

Electrostatic adhesion of polymer particles to a foil electrode

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Abstract. The SPABRINK EU project requires temporary adhesion of coloured solid “ink” particles to a surface, for later recovery and reuse. This is achieved through the use of dielectrophoretic force under the control of a voltage applied to an interdigitated electrode pattern on the polymer foil. One concern is the ability to hold particles under vibration conditions. In this paper we present an experimental study of the adhesion of 50-300 μm polymer particles to an experimental interdigitated electrode structure on flexible polymer foil. Powder loss as a function of calibrated displacement and applied voltage to the electrodes are presented. This is compared with theoretical results obtained by modelling adhesion using Pohl’s equation in terms of an “adhesion factor”. Some difficulties in directly comparing experimental and modelling results are discussed.

1. Introduction

The SPABRINK project (www.spabrink.eu) requires that coloured “ink” particles are attached to a planar surface “foil” to form a temporary image that can be held or released under electronic control. This provides novel printed image enabling reuse of the ink particles for low cost environmentally friendly advertising display applications. The image is required to be held for hours or days. Initial experiments had used charged particles or surfaces, but highly insulating particles are needed to hold charge for long periods, and it is difficult to control charge on the particles, especially over long periods of time and humid conditions. It is not simple to switch electrophoretic forces under electronic control, and high particle charge levels and voltages would be required for adhesion. Gravitational force increases rapidly compared to electrostatic force as the particle size increases, and so large particles will not easily adhere. In contrast, dielectrophoretic theory predicts that dielectrophoretic force is proportional to particle volume [1].

$$F = 0.5 \left(\frac{4}{3} \pi a^3 \right) \varepsilon_1 \varepsilon_0 \left(\frac{3(\varepsilon_2 - \varepsilon_1)}{\varepsilon_2 + 2\varepsilon_1} \right) \nabla[E]^2$$

where F is the force on the particle, a the particle radius, ε_2 and ε_1 the relative permittivity of the particle and surrounding medium (air, $\varepsilon_1 = 1$) respectively, ε_0 is the permittivity of free space and E the electrostatic field. The dielectrophoretic force and gravitational forces both increase with particle volume, so the ability to suspend particles should be nearly independent of particle size. It is possible to suspend surprisingly large particles using highly divergent surface fields produced by closely spaced electrodes at modest voltages. Fields up to breakdown field strength can be produced by a closely spaced electrode pattern on a surface under modest voltages (up to 1000 V) under electronic control. Particle dielectric properties rather than conductivity are the key parameters. It should be possible to hold particles for as long as power is supplied to the electrodes. With d.c. excitation low power consumption would be expected. The system would be expected to be insensitive to atmospheric humidity. Despite these advantages, dielectrophoretic manipulation appears to have been



mainly used with micro and nano particles, with the exception of Calle et al.'s work [2] on moon dust control.

In order to create strong divergent fields at the surface of the foil, an interdigitated electrode structure having electrode and gap widths of 500 μm has been used [3]. Particles were shown to adhere successfully not only to the electrode surface, but also to the reverse (non-electrode) side of the polymer foil, at least for foil thicknesses up to 100 μm . It was then of interest to test the strength of adhesion to the vertical surface against vibration and the effect of reducing supply voltage. This paper explores the effects of these using polyester particles supplied by a partner in the SPABRINK project.

2. Methodology

2.1. Experimental

The electrode system used was an interdigitated copper structure with electrode and gap widths of 500 μm , inkjet printed on a 115 μm thick polyester foil. The foil was mounted in a rigid plastic frame supported from an electromagnetic vibrator that gave a displacement of 0.52 mm per volt applied. This was driven using 133 ms rectangular pulses to give a controlled displacement with each rising and falling edge of the waveform. The vibrator and foil were mounted on a rotating support so that powder could be applied in a horizontal position and then rotated to vertical.

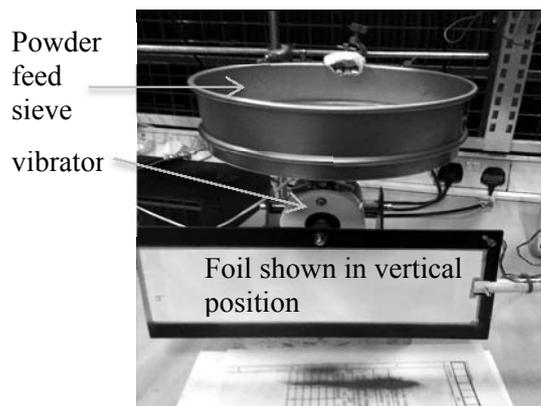


Figure 1. Experimental arrangement . In this photograph the foil has been turned to the vertical position and fallen powder may be seen on the paper beneath it. The electrodes are not visible as they are on the rear surface of the foil.

The foil was energized from a d.c. high voltage power supply via 20 M Ω resistor for protection against sparking or accidental short circuits. The d.c. current consumption of the electrode structure was <1 mA. A multimeter directly measured the voltage across the electrode structure.

The foil was cleaned with methanol and neutralised using an ioniser before each application of powder. A leveled spatula was used to measure repeatable quantities of powder, which was passed through a 90 μm mesh sieve using a brush to produce a 20 mm diameter uniform thin layer of 63-90 μm diameter material on the foil. With the powder and voltage applied, the vibrator and foil were turned to vertical (Figure 1). Fallen powder was collected and weighed. The foil was subjected to “there and back” displacement of various distances using the vibrator. Fallen powder was again collected and weighed. This was repeated until all the powder had been removed by vibration. The experiment was repeated five times for each powder loss data point and the average of the results taken.

2.2. Modelling

A 2-dimensional electrostatic model was developed of the foil and electrode arrangement [3]. We defined an “adhesion factor” as the ratio of dielectrophoretic to gravitational force normal to the foil surface, taking into account material dielectric constant and density. An adhesion factor >1 indicated that adhesion would be expected. The forces were plotted as shading on a model, giving indication of where regions of strong and weak adhesion would occur (Figure 2). The amount of powder that could

be expected to adhere to the surface could then be estimated by finding the area of the model for which the adhesion factor was >1 .

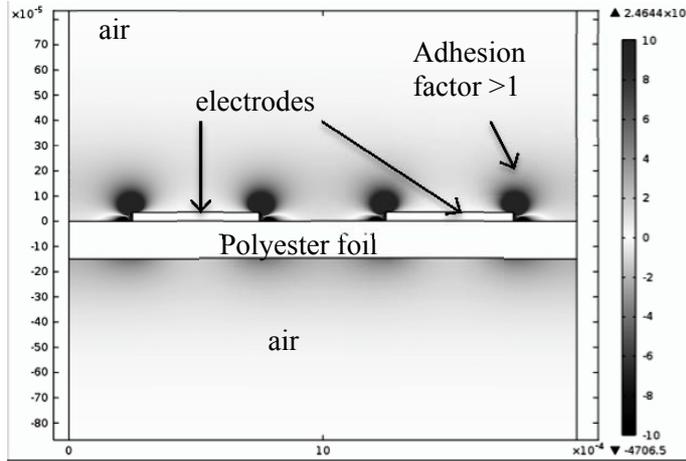


Figure 2. 2-dimensional electrostatic model showing regions of strong adhesion force (adhesion factor >1) around the edges of the electrodes

3. Results and discussion

The loss of powder from the foil due to foil displacement is given for PET powder in Figure 3. Negligible powder was lost with foil displacement less than 0.5mm, showing surprisingly strong adhesion. All the powder was lost for displacement greater than 3 mm.

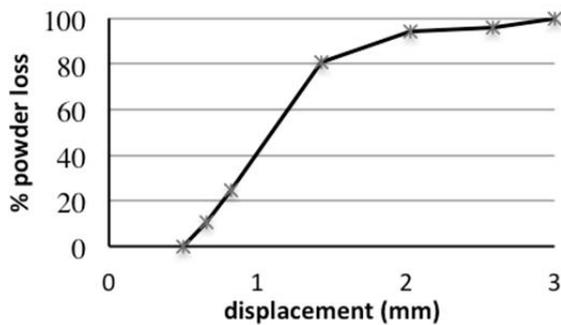


Figure 3. Powder loss due to vibration at various displacements

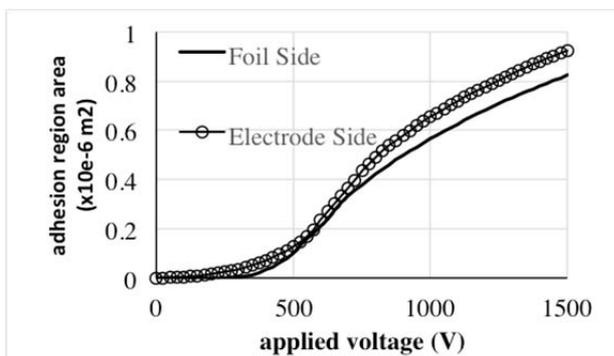


Figure 4. Adhesion region area modeled for a $115 \mu\text{m}$ foil as a function of applied voltage for electrode and non-electrode (foil) sides

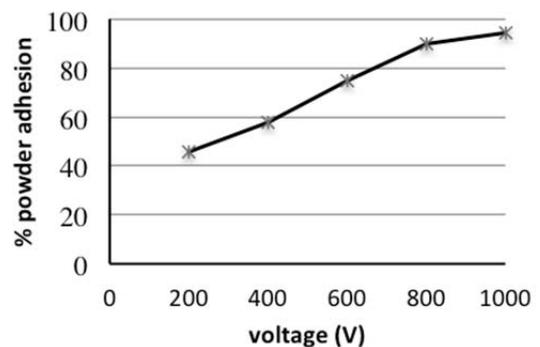


Figure 5. Powder loss from the non-electrode side of foil as a function of supply voltage for a $115 \mu\text{m}$ foil

The electrostatic model predicts that the area having adhesion factor >1 is reduced as the foil applied voltage is reduced. For a 50 μm foil, the area of the region of adhesion on the non-electrode side of the foil is similar to the electrode side. For a 115 μm foil, the adhesion region area is reduced on the non-electrode side (Figure 4) as the adhesion force is spread and attenuated due to the foil thickness. A threshold of adhesion appears, in this case around 500 V for a 115 μm foil. In our practical experiments, using a 115 μm foil and polyester powder we found that an average of 94% of the powder adhered at the maximum applied voltage of 1000 V, and this fell to 54% at 200 V.

The experimental results are broadly in line with our predictions although adhesion at low voltages was much greater than expected. It is difficult to directly predict the powder mass adhesion for a variety of reasons. The packing fraction of a powder is not known and can be expected to be variable with applied force. Secondly, Pohl's equation for dielectrophoretic force assumes the presence of one spherical particles. In practice there are many non-spherical particles in a packed layer. This can be expected to affect the strength and divergence of the field, and hence the dielectrophoretic adhesion forces. The model also assumes uncharged particles. In practice this is unlikely to be the case with a highly insulating material like polyester, and the method of handling the powder may have a large effect on particle charging. The powder was found to adhere preferentially to the positive electrode, and it seems likely the powder became negatively charged by brushing it through the sieve. So, it seems likely that the adhesion force observed here is due to a mixture of dielectrophoretic and electrophoretic force.

4. Conclusions

We have shown that 2-d electrostatic modeling can be used to make general predictions of the behavior of dielectric particles adhering to an interdigitated electrode with d.c. voltage applied. Particle adhesion to the electrode and non-electrode sides of the foil has been shown to withstand shaking with displacement up to 0.5mm. Higher displacements up to 3 mm led to increasing powder loss, with 100% loss for over 3mm displacement.

Powder adhered well to the non-electrode side of a 115 μm foil with 1000 V applied, losing only around 6% of material when shaken. Material loss rose to 10% at 800 V and 54% at 200 V applied. The adhesion forces in this experimental work are likely to include electrophoretic force due to negative charge on the polymer particles as well as dielectrophoretic forces.

Acknowledgement

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References

- [1] Pohl H A 1978 *Dielectrophoresis*. Cambridge University Press. ISBN 0 521 21657 5
- [2] Calle C I, Buhler, C R, McFall J L and Snyder S J 2009 *J. Electrostat.* **67** 89-92
- [3] Smallwood J, Praeger M, Chippendale R and Lewin P 2014 Dielectrophoretic adhesion of 50-300 μm particles under ambient atmospheric conditions. Dielectrophoresis 2014, Institute of Physics London