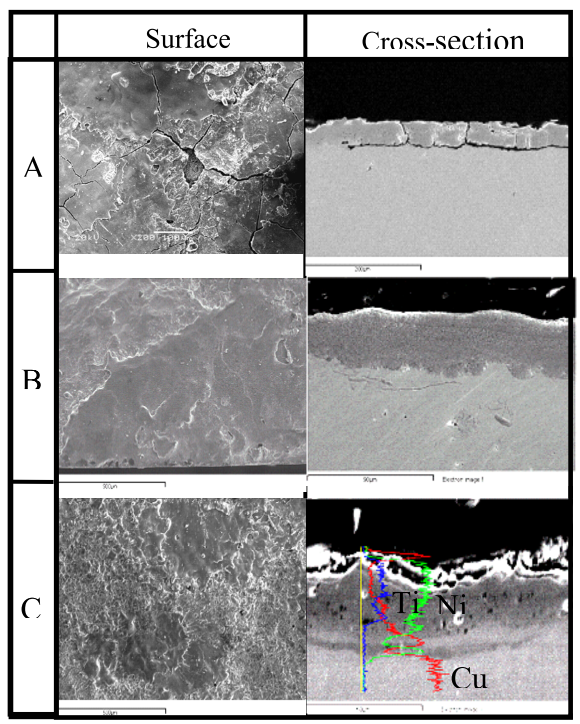

Fig.1 SEM images of surface and cross-section of as-coated (A) and laser treated (B) TiC_P/Ni coatings as well as Ni/(TiC_P/Ni)/Ni coating (C)

XRD patterns (Fig.2) indicated the main constitution phases of TiC_P/Ni coating and multi-Ni/(TiC_P/Ni)/Ni coating were TiC, Ni and Cu. There was no discernible peak from any other Ti-Cu or Ti-Ni intermetallic phases, showing mixing was purely physical in nature where Cu and Ni acted as binders. Fig.3 shows the distribution of hardness from the top surface of the coatings. TiC_P/Ni coating showed highest hardness (~HV 1100). Multi-Ni/(TiC_P/Ni)/Ni coating presented lowest hardness around HV 500, however, this hardness value was still quite harder than the copper alloy (HV 180). Laser treatment also reduced the hardness of TiC_P/Ni coating due to the extensive mixing of Cu into the coating. It is found that a narrow softening zone (heat-affected zone) was present within the substrate underneath the coating for ESD process. However, after laser scanning, a significant HAZ was formed, resulting in substantial softening of the substrate.

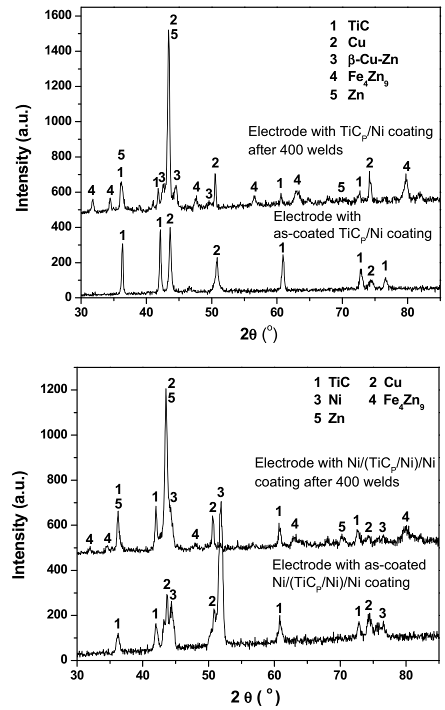

Fig.2 XRD patterns of TiC_P/Ni and multi-Ni/(TiC_P/Ni)/Ni coatings before and after welding

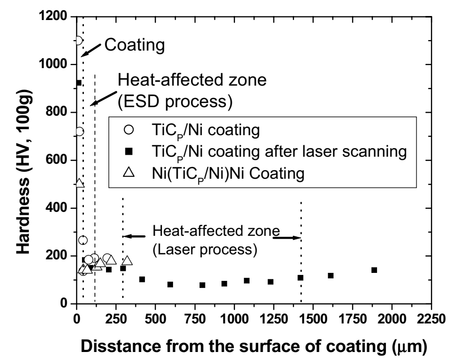

Fig.3 distribution of hardness

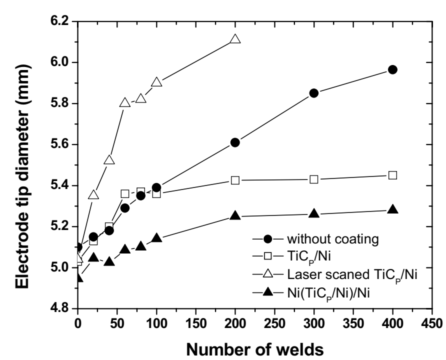

Fig.4 Growth of electrodes tip

Electrode tip growth has been suggested as the dominant process that determines electrode life when resistance spot welding Zn-coated steels. It is also known that in terms of electrode wear rate, the change in the electrode tip diameter with increasing number of welds is more important than the absolute value of electrode face diameter itself. As shown in Fig.4, the tip diameter growth rate of the electrode with TiC_P/Ni coating was similar to that of the electrode without coating before 100 welds. However, the former was much less than the latter when number of welds exceeded 100. On the contrary, the electrode with multi-Ni/(TiC_P/Ni)/Ni coating showed smaller tip diameter growth rate than that with TiC_P/Ni coating up to 400 welds. On the other hand, electrode with laser-treated TiC_P/Ni coating showed the fastest growth rate largely due to softening of the substrate.

After 400 welds, the intensity of TiC peaks significantly reduced, indicating a loss of TiC_P/Ni coating during welding due to sticking and removal to the sheet (Fig.2). In addition, β-Cu-Zn alloy has formed resulting from the reaction between Zn and electrode. Different from TiC_P/Ni coating, predominant phases of the as-deposited Ni/(TiC_P/Ni)/Ni coating were Ni and TiC. After 400 welds, the intensity of Ni decreased, indicating the loss of the top Ni layer. However, the Ni/(TiC_P/Ni) coating was still maintained on the electrode surface, as evidenced by strong TiC peaks. Moreover, no evidence was evident that the reaction of the copper alloy substrate with the molten Zn had taken place.

Fig.5 shows the cross-section of electrode with TiC_P/Ni coating after 100 and 400 welds. The thickness of TiC_P/Ni coating decreased to about 20 μm. It is interesting to find that the TiC_P/Ni coating can be divided into two different regions. (i) The region close to the outer surface was granular and loose. (ii) The region adjacent to copper alloy substrate was relatively dense as compared to the granular region. But some grooves and cracks that had been sealed by Zn-Fe alloy existed within the this region. In addition, Fig.5 clearly shows that Zn mainly penetrated through granular region and grooves and cracks to react with copper to form a 12 μm thick Cu-Zn alloy layer (Fig. 5) underneath the coating. After 400 welds, the integrated and dense TiC_P/Ni coating was no longer present, leaving a non-continuous, loose, TiC_P/Ni coating on the surface. The thickness of Cu-Zn alloy layer increased to 30 μm, and cracks had formed within the Cu-Zn alloy layer due to its brittleness.

Except for rarely observed cracking within Ni/(TiC_P/Ni)/Ni coating, the coating was dense and adhered to the substrate after 100 welds (Fig.5). Zn was mainly present on the coating surface and did not show much diffusion into the substrate to form Cu-Zn alloys. The electrode with Ni/(TiC_P/Ni)/Ni coating after 400 welds demonstrated that the coating had started to develop cracking (Fig.5). In addition, delamination at coating-substrate interface was also visible (Fig.5). As a result, Zn was found to penetrate and diffuse into the coating mainly through the cracks and delamination. However, different from TiC_P/Ni coating, multi-Ni/(TiC_P/Ni)/Ni coating did not exhibit granular and loose structure up to 400 welds. Particularly, Zn seemed to have more difficulty in diffusing through the Ni layer than through the TiC_P/Ni coating. Consequently, no visible Cu-Zn alloy layer could be found.

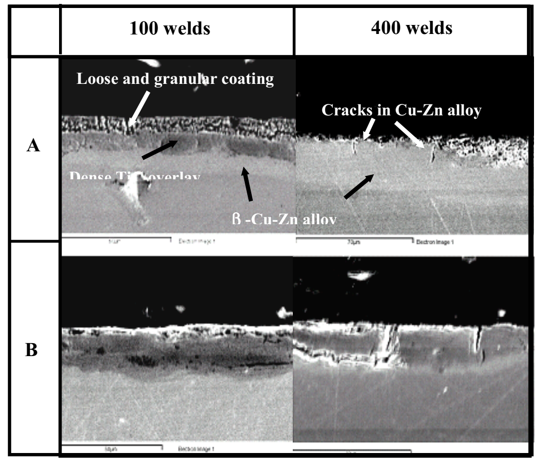

Fig.5 SEM cross-section of electrodes with TiC_P/Ni and Ni/(TiC_P/Ni)/Ni coating after 100 and 400 welds.

Conclusions

Deposition of a TiC_P/Ni coating onto the surface of a copper alloy electrode causes extensive cracking within the coating and delamination at the interface between the coating and substrate. During multi-deposition of Ni/(TiC_P/Ni)/Ni, although Ni does not react chemically with TiC, Ni acts as an excellent binder and may increase the toughness of the coating. Consequently, multi-deposition of Ni/(TiC_P/Ni)/Ni produces dense coatings and a well-bonded interface due to mixing of the Ni with the TiC_P/Ni. Post laser treatment of TiC_P/Ni coating could eliminate cracks and improve coating quality; however, the softening of copper alloy substrate limited the application of laser treatment to welding electrodes. With Ni/(TiC_P/Ni)/Ni coating on the electrode surface, pitting (erosion) of electrode was remarkably reduced, and hence showed a slower growth rate of the tip diameter.

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