Fishbone Pattern Phenomena on a Non-Conductive Substrate in Electrohydrodynamic Discharging

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ABSTRACT

During EHD discharging, when the charge is accumulated around the pattern on the non-conductive substrate, the direction of the electric field in the vicinity of the substrate is formed on the reverse. Due to this, the scattering of broken charged droplets is occurs. These scattered droplets are irregularly dispersed around the accumulated charged pattern in the previous. We have found that the irregular satellites/sprays are formed in a regular pattern. Especially the regular patterns in the shape of a fishbone are well formed under specific conditions such as such as the speed of the moving stage between 25 mm/s, the applied voltage more than 1.6kV and the nozzle outer diameter less than 10µm.

Keywords: EHD, Fishbone Pattern, Satellites/sprays

1 INTRODUCTION

The intense electric field concentrated on the meniscus at a nozzle orifice is able to trigger the electro-hydrodynamic (EHD) discharging of tiny droplets or jets [1-2]. This EHD discharging has a greater advantage of finer patterns using a variety of ink materials with a wider range of ink viscosity reaching thousands CPs. In recent years, finer patterning based on EHD discharging has been investigated by a number of researchers [3-5]. However, the electric field distribution along the pathway from the nozzle to the substrate plays a critical role for the determining the pattern shape. This field distribution is changed continuously by the electrostatic interaction of the charged droplets or jets. Also, during EHD discharging, some part of charged droplets or jets may be broken down to tiny satellites/sprays [6-7]. Furthermore, if the charges induced in the droplets or jets are accumulated on a non-conductive substrate, distorting the original field and deviating droplets or jets away from the target. In the previous study, it is verified that the satellites/sprays can be effectively controlled by optimizing parameters [8-9] Another point of view, by this distorting phenomenon, the various pattern shapes appear. Especially this paper presents the regular pattern phenomena with the shape of a fishbone on a non-conductive substrate in EHD discharging.

2 EXPERIMENTAL SETUP

Fig. 1 shows the schematic of experimental set-up for EHD discharging. The ink used in the experimentation was a, commercially available, solvent pigment ink (InkTec Co., Ltd., K 300). The surface tension coefficient and the viscosity of the ink used were, respectively, 30~32 dynes/cm and 10~12 cps at 25±5℃. The selected ink has been known to be stable for generating a cone-jet mode of jetting. The ink was supplied through the chamber to the nozzle with a constant pressure by a pressure controller. In this study, we had to use a tapered glass nozzle of various sizes. The substrate is located on a metal plate that provides an electrically grounded conducting support. The plate is equipped with a vacuum chuck and connects to a computer-controlled x and y axes moving stage. In order to observe the printing, a high speed camera with a micro-zoom lens and a LED light source were used. Printing images were analyzed through a microscope. To study for the fishbone pattern phenomena with the specific conditions, extensive experiments were conducted under various parameters settings, such as the distance between the substrate and the nozzle (working distance), the speed of the moving stage, applied voltage and nozzle outer diameter.

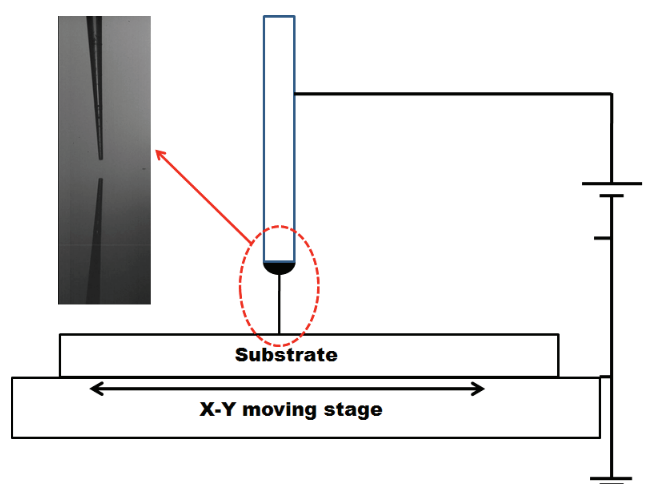

Figure 1: Illustrations of EHD discharging system.

3 RESULTS AND DISCUSSION

As seen by Fig. 2(a), during EHD discharging, some part of jet may be broken down to tiny satellites/sprays due to the electric field distribution [3-4]. Furthermore, compared to conductive substrate, the charges induced jet in non-conductive substrate is scattered due to accumulated charged pattern, as shown in Fig. 2(b) and Fig. 2(c). Even if the distance between the nozzle and the substrate is close enough, these scattering phenomena on a non-conductive are occur by the accumulated charged pattern. These scattered droplets are irregularly dispersed around the accumulated charged pattern in the previous.

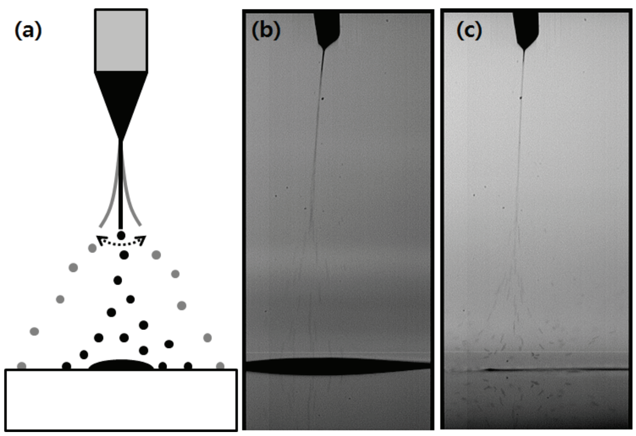

Figure 2: (a) A schematic diagram of satellite droplet and scattering phenomenon (b) and (c) images of discharging captured by a high speed camera: (b) conductive substrate (b) non-conductive substrate

Fig. 3 shows the ink pattern image in a situation in which the substrate is stopped. In the case of the conductive substrate, dot pattern of a certain shape is formed, but in the case of a non-conductive substrate, the pattern of the spray type is formed around the center, as shown in fig.3 (a) and 3 (b). In particular, it can be confirmed that by using the microscope image of figure 3 (c), the pattern of concentric circles are formed around the center. This pattern shows that the irregular satellites/sprays are formed in a regular pattern.

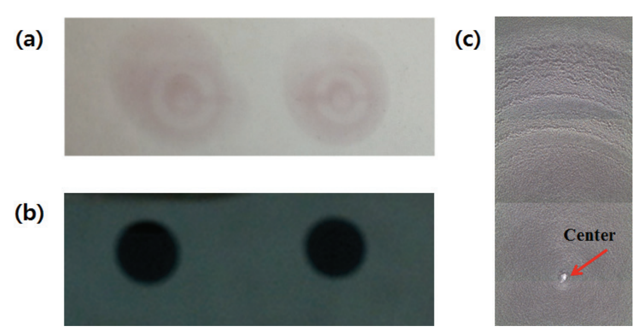

Figure 3: The ink pattern printed on the substrate in stopped state: (a) non-conductive substrate (b) conductive substrate (c) microscope image on a non-conductive substrate

Fig. 4 shows the line patterning results in a situation in which the substrate is moved. In the case of the conductive substrate, the line width only changed according to the parameters, such as the distance between the substrate and the nozzle (working distance, WD), the speed of the moving stage, and the applied voltage, without any spray and/or satellites. On the other hand, for non-conductive substrate, lines can be patterned only under the specific parameter conditions. Outside the specific parameters range, the scattering effect is generated around the patterned line due to the charges accumulated on the patterned lines [9]. In particular, we have confirmed that the regular pattern in the shape of a fishbone is formed under specific conditions.

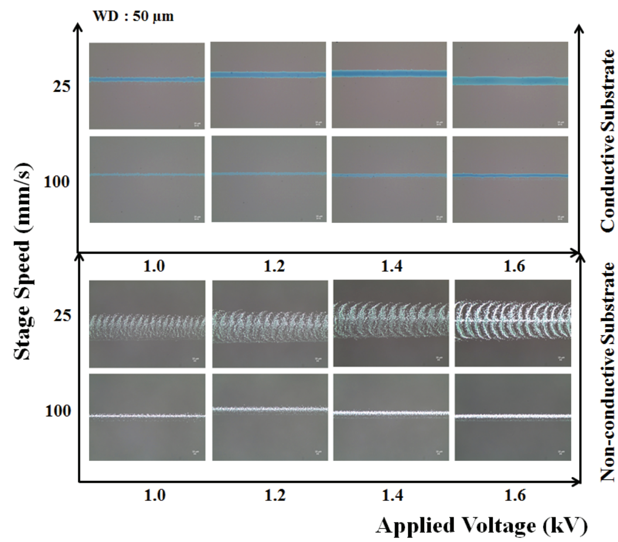

Figure 4: Comparison of the line patterning results from the conductive substrate and a non-conductive substrate in moved state:

In order to study the scattering phenomena, extensive experiments were performed with electric field simulations under various conditions. Fig. 5 shows the vector distribution of electric field between the nozzle and the substrate by COMSOL. If there is no pattern on a non-conductive substrate, the direction of the electric field vector distribution only appears toward the substrate. However, when the charge is accumulated around the pattern on the substrate, the direction of the electric field in the vicinity of the substrate is formed on the reverse. Due to this, the scattering of broken charged droplets is occurs. In order to investigate the variation of electric field distribution according to the amounts of charge on the pattern, a simulation was conducted by the variation of charge. As shown in Fig. 5, when the surface charge is increased from 0.0003 to 0.0004 C/m^2, the direction of the electric field near the substrate is changed on the reverse. Also, the electric field intensity near the substrate in the opposite direction increases as the charge increases. As a result, scattering phenomena become stronger as the amounts of charge increase.

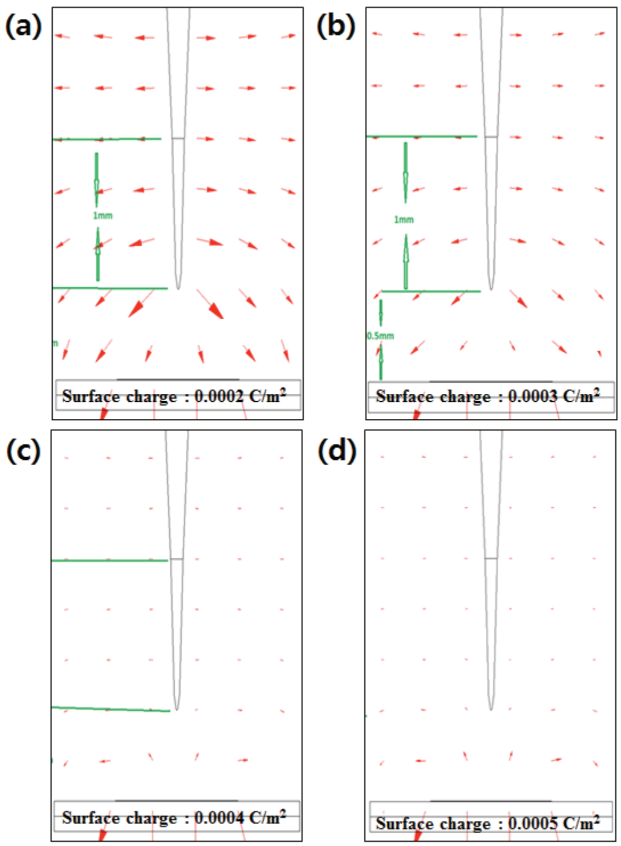

Figure 5: Variation of electric field distribution according to the amounts of charge on the pattern.

Fig. 6 shows the line patterning results under various parameters settings, such as the distance between the substrate and the nozzle (working distance, WD), the speed of the moving stage, the applied voltage and the nozzle outer diameter. As shown in Fig. 6 (a), when the working distance is too far, line of spray shape is formed. When the working distance is close enough in less than 100 µm (WD is shorter than the length of jet), fine line can be patterned under the specific parameter conditions, such as the speed of the moving stage more than 50 mm/s, the applied voltage between 0.8 kV and 1.6 kV and the nozzle outer diameter less than 10 µm. Relatively, even if the working distance is close, due to an increase of the applied voltage and a decrease of the stage speed, the effect of accumulated charged pattern becomes stronger, specific patterns in the form of fishbone is formed. These fishbone pattern phenomena are well formed under the specific parameter conditions, such as such as the speed of the moving stage between 12.5 mm/s and 25 mm/s , the applied voltage more than 1.6kV and the nozzle outer diameter less than 10 µm, as shown in Fig. 6. However, each parameter, as well as influence the effect of the scattering according to the accumulated charged pattern individually, a number of parameters influence the complex.

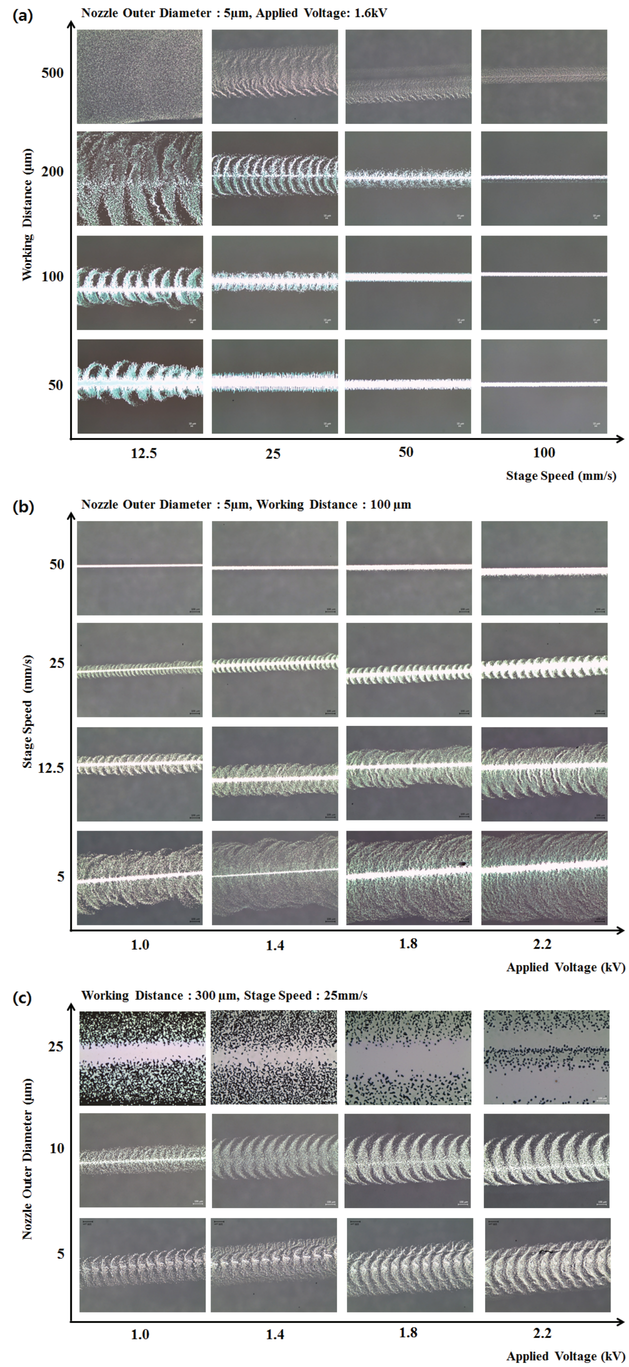

Figure 6: The line patterning results under various parameters settings, such as the distance between the substrate and the nozzle (working distance, WD), the speed of the moving stage, the applied voltage and the nozzle outer diameter.

For example, if the stage speed is more than 50mm/s, the pattern is formed in the shape of a line by the effect of the scattering according to accumulated charged pattern is weakened, but when the speed is less than 5mm, the effect of scattering is too strong, broken charged droplets becomes severe disperse, pattern is formed in the shape of bumpy line, as shown in Fig. 6 (b). However, even in the specific condition that at which the fishbone pattern is properly displayed, the voltage is too low and/or the working distance is too far, the effect of the scattering reduced, fishbone pattern is not displayed. That is, in order for the fishbone pattern is formed, between the substrate and the charges induced jet, the effect of scattering in the specific range is required. As shown in Fig. 6 (c), nozzle size is too large to 25 µm or more, the amount of discharged jet is too many, the spray shape was sown around the pattern of center line.

4 CONCLUSIONS

In this paper, we reported fishbone pattern phenomena on a non-conductive substrate in EHD discharging. When the charge is accumulated around the pattern on the substrate, the direction of the electric field in the vicinity of the substrate is formed on the reverse. It is verified using simulation that scattering phenomena become stronger as the amounts of charge increase. Due to this, the scattering of broken charged droplets is occurs. These scattered droplets are irregularly dispersed around the accumulated charged pattern. We have found that the regular pattern in the shape of a fishbone is formed under specific conditions. That is, in order for the fishbone pattern is formed, between the substrate and the charges induced jet, the effect of scattering in the specific range is required.

5 ACKNOWLEDGMENT

This work was supported in part by NRF-2013M1A3A02042335, the Ministry of Science ICT and Future Planning, Korea.

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