A computational study of charged bumpy particle adhesion and detachment from the rough surface

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Outline

- Adhesion and detachment of rough and bumpy particles from surfaces
- Effect of roughness parameter on the total adhesion force of a particle with small roughness
- Effect of different scales of surface roughness on the particles removal
- Electrostatic detachment of charged bumpy and rough particles
  - Effects of number of bumps
  - Effects of particle diameter
  - Effect of Charge
  - Effect of capillary force

Objective

To provide an understanding of adhesion and detachment of charged bumpy particles in contact with smooth and rough surfaces turbulent flows in the presence of an imposed electric field.

Applications

Xerographic and microelectronic industries
Solar energy (minimizing dust deposition on the solar photovoltaic panels)
Aerospace industries (protecting NASA's equipment, including solar panels from the dust storm on Mars)
Environmental science and pollution control

Rough particle on the smooth surface

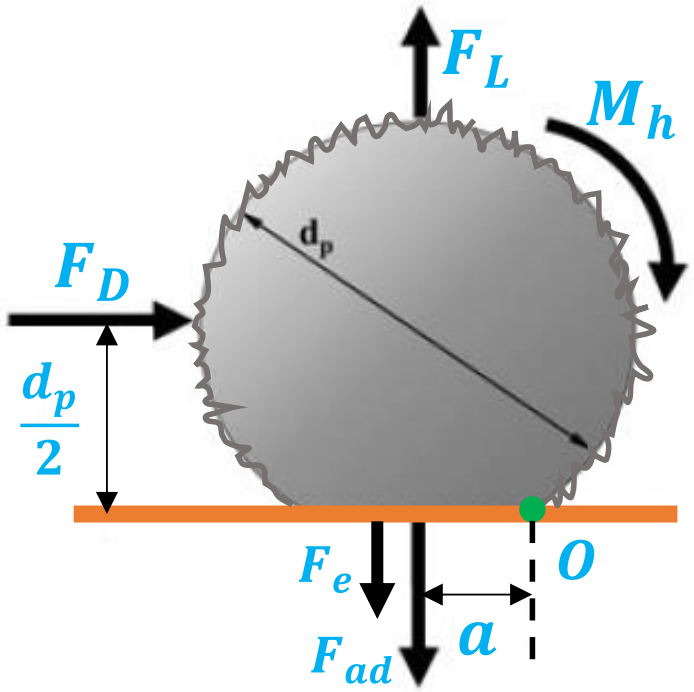

Fig.1(a). Schematics of the forces acting on a particle with fine roughness in a cross flow.

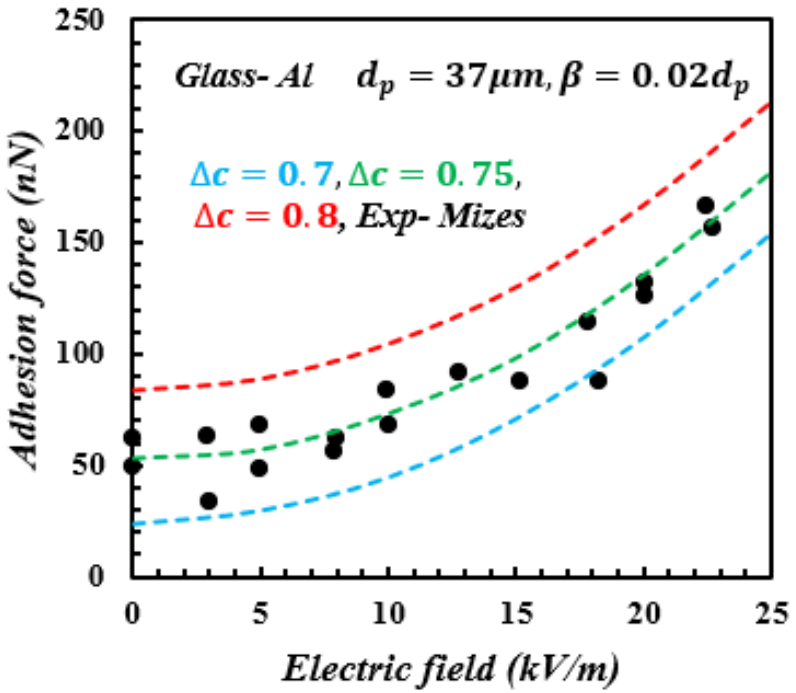

Fig. 1(b). The total adhesion (van der Waals and electrostatic) force for glass particle on an aluminum surface.

- **With increasing the roughness parameter, the adhesion force increased.**
- **The total adhesion forces have a direct relationship with the magnitude of the electric field.**

[1] H. A. Mizes, J. Adhesion Sci. Technol. 8 (1994) 937-953

Bumpy particle on the smooth surface with/without capillary force

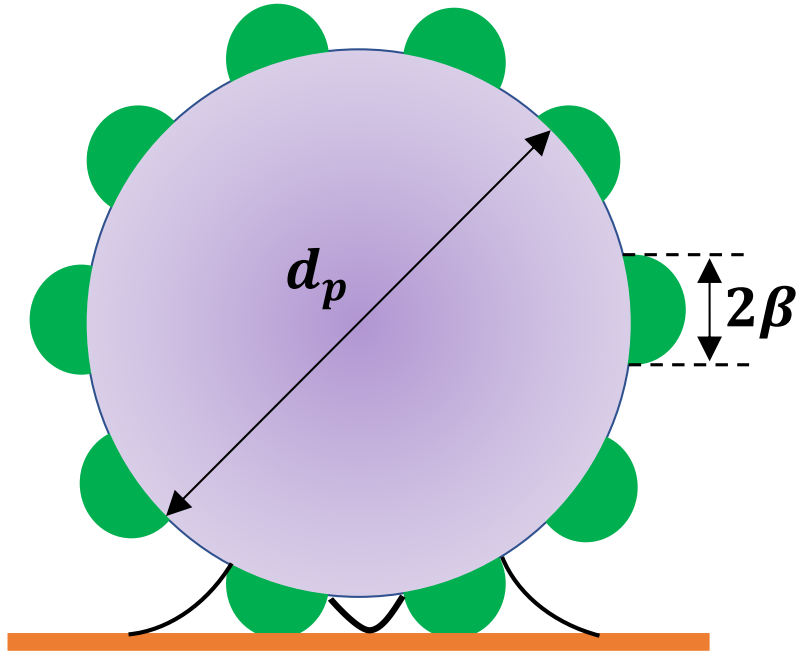

Fig.2(a). Schematic diagram of a bumpy particle and contact bumps in the presence of a capillary meniscus

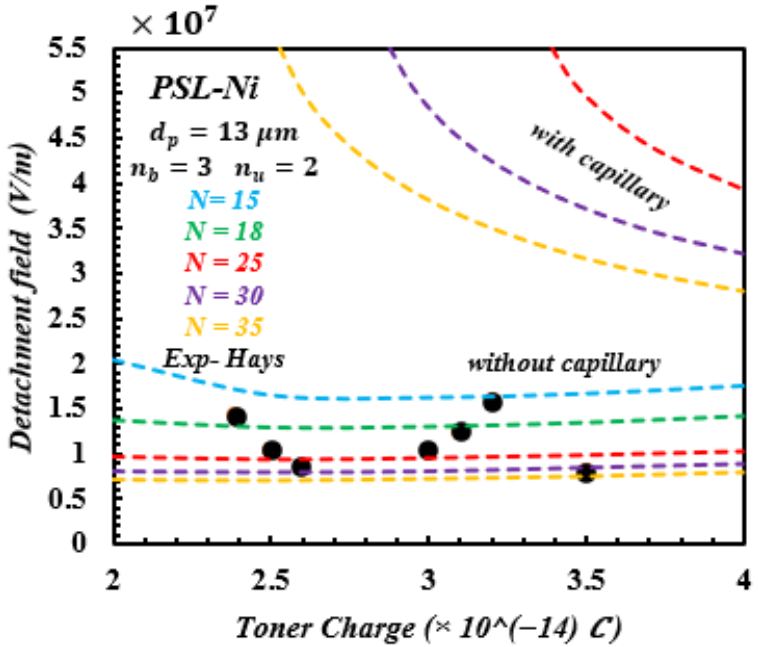

Fig.2(b). Comparison of electric detachment fields for bumpy particles with and without capillary force for toner particles on a nickel carrier beads.

- The detachment electric field increases significantly as a result of the presence of the capillary force.
- The electric field intensity for particle detachment increases with the increase of the particle charge when the capillary force is presented.
- The detachment electric field intensity decreases with the increase of number of bumps.

[2] D. A. Hays, Photogr. Sci. Eng. 22 (1978) 232-235

Large-scale surface roughness

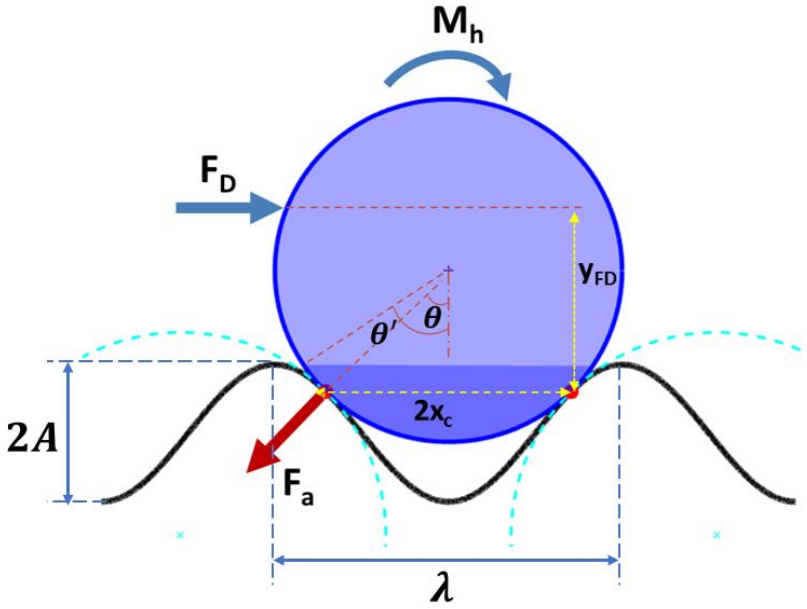

Fig. 3(a). Schematic of force balance on the particle

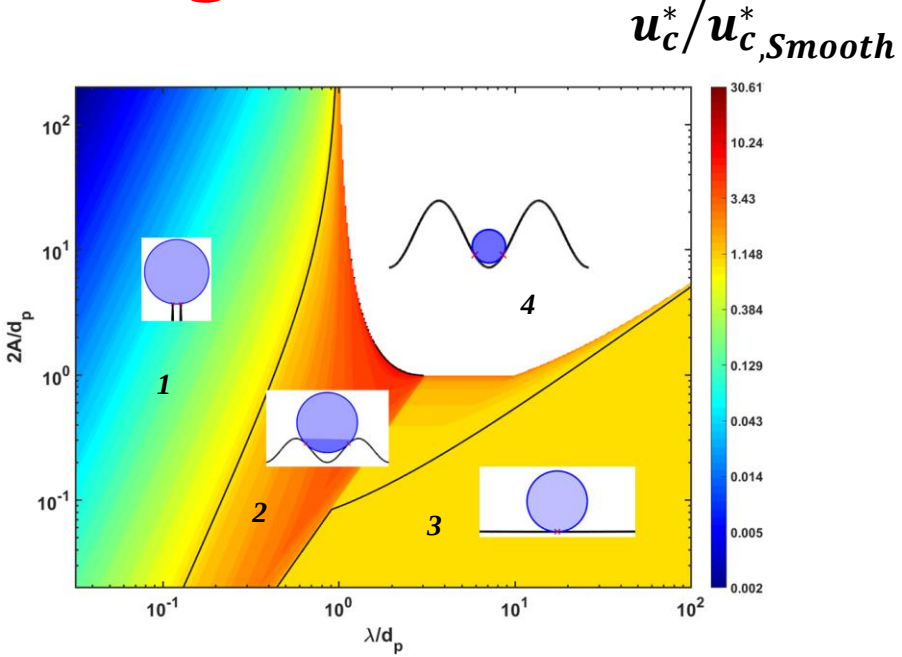

Fig. 3(b). Critical shear velocity ratio contour as function of wavelength and amplitude for 10μm glass particle on glass substrate [3]

Region 1. The particle detachment is much easier than the smooth surface because of the smaller contact areas.

Region 2. The particle removal process is more difficult than the smooth surface, due to the less exposure to the flow and higher resistance moment.

Region 3. The surface roughness wavelength is much larger than the size of a particle. The surface behaves as a smooth surface.

Region 4. the surface roughness is much larger than the particle size, the removal is impossible.

[3] Babak Nasr, Goodarz Ahmadi, Andrea R. Ferro, Suresh Dhaniyala, Aerosol Science and Technology, 54 (2019); https://doi.org/10.1080/02786826.2019.1692126

Charged bumpy particle on the rough surface

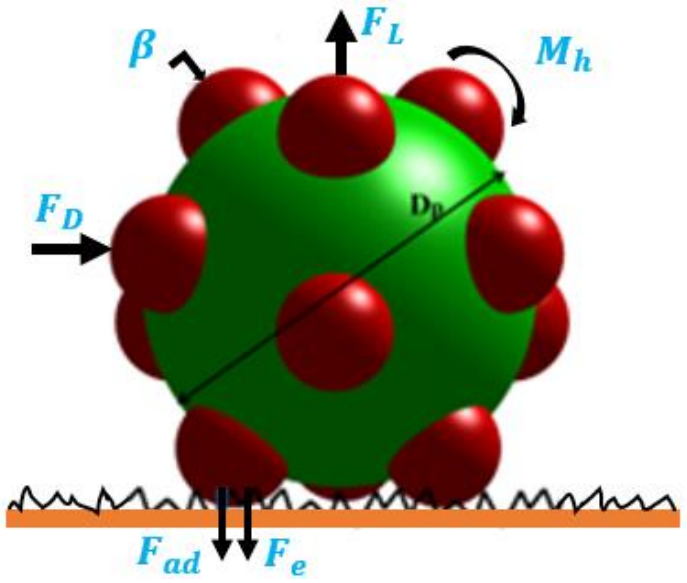

Fig.4(a). Schematic force diagram illustrating bumpy particle on rough surfaces.

$$[4]:\ F_{adh}^{bump} = \left(\frac{d_p}{n_u n_b \sqrt{N_b}\, K}\right)^2 \left[\frac{0.15\,\pi^2\, n\, W_a\, \beta_b\, e^{\left[\frac{-0.6}{\Delta_c^2}\right]}}{\sigma}\right]^3 \qquad (1)$$

$$F_e = -1.5\,q\,E - \frac{q^2}{4\pi\varepsilon_0}\left(\frac{\left(1-\left(\frac{3}{N}\right)^2\right)^2}{d_p^2} + \frac{\left[(4n_b^2+1)^{\frac{3}{2}} + 2\right]\left(\frac{3}{N}\right)^2}{3\beta_b^2(4n_b^2+1)^{\frac{3}{2}}}\right) - 72\,\pi\,\varepsilon_0\,\beta_b^2\,E^2 \qquad (2)$$

[4] Babak Nasr, Goodarz Ahmadi, Andrea R. Ferro, Suresh Dhaniyala, Aerosol Science and Technology, 33 (2019); https://doi.org/10.1080/01694243.2019.1650989

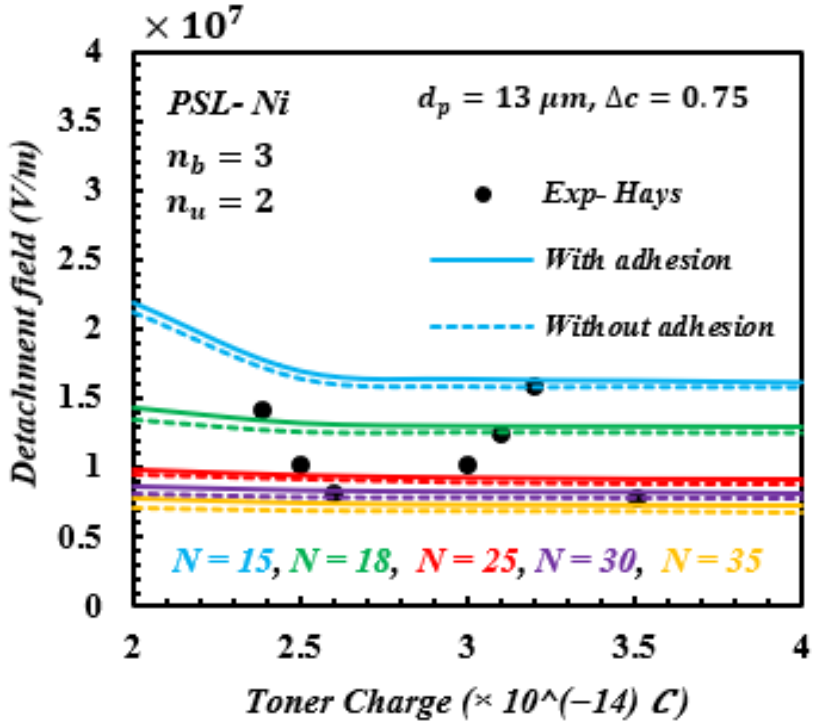

Fig.4(b). Electric detachment field for bumpy particles from a rough surface

- **The detachment field has an inverse relationship with the particle charge and the number of bumps.**
- **The value of the detachment field with adhesion force is higher than without adhesion force.**
- **There is a good agreement between the present analytical result and experimental data.**

The effect of number of bumps on the detachment field (bumpy particle-smooth surface)

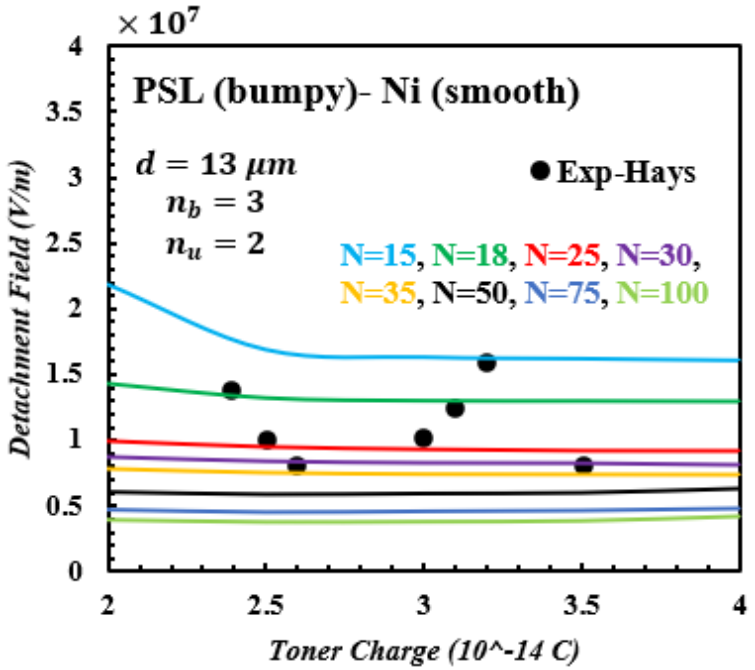

Fig.5. Effect of number of bumps on the detachment field

By decreasing the number of bumps for a fixed toner charge, the electric detachment field increases. This is because of increase of the amount of charge on each contact bumps.

The effect of particle diameter on the detachment field (bumpy particle-smooth surface)

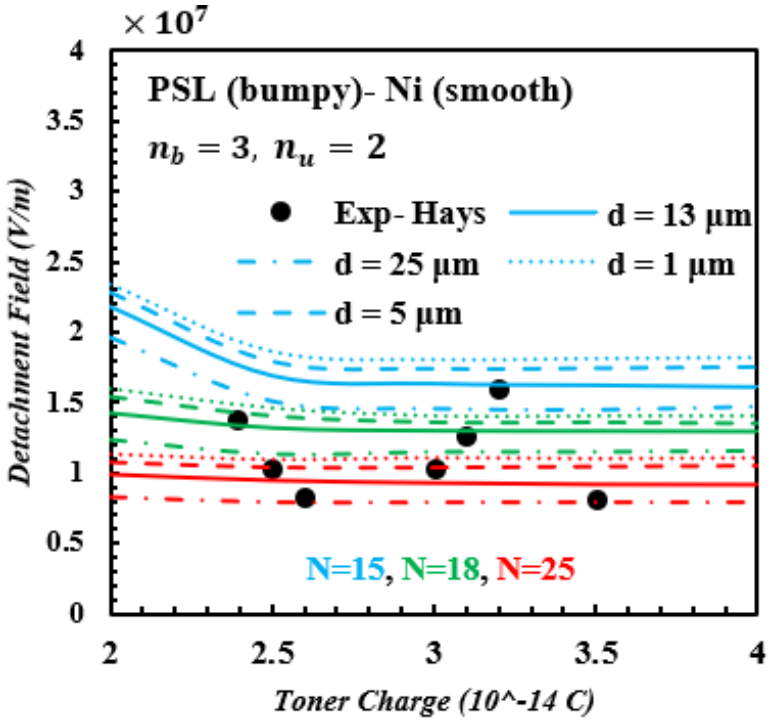

Fig.6. **Effect of particle diameter on the electric detachment field for a fixed toner change.**

By decreasing the particle diameter the detachment field increases. This is because of decreasing the particle diameter leads to charges on the bumps being closer to the surface generating larger image force.

Conclusions

- **With increasing the roughness parameter (Δc) from 0.7 to 0.8 the adhesion force is increased.**
- **The total adhesion force (van der Waals & electrostatic forces) increased by increasing the electric field.**
- **The detachment electric field increases with presence of capillary force.**
- **When the surface roughness is larger than the particle diameter, the particle removal from the surface by an external flow is impossible.**
- **For fixed particle charge, the detachment electric field has an inverse relationship with the number of bumps.**
- **The detachment electric field with adhesion force is slightly higher than without adhesion force.**
- **For fixed particle charge, there is an inverse relationship between the detachment electric force and the particle diameter.**

Thank You!

Questions?