Attaching Force Estimation of Conductive Ball at Electrode to Control by Electrostatic Force

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Abstract

A movement of conductive solder balls by an electric field is investigated using a ball-jumping observation test. Two electrodes, upper and lower, were set parallelly, and the balls were put on the lower electrode. A voltage applying between the electrodes was increased, and a ball-jumping started voltage and an interval time from a time of onset of applying voltage to a time when the first ball jumped were measured. An effect of the first setting condition of balls on the lower electrode on the voltage and the time was evaluated. The tests were conducted in a room with constant temperature and humidity, which were varied as the test parameter. It was found that the ball-jumping started voltage was strongly affected by the first setting condition of balls, and arranging balls in one layer contributed to flying out of balls at a lower applied voltage comparing to stacking balls in some layers on an electrode. The test results implied that an increase in an environmental humidity increased the voltage needed for ball-jumping, and this is due to an increasing in a liquid bridge force between balls.

1. Introduction

Electrophotographic technology has been widely used for digital copiers, laser printers, LED printers, facsimiles and so forth. Electrophotography is a technology for controlling powder to form desired powder images, and in ordinary electrophotography, an insulative powder toner is used. On the other hand, the technology of using a conductive powder toner with relatively high conductive property has been developed. The conductive powder is good controllability, because the charge of powder is determined by an external electric field around the powder, and has been recently applied to new recording technology such as an electrostatic display and an electric paper. Moreover, a toner cloud beam (TCB) method using a conductive toner has been studied for the purpose of developing small size of simply designed new printing machines, and a detailed behavior of the conductive toner between electrodes applied voltage was evaluated, and its mechanism was suggested [1].

In this study, the controllability of the conductive solder ball by an electric field was examined for fundamental conditions such as an arrangement of balls and an environmental humidity. It can be expected that controlling the conductive ball using an electrostatic force produces the possibility of new applications.

2. Experimental

2.1 Ball-jumping observation test set-up

Ball-jumping observation tests [2] were carried out to investigate a motion of balls by an electrostatic force using an experimental set-up shown in Fig. 1. Two electrodes (50 mm × 50 mm × 1.5 mm^t) made by copper, upper and lower, were prepared and set parallelly with a distance of 5 mm using an acrylic board. The lower electrode was precisely placed in a horizontal position with a water-leveling bottle. Some solder balls 80 μm in diameter were put on the lower electrode. A voltage was applied between the electrodes at an interval of 30 V from 1650 V to 3000 V using a high voltage generator. The motion of balls between the electrodes was observed by a high speed camera, and the images were recorded as digital data. The voltage and the elapsed time were measured when the first ball jumped. A light of a halogen lamp was illuminated from behind the two electrodes as illustrated in Fig. 1 to obtain the clear images of ball moving. The tests were conducted in a room with constant temperature and humidity.

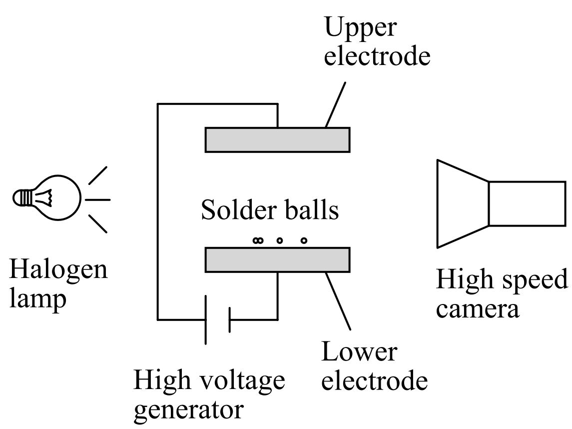

***Figure 1** The experimental set-up for ball-jumping observation tests, consisting of upper and lower electrodes, a high voltage generator, a high speed camera and a halogen lamp.*

2.2 The first setting condition of balls

To investigate an effect of the first setting condition of balls on the lower electrode on a ball-jumping started voltage, two ball setting conditions below were prepared;

(1) placing some balls like a mountain at one point of the electrode surface (see Fig. 2 (a)), and
(2) distributing some balls almost uniformly on the surface of the electrode to be formed one layer of balls (see Fig. 2 (b)).

The ball setting condition (2) was obtained according to a procedure described below. Some balls were enclosed in a ϕ 10 mm hole made in an acrylic board sandwiched between two electrodes. Then enough voltage (in this case, more than 3000 V) for the balls to jump was applied between electrodes. Almost all balls were jumped, and collided each other on the electrode surfaces and in the space between the electrodes, resulting in uniformly scattered on the lower surface as shown in Fig. 2 (b).

The voltage applied was changed up to 3000 V with an interval of 30 V. A temperature and relative humidity of the room were kept at 15 ℃ and 40 to 50 %, respectively.

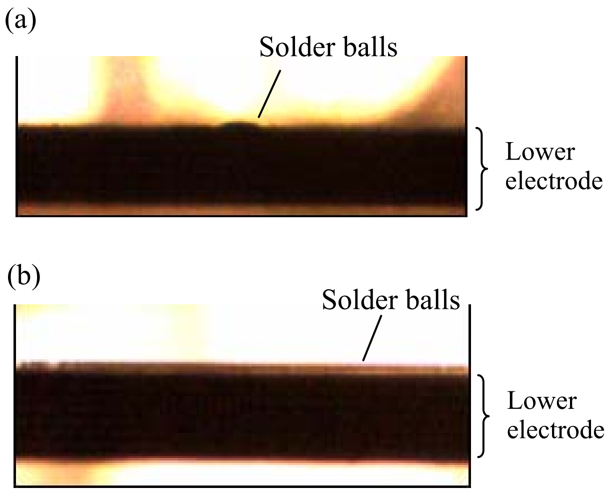

Figure 2 *Images of the solder balls on the lower electrode; (a) is in the ball setting condition (1), and (b) is in the ball setting condition (2).*

2.3 Relative humidity

As a size of ball is smaller the adsorption of moisture on the surface can not be negligible. A moisture adsorbed on surfaces of balls forms a liquid bridge with surrounding balls. A force of liquid bridge becomes about 10 times larger than a coulomb force as for particles with a few ten μ m size [3]. Therefore, an effect of environmental humidity on a ball-jumping started voltage was evaluated by changing the relative humidity of the experimental room. The relative humidity of the room was kept at 50 % and 90 %. Balls before the tests were restored in a small cylindrical glass container. Using above-mentioned (2) method, the balls were set uniformly on the lower electrode, and the voltage from 1650 V to 3000 V with an interval of 30 V was applied.

3. Results and Discussion

3.1 States of ball jumping

Figures 3 (a) - (c) show the images of the electrodes and their space taken by a high speed camera for the cases applied 3000 V between the electrodes in the ball setting condition (1). Images (a) and (b) were shots in 0.26 s and 0.49 s after applying the voltage, respectively, and image (c) represents a shot after ceasing the voltage applying. In the case of an applied voltage of 3000 V, a jumping of the first ball occurred in 0.21 s from the voltage applying. Therefore, Fig. 3 (a) indicates an image in 0.05 s after the first ball jumping, and implies that balls were attracted to the upper electrode to be flied out of a mountain located in the center of the lower electrode in the figure. In 0.49 s, as shown in Fig. 3 (b), the balls were randomly jumped not only from the mountain but also from the areas surrounding the mountain, and moved up and down between the electrodes. It is noted from Fig. 3 (c) that the balls kept on the surface of the upper electrode even in a state of applying no voltage between the electrodes. The phenomenon may be caused by a liquid bridge between a ball and a surface of the electrode.

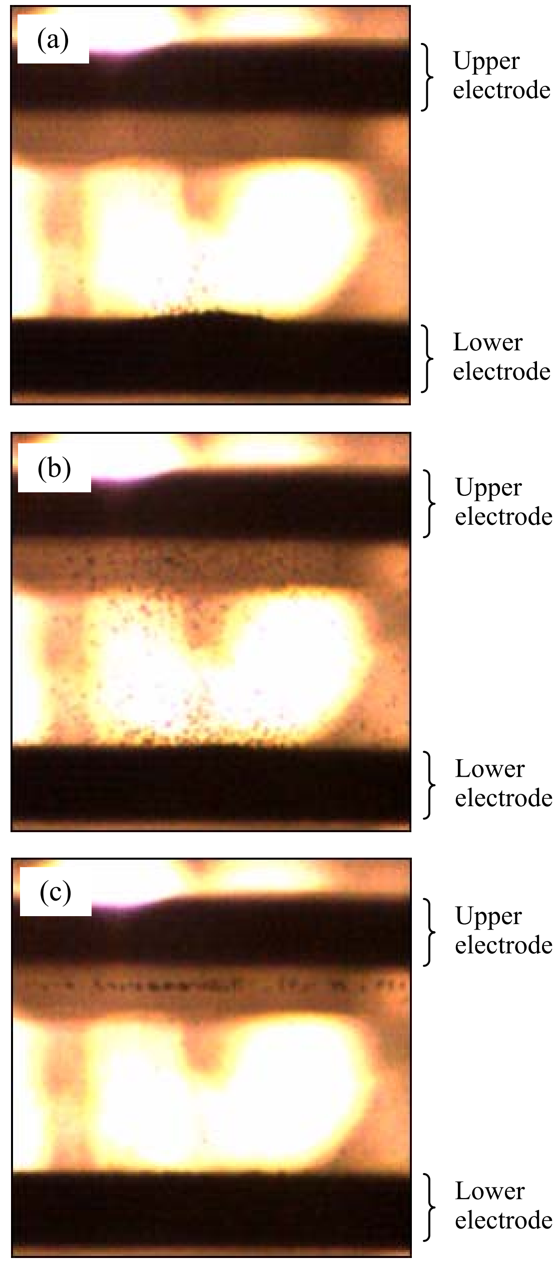

Figure 3 *The images of movement of balls between the electrodes taken by a high speed camera at an applied voltage of 3000 V in the case of the ball setting condition (1).*

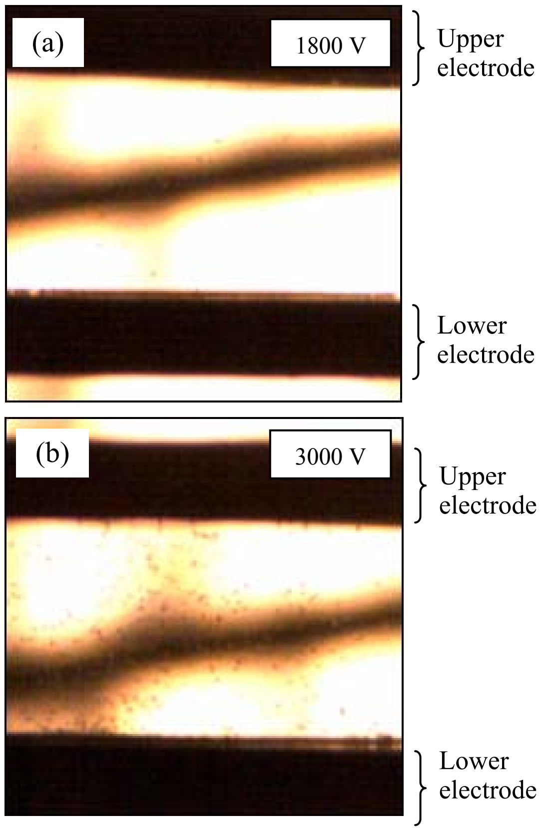

Figure 4 *The images of movement of balls between the electrodes taken by a high speed camera in the case of the ball setting condition (2).*

Meanwhile, the images of Figs. 4 (a) and (d) show movements of balls between electrodes in the case of the ball setting condition (2), in which the balls were uniformly distributed and formed one layer, and were obtained when performed at a relative humidity of 50 %. As shown in Fig. 4 (a), the balls randomly started to jump out of the whole of the electrode at an applied voltage of 1800 V. Observing the continuous images from a shot of Fig. 4 (a), it seems that the first jumped some balls became a trigger and then a plenty of balls flied. Fig. 4 (b) indicates a state of the jumping balls at an applied voltage of 3000 V, demonstrating that up-and-down movement of the balls looks like a cloud.

3.2 Ball-jumping started voltage

Figure 5 shows response times as a function of the voltage applied to the electrode for the ball setting conditions of (1) and (2). The response time means an interval time from a time of onset of applying voltage to a time when the first ball jumped. Concerning the condition (1), a motion of the balls was not observed at an applied voltage of less than 2550 V, and a jump of the first ball occurred at 2550 V with a response time of 1.04 s. The response time was decreased with an increase in the applied voltage. On the other hand, in the case of the condition (2), the first motion of balls was confirmed at a lower voltage and for a shorter time compared to the case of the condition (1). Note that a long response time of 1.2 s was irregularly obtained at an applied voltage of 2400 V in the condition (2), and the cause has not been clear at the moment. In this way, it was found that the ball-jumping started voltage is strongly affected by the first setting condition of balls on the lower electrode. Namely, it is implied that a state of arranging balls in one layer on an electrode can be flied out a ball at a lower applied voltage in comparison with that of stacking balls in some layers on an electrode. The top of stacked balls is relatively difficult to be charged-up by existences of oxide surfaces of balls and a space between balls.

Moreover, Fig. 5 represents an effect of a relative humidity on a ball-jumping voltage and a response time. For the case of 50 % relative humidity, the balls started to jump at an applied voltage of 1800 V and for a response time of 0.40 s. When a relative humidity was 90 %, an applied voltage of 1800 V did not bring the ball jumping, and 2100 V was needed for attracting the balls toward the upper electrode. This experimental result implies that an environmental humidity influences the jumping of balls. As above-mentioned, increasing in humidity, more moisture is adsorbed on a surface of ball, and a liquid bridge force increases. The liquid bridge force disturbs lift-off of ball from a surface of electrode. That is, in order to be jumped a ball, an electrostatic force overcoming the liquid bridge force is needed. Therefore, not only a humidity in a room but also moisture adsorption of ball must be controlled for a stable control of balls using an electrostatic force. In this study, it was found that when balls were kept at a relative humidity of 90 % for more than 2 minutes, no movement of the balls was observed even at an applied voltage of 3000 V. While, in the case of a relative humidity of 50 %, this phenomenon did not occur, and a jumping of balls was confirmed.

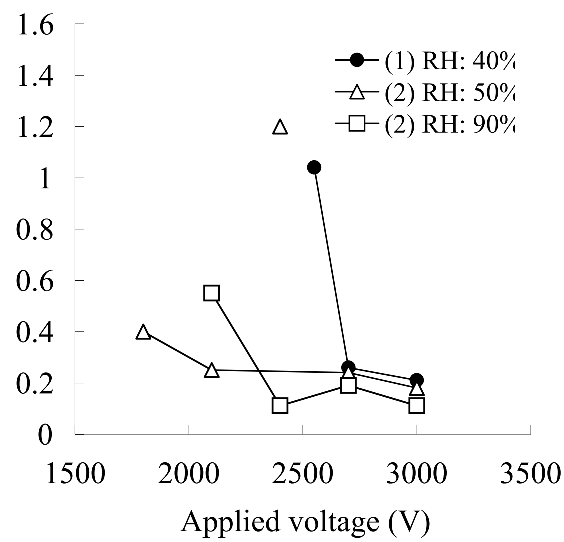

Figure 5 *The variations of the response time as a function of the voltage applied between electrodes.*

4. Summary

The ball-jumping observation tests were carried out to investigate the behavior of solder balls (80 μm in diameter) by the electrostatic force. The voltage applied between the electrodes was varied, and the ball-jumping started voltage and the response time were measured. The effect of the first setting condition of balls on the lower electrode and the relative humidity in the room on the started voltage and the response time was evaluated. The major results are summarized as follows.

(1) The first setting condition of balls strongly affected the ball-jumping started voltage, and the state of arranging balls in one layer on the electrode can be jumped out the balls at the lower applied voltage comparing to that of stacking balls in some layers on the electrode.

(2) The environmental humidity influenced the jumping of balls, and the increase in the environmental humidity increased the voltage needed for ball-jumping. This is suggested to be due to the increase in the liquid bridge force by adsorption of more moisture on the surfaces of balls.

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