Study on Transfer of Insulating Material with Discharge Pulses

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Abstract

In this study, the transfer of insulating material from an electrode to a workpiece with discharge pulses was investigated. A method of transferring a conductive material has already been developed. However, for an insulating material, it is necessary to transform it into conductive electrode to allow discharge. In this report, zinc was used to bind the insulating material in order to form the electrode, and the zinc also works as a medium to transfer the insulating material during discharges. for the transfer of the insulating material as well as the binder of the electrode. It was expected that heat generated by discharges vaporizes all zinc elements and only the insulating material would remain on the surface of the workpiece. In fact, however, it was difficult to remove those zinc elements and a large amount of zinc remained in the layer. In this report, a method of reducing the elements of zinc from the layer was investigated.

Key words: Electrical discharge, coating, surface treatment, insulating material

1. INTRODUCTION

Many attempts have been made to add functions to the surface of various parts and to add value. For example, Kaneko et al.¹⁾ tried to give parts the function of controlling the friction by machining fine grooves on the surfaces of mechanical parts. Also, Uehara et al.²⁾ studied a method using a roller tool for the purpose of making a fine shape to the surface of an automobile engine or transmission part. In addition to this, there are also researches to apply surface microfabrication to exert functions such as water repellency and hydrophilicity. It is thought that increasing the function of parts surfaces in these ways will become more important in the future.

In this research, in order to impart functions on the workpiece surface, it is aimed to deposit the functional materials firmly so that they do not peel off from the surface. Surface treatment technology using pulsed discharge has been researched and developed as a technique for transferring conductive functional material to metal surface and firmly attaching it^{3) - 10)}, and some have already been put to practical use. However, the similar method cannot be used in the case of insulating material although many of the functional materials are insulators. In this research, a new technology to attach the insulating material tightly on the metal surface tightly is proposed. If the insulating material can be freely adhered to the metal surface, various functions can be imparted to the surface of the object more than ever.

2. METHOD OF TRANSFERING INSULATING MATERIAL

The phenomenon of conductive material adhesion using pulsed discharge is not yet fully clarified. In this work, for ease of explanation, the method is briefly described as follows. In the case where a tool electrode is made of conductive material and it is to be deposited on the workpiece surface during discharging, portion of the tool surface confronting the workpiece is removed and attracted to the workpiece. However, in the case of an insulating material, no discharge will be generated. Therefore, modification of the tool is required; where a conductive material that allows discharge to occur should be used as binder, and also it will become a medium to transport the insulating material. Therefore, as shown in **Fig.1**, a method using zinc (Zn), which is a low-boiling material, as a

Fig.1 Structure of the electrode

Fig.2 Description of the process

transport medium was studied. By adding Zn to the electrode material, conductivity is imparted to the electrode and discharge can be generated (**Fig.2**). It is expected that Zn is evaporated by the heat of discharge and that only the insulating material remained on the workpiece surface.

3. PRODUCTION OF ELECTRODE AND DISCHARGE TEST

Electrodes using TiO_2 as insulating material were fabricated. The final aim of the electrode using TiO_2 is to add photocatalyst function to the metal surface, but in the experiment of this report, the purpose was to confirm whether transfer of the insulating material is possible.

The method for manufacturing the electrode is as follows. First, Zn powder (particle size about 2 μm) and TiO_2 (particle diameter about 0.1 μm) (average particle size determined from SEM photograph) were mixed in a weight ratio of 7: 3, 8: 2, 9: 1. Mixing was carried out using a mortar for about 2 hours each. Thereafter, the mixed powder was placed in a cylindrical mold having a diameter of 15 mm and pressed at a molding pressure of 970 MPa to form a coin shape. Since formed green compact had high resistance, it was heated in an atmospheric furnace at about 450°C for 2 hours in order to lower the resistance. The SEM photographs of the fabricated electrodes are shown in **Fig.3**. The large grains that appear white in the photographs are Zn powders, and the black part around them is TiO_2 powders. Because Zn grains are seen to be buried in TiO_2 powders with a small grain size, it was necessary to set the weight ratio of Zn to TiO_2 as Zn: TiO_2 = 8: 2 or more in order to realize conductivity. In Fig.3 (a), it can be seen that Zn grains are not in contact with each other at Zn: TiO_2 = 7: 3, thus, sufficient conductivity cannot be realized. Since the Zn elements were not in contact, the strength of the electrode was low, and thus difficult to be handled.

(a) Zn: TiO_2 =7:3

(b) Zn: TiO_2 =8:2

(c) Zn: TiO_2 =9:1

Fig.3 SEM images of the Zn+ TiO_2 electrodes

Then, materials transfer experiment by pulsed discharge was carried out with the fabricated electrodes. Among the electrodes, two types of them, Zn: TiO_2 = 8: 2, and 9: 1, which had sufficient strength to withstand the handling were used. The outline of the experimental equipment used is shown in **Fig.4**. Pulsed discharges were generated within the gap between the electrode and the workpiece that were immersed in dielectric oil.

Table 1 shows three sets of conditions of the discharge pulse used in the experiment. During the processing, the electrode jumping operation performed in the normal electric discharge machining was performed, and the flushing of the oil was not performed. Stainless steel (SUS304) plates were used as workpieces. Discharge was generated for 5 minutes under each condition, and the surfaces of the workpieces were observed.

4. OBSERVATION AND EVALUATION OF TREATED SURFACE

SEM observation, element mapping of Ti and Zn, and elemental analysis of the processed surfaces were carried out. **Fig.5** shows the SEM image and the result of elemental mapping of Ti and Zn on the surface. The workpiece was processed for 5 minutes under No. 3 condition of Table 1 with the electrode of Zn: $\text{TiO}_2 = 8: 2$. It can be confirmed that TiO_2 (Ti among components of TiO_2) adheres to the workpiece. Although not shown, the mapping result of oxygen O is almost the same, and it is considered that TiO_2 which is an insulating material can be moved by discharge. On the other hand, although Zn was expected to evaporate by the heat of discharge, a considerable amount remained on the surface of the workpiece under the conditions of this experiment, though it was much lower than the ratio of the components of the electrode.

Fig.6 shows the amount (mass% ratio) of Zn and

Fig.4 Experimental apparatus

Table 1 Experimental conditions

Condition No.	Discharge current (A)	Discharge duration (μs)	Pulse interval time (μs)
1	10	4	64
2	10	8	128
3	10	16	256

Ti analyzed by EDS (Energy dispersive X-ray spectrometry). The ratio of the Zn element and Ti element attached to the workpiece was shown in the graph under the condition that the peak current of the discharge pulse was kept same at 10 A. In this condition pulse duration was changed (the ratio of Zn and Ti with Zn and Ti as 100%). From

(a) SEM image

(b) Elemental mapping of Ti

(c) Elemental mapping of Zn

Fig.5 SEM image and elemental mapping images of discharged surface (with the electrode of Zn: $\text{TiO}_2 = 8: 2$)

Fig.6 Relationship between discharge duration and elemental mass %

the result, adhesion amount itself tended to increase as the discharge duration was longer. In Fig. 6, only the ratio of Zn and Ti among the components of the electrode material supplied to the workpiece side was shown, and it can be considered that it shows the ratio of Zn evaporation is large or small. As the discharge pulse duration becomes longer, the ratio of Zn tends to decrease compared to Ti, and it can be considered that Zn becomes easy to evaporate and the ratio of Zn becomes small as the heat input in one discharge increases. Also in the case of the electrode with Zn: TiO₂ = 9: 1, the relationship between the discharge pulse duration and the ratio of Zn was similar. However, the electrode with Zn: TiO₂ = 9: 1 had strong bonding between the Zn grains and became a hard electrode, so the adhesion amount of the Ti and Zn materials to the work piece was small.

Through this experiment, it has been successful to transfer the insulating material to the workpiece using Zn as a carrier medium, but it was impossible to remove Zn from the surface only by discharge during processing.

It has been reported by Hattori et al.¹¹⁾ that fluorescent material Zn₂SiO₄: Mn²⁺ is attached to a workpiece and that the fluorescence phenomenon is confirmed by this method.

5. MICRONIZATION OF ZINC PARTICLE IN ELECTRODE

When the experiment was performed using the electrode manufactured by the method described above, the deposit on a workpiece contained a large amount of Zn, and a layer of insulating material without Zn could not be formed. Therefore, in order to impart conductivity to the electrode with a small amount of Zn, an

experiment was carried out to miniaturize Zn. In order to pulverize the powder, a planetary ball mill (P-6) made by Fritch was used. Approximately 40g of mixed powder and steel balls were placed in a pot, encapsulated in Ar gas and rotated at a rotation speed of 300 rpm (**Fig.7**). **Fig.8** shows SEM photographs of electrodes and the results of element mapping of Zn of the same area. The electrode on the left side was the one using powder Zn: TiO₂ = 3: 7 mixed in a mortar for 1 hour, and the one on the right side was made of the powder pulverized and mixed with a planetary ball mill for 2 hours (molding pressure 550 MPa). In the case of an electrode mixed in a mortar, grains of Zn were scattered and were not in contact with each other, so there was no conductivity. While in the case of the electrode made with the planetary ball mill, although grains having a large size were present in some spots, Zn was miniaturized and conductivity could be imparted. **Fig.9** shows the relationship between the mixing and pulverization time with the planetary ball mill and the resistance value of the electrode measured by the four probe method. Conductivity was realized with

Fig.7 Mixing and comminution with a planetary ball mill

Fig.8 Difference of the electrode due to the difference in mixing method

Fig.9 Relationship between mixing time and electrode resistance

pulverizing and mixing time of 2 hours, but when mixed for about 4 hours or more, it was found that the resistance value further decreased by two orders of magnitude. It can be seen that good electrical conductivity can be realized to the electrode with a smaller amount of Zn than in the prior method by finely grinding and mixing the Zn powder.

6. OBSERVATION AND EVALUATION OF TREATED SURFACE

Next, using the fabricated electrode, discharge was generated on the surface of the steel and the adhesion test of the electrode material was carried out. Discharge conditions were set to a peak current value of 8 A, a discharge pulse duration time of about 8 μ s, a pulse interval time of about 128 μ s, and processing was continued for about 7 minutes. The electrical conditions that the peak current was lower than the condition in Section 4 was used in order to improve the surface roughness of the workpiece surface in expectation that Zn was evaporated easily by the pulverization of the electrode material. An SEM photograph of the surface of the workpiece which was processed using an electrode made of powders of Zn: TiO₂ = 3: 7 pulverized and mixed for 10 hours is shown

Fig.10 SEM picture of discharged surface

in **Fig.10**. It is observed that the electrode material melted and adhered to the surface of the workpiece. The result of EDS on the surface was Ti: 45%, O: 29%, Zn: 1%, Fe: 25% in mass %. Considering that Ti and O existed as TiO₂ since the ratio of Ti to O was almost equal to the ratio of Ti and O in TiO₂, the ratio of Zn and TiO₂ in the deposit was about 1: 74, and Zn ratio was suppressed to 2% or less by weight. The reason why Zn could be reduced drastically was considered that Zn was easily evaporated by the heat of discharge.

7. CONCLUSIONS

A method to transfer insulating material of the electrode to the workpiece by pulsed discharge was investigated. The conclusions obtained are as follows;

- An electrode was made using Zn, which is a low melting point and low boiling point material, as a carrier medium, and the insulating material could be transferred to the surface of the workpiece by pulsed discharge.
- It was expected that Zn was evaporated by the heat of discharge and that Zn did not remain on the surface of the workpiece, but Zn remained on the workpiece surface although it was much smaller than the electrode component ratio.
- The longer the pulse duration of the discharge pulse, the lower the ratio of Zn remaining on the workpiece surface. It is considered that this was because Zn tended to evaporate more easily by increasing the energy of the discharge pulse.
- It was found that the resistance value of the electrode could be lowered by pulverizing the Zn powder and that the ratio of Zn in the deposit adhered to the workpiece by the discharge pulse could be drastically reduced.

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