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WORKING PRINCIPLES OF 3D XEROGRAPHY

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ABSTRACT: This research is a continuation of the development of 3D Xerography (3DX). The adhesion force between molten medium density polyethylene (MDPE) particles to a Teflon substrate was investigated. Special attention was placed on the molten state adhesion experiment as it is among the first of its kind to be performed. The experiment was done using the centrifuge method. The particles were placed on substrate, melted and spun at angular velocities up to 17000rpm and analyzed to determine the adhesion force. The experimental results show that the particle adhesion force increases as particle size increases. In other words, the smaller the particle, the higher the tendency it detaches from the substrate. Due to the change in state from solid to liquid, wetting was observed to significantly increase adhesion force. It was further observed that the percentage of particles adhering to the substrate with respect to the adhesion force follows a log-normal distribution which conforms to results from earlier research.

1. INTRODUCTION

Adhesion is an attraction between two individual solid bodies in a common contact surface that has been produced by intermolecular attractive forces builds up at close distances according to Felicetti et al. (2009). In order to calculate the minimum electric field strength needed for 3DX to work consistently, it is necessary to first know the amount of force needed to separate molten MDPE particles and Teflon. The total adhesion force existing between two contacting objects are due to the combine effects of Van der Waals forces, electrostatic and capillary forces as stated by Felicetti et al. (2009). All these forces are additionally dependable on the particle format, particle size, surface roughness, relative air humidity and contact pressure applied.

The fundamentals underlying the working principles of 3D Xerography (3DX) printing were investigated in this paper. 3DX, as described by Tan and Chua (2011) and Tan (2009), is a 3D printing method that works on the basis of electrostatics. The method has many similarities to xerography which is the dominant method of reproducing 2D images in photocopiers and laser printers. 3D models are fabricated layer by layer by selectively binding loose powders together with molten build materials. Transportation and deposition of these molten materials are done through the use of electric field via electrostatic attraction and repulsion. At the moment, 3DX is still under the development as many factors influencing the process are still being studied.

The work described in this paper is part of a larger study to understand 3DX and electrostatic repulsion. Molten medium density polyethylene (MDPE) particles are deposited on a Teflon substrate and then separated using centrifugal force to simulate the process of transferring molten build materials from one substrate to another which is used in 3DX.

2. METHOD

2.1 Materials

Medium density polyethylene (MDPE) powder, available from GoodFellow, was utilized here. In order to achieve the molten state, the MDPE particles were heated above its melting point of 107.7°C to 116.4°C as determined by DSC. At the start of each experiment, the MDPE powder has to be heated to at least 120°C. From this temperature, the material will cool down gradually to 107°C before solidifying, therefore the experiment has to be completed in this time frame in order to ensure that the MDPE particles remained molten throughout the experiment.

Images of MDPE particles obtained from an optical microscope under 50x magnification are presented on figure 1. Notice the difference of the particles in the *before* and *after* images. Figure 1(a) shows the particles in its dry state and they are irregularly shaped. However, after they are melted, the material began to take on a spherical form as shown in figure 1(b). Contact area increases tremendously due to wettability and the contact angle observed indicates that the solid/liquid interaction is omniphobic according to Mittal (2009). The surface energy values for Teflon and MDPE are 18mJ/m² and 33mJ/m² respectively. The density for this experimental MDPE particle was stated by the supplier to be 0.935g/cm³.

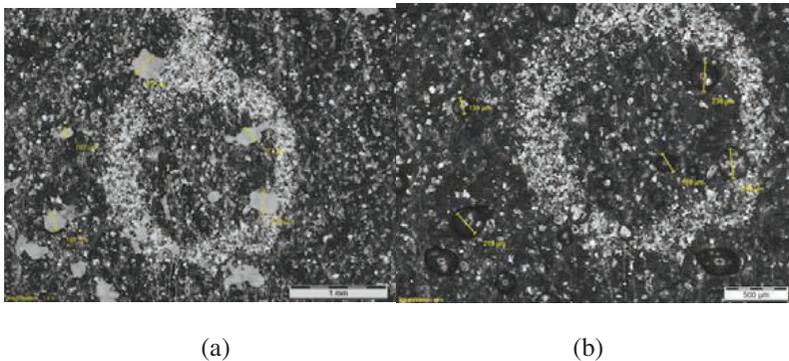


Figure 1: (a) Image of MDPE particles in the solid state. (b) Image of the MDPE in the molten state.

2.2 Methodology

The centrifuge method was selected to measure adhesion. This method was introduced in Krupp (1967) and has been widely used due to its simplicity and versatility. Its advantage is that it allows a large number of particle samples to be tested on the surface desired in a single experiment. In this manner, it will yield a more representative experimental value for the overall particle adhesion. This centrifugal force can be calculated from equation 1 below. The magnitude of the adhesion force is equal to the centrifugal force but applied in the opposite direction ($F_{\text{centrifugal}} = -F_{\text{adhesion}}$).

$$F_c = m\omega^2 R_c \quad (1)$$

F_c , centrifugal force; m , particle mass; R_c , centrifugal radius; and ω , angular velocity.

The adhesion force can be calculated from the experimental data based on the retention curve which is the plot of the percentage of particles remaining as a function of the centrifugal force. The force derived to detached 50% of the samples from the substrate will be selected to represent the set of experimental adhesion force performed on the particle-substrate as stated by Lam et al. (1991). As the mass of the particle influences the centrifugal force, it will be calculated with equation 2. The centrifugal radius used in this experiment will be 0.01m.

$$m = \rho_p V_p \quad (2)$$

ρ_p , particle's true density; and V_p , particle's volume.

The entire centrifugal experiment was carried out with two different rigs. For angular velocity from 1000 rpm to 5000 rpm, a modified Zipocrit Microcentrifuge was used and from 5000 rpm to 17000 rpm a modified Dremel 4000 driller was used. The axis of rotation is orthogonal to the surface of the Teflon substrate. The particles were carefully positioned onto the substrate's center aligning with the rotor's rotational axis to prevent additional stray forces from acting on them.

For the calculation of the particle's mass, the V_p term in equation 2 varies depending on the sphericity of the particle as discussed earlier. Since the molten MDPE is identified to give a relatively round particle, an estimate for the volume will be in the form:

$$V_p = \frac{4\pi r^3}{3} \quad (3)$$

The calculated mean masses at different size ranges of the molten MDPE were recorded. These three different particles mean diameter sizes were 316 μ m, 473 μ m and 618 μ m. Their respective calculated masses were 1.54x10⁻⁸ Kg, 5.18x10⁻⁸ Kg and 1.15x10⁻⁷ Kg.

Due to the variety of sizes obtained from the supplier, the particles have to be sorted into 3 size ranges. The MDPE particles were then manually placed onto the Teflon substrate with a needle. The sorted particles were then examined under a digital microscope (Dino-Lite) and an image analyzer software was used to capture the exact particle's position on the substrate before starting a new round of experiment.

The substrate was spun at different angular velocity. Spin-off rpm were 1000, 3000, 5000, 7000, 9000, 11000, 13000, 15000, and 17000 rpm for duration of 30 seconds. Felicetti et al. (2009) observed that the time length of the experiment does not influence the amount of particles being detached therefore a 30 seconds time period was selected to expedite the process and not exceed the time limit of 38 seconds. At the start of each round of experiment, the substrate and rotor will be heated up via an Iroda flame torch to generate a surface temperature of about 120°C as determined by a non-contact infrared thermometer. It was observed that the substrate surface temperature takes around 38 seconds to cool down from 120°C to 107°C. Therefore, to ensure that the spin-off test is completed while the particles are still molten, the entire experiment has to be completed within this time frame. It is expected within the first few seconds after starting the centrifugal machine, the molten particles will be overcome by the centrifugal force acting on them and will be flung off before they solidifies. After each spin-off, a comparison to the initial image will be made to determine the number of particles still adhering onto the substrate. Using this

experimental data, the adhesion force between the particles and the substrate can be calculated using equation 1. The angular velocity of equation 1 is given by the rpm which causes 50% of particles to be removed from the substrate at the end of the experiment.

3. RESULTS AND DISCUSSION

Experimental results obtained from the centrifuge method on the particle-substrate in relation to the effects of particle size and adhesion force will be discussed.

Figure 2 shows the outcome of molten MDPE particles subjected to spin-off forces at various angular velocities. It shows the percentage of molten MDPE particles still adhering to the substrate in relations to the angular velocities separated according to their particle sizes. From the figure, one can observe that as the particle size increased, the number of particles still adhering to the substrate declined more gradually as rpm increases although the initial drop was more abrupt. In other words, it requires more centrifugal speed to overcome the adhesion between the particle-substrate. Notice that the leftover percentage for all sizes was slightly more than the 50% probability mark required to calculate the geometric median adhesion forces. In order to remove the particles completely from the substrate, it is estimated that the maximum angular velocity has to be doubled which translates to about 34000rpm.

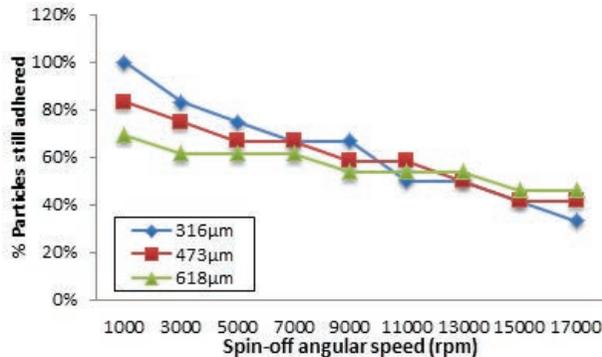


Figure 2: Percentage of molten MDPE particles adhered to the Teflon coated surface with different spin-off angular velocity and mean diameters.

Figure 3 shows the percentage of molten MDPE particles still adhering to the Teflon substrate with respect to the necessary centrifugal force needed to remove them at various angular speeds. It was plotted in a logarithmic-probability scale. The curves obtained for individual mean diameter behaves in a linear manner. These suggest that the particles still adhering to the surface with respect to the required force to dislodge them satisfy a log-normal distribution which conforms to what is observed by Zimon(1982).

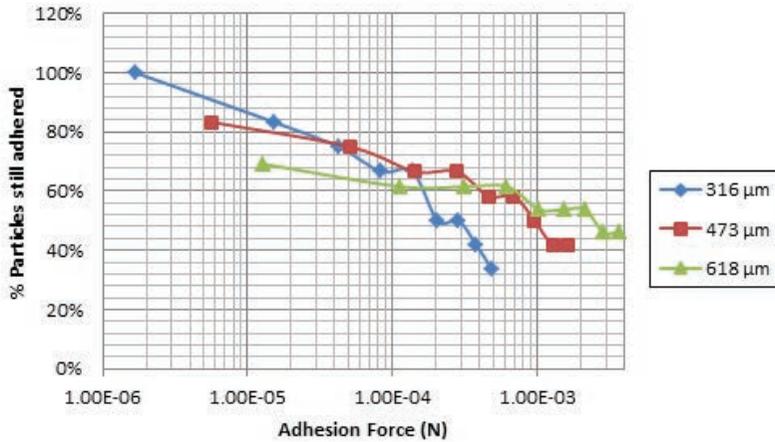


Figure 3: Percentage of molten MDPE particles still adhered to the Teflon coated plates versus adhesion force.

The DMT equation did not provide an accurate estimate for the solid/liquid interface here. Due to the inability of the DMT equation in considering the effects of the molten state, the values should only be used as a guide. The fact is that the DMT equation, which considers only the surface energy between contacting solid particles, does not account for the effects of wetting. Therefore, it is reasonable to find the experimental force values higher.

The significant increase (10x – 30x) in adhesion force which shows a much larger contact area between a molten particle and the substrate as compared to a solid particle that promotes adhesion. Even with a relatively rough substrate, the molten material will be able to mold itself more closely onto the surface irregularities.

5. Conclusion

The experimental adhesion force observed between the particle-substrate increased linearly as the particle size increases. On the other hand, the percentage of the particles adhering to the substrate was shown to reduce gradually as particle size increases. Wetting plays apart on top of the Van Der Waals force for the molten MDPE particle, leading to a much higher experimental force as compared to the theoretical force.

The percentage of particles adhering to the substrate with respect to the various amount of adhesion force in a logarithmic-probability scale was observed to satisfy a log-normal distribution which conforms to earlier results obtained by other researchers.

The DMT equation did not provide an accurate estimate for the solid/liquid interface investigated herein. Due to the inability of the DMT equation in considering the effects of the molten state, the values should only be used as a guide. The fact is that the DMT equation, which considers only the surface energy between contacting solid particles, does not account for the effects of wetting. Therefore, it is reasonable to find the experimental force values higher.

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