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Coatings on Resistance Welding Electrodes to extend life

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ABSTRACT

TiC_P/Ni coating has been deposited onto the electrodes by electro-spark deposition to improve electrode life during resistance welding of Zn-coated steels. However, welding results revealed that molten Zn penetrates into coating through the cracks and then reacts with substrate copper alloy to form brasses. In the present work, laser treatment was performed on the TiC_P/Ni coated electrodes to eliminate cracks formed in the as-deposited TiC_P/Ni coating. In addition, a multi-electro-spark deposition of Ni, TiC_P/Ni and Ni has also been carried out to improve coating quality. On the other hand, a TiB_2 coating was also investigated. those coatings were characterized by electro-microscopy, energy-dispersive X-ray analysis, X-ray diffraction and micro-hardness tests. The results showed that cracks within the as-deposited TiC_P/Ni coating could be eliminated with the use of laser treatment or a multi-layer deposition process. However, softening of copper substrate after laser treatment was a problem that restricted welding performance. Welding tests showed that the multi-layer Ni/(TiC_P/Ni)/Ni coating acted as a better barrier to decrease alloying between the copper alloy and molten Zn as well as pitting (erosion) of electrode. The TiB_2 coating demonstrates its potential application on the electrode to further improve the electrode's life.

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 components 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 that can be achieved in a fixed period due to the need for frequent electrode dressing and/or electrode changes. Electrode degradation during RSW of coated steels has been the subject of many studies, in which for example developments in electrode materials and design of electrode have been explored in an effort to improve weldability and increase electrode life. [1-6]. On the other hand, coating on electrode surface has been suggested as a method by which to extend electrode life. For example, Dong and Zhou [7] have shown that an electrode with electro-spark deposited TiC_P/Ni composite coating (TiCAP™, a trademark of Huys Industries Limited, Ontario, Canada [7]) can extend the life of micro-resistance welding electrodes. Their tests found the coating increases tip life by approximately 70 percent by reducing the amount of local bonding between electrode and Ni sheet. More recently, in addition, 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 shown that TiC_P/Ni coating acts as a barrier against erosion and alloying of electrode by molten Zn [8]. TiC_P/Ni composite coating, however, is still needed modification to present better performance as a barrier layer due to presence of cracks within the coating and delamination at the coating-substrate interface [8]. 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. In addition, a new coating material of TiB_2 is also deposited and studied.

EXPERIMENTAL

RSW electrode used was a standard FB-25 domed electrode. The electrode base metal was precipitation strengthened and cold worked Cu-0.84wt.%Cr-0.05wt.%Zr alloy. A sintered TiC_P/Ni composite and a TiB_2 composite rods as well as a pure Ni rod were used to deposit coatings on the electrodes. The volume percentage of TiC or TiB_2 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. Whereas, TiB2 composite contained (wt.%) 85.2Ti, 2.9Ni, 6.2 Mo and 5.8 W. Deposition of coatings was carried out using a self-developed electro-spark deposition (ESD) machine with a handheld gun in air at room temperature. 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, 9000 A and 8500 A for uncoated, TiB_2 coated and TiC_P/Ni 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 X-ray diffractometer (XRD).

RESULTS AND DISCUSSION

1. EVALUATION OF COATINGS BEFORE WELDING

1.1 SEM and EDX analyses

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 40μm. 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 tress 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. Similar to the TiC_P/Ni composite coating, cracks could also be observed on top TiB_2 composite coating, as shown in Fig. 2. However, from the cross-section view, it was found that TiB_2 coating was denser and more compact than TiC coating, only a few cracks existed within the coating. In addition, Fig. 2 shows TiB_2 coating adhered well to the substrate, no interfacial delamination was observed.

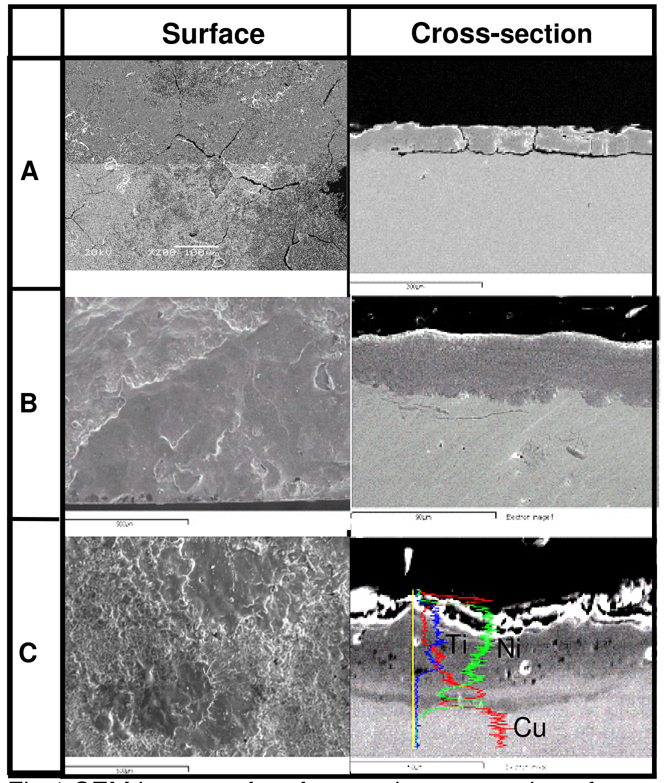

Fig.1 SEM images of surface and cross-section of as-coated (A) and laser treated (B) TiC_P/Ni coatings as well as Ni/(TiC_P/Ni)/Ni coating (C)

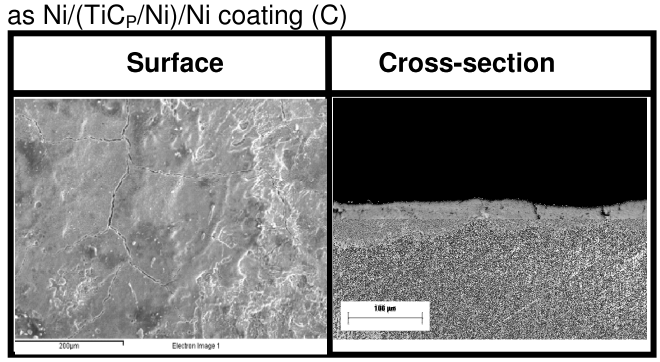

Fig.2 SEM images of surface and cross-section of TiB_2 composite coating

1.2 XRD analysis

XRD patterns (Fig.3) 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.

1.3 Hardness tests

The mechanical property of coatings was characterized by hardness tests. The hardness of TiC_P/Ni, laser post-treated TiC_P/Ni, Ni/(TiC_P/Ni)/Ni and TiB_2 coating was HV 1100, HV 1000, HV 500 and HV 1105, respectively. As-deposited TiC_P/Ni and TiB_2 coating showed a much higher hardness than Ni/(TiC_P/Ni)/Ni coating. Laser treatment also reduced the hardness of TiC$_P$/Ni coating due to the extensive mixing of Cu into the coating. Generally, it was believed that Ni/(TiC$_P$/Ni)/Ni coating had a relatively higher toughness than formers. Fig.4 shows the distribution of hardness from the top surface of the coatings. All the coatings were harder than the copper alloy (HV 180). 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.

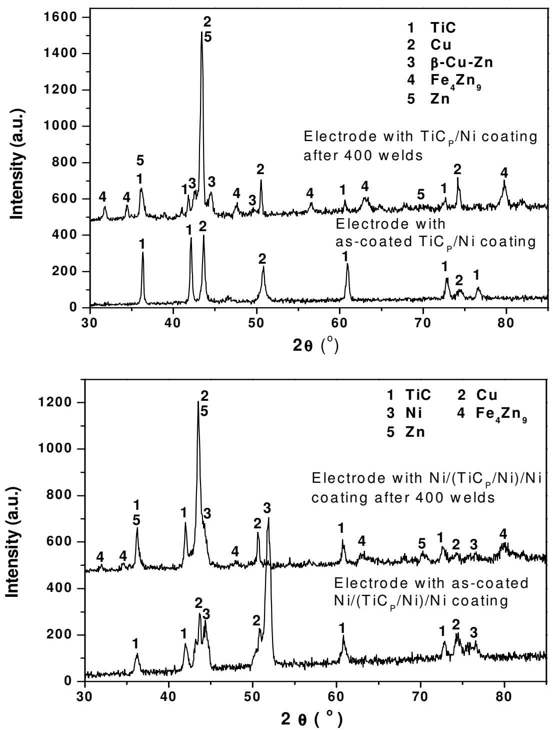

Fig.3 XRD patterns of TiC$_P$/Ni and multi-Ni/(TiC$_P$/Ni)/Ni coatings before and after welding

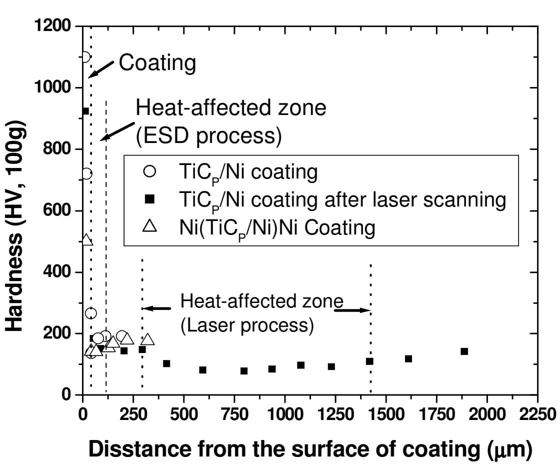

Fig.4 distribution of hardness

2. ELECTRODE STATIC RESISTANCE

To investigate the effect of coatings on resistance welding, the electrode static resistance was first measured with one sheet added to the resistance circuit; the electrical path includes the electrode bulk resistance, resistance of coatings, the bulk resistance of the single sheet, and two electrode-sheet interfaces. The result showed that uncoated electrode produced a resistance of 22.8 μOhm. With the coating on the surface of electrode, the resistance was increased to 33.9 μOhm, 31.2 μOhm and 29.8 μOhm for TiC$_P$/Ni, Ni(TiC$_P$/Ni)/Ni and TiB_2 coatings, respectively, since TiB_2 is more conductive than TiC.

3. SEM OBSERVATION AND XRD ANALYSES OF ELECTRODE WITH COATING AFTER WELDING

SEM observation demonstrated that molten Zn penetrated into TiC$_P$/Ni coating from 1st weld through cracks within the coating. Fig.5 shows the cross-section of electrode with TiC$_P$/Ni coating after 100 and 400 welds. The thickness of TiCP/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 30μm, and cracks had formed within the Cu-Zn alloy layer due to its brittleness. However, except for rarely observed cracking within Ni/(TiC$_P$/Ni)/Ni coating, the coating was dense and adhered to the substrate after

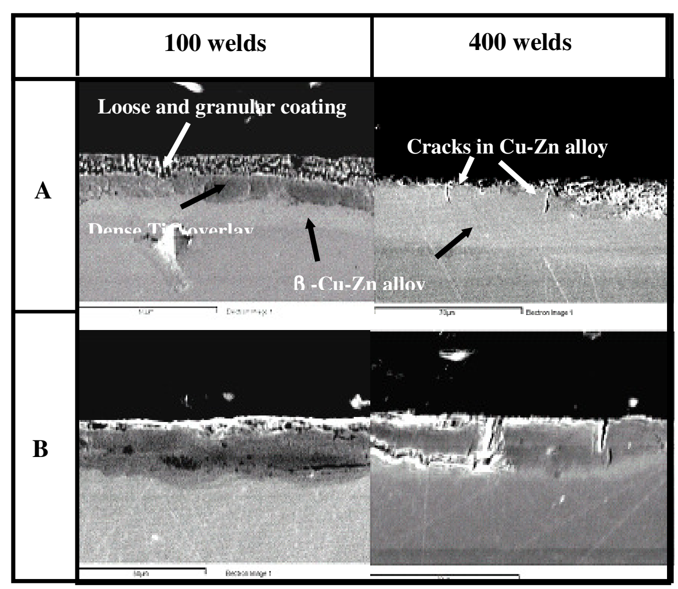

Fig.5 SEM cross-section of electrodes with TiC$_P$/Ni (A) and Ni/(TiC$_P$/Ni)/Ni coating (B) after 100 and 400 welds

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. 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.3). 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.3).

4. ELECTRODE TIP GROWTH

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.6, 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

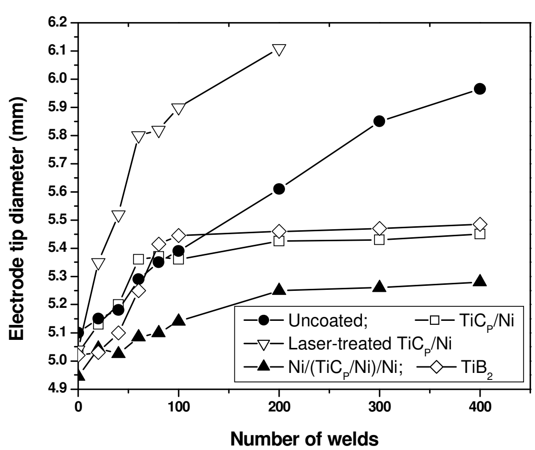

Fig.6 Growth of electrode tip

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. Although electrode with TiB_2 coating showed a similar growth rate with TiC_P/Ni coating, TiB_2, as a new coating material which is more conductive than TiC, demonstrates itspotential application on the electrode to further improve the electrode's lfe via multi-layer coating process.

CONCLUSION

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. TiB2, as a new coating material which is more conductive than TiC, demonstrates its potential application on the electrode to further improve the electrode's life via multi-layer coating process.

REFERENCES

1. P. Howe and S. C. Kelly, "A Comparison of the Resistance Spot Weldability of Bare, Hot-Dipped, Galvannealed, and Electrogalvanized DQSK Sheet Steels", International Congress and Exposition, Detroit Michigan, February 29-March 4, 1988.
2. R. Holliday, J. D. Parker and N. T. Williams, Welding in the World, 37 (1996), 186-193.
3. R. Holliday, J. D. Parker and N. T. Williams, Welding in the World, 35 (1995), 160-164.
4. T. Saito, Y. Takahashi and T. Nishi, Nippon Steel Technical Report, 37 (1988), 24-30.
5. L. M. Friedman and R. B. McCauley, Welding Journal, Oct. (1969), 454s-462s.
6. R. Holliday, J. D. Parker and N. T. Williams, Key Engineering Materials 99-100 (1995), 95-102.
7. S. Dong and Y. Zhou, Metal. And Materials Trans. A., 34A (2003), 1501-1511.
8. K. R. Chan et al, Submitted to Welding Journal.

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