Separation of Metal from Metal-Plated Plastic by Pulsed Power

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A new method to separate the metal from metal-plated plastic is proposed, and experimentally its effectiveness is confirmed. The pulsed high voltage is applied between two rod electrodes covered by ceramics. The discharge electrodes are moved with a high speed by a robot. The pulsed arc discharges produce the plasmas between two electrodes and the surface of metal-plated plastic, and the shock wave is produced when a part of metal layer is vaporized. Then the plated metal comes off from plastic. Both the removed metal and the plastic can be recycled as materials.

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

1. Introduction

The metal-plated plastic has been made for producing the metallic feeling with the light weight and has been used in household appliances, cars and others. These metal-plated plastics have been buried in the ground after disposing because there is no effective method to recycle it. Though the treatment using an acid-alkali and the electrostatic separation after pulverizing were tried, these technologies are not realized due to the need of a solvent recycle and high cost.

In this work, a new method to separate the metal and the plastic is proposed, and its possibility of realization is experimentally confirmed. The pulsed high voltage is applied between two rod electrodes covered by ceramics. The electrodes are moved with a high speed by a robot. The pulsed arc discharge through metal layer is produced between two electrodes, and then the shock wave^(1, 2) is produced when a part of metal layer is vaporized. After that, the plated metal exfoliates from plastic. The both of removed metal and plastic can be recycled as materials.

2. Experimental Apparatus

Figure 1 shows a sample of the metal-plated plastic used in the experiments. The thickness of plated-Cr, -Ni and -Cu were 0.3 μm , 10 μm and 30 μm , respectively. 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 pulsed power circuit. The two rod 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 2,828 mm/s and ± 0.02 mm, respectively, in order to fit the throughput requested by the industries.

Fig. 1. Sample used for the metal separation

Fig. 2. Photograph of apparatus

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Fig. 3. Schematic circuit of electric power source

Fig. 4. Schematic configuration of rod electrodes

Figure 3 shows the schematic circuit of pulsed electric power source to the rod electrodes. The capacitor of 400 nF is charged by the high voltage DC power source (HDV-50kV3US, Pulse Electric Engineering Co., Japan) through the charging resistor. The charging voltage is changed from 5 to 15 kV. The stored energy into the capacitor is applied between two rod electrodes via the pulse transformer. The applied voltage between discharge electrodes is measured by the voltage divider (EP-100K, Pulse Electric Engineering Co., Japan), and the discharge current through the electrodes is measured by the Pearson current monitor (Model-110A, Pearson Electronics, USA).

Figure 4 shows the schematic configuration of the discharge electrodes. The diameter of and the separation of two tungsten rod electrodes were fixed at 0.5 mm and 4 mm, respectively, during experiments. The distance between the discharge electrodes and a sample is shown as 'gap separation'. The tungsten electrodes are usually covered by ceramic tubes except the tips, as shown in Fig. 4.

3. Experimental Results

Figure 5 shows the typical waveforms of voltage between two rod electrodes and current through the electrode of high voltage side. The charging voltage of the capacitor in Fig. 3 is 10 kV, and the gap separation is 0 mm. The waveforms of voltage and current show the damping LC oscillation except the electric power input as the resistive load around the first rise of voltage.

Figure 6 shows the dependence of input energy between two electrodes, which is calculated from the waveforms of voltage and current, on the gap separation. The parameter in Fig. 6 is the charging voltage, V_{ch} , to the capacitor. The input energy is almost constant even though the gap separation is changed. In the case of the charging voltage of 5 kV, the discharge does not occur over 0.5 mm of gap separation, because the dielectric breakdown voltage of air is larger than the applied voltage. The maximum input energies between two electrodes at 5, 10 and 15 kV correspond to 47, 44

Fig. 5. Typical voltage and current waveforms

Fig. 6. Dependence of input energy to the discharge on the gap separation as a parameter of charging voltage

and 37 % of the stored energies of 400 nF capacitor, respectively.

Figure 7 shows the dependence of the removed area of the metal layer on the gap separation as a parameter of V_{ch} . The removal areas at 0.1 mm gap separation are 5.7, 3.7 and 1.5 mm² for V_{ch} of 15, 10 and 5 kV, respectively. The removed area increases with V_{ch} and decreases with the gap separation except the gap separation of 0 mm.

Figure 8(a) shows the photographs of the surface of metal-plated plastic after the treatment. In this data, the gap separation is 0 mm. The upper and lower photographs are for the cases without and with the ceramics covering the tungsten electrodes, respectively. The charging voltages, V_{ch} , are varied from 5 to 15 kV. The two spots made vertically correspond to the places of two rod electrodes. The six spots on one photograph are caused by three shots at the different places, namely one shot makes two spots corresponding to the two tungsten electrodes. Notice that the metals are removed at a large area with the connection of two spots by one shot, in the case of 15 kV with ceramics. The separated metals are shown in Fig. 8(b).

Figure 9 shows the comparison between the brand-new ABS resin and the ABS resin made by the treated ABS resin using the discharge in this work for the tension strength, the bending strength and the impact property. The ABS resin from the treated ABS resin includes the contamination by discharges - W, Cr, Ni and Cu, for example. The ABS resin after the discharge treatment has almost the same strength and property as the new one.

The phenomena of the metal separation from the metal-plated plastic are schematically shown in Fig. 10. The arrows indicate the current pass. The plated metal near the two rod electrodes has the higher current density, and therefore is easily vaporized. The other parts of plated metal are liquefied or heated from the calculation

Fig. 7. Dependence of the removed area of the metal plating on the gap separation

(a)

(b)

Fig. 8. (a) Photographs of the metal-plated plastics after shots, (b) photograph of the separated metals

of input power. The shock wave produced near the electrodes removes the metal plating. The detail calculation is described in the next chapter.

4. Analyses of Copper Layer Explosion

To consider the separating process, the calculations of heating the copper layer are performed. Since the thickness of copper layer is much small than its width, a simple modeling shown in Fig. 11 is available⁽³⁾. The copper layer is divided into the small square cells. It is assumed that a cross striped circuit network consists of only resistors. A lot of circuit equations are yielded so that plenty but simple simultaneous equations are obtained. The currents on each branch in cells are solved on a computer.

The energy deposited into each cell heats the copper layer. The dependence of copper resistivity on the deposited energy, which was experimentally obtained, is shown in Fig. 12^(3, 4). The experimental procedure is as follows: the copper wire of 0.05 mm in diameter and 18 cm in length in water was exploded by the pulse current from a charged capacitor. The calculations based on the specific heat estimate the presence of melting phase between

Fig. 9. Comparison between new and treated ABS resins

Fig. 10. Phenomena of the metal separation from the plastic

Fig. 11. Equivalent circuit for analysis

0.4 kJ/g and 0.6 kJ/g and the beginning of vaporization around 1.4 kJ/g, as shown in Fig. 12. Introducing the resistivity evaluated from this figure into the simultaneous equations, the phenomena are momentarily simulated.

Under the condition that the thickness of copper layer is 30 μm , the two electrodes are placed with the separation of 4 mm. The DC current of 1 kA is used instead of the damping LC oscillation in the experiment, in order to pay attention to only the physical phenomena. The distributions of deposited energies on the layer till 100 and 130 μs after applying 1 kA are shown in Figs. 13 (a) and (b), respectively. The x-axis and y-axis in the figures show the

Fig. 12. Variation in resistivity of copper

(a) 100 μ s (b) 130 μ s

Fig. 13. Distribution of deposited energy in copper layer

surfaces of the copper layer. The gray-scaled mapping represents a distribution of deposited energy into the copper layer. Note that Fig. 13(b) has a different gray-scaling for energy from Fig. 13(a). Since time-dependent factors are ignored in this calculation, the dc

current is adopted. The thermal conducting process is slower than the phenomenon of the metal removal for example. The two white spots in the figures correspond to the positions of two electrodes. The arrangement of Fig. 13 agrees with the rotated arrangement of Fig. 10 with 45 degrees anticlockwise. At $t = 100 \mu$ s, the vaporizations start on the areas extremely close to the electrodes (Fig. 13(a)), since the vaporizations begin around 1.4 kJ/g as shown in Fig. 12. At $t = 130 \mu$ s, the vaporized areas expand radially. Although the heating of center region between two electrodes proceeds, the copper remains on solid state.

The analyses on a computer indicate that the vaporizations of copper layer proceed radially from the points on the electrodes and the vaporization process forward another electrode is a little faster. The liquid phase of the copper layer exists on the narrow belts close to the circles of the vaporizations. The other area is slowly heated and the copper layer remains on solid state at the present. Since the heating of the area between the electrodes is stronger than the other area, liquefaction of the area will start faster. Since this calculation does not support the re-strike consisting of surface discharges and/or discharges of copper vapor, it is difficult to predict the later liquefaction and the course of expansion of vaporizing area completely. It seems that the vaporizing areas predicted with this analysis well agree with the areas where the copper layer is removed in the photos of Fig. 8(a) without ceramics. The excellent metal separation from plastic occurs at Vch of 15kV with ceramics as shown in Fig. 8(a). It might be necessary for the analysis of this phenomenon to include the mechanism of the metal separation by shock waves.

5. Summary

The new method to separate the metal and the plastic is proposed, and experimentally its effectiveness is confirmed. The pulsed high voltage is applied between two rod electrodes covered by ceramics. The electrodes can be moved with a high speed by a robot in order to fit the throughput requested by industries. The shock wave might be produced when a part of the thin metal layer is vaporized. Then the metal plating comes off from plastic. Both the metal and the plastic can be recycled as materials.

The analysis using a computer shows the existence of the vaporized areas near two electrodes. The analysis including the behavior of shock waves is the next subject.

The new separation technique of the metal plating on plastics will be used not only the parts of household appliances and cars for the metal feeling but also the metals on the circuit board, the PDP and CD-R.

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