RECYCLE OF METAL-PLATING PLASTICS BY PULSE ARC DISCHARGE

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The method of recycling the metal-plating plastics has been developed. Pulse arc discharges can remove metal on plastics. A reliable equipment is successfully constructed by using an electric discharge system which uses a thyristor for a switch. The two electrodes are heated by auxiliary electric discharge, and the electric discharges can be maintained between electrodes. Therefore, it became possible also on low charge voltage like 3kV to enlarge distance between electrodes and plating. The discharge electrodes are moved with high speed by a robot. The plastics and metal separated by pulse arc discharges are able to recycle.

Keywords: metal plated plastics, recycling, pulsed power, arc discharge

1. Introduction

Metal-plating plastics have been used in household appliances, cars and others. Metal and plastics have to be separated for recycle. There are some system which recycles the defective work of the metal-plating plastic produced at the factory. There are a crush separation system by corona separation and magnetic separation and a melting separation system dipped into an acid or an alkali. The crash separation system cannot use high-cost at a small-scale recycling factory because of the expensive recycling equipment for extensive processing. And since proper processing cannot be carried out a plating ingredient and film thickness are unknown, a melting separation system degrades the performance of plastics. Then, an effective recycling method to separate metal and plastics has been developed using pulse arc discharges by pulsed power at a small-scale recycling factory. A high-voltage pulse is applied between two rod electrodes. A large current flows through a metal thin film. A part of the metal thin film is vaporized by heating and the pulsed arc discharges produce the plasmas between two electrodes. A shock wave is produced at this time and a metal thin film is removed from plastics. Since melted and vaporized metal is instantaneously scattered from plating, plastics do not melt. Two electrodes covered with ceramics tube were used for an effective separation[1].

In this report, comparative experiments are carried out using three kinds of pulse arc discharge circuits. The equipment with the pulse electric discharge circuit and the XYZ robot was constructed. Furthermore, the comparative experiments of electrode material are carried out to improve the removal efficiency. The analysis of metal and plastics which are separated is done and it is investigated whether those materials are able to be recycled.

2. Experimental apparatus

Figure 1 shows a sample of the metal-plating plastics used in the experiment. The ingredients of plating are Cu, Ni, and Cr in electroplating on ABS (acrylonitrile butadiene styrene) currently widely used as an ornament of a plastic. Thickness of Cr, Ni and Cu, which are measured by EDX (Energy dispersive X-ray spectrometry), are 0.14, 7.0 and 21μm, respectively. Resistivity of Cu, Ni, Cr are 1.69×10^{-8}, 6.90×10^{-8}, and $13.2\times10^{-8}\Omega$m, respectively.

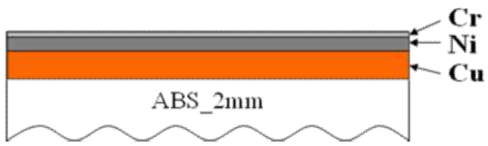

Fig.1 Sample used for metal separation.

Figure 2 shows the photograph of experimental apparatus. This consisted of a XYZ robot (CRZQ-U2010A, Hirata,Japan), a robot controller, discharge electrodes, a dc power supply and pulse power circuit. The two electrodes are set at the robot arm. The three dimensional movement of robot arm can be controlled by a robot controller. The maximum speed and the spatial accuracy of the robot arm are 2,000mm/s(X,Y-axis), 1,000mm/s(Z-axis) and ±0.02mm, respectively. And the movable ranges of X, Y, and Z axis are 500, 300, and 200mm, respectively, in order to fit the throughput requested by the industries. In this experiment,

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in order that a removal part may not overlap the removal area per single pulse, the speed of the robot arm is 100mm/s, moreover, when removing all the plating, the speed of a robot arm is 30 mm/s.

Figure 3 shows the schematic configuration of rod electrodes. Two electrodes are covered with the ceramics tube containing Al_2O_3, SiO_2, CaO and Na_2O. The two electrode interval is defined as an electrode distance, and the distance between the electrode tip and sample is defined as a gap separation. In order to compare removal efficiency, the electrode material from which heat resistance and resistivity differ is used. Tungsten, copper-tungsten, silver-tungsten, and copper which are used for electrical discharge machining are used for the electrode. The length of electrodes is 60mm. The diameter of electrodes is 1.0 mm. The outer and inside diameters of ceramics tube are 2.5 mm and 1.5mm, respectively.

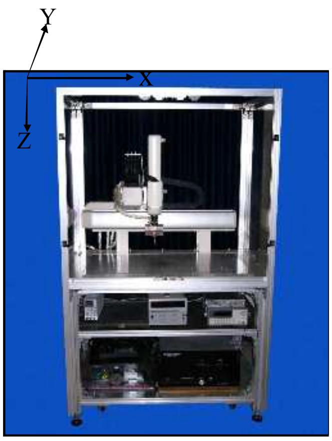

Fig.2 Photograph of apparatus.

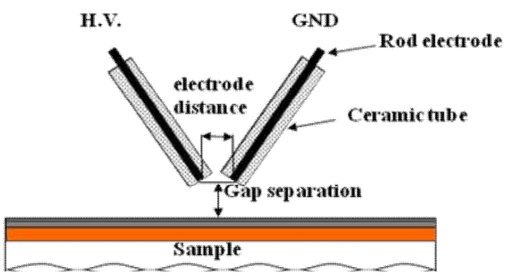

Fig.3 Schematic configuration of rod electrodes.

Figures 4-6 show the pulse electric discharge circuits for comparing removal efficiency. Recycling is difficult if recycling cost is higher than new material cost. Therefore, removal efficiency makes it increase and it is necessary to make recycling cost inexpensive.

Figure 4 shows the pulse electric discharge circuit which uses a trigger spark gap switch. The switch is controlled by the pulse generator and the trigger module. The capacitor of 400 nF is charged by the high voltage DC power source. The charging voltage is 15 kV. The output energy is transmitted to electrodes through a transformer, and the pulse arc discharges are generated between electrodes and metal-plating.

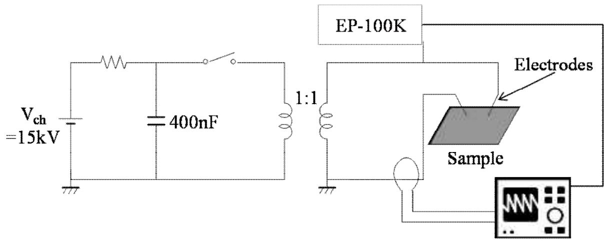

Fig.4 Schematic electric discharge circuit which uses a trigger spark gap switch.

Figure 5 shows the pulse electric discharge circuit which uses a thyristor. A thyristor is triggered by the pulse generator. In consideration of the reliability of a thyristor, charge voltage is 3kV. By use of the capacitor of a catalog model, the capacitor is 11μF (2.2μFx5) so that input energy might become close to the circuit of Figure 4. There is the magnetic switch of secondary side circuits in order to prevent that secondary side circuit discharge before setting voltage. The voltage increases 5 times at the transformer and becomes 15 kV at the 400 nF capacitor. After the magnetic switch turns on, the energy is applied to the electrodes.

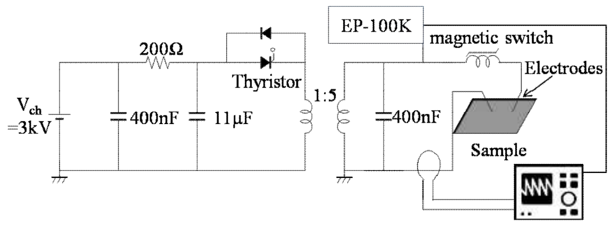

Fig.5 Schematic electric discharge circuit which uses a thyristor and a magnetic switch.

Figure 6 shows the pulse electric discharge circuit using the same thyristor as Figure 5. The charging voltage is also 3 kV. The magnetic switch is not used, and the amplification factor of the transformer is 1.

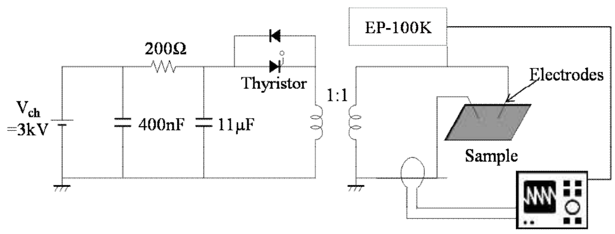

Fig.6 Schematic electric discharge circuit which uses a thyristor.

The applied voltage between electrodes is measured by the high voltage probe, EP-100K, and the current through the electrodes is measured by the Pearson current monitor. The area in which plating is removed from the plastic is defined as the removal area. The removal area is measured using the photography picture of a CCD camera.

3. Result and Discussions

3.1 Electric discharge circuits

Figure 7 shows the current waveforms by the pulse electric discharge circuits of Figures 4-6. Pulse electric discharges are generated between electrodes and metal-plating.

The electrode is tungsten with 1.0mm in diameter. A gap separation is 0.4mm. In the circuit of Figure. 6, since the charging voltage is restricted to 3kV from the reliability of a thyristor, the gap separation becomes short to cause the electric discharge. An electrode distance is 2mm. The pulse repetition is 6 pps (pulses per second), and the speed of robot arm is 100 mm/s. The size of metal-plating is 100(L) x70(W) x2 (t) mm. The input energy, peak current and pulse width in the circuits of Figures 4-6 are 49.5 J/pulse, 3.1kA, 16.6 µs, and 49.5 J/pulse, 2.4kA, 4.5 µs, and 45 J/pulse, 3.5kA, 3.2 µs, respectively. Plastics do not melt even at 16.6 µs of the longest electric discharge time. Removal areas are 13.8, 8.2, 38.4mm^2 by using the circuits of Figures 4-6, respectively. The removal efficiency is defined as removal area/input energy. In the case of the circuit of Figure 6, the high removal efficiency of 0.78 mm^2/J is obtained. As a result of comparing three pulse electric discharge circuits, it produces the reliable equipment to enlarge the gap separation. The auxiliary electric discharge system is developed as a method of enlarging the gap separation. The two electrodes are heated by auxiliary electric discharge, and the electric discharges can be maintained between electrodes even for larger gap separation, at which the electric discharge does not occur for a single shot.

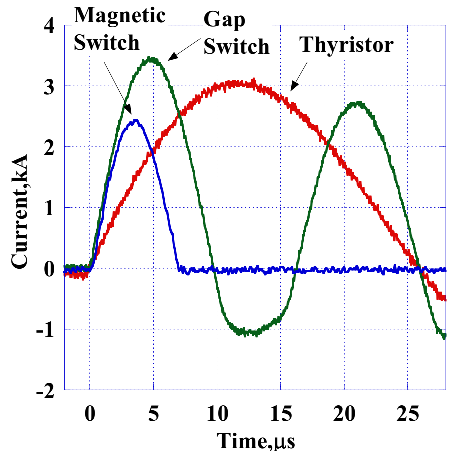

Fig.7 Current waveform.

3.2 Removal efficiency

Figure 8 shows the dependence of the removal efficiency on the gap separation for the electrode materials of silver-tungsten, copper-tungsten and tungsten. The electrode is 1.0 mm in diameter. The electrode distance is 3mm. The pulse repetition rate is 6 pps and the speed of robot arm is 100 mm/s. The number of electric discharges is 120 shots including auxiliary electric discharges. The gap separation is changed from 0.5 to 3.0 mm. During the auxiliary electric discharges, the electrodes, the copper electrodes have damage. The silver-tungsten electrodes have damage during the experiment of the separation between metal and plastics, except the gap separation of 1.0mm. The tungsten content of silver-tungsten and copper-tungsten are 65%, 70%, respectively. Removal area is increasing with the shock wave [1] therefore ceramics and electrodes have received the shock wave. Breakage has generated the copper electrode which does not contain tungsten with high hardness, and the silver-tungsten electrode containing with little content of tungsten. On all the conditions, the silver-tungsten electrodes have the highest removal efficiency.

Figure 9 shows the dependence of the electrode use efficiency on the gap separation for the electrode materials of silver-tungsten, copper-tungsten and tungsten. Electrode use efficiency is defined as the removal area / electrode ablation. The amount of electrode ablation is the total amount of ablation of the high-voltage electrode and the ground electrode. The amount of electrode ablation is obtained from a product of the difference of the length of the electrode before and after electric discharges and the cross-section area of electrodes. In the case of gap separation of 1 mm, the electrode use efficiency of copper-tungsten electrodes is 1.4 times as large as one of silver-tungsten electrodes. In the cases of gap separation of 1.5mm and 2.0mm, the tungsten electrodes are more efficient than the copper-tungsten electrodes for the electrode use efficiency. Although the removal area of tungsten electrodes per one pulse is small, the electrode ablation is small. The cost of an electrode of tungsten is 29 and 14 times cheaper than the silver-tungsten and copper-tungsten electrodes, respectively. In an electrode of 1.0 mm in diameter, the price productivity of tungsten is the highest.

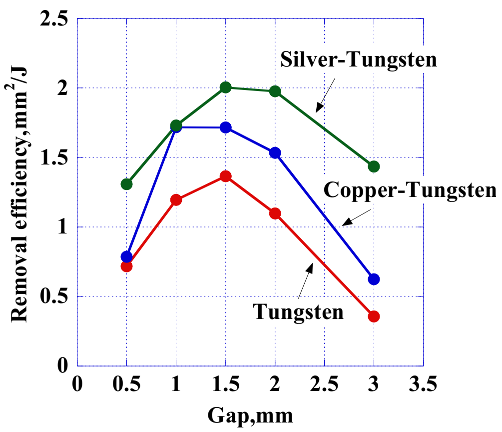

Fig.8 Dependence of the removal efficiency on the gap separation for different electrode materials.

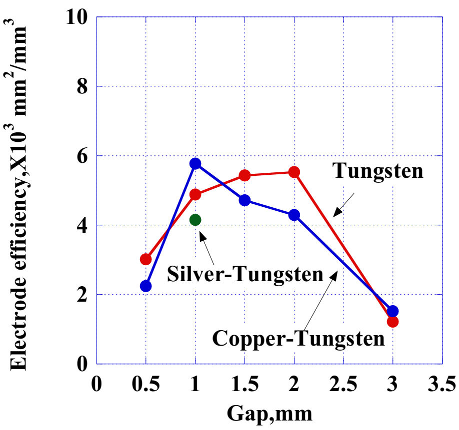

Fig.9 Dependence of the electrode use efficiency on the gap separation for different electrode materials.

3.3 Evaluation for recycle of Metal-plating plastics

The metal removal from plastics is performed using auxiliary electric discharges. The pulse electric discharge circuit shown in Figure. 6 is used. The electrode material is tungsten with 1.0mm in diameter. An electrode distance is 3mm. A gap separation is 2.0mm. Pulse repetition rate is 6 pps and the speed of robot arm is 30 mm/s. The pitch of a width direction is 4mm. The size of metal-plating plastics is 100(L) x70(W) x2 (t) mm. Under these conditions, all the metal is able to be removed from plastics. In order to prevent scattering of the removed metal, the metal-plating plastic is enclosed in the acrylics case, and the electrode part is covered with the PVC sheet. The metal around the sample is collected.

3.3.1 Evaluation of plastics

Figure 10 shows the photograph of the surface of plastics after the metal removal. The removal starts from the lower right and the robot arm moves in the direction of length. Then, the electrodes move 4 mm in the direction of width, and move in the length direction again. This operation is repeated and the metal is separated from the metal-plating plastics. And it is ended at the upper right of Figure 10. The surface of the sample is covered by a black substance. The plastics surface immediately after removing the metal is the white of a plastics base. The robot arm moves to a width direction, and comes back near the white plastics. The black substance produced by an electric discharge will come on the white plastics, and covers on them. The top part of plastics in Figure 10 has a little black substance.

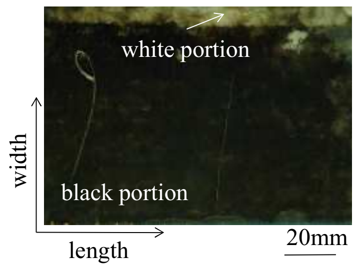

Fig.10. Photograph of the surface of plastics after the metal removal.

All of the black substance cannot be removed by a soft cloth. The surface observation is done by SEM (scanning electron microscope), and the element is analyzed by EPMA (Electron Probe Micro Analyzer). Figure 11 shows the SEM photograph of black substances, and the spectrum of EPMA. Figure 12 shows the SEM photograph of white part, and the spectrum of EPMA. As for the spectrum of EPMA, the X-axis shows energy and the Y-axis shows the X-ray strength. As for the black substance, many residues of the shape of powder or the shape of a film are observed. In the ultimate analysis, Cu and Ni of metal-plating plastics are detected. Moreover, O is also detected. And a little Al and Si from a ceramics tube are also detected. The C is the principal components for the white part. The metals are not detected.

If the metal component of the metal-plating plastics has adhered on plastics, it is difficult to recycle plastics. Then, in order to remove the adhering black substances, pulse arc discharges are again performed immediately after carrying out the metal removal, and the shock wave generated between electrodes removes the black substance successfully. Air or electrodes is momentarily heated by arc discharge, and that the rapid pressure increase occurred locally considers a shock wave to be the cause. The conditions of pulse arc discharges are the same conditions as the metal removal. A gap separation is 2.0mm.

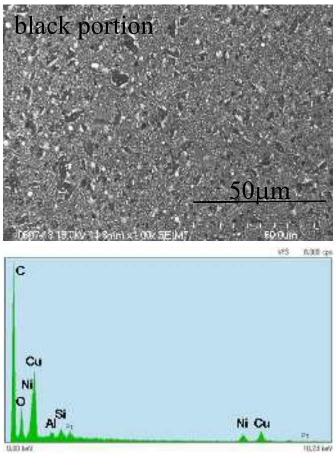

Fig.11. SEM photograph of black substances, and the spectrum of EPMA.

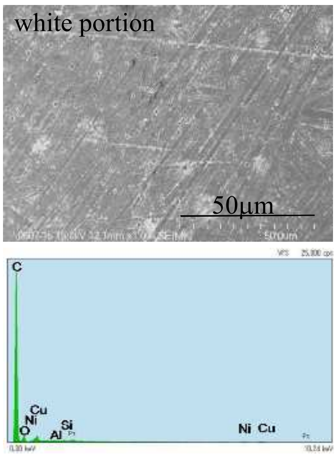

Fig.12. SEM photograph of white part, and the spectrum of EPMA.

Figure 13 shows the plastics surface after a shock wave removes black substances. Although the black substance is removed, somewhat black portion of plastics remains. The surface observation at the black and white portions is done by SEM and the element is analyzed by EPMA. Figure 14 shows the SEM photograph. There are substances with a size of tens of micrometers at black portion. From the analysis of element, W at electrodes and Al at ceramics tube are detected. A little Cu from metal-plating plastics is also detected. The shock wave of the pulse arc discharge generated between electrodes has removed the black portion mostly. Although a white part is a plastics base mostly, the metal grains with micrometers have adhered slightly. The component of these metal grains is Cu and Ni of the metal-plating plastics. Those residues are removable with a mechanical polish.

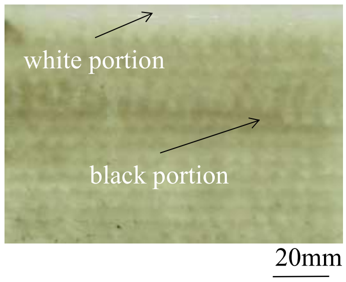

Fig.13. Photograph of plastics surface after a shock wave removes black substances.

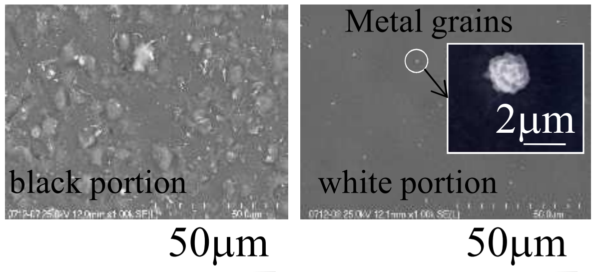

Fig.14 Surface observation at black and white portions by SEM.

3.3.2 Evaluation of metals

Since it adheres to the PVC sheet and acrylics case of the prevention from scattering, all the removed metal is unrecoverable. Therefore, mass balance is unknown. However, composition of the collected metal is important in order to evaluate recycling value. Then, the collected metal was evaluated. The collected metal before removing a black portion is classified by the size using the sieve, and the weight is measured with the balance. Metal classified into 63 μm or more has large metal grains and the crushed sheet metal. The metal classified into 63 μm or less is powder. Figure 15 shows the photograph of the typical form of the removed metal. Metallic powder of 63 μm or less is 63 mass% of the weight. Many of removed metal components serve as powder, and they are collected. Powder of 32 μm or less is 41 mass% of the weight, and most quantity. Furthermore, the powder metal of 92.7% does not adhere to a magnet.

Semiquantitative analysis of according the collected metal is done by to EDX was conducted. The amount result of judgments was standardized of three components of metal-plating. A result is shown in Table 1. The powder adhering to a magnet contains many Ni and the powder not adhering to a magnet contains many Cu mainly. However, since Cu and Ni are mixed even if it carries out magnetic separation, value does not improve. When the content of all the collected metal is calculated, Cu, Ni, and Cr are 72.0, 27.4 and 0.6mass % of the weight, respectively. The collected metal has less Cu than metal on plastics. Since there is much content of Cu and Ni, the collected metal can supply to the process of copper refinement which can separate Cu and Ni.

Fig.15 Photograph of the removed metal.

Table 1. Result of element analysis .

	Powder(<63μm)		>63μm
	Magnetic	Non-magnetic	
Cu	31.2	73.4	71.5
Ni	67.1	26.1	27.7
Cr	1.7	0.5	0.8

4. Summary

The separation of metal-plating plastics has been done using pulse arc discharges. The comparison examination of the pulse electric discharge circuits was carried out. Also the comparison examination of the electrode material was performed. The evaluation of removed metal and plastics were carried out and recycling efficiency was examined. As a result, the following conclusion was obtained.

(1) Removal efficiency using the pulse arc discharge circuit with the thyristor is highest. The charging voltage was 3kV, and an auxiliary electric discharge system was used

(2) The optimal electrode material based on cost is tungsten.

(3)Although the black substance adheres on the plastics surface, it is removable with the shock wave caused by a pulse arc discharge.

(4)Much of the removed metal is less than 32 μm in diameter. Cu and Ni of the removed metal can recycle the in the process of copper refinement.

[1] H.Akiyama, T.Nagashima, T.Namihira, Y.Kato, N.Shimomura, S.Katsuki, and T.Hisazumi, "Separation of Metal from Metal-Plated Plastics by Pulsed Power", IEEJ Transactions on Fundamentals and Materials. Vol.125, No.12, pp.1006-1010, 2005.