Effects of Nanoparticle Coating on the Adhesion of Emulsion Aggregation Toner Particles

Xiarong Tong, Weiqiang Ding and Cetin Cetinkaya *

Department of Mechanical and Aeronautical Engineering, Center for Advanced Materials Processing, Wallace H. Coulter School of Engineering, Clarkson University, Potsdam, NY 13699-5725, USA

Received in final form 14 September 2009

Abstract

Toner is a key material for the xerographic printing and copying industry. Compared to conventional pulverized toner particles, emulsion aggregation (EA) toner particles could adhere more strongly to substrates and their property distributions are narrower because of their near-perfect spherical shape and higher surface free energy. However, in general, uncoated EA toner is more difficult to transfer and clean during printing/copying processes for the same reasons. Nanoparticle additives could be used as control agents to reduce the toner particle–substrate adhesion. In order to optimize their adhesion and handling performances, an accurate adhesion characterization of the toner particles coated with different levels of additives is required. In current study, two non-contact adhesion characterization techniques based on acoustic air-coupled excitation and ultrasonic base excitation are presented. Their use for the adhesion characterization of individual bare toner particles with an average diameter of 6.0 µm on silicon substrates, and their silica nanoparticle coated variants with a surface area coverage (SAC) of 50% is demonstrated. The techniques are based on the detection of the resonance frequencies of rocking motion of micro-spheres. The out-of-plane transient displacement responses of the rocking particles are captured by a laser interferometer, and the natural frequencies of particle rocking motion obtained from transient displacements at the top of particles and the substrate are related to the strength of the adhesion bond. It is reported that the work of adhesion values of the 50% SAC-coated toner on silicon substrates are almost an order of magnitude lower than those for the bare ones.

1. Introduction

Adhesion (weak intermolecular interactions or van der Waals forces) can be a dominant force at the micrometer length scale. Accurate adhesion characterization of

© Koninklijke Brill NV, Leiden, 2010 DOI:10.1163/016942409X12541266699518
micro-scale objects (e.g., micro-particles, micro-machined moving parts, micro-electronic components and biological cells) is, therefore, essential for various industries such as printing/copying, pharmaceuticals, MEMS (micro-electromechanical systems) and semiconductor manufacturing. In the printing/copying industry, to improve the image quality, new generation chemical toners such as the emulsion aggregation (EA) toner with tighter particle size, shape and property distributions have been synthesized [1]. Specifically, it is known that the near-spherical EA toner could produce images with higher resolution than the conventional pulverized toner [1]. However, since the bare EA toner particles appear to adhere more strongly to flat surfaces than the pulverized toner particles, it is often more difficult to clean the residues of such particles on the photoreceptor surface, and their adhesion properties need to be controlled. In order to tune the adhesion of EA toner particles, additives such as silica nanoparticles are commonly used to coat the toner particle surface to lower its adhesiveness [2–4]. It is, therefore, important to develop techniques for the accurate characterization of the adhesion properties of nanoparticle-coated toner particles. In this study, adhesion characterization of the bare and nanoparticle-coated EA toner micro-particles on flat substrates is reported using two non-contact/non-destructive techniques.

In past few decades, several particle–substrate contact mechanics models for particle adhesion have been developed, such as Johnson, Kendall and Roberts (JKR) [5], Derjaguin, Muller and Toporov (DMT) [6] and Maugis and Dugdale (MD) models [7]. It was later demonstrated that all these one-dimensional (out-of-plane) adhesion models were related and a unified theory was presented [8]. Many experimental techniques have also been introduced and utilized for determining the adhesion properties of toner particles, such as the colloid probe technique, centrifuge detachment technique and the electric field detachment technique, as described in Refs [9–12]. The centrifuge detachment technique and the electric field detachment technique are used to measure average adhesion properties of a group of toner particles on a surface. Although the colloid probe technique is utilized for individual toner particle adhesion measurement, it is essentially a destructive method since the irreversible attachment of the particle to the probe is required.

In recent years, adhesion characterization methods based on the rolling resistance moment of an individual particle have been introduced [13–17]. In addition to the determination of work of adhesion, it was also demonstrated that the rolling resistance moment of a particle–flat surface bond could be used to predict the initiation of rolling-based detachment of a particle [14]. With a lateral pushing measurement method in a contact manner, the work of adhesion of the bond between bare EA toner particles and silicon substrate was also used to confirm the existence of the rolling resistance [14].

In current study, two non-contact/non-destructive techniques are detailed and utilized for the work of adhesion characterization of individual bare and coated EA toner particles on flat surfaces to understand and quantify the effect of nanoparticle coating on the adhesion performance of such toner particles. These techniques
have been previously used to characterize the adhesion of polystyrene latex micro-
pheres on a silicon substrate [15, 16]. In this work, the techniques are used to
vestigate the influence of the surface roughness created by nanoparticles of poly-
mer micro-spheres on their adhesion properties. In the reported experiments, the
bare and coated near-spherical EA toner particles are dry-deposited on the sili-
con substrates and their oscillatory rocking motions on surfaces are excited by
an acoustic air-coupled transducer or an ultrasonic base (contact) transducer in a
non-contact manner. A fiber vibrometer (interferometer) is utilized to record the
transient out-of-plane response of the particle on the substrate under impulsive ex-
citations. It has been previously demonstrated that the resonance frequency of such
a rocking motion could be related to the work of adhesion of the particle–substrate
system without contacting and altering the surfaces of the particles [15]. In addition,
since these methods require no dislodgement of the particle, the adhesion proper-
ties can be monitored for the same particle at the same contact point under various
conditions, such as different levels of temperature, humidity and electric charge in
the contact zone.

2. Materials

Two sets of experimental EA toner particles were utilized for the current study. The
bare toner particle (see Fig. 1 for a scanning electron microscopy (SEM) im-
age) and the coated toner particle with a nominal surface area coverage (SAC) of
50% (Fig. 2) are both nearly spherical with average diameters of around 6.0 µm.
The outer layer of the bare toner particle is a copolymer shell, and wax, resin
and colorants are enclosed inside. The 50% SAC toner particles are prepared by
coating such bare toner particles with silica (SiO2) nanoparticles that covered ap-
proximately 50% of the surface area. The average diameter of the individual silica

![Figure 1. (a) An SEM image of a bare toner particle with a diameter of 4.95 µm at a magnification of 15 000× and (b) a close-up SEM image of the surface of the bare toner particle covered with thin gold nanofilm coating at 50 000× magnification.](image)
Figure 2. (a) An SEM image of a silica nanoparticle-coated toner particle with a diameter of 5.55 µm at a magnification of 14,000× and (b) a close-up SEM image of the surface of the surface-coated toner particle covered with thin gold nanofilm coating at 50,000× magnification. The average diameter of the silica nanoparticles is 24 nm.

nanoparticle is around 24 nm, but some nanoparticles form clusters of over 100 nm in size (Fig. 2(b)). These experimental toner particles were prepared using the EA process [18] and subsequently surface coated using a toner blender at the Xerox Research Center (Webster, New York, USA), and they were used as-received with no aging or chemical treatment. The toner particles were dry-deposited onto a plasma cleaned single-crystal silicon substrate (p-type doped (100) oriented wafer) just prior to the experiments, and the actual diameters of the individual toner particles used in the experiments were determined based on the digital images obtained under an optical microscope. The adhered individual toner particles were acoustically excited and their adhesion properties were characterized.

3. Adhesion Theory

When a particle–substrate system is subjected to sufficiently strong external acoustic fields, the out-of-plane and oscillatory rocking motions of the particle bonded to a flat substrate occur [15]. In the out-of-plane direction, the particle–substrate adhesion bond acts like a non-linear spring [15], and in rocking motion the particle moves in free rotational oscillations on the substrate with respect to its contact point without dislodgement [14, 15]. The JKR model can be utilized to determine the stiffness coefficient of the bond and the natural frequency of the out-of-plane motion for the particle–substrate pairs with known properties [15]. However, for rocking motions, as discussed below in detail, a two-dimensional adhesion model is needed. As reported in a previous study [15], the natural frequency of the out-of-plane motion of a particle with a radius $r$ is approximated as

$$f_0 = \frac{3\alpha^{1/6}}{2^{11/6}r\sqrt{\pi \rho \beta^{1/3}}},$$

(1)
where $W_A$ is the work of adhesion, $\alpha = 3\pi r W_A$, $\beta = 3r [E_2(1 - \nu_1^2) + E_1(1 - \nu_2^2)]/4E_1E_2$ and the mass density ($\rho_1$), Young’s modulus ($E_1$) and Poisson’s ratio ($\nu_1$) of the bare polymer toner particle material are estimated as $\rho_1 = 1000$ kg/m$^3$, $E_1 = 2.77$ GPa and $\nu_1 = 0.33$ for current study. For the silicon substrate, in the natural frequency calculations, the following properties are used: $\rho_2 = 2329$ kg/m$^3$, $E_2 = 127$ GPa and $\nu_2 = 0.28$ [15]. For a similar type of EA toner particles with an average diameter of around 9.0 µm on a silicon substrate, the work of adhesion ($W_A$) of about 23 mJ/m$^2$ was previously reported by utilizing an AFM (Atomic Force Microscopy)-like contact method [14]. Based on this value, the natural frequency ($f_0$) of the out-of-plane motion of the 6.0 µm toner particle on the silicon substrate is estimated to be around 8.72 MHz.

In addition to the out-of-plane displacement, the particle makes a rocking motion and a two-dimensional model for this mode of motion is required (Fig. 3). Assuming no out-of-plane vibrational motion with comparable amplitudes takes place during this motion, the out-of-plane displacement ($\delta$) (due to particle rocking) of the particle measured by the interferometer is related to the rotational motion ($\theta$) of the particle by $\delta \approx 2r(1 - \cos \theta)$. This assumption is reasonable since the rocking stiffness is substantially lower than the out-of-plane stiffness and, consequently, its resonance frequency is substantially lower than that of the out-of-plane motion [15, 16]. The relationship between the natural frequency of the rocking motion of a particle on a flat substrate and the work of adhesion is given as [15]

$$f_r = \frac{1}{4\pi r^{3/2}} \sqrt{\frac{45 W_A}{\rho}},$$

(2)
where $\rho$, $r$ and $W_A$ are the mass density, the radius and the work of adhesion of the micro-spherical toner particle material, respectively. For a spherical toner particle on a silicon substrate with a work of adhesion of 23 mJ/m$^2$, a mass density of 1000 kg/m$^3$ and a diameter of 6.0 µm, the natural frequency of the rocking motion ($f_r$) is estimated to be around 604.5 kHz based on equation (2), which is substantially lower than that of the out-of-plane motion. It is important to note that there exist infinite numbers of planes in which the rocking motion can occur. In case of anisotropic work of adhesion, the observation of a number of resonance frequencies should be expected for the same particle since adhesion property depends on the direction of motion and rocking motion takes place on several planes.

Due to the substantial discrepancy between the out-of-plane stiffness and rocking stiffness, there is a large difference between the natural frequencies of the out-of-plane motion and the rocking motion of a spherical particle on a substrate, which provides a good mode separation in the frequency response bandwidth. The natural frequencies of rocking motion are considerably easier to detect and to utilize to determine the work of adhesion since, due to its low rocking stiffness, its amplitude is much larger than that of the out-of-plane motion. The natural frequency of the out-of-plane motion is a function of the elastic properties of the particle–substrate system (equation (2)) while the natural frequency of rocking motion seems to be independent of the elastic properties, which is somewhat counterintuitive, as reported and discussed earlier [15, 16].

4. Experimental Setup and Procedures

A set of experiments were designed and carried out to extract the rocking motion natural frequencies of toner particles on a substrate from their dynamic (transient) responses to an impulsive external excitation. The instrumentation diagram of the setup used in the reported experiments is depicted in Fig. 4. Two types of transducers (air-coupled and contact) used in the experiments were excited by a square electrical pulse from a pulser/receiver unit (Panametrics, model 5077PR) at a central frequency of 100 kHz with an amplitude of 400 V. The transducer is mounted on an $xy$-translational stage for precise positioning of the excitation source. Positions of particles were monitored by a charge coupled device (CCD) camera embedded in an optical microscope during the experiments. A laser Doppler vibrometer LDV (Polytek vibrometer controller unit OFV 3001), a fiber interferometer unit (OFV 511), and an ultrasonic displacement decoder (OVD 030) were integrated with the optical microscope. The laser beam from the fiber interferometer unit was transmitted through the microscope objective lens to focus on single particles or on the substrate to conduct transient out-of-plane displacement measurements [15, 16]. The vibrometer recorded the transient out-of-plane displacement response ($\delta$) of the particle on the substrate with no physical contact with the particle. The resonance frequencies of the bond were identified by applying the Fast Fourier Transform (FFT) routine to the transient responses of substrate and particles.
the extracted resonance frequencies of rocking motion, the work of adhesion of the particle–substrate system was extracted using equation (2).

The air-coupled transducer was mounted at an angle on the side of the particle–substrate system as depicted in Fig. 5(a) and 5(b). The toner particles were dry-deposited on a silicon substrate, and the particle–substrate system was used as acoustic excitation target [16]. Their vibrational motions were excited by the air-coupled transducer in a non-contact manner. Based on the work of adhesion values reported in Ref. [14], the transducers with various central frequencies and bandwidths were chosen as acoustic excitation sources. The following two types of air-coupled transducers were employed in the reported experiments: (i) a transducer (QMI AS225Ti) with a central frequency of 225 kHz and a bandwidth of 185–260 kHz and (ii) a transducer with a central frequency of 1.0 MHz and a bandwidth of 50 kHz–3.0 MHz.

The base excitation setup is similar to the air-coupled excitation setup (Fig. 6(a)). The only procedural differences are in the type of the transducer used and the relative position of the transducer mounted in the experimental setup. In case of base excitation, instead of air-coupled transducer excitation from the side, the silicon wafer with toner particles deposited was placed on top of an ultrasonic contact transducer. Coupling gel was applied to ensure sufficient acoustic transmission from the contact transducer to the substrate (Fig. 6(b)). The ultrasonic field from the contact transducer excited the vibrational motion of the substrate and, consequently, particles on the surface of the substrate were excited to make out-of-plane motions. In the reported base excitation experiments, the following three types of contact transducers were utilized: (i) a transducer (Panametrics, V682) with a central frequency
of 3.5 MHz and a low frequency component of bandwidth from 50–600 kHz, (ii) a transducer (Valpey Fisher ILO.610) with a central frequency of 0.5 MHz and a bandwidth of 50–700 kHz and (iii) a transducer (Valpey Fisher ILO.610) with a central frequency of 0.2 MHz and a bandwidth of 50–280 kHz.

The average work of adhesion values of bare polymer and 50% SAC-coated toner particles with average diameters of 6.0 µm were previously reported as 23 mJ/m² and 4.0 mJ/m², respectively, based on a contact method [14, 19]. From equation (2), the corresponding rocking resonance frequencies are determined to be around 500 kHz and 205 kHz for the bare polymer and 50% SAC-coated toner particles, respectively. These calculated frequencies are utilized to determine the types of transducers and the bandwidth of the electrical pulse source in the experiments.
Figure 6. (a) Schematics of the base excitation experimental setup and (b) a close-up image of the measurement area of the base excitation setup with a 3.5 MHz transducer.

To capture the transient response of a substrate, the laser spot of the fiber interferometer was first focused on the substrate in the neighborhood of a particle with the 100× magnification objective lens of the optical microscope, as shown in Fig. 7(a). The out-of-plane transient response (δ) of the substrate surface to the acoustic vibration field was acquired by the LDV. The decoders of the LDV generated a waveform (transient response) in time domain corresponding to the out-of-plane motion of the substrate surface. The xy-translation stage was used to place and focus the laser spot onto the top surface of a single particle (Fig. 7(b)). The out-of-plane motion for each particle was acquired and stored. This procedure was repeated for a number of individual particles on the silicon substrate, and the corresponding waveforms were digitized and recorded by the oscilloscope for signal processing. In order to deter-
mine the work of adhesion between the toner particle and the silicon substrate, the resonance frequencies of rocking motion of the particle on the substrate were extracted from the transient responses of the particle and the substrate. For each set of measurements with a specific type of toner excited with a specific transducer, a set of 12 particles on the silicon substrate were used. During the experiments, it was observed that some particles tended to agglomerate and others made various translational motions due to lack of strong contact bond with the substrate. It was also observed that particles formed packs (groups of few particles) and rotated together with respect to a contact point, as reported previously [20]. In current study, only single oscillating particles with no dislodgement are considered for measurements to extract the resonance frequencies of rocking motion. It is noteworthy that various other types of motions are observed, and it is evident that acoustic excitation leads to several types of complex motions of particles on the surface under the influence of adhesion and inertia.

5. Results and Discussion

The transient out-of-plane responses of single micro-scale toner particles on a substrate were acquired and processed for the work of adhesion characterization of bare and nanoparticle-coated toner particles. These waveforms were transformed into the frequency domain by an FFT routine. The rocking resonance frequencies were extracted from the frequency responses and the work of adhesion values between particles and substrate were determined. The representative out-of-plane transient displacements and corresponding frequency responses of the rocking motion of the bare polymer and 50% SAC-coated toner particles on the substrate with air-coupled and contact ultrasonic excitations are presented in Figs 8–12. In these figures, the amplitude peaks of the particle responses which shift with respect to those of the substrate are indicated by the rectangular boxes. The amplitude peaks of the particle
Figure 8. (a) Transient response of a 50% SAC toner with a diameter of 8.46 µm excited by an air-coupled transducer with a central frequency of 225 kHz on the silicon substrate, (b) its frequency response and (c) a close-up of low frequency portion of the frequency spectrum. The rectangular boxes indicate the amplitude peaks of the particle responses which shift with respect to those of the substrate; the arrow indicates the selected frequency peak.

responses, for which there is no corresponding resonance frequency of the substrate, are selected as the rocking resonance frequencies of the particles, and they are used for extracting the work of adhesion of the system. The selected frequency peaks are indicated by arrows.

Using the material properties listed in previous section and the measured particle diameters through the recorded optical images, the work of adhesion values of the particle–substrate systems are determined from the identified rocking resonance frequencies using equation (2). The work of adhesion values for the bare toner particles are determined in the range of 20–22 mJ/m². This result agrees well with the results from independent lateral pushing measurements on the same type of EA.
Figure 8. (Continued.)

Figure 9. The frequency response of a bare toner with a diameter of 6.29 µm excited by an air-coupled transducer with a central frequency of 1 MHz on a silicon substrate. The rectangular box indicates the amplitude peaks of the particle responses which shift with respect to those of the substrate; the arrow indicates the selected frequency peak.

toner particles [14], and is also within the same range as for other spherical toner particles reported in Ref. [21]. Those for 50% SAC-coated toners are calculated in the range of 2.8–4.4 mJ/m². The types of transducers used, the work of adhesion values based on the contact measurement method, and the extracted work of adhesion values based on the current non-contact measurement methods are summarized in Table 1. It is observed that the work of adhesion values for the same type of toner
Figure 10. (a) Transient response of a 50% SAC toner with a diameter of 4.87 µm excited by a base transducer with a central frequency of 200 kHz on the silicon substrate, (b) its frequency response and (c) a close up of low frequency portion of the frequency spectrum. The rectangular boxes indicate the amplitude peaks of the particle responses which shift with respect to those of the substrate; the arrow indicates the selected frequency peak.

The experimental work of adhesion values for the coated toner particles with an SAC of 50% on silicon substrates are an nearly order of magnitude lower than those for the bare ones. The nature of contact altered due to the presence of nanoparticles at the contact is the main reason for such a substantial reduction. The actual toner particle–substrate adhesion is dominated by the silica nanoparticle–substrate inter-
Figure 10. (Continued.)

The frequency response of a 50% SAC toner with a diameter of 6.08 µm excited by a base transducer with a central frequency of 3.5 MHz on the silicon substrate. The rectangular box indicates the amplitude peaks of the particle responses which shift with respect to those of the substrate; the arrow indicates the selected frequency peak.

Figure 11. The frequency response of a 50% SAC toner with a diameter of 6.08 µm excited by a base transducer with a central frequency of 3.5 MHz on the silicon substrate. The rectangular box indicates the amplitude peaks of the particle responses which shift with respect to those of the substrate; the arrow indicates the selected frequency peak.

action rather than the direct toner micro-sphere–substrate contact. Here the same adhesion model is employed to extract the work of adhesion of 50% SAC-coated toner particles on a silicon substrate as the one used for bare particles. Therefore, the calculated work of adhesion for the coated toner particles should be considered an effective value rather than an absolute property measure. The strength of the bond between the coated toner particles and the silicon substrate is determined by interactions between silica nanoparticles and the substrate rather than by only the
Figure 12. The frequency response of a bare toner with a diameter of 5.33 µm excited by a base transducer with a central frequency of 500 kHz on the silicon substrate. The rectangular box indicates the amplitude peaks of the particle responses which shift with respect to those of the substrate; the arrow indicates the selected frequency peak.

Table 1.
Summary of the work of adhesion data for the toner particles measured by the base and air-coupled excitation methods

<table>
<thead>
<tr>
<th></th>
<th>Bare toner</th>
<th>50% SAC toner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average diameter (µm)</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Estimated work of adhesion (mJ/m²)</td>
<td>23</td>
<td>4.0</td>
</tr>
<tr>
<td>Estimated resonance frequency (kHz)</td>
<td>500</td>
<td>205</td>
</tr>
</tbody>
</table>

Base excitation

<table>
<thead>
<tr>
<th></th>
<th>Bare toner</th>
<th>50% SAC toner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of base transducer</td>
<td>0.5 MHz</td>
<td>0.2 MHz</td>
</tr>
<tr>
<td>(Bandwidth (kHz))</td>
<td>(50–700)</td>
<td>(120–280)</td>
</tr>
<tr>
<td>Measured frequency (kHz)</td>
<td>577.8–653.4</td>
<td>183.1–229.1</td>
</tr>
<tr>
<td>Work of adhesion (mJ/m²)</td>
<td>11.1–23.6</td>
<td>1.7–2.8</td>
</tr>
<tr>
<td>Type of base transducer</td>
<td>3.5 MHz</td>
<td></td>
</tr>
<tr>
<td>(Bandwidth (kHz))</td>
<td>(50–300)</td>
<td></td>
</tr>
<tr>
<td>Measured frequency (kHz)</td>
<td>178.3–263.7</td>
<td></td>
</tr>
<tr>
<td>Work of adhesion (mJ/m²)</td>
<td>2.2–3.7</td>
<td></td>
</tr>
</tbody>
</table>

Air-coupled excitation

<table>
<thead>
<tr>
<th></th>
<th>Bare toner</th>
<th>50% SAC toner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of air-coupled transducer</td>
<td>1.0 MHz</td>
<td>225 kHz</td>
</tr>
<tr>
<td>(Bandwidth (kHz))</td>
<td>(50–3000)</td>
<td>(185–260)</td>
</tr>
<tr>
<td>Measured frequency (kHz)</td>
<td>559.8–640.1</td>
<td>205.9–227.7</td>
</tr>
<tr>
<td>Work of adhesion (mJ/m²)</td>
<td>15.8–25.7</td>
<td>4.1–5.4</td>
</tr>
</tbody>
</table>
contact of bare polymer micro-particles to the silicon substrate. The effective value of work of adhesion for the coated toner particles provides a means for a direct comparison of the adhesion performance of toner particles with or without external additives. The measurements reported in this investigation are useful for toner design to tailor the adhesion properties of a given type of toner for quantifying the particle handling requirements and the adhesion performance. Accurate modeling of the actual work of adhesion between the nanoparticle and substrate is important, but is beyond the scope of the current study.

6. Conclusions and Remarks

The effect of nanoparticle coating on the adhesion properties of individual near-spherical EA toner particles on silicon substrates is investigated. Two non-contact/non-destructive techniques, based on the vibrational motion of micro-spherical particles under acoustic air-coupled and ultrasonic base excitations, are presented and their utility is demonstrated. Two types of near-spherical EA toner particles, namely bare and 50% SAC particles with the same average diameter of around 6.0 µm, are tested. It is observed that the measured work of adhesion values of coated toner particles with an SAC of 50% on silicon substrates are nearly an order of magnitude lower than those of the bare ones. The significant reduction of the adhesion between the coated toner particles and substrate due to nanoparticle coating provides a method to optimize the adhesion performance of the EA toner in printing or copying processes for both toner transfer efficiency and residual toner particle cleaning. It is observed that the work of adhesion values determined based on these two non-contact experimental methods are close, and they are in good agreement with the estimated work of adhesion values reported using an independent AFM-like contact method. Compared with other adhesion characterization techniques, the main advantages of the current methods include: (i) their non-contact and non-destructive nature, (ii) same-spot adhesion measurement ability and (iii) applicability to individual particles in ambient conditions.

Acknowledgements

The authors thank to Drs. Santokh S. Badesha, Kock-Yee Law and Grazyna Kmiecik-Lawrynowicz of Xerox Corporation for fruitful discussion and sample toners. The authors acknowledge the New York State Energy Research and Development Authority (NYSERDA) and Xerox Corporation for providing partial funding and the toner materials, respectively, for the research program. The interferometric equipment employed was acquired through a grant from the National Science Foundation (Nanoscale Exploratory Research Program, Award ID 0210242).
References