Preparation of Ti-Al Intermetallic Compound by Wire Arc Spraying

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Electric arc spraying with dual wires is an economical coating process finding diverse applications. The purpose of this work is to develop a new preparation method of titanium-aluminum intermetallic compounds by the wire arc spraying. Titanium wire used as the anode and aluminum wire used as the cathode have been sprayed with air used as an atomizing gas. The intermetallic compounds, such as Ti_3Al and TiAl, have been prepared during the droplet deformation on the substrate as well as during the droplet flight. The wire arc spraying provides new attractive process for preparation of intermetallic compounds. The higher melting temperature materials can be used as the anode, while lower melting temperature material used as the cathode for obtaining of the better droplet dispersion produced from the corresponding wires. Enhancement of the intermetallic compound preparation results from higher substrate temperature.
Key words: arc spray, coating, intermetallic compound, titanium, aluminum

1. INTRODUCTION

Electric arc spraying with dual wires is an economical coating process finding diverse applications. Arc spraying has been used widely to coat engineering structures to protect them against corrosion and wear. The material to be deposited is introduced into the arc in the form of two wires serving as consumable arc electrodes. A cold gas jet across the arc drives the molten atomized droplets from the electrode tips as illustrated in Fig. 1.

Arc fluctuations due to periodic removal of molten droplets from the electrode tips have strong effects on the droplet formation, therefore on the coating properties. The correlations between the electrical fluctuations, the droplet formation, and the coating properties have been investigated [1,2]. The gas flow - droplet interaction such as turbulence and oxidation are considered important parameters for coating quality control. Finding correlations between these phenomena and the coating properties will lead to development of new material processing

Intermetallic compound coatings, alloy coatings or metal-ceramic composite coatings can be obtained by wire arc spraying with cored wires or pre-alloyed wires. Nickel-aluminum intermetallic compound coatings have been obtained by spraying of the cored wires, Ni-20 wt% Al [3]. Zinc-aluminum alloy coatings have been obtained by spraying of the pre-alloyed wires, Zn-15 wt% Al [4]. Another method for preparation of intermetallic compounds is to spray the two different wires. Zinc-aluminum pseudo-alloy coatings have been obtained by spraying of zinc and aluminum wires [4]. The preparation of intermetallic compounds using different wires is rather challenging topics because of the difficulty of the electrode control of the different wires, however this preparation method will provide the wide variety of compounds consisting of the corresponding two wires.

Titanium-aluminum intermetallic compounds, Ti_3Al and TiAl, have attractive characteristics, such as low density, high creep resistance. These intermetallic compounds additionally have other advantages include good oxidation resistance at high temperature and strength retention at elevated temperatures. These intermetallic compounds have been actively researched for application in aerospace, automobile and gas turbine engines. A Ti-Al phase diagram is shown in Fig. 2.

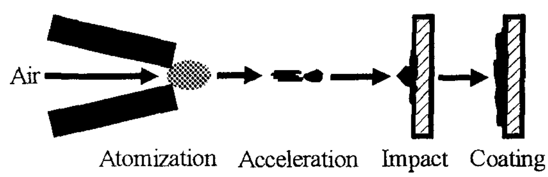

Fig. 1 Model of arc spraying.

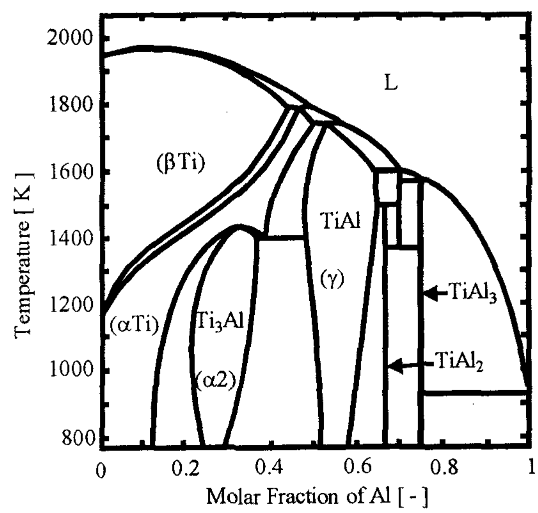

Fig. 2 Phase diagram of Ti-Al.

The purpose of this work is to develop a new preparation method of titanium-aluminum intermetallic compounds by the wire arc spraying with titanium and aluminum wires. The investigation of the electrode characteristics of the wire arc spraying with different wires are indispensable for the preparation of intermetallic compounds, because production of the droplets from the corresponding wires are affected by the electrode fluctuation, then coating characteristics are depends on the droplet dispersion.

2. EXPERIMENTAL

2.1. Experimental apparatus

The Sulzer Metco 4R arc spray system used consists of a power supply, a control unit and an arc spray gun. The schematic diagram of the experimental apparatus is shown in Fig. 3. Aluminum and titanium wires with diameter of 1.6 mm have been sprayed with air used as an atomizing gas. Three different wire configurations are used to obtain the correlations between the electrode fluctuation and the droplet formation; dual aluminum wires, dual titanium wires, and the combination of aluminum wire as the cathode and titanium wire as the anode. An additional wire configuration, aluminum and titanium wires with reverse polarity, is used for comparison of the droplet dispersion. Coatings and droplets have been obtained with arc voltages from 24 V to 33 V, with arc currents from 100 A to 200 A, with atomizing gas pressures from 100 kPa to 500 kPa. The stand-off distance between the spray gun and the substrate ranges from 100 mm to 200 mm. The spraying time was set at 0.5 s.

2.2. Voltage fluctuation

Arc voltage fluctuation has been measured with a digital oscilloscope. The arc voltage fluctuation implies the fluctuation of the electrode movement, therefore the arc voltage fluctuation affects the droplet formation, then indirectly affects the coating properties.

2.3. Droplet analysis

Droplets have been collected on ice used as the substrate. Cumulative fraction and the average diameter of the droplets have been measured from the scanning electron microscopy (SEM) photographs. The number of the measured droplets is about 300 for each condition. The composition of droplets has been analyzed with X-ray diffraction (XRD) by CuKα (154.06 pm).

2.4. Coating analysis

Coatings have been prepared on the substrate of SUS 304. The composition of Ti-Al intermetallic compounds in the coatings has been analyzed with XRD. The distributions of titanium and aluminum contents of the coatings have been also measured with XRD to investigate the dispersion of the droplets produced from the corresponding wires.

3. RESULTS AND DISCUSSION

3.1. Amplitude of arc fluctuation

The arc voltage fluctuations with three different wire configurations recorded with a digital oscilloscope are presented in Fig. 4. Arcing and melting of the consumable electrode tips are intermittent on a short time scale. The periodic variation of the arc length is observed because the wire melting rate and the

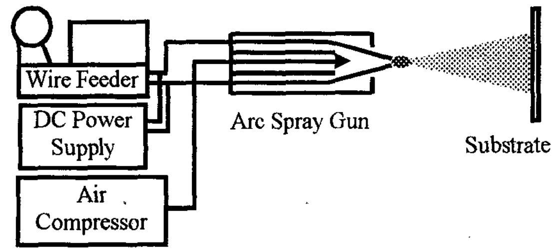

Fig. 3 Schematic diagram of the experimental apparatus.

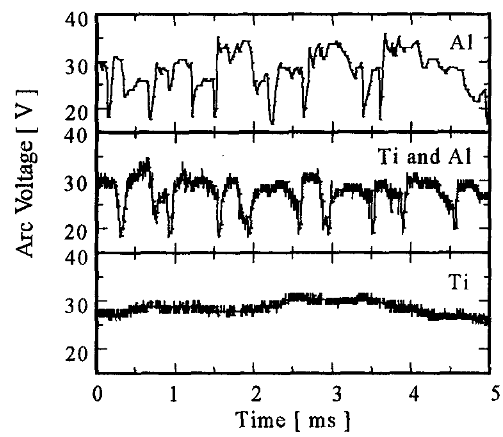

Fig. 4 Arc voltage fluctuations with Al, Ti and the combination of Al and Ti electrodes at 30 V, 200 A, 300kPa.

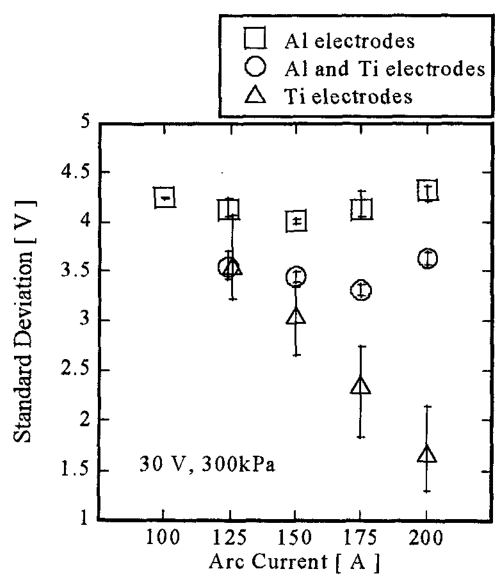

Fig. 5 Comparison of standard deviations of the voltage fluctuation among different electrode configurations.

wire-feeding rate are not matched. The periodic waveforms of the voltage fluctuation correspond to the periodic shortening of the arcing gap. The most stable fluctuation has been obtained with dual titanium wires, while the most unstable with dual aluminum wires. The unstability of the dual aluminum wires is attributed to the strong oxidation of the electrodes.

The amplitude and the frequency as well as the waveform of the arc fluctuations are regarded as important parameters for the indication of the droplet formation [1,2]. Standard deviations of the voltage fluctuations are adopted as the indication for the amplitude of the fluctuations. Comparisons of the amplitude of the voltage fluctuation among the three different wire configurations at different arc currents are shown in Fig. 5. Dual titanium wires leads to the smallest amplitude of the voltage fluctuations especially at higher current. The smallest amplitude indicates the stable fluctuation of the electrodes.

3.2. Droplet formation

The cumulative fractions of the droplet diameter with three different wire configurations are presented in Fig. 6. The smallest droplets have been produced by dual titanium wires which cause the stable fluctuation of the electrodes, while the largest droplets by dual aluminum wires which cause the unstable fluctuation of the electrodes. These results suggest that the stable electrode fluctuation can be related to the production of smaller droplets. Control of the size distribution of the droplet produced from different wires is important to prepare intermetallic compounds by the wire arc spraying.

The XRD peaks of the intermetallic compounds prepared in the droplets are shown in Fig. 7 with changing the arc current. The Ti-Al intermetallic compounds consist of TiAl (2θ = 38.96°), $TiAl_2$ (2θ = 38.90°), and Ti_3Al (2θ = 39.12°) The peaks of the Ti-Al intermetallic compounds are presented as the relative intensity to the aluminum peaks at 2θ = 44.74°. The intermetallic compounds can be prepared in the droplets during the flight, however the contents are small by comparison of the contents in the coatings prepared on the substrate as shown later.

3.3. Coating properties

An example of the XRD chart of the coatings prepared at 200 A is presented in Fig. 8. The XRD peaks resulting from the intermetallic compounds, such as TiAl, are found in this figure. The metal oxides, Al_2O_3 and TiO_2, and the metal nitrides, TiN, have been also prepared. The wire arc spraying is capable of preparation of intermetallic compounds with economical process. The XRD peaks due to the intermetallic compounds in the coatings are much stronger than those in the droplets. The intermetallic compounds are mainly prepared during the droplet deformation process on the substrate, while the compounds with small amount are prepared during the droplet flight. This result indicates that the dispersion of titanium and aluminum droplets produced from the corresponding wires is one of important factors for obtaining better coating qualities.

The radial distributions of titanium, aluminum, and Ti-Al intermetallic compounds in the coatings are shown in Figs. 9 and 10. The coatings have been prepared with

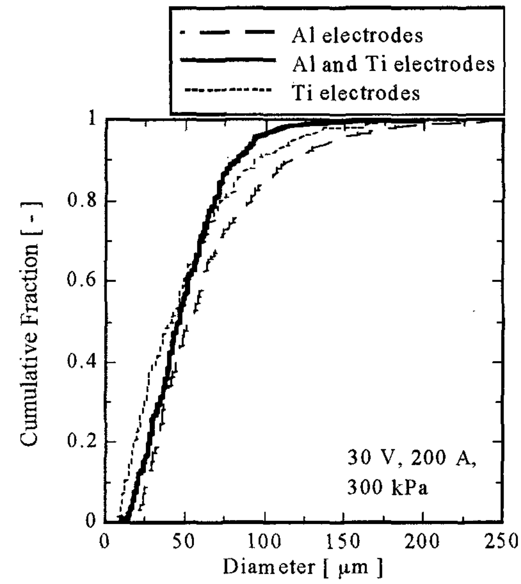

Fig. 6 Cumulative fraction of droplet diameter with different electrode configurations.

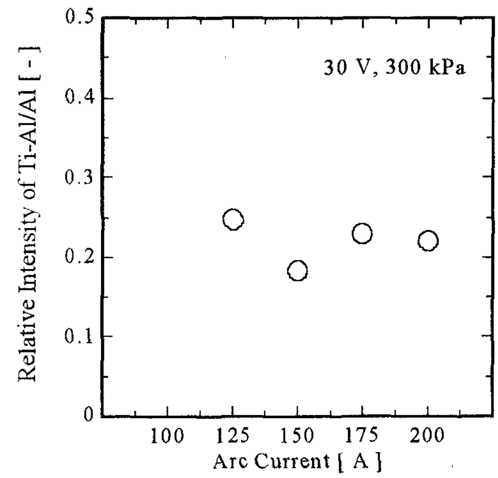

Fig. 7 Effect of arc current on relative XRD intensity of Ti-Al/Al in the droplets.

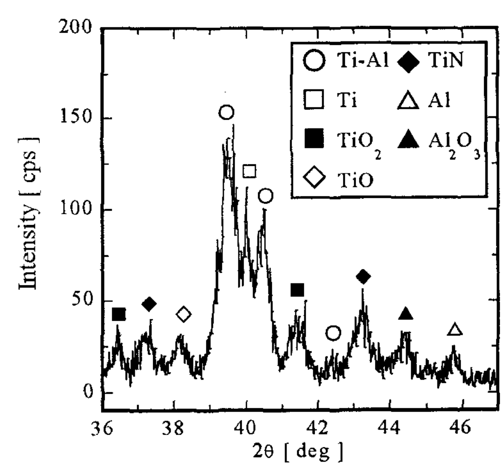

Fig. 8 XRD chart of the coating at 30 V, 200 A, 300 kPa, 150 mm.

relatively short spraying time to reduce the preparation of the compounds on the substrate. Figure 9 shows the coating compositions prepared by aluminum wire as the cathode and titanium wire as the anode, while Fig. 10 shows the compositions prepared by the reverse polarity. These distributions are presented as the ratio of the corresponding XRD intensities. The coatings prepared by titanium wire as the cathode show the localized distributions of titanium droplets. On the other hand, the coatings prepared by titanium wire as the anode show the well-balanced distribution of titanium and aluminum droplets. These results reveal that titanium wire used as the anode leads to better distributions of titanium and aluminum droplets, resulting in larger amount of the prepared compounds.

Heat flow into the anode is usually higher than the cathode, because electrons ejected from the cathode carries energy into the anode. This indicates that the higher melting material can be used as the anode, while lower melting material as the cathode. For preparation of Ti-Al intermetallic compounds, titanium having its melting temperature at 1953 K can be used as the anode, and aluminum having its melting temperature at 933 K as the cathode.

Effects of the arc current on the wire feed rate and on the Ti-Al intermetallic compound preparation are shown in Fig. 11. The prepared amounts of the intermetallic compounds are presented as the ratio of the corresponding XRD intensity at $2\theta = 39^\circ$ to the titanium intensity at $2\theta = 40.17^\circ$. The deposition efficiency is about 60 %, then the deposition amount as well as the ratio of the prepared intermetallic compounds increases with an increase in the arc current. Higher heat flow to the substrate at higher current results in enhancement of the compound preparation. This result reveals that the compounds are mainly prepared on the substrate.

4. CONCLUSIONS

The intermetallic compounds, such as Ti_3Al and TiAl, have been prepared by the wire arc spraying with titanium wire used as the anode and aluminum as the cathode. The results indicate that the wire arc spraying provides new attractive process for preparation of intermetallic compounds or alloys. The higher melting temperature materials can be used as the anode, while lower melting temperature material as the cathode for obtaining of better droplet dispersion produced from the corresponding wires. The compounds are mainly prepared during the droplet deformation process on the substrate. Enhancement of the intermetallic compound preparation results from higher substrate temperature.

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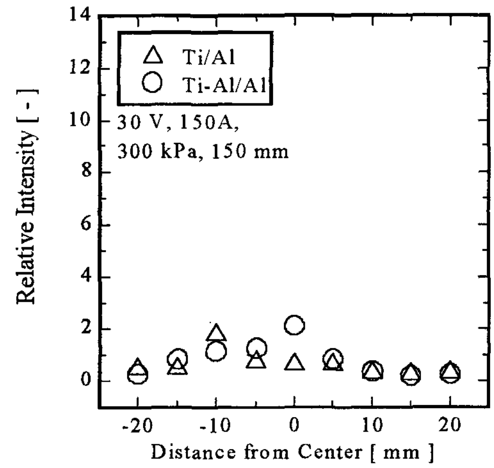

Fig. 9 Radial distribution of Ti/Al and Ti-Al/Al in the coating with Ti wire as anode.

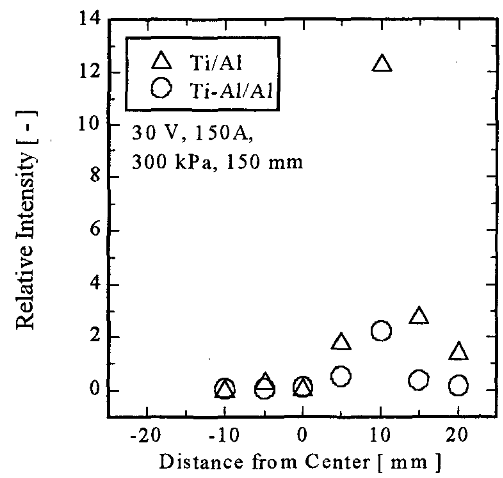

Fig. 10 Radial distribution of Ti/Al and Ti-Al/Al in the coating with Ti wire as cathode.

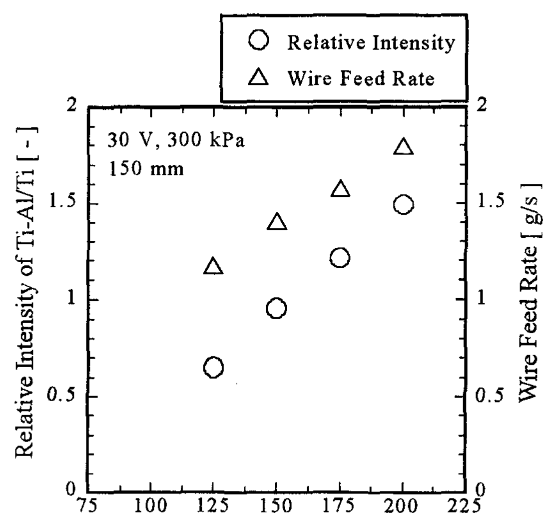

Fig. 11 Effect of arc current on wire feed rate and on relative XRD intensity of Ti-Al/Ti in the coatings.

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