

# Contact Cleaning for Functional Coatings in Emerging Technologies

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*Abstract:- Appropriate application of contact cleaning within production of coated products can significantly reduce defects caused by particulate contamination. In the emerging technologies such as OPV, Plastic Electronics and Displays there is a requirement for high barrier coatings where even tiny defects are detrimental to product lifespan. This paper will discuss the research which has been carried out into some of the variables related to contact cleaning in order to tailor the cleaning performance to the specific application.*

## Background

The emerging technologies are placing much greater demands on Contact Cleaning than its traditional applications. In particular the size of particles which pose a risk to the integrity of the product functionality has become significantly smaller. Also, where the product coating has electrical or chemical functionality, certain types of contamination such as metal particles are extremely detrimental. It is now becoming increasingly necessary to be able to tailor the cleaning system to both the size and type of contamination to optimize its efficiency.

For any Contact Cleaning system to be effective the adhesion force between the elastomer cleaning roller and the particle of contamination must be greater than the adhesion force holding the particle onto the substrate being cleaned. While there are a very large number of variables which affect the adhesion force, one of the most significant ones is contact area. To maximize the adhesion force the contact area between the surface of elastomer cleaning roller and the surface of the particle of contamination must also be maximized. Surface roughness is a key factor in contact area.

Previous research into the adhesion of small particles has indicated that electrical and chemical forces also play a significant effect in adhesion forces, implying that the adhesion forces may vary according to the type of material of which the particle of contamination is composed.

This paper is the first reporting on a programme of research which aims to scientifically quantify some of the major variables impacting the adhesion forces between particles and elastomer rollers. The initial research is based on the existing portfolio of elastomers with the aim of developing new elastomers tailored to specific applications.

## Research Objectives

- 1 Provide surface roughness information on the five elastomers
- 2 To provide data relating to the nature of adhesive forces between three different types of particle of standard size and geometry and five different elastomers .

## Methodology

The atomic force microscope (AFM) is a member of the family of scanning probe microscopes (SPMs). The concept on which most SPMs are based is the generation of surface images by measuring the physical interaction between a sharp tip and the sample rather than by using an incident beam (light or electrons) as in classical microscopy.

In atomic force microscopy, the sample surface is scanned by a miniature cantilever with a sharp tip (several nm in diameter) at its end. The tip apex is in continuous contact with the surface, or in intermittent contact. Movement of the tip is monitored by reflecting a laser beam off the end of the cantilever. The tip moves up or down when imaging a sample as it follows the surface structure of the sample, which shifts the beam between upper and lower photodiode components, creating voltage differences that are electronically rendered into height information. Horizontal movements of the beam are also recorded, corresponding to frictional phenomena on the surface. To produce high quality image, the AFM must be capable of controlling the tip-sample interaction with great precision. This is accomplished with the use of an electronic feedback loop, which safeguards the tip and sample by keeping force or distance between them at a user-specified value.

Generally, the AFM can be operated in two modes: (i) contact mode and (ii) intermittent contact mode. In the contact mode, the AFM tip touches the sample surface constantly, hence images are created by recording the piezo position required to keep the force constant. In the intermittent contact (tapping) mode, the cantilever oscillates at a set frequency and touches the surface intermittently to reduce the dragging lateral forces.

## Experimental setup

The experiments were carried out at the facilities of Polymer Institute at the University of Sheffield.

Samples were taken using a surgical blade from different places on the elastomer rollers provided, and then glued on a steel stub for future use. Extreme care was taken during the whole process to avoid any contact with the sample surface. The samples were designated “Soft”, “Panel”, “Film” “F3” and “Nanoclean” and vary both in their chemical composition and in their method of manufacture which results in different surface characteristics.

Both adhesion and surface topography measurements were performed on a Digital Instruments Nanoscope III Multimode atomic force microscope (Digital Instruments, Cambridge, UK). Topographic images were acquired by using silicon Tapping mode cantilever (MPP, Veeco). The nominal tip radius was less than 20 nm. Acquired AFM images were processed by Nanoscope software (V5.31).

For the adhesion experiments, a single silica particle (Duke Scientific Co., CA, USA; certified mean diameter of 10  $\mu\text{m}$ ), or (polystyrene) latex particle (Duke Scientific Co., CA, USA; certified mean diameter of 10  $\mu\text{m}$ ) was attached to the end of a tipless cantilever (NSC-12, Mikromasch). For gold-coated silica colloidal probes, an Edwards Auto 306 bell jar vacuum coater system was first used to deposit a 5-nm-thick layer of chromium, with a deposit rate in the region of 0.05 nm s<sup>-1</sup>. Following deposition of the chromium adhesion promoting layer, the system was allowed to cool down for approximately 20 min prior to deposition of a 20-nm-thick layer of gold, at a typical deposition rate of 0.05 nm s<sup>-1</sup>. These particles have different degrees of hydrophobicity with polystyrene being the most hydrophobic and silica the least.

Force-displacement curves were collected over 300 locations on each sample, and then processed by using software known as Carpick’s toolbox to calculate the adhesion forces. The nominal spring constant of the cantilever is 7.5 N/m, which is provided by the manufacturer.

## Results

### (i) Topological analysis

Intermittent mode AFM imaging was performed in air, at different scan scale (1, 2, and 5  $\mu\text{m}$ ). Typical height and corresponding amplitude images of samples are shown in Figure 1. Surface roughness was calculated based on each individual height image, where the roughness is the (RMS) average vertical deviation from the mean line (the ideal surface). The surface roughness results are shown in Table 1.

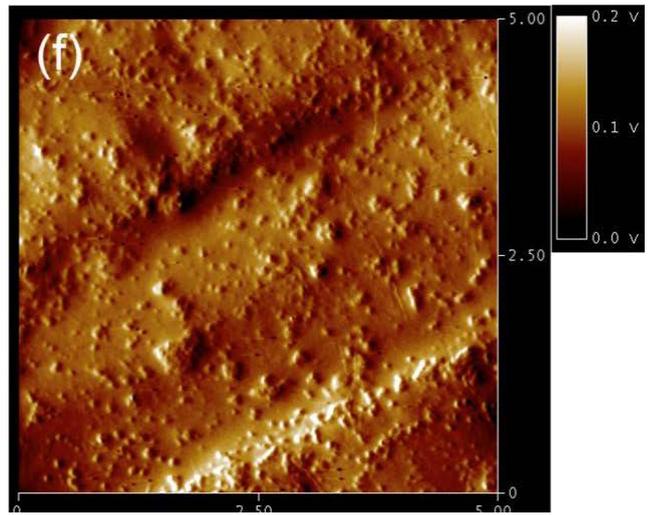
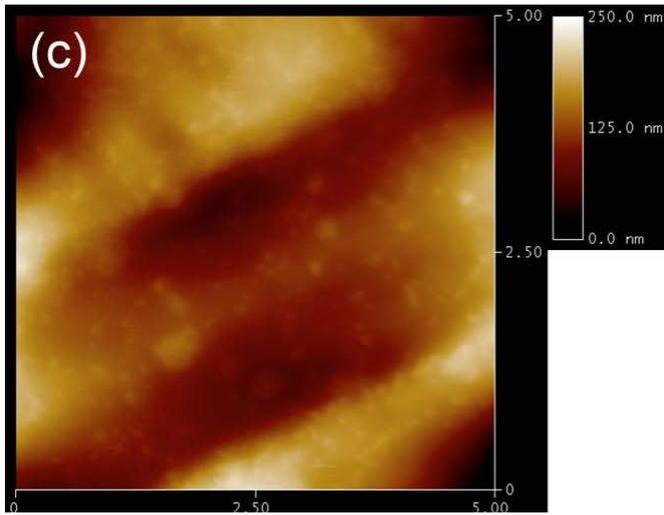
Scan Size \ Sample name	1	2	3
<b>Soft</b>	2.169	11.143	38.582
<b>Panel</b>	7.355	13.493	23.467
<b>Nanoclean</b>	3.616	1.400	6.292
<b>Film</b>	7.453	16.861	18.54
<b>F3</b>	31.009	49.085	98.334

**Table 1:** *Roughness (nanometre) of elastomer samples that acquired at different scan size.*

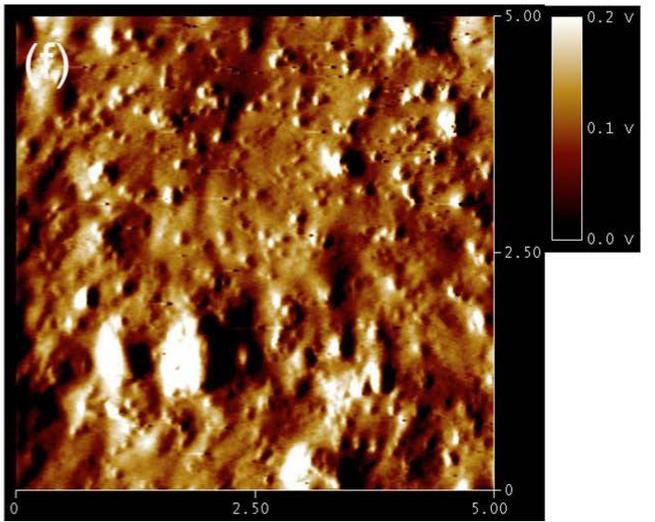
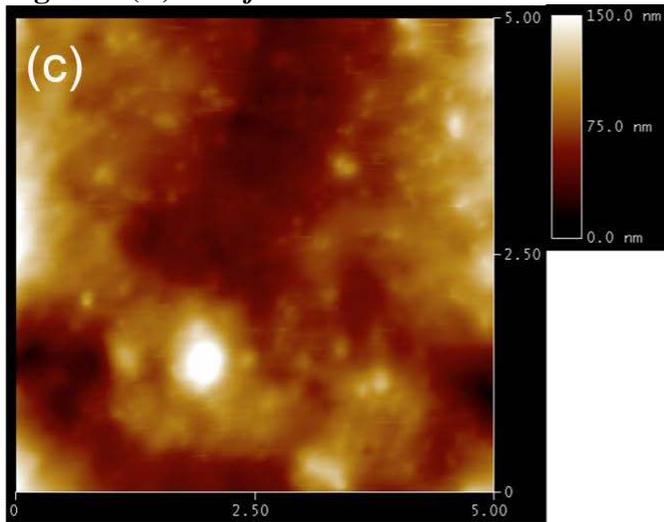
It was found that the ‘*Nanoclean*’ sample has a flat surface, less roughness throughout all scan scales, whilst the ‘*Panel*’ and ‘*Film*’ samples have a rather flat surface at small scale ( $\sim 1\mu\text{m}$ ).

It is also worth noting that the surface roughness of the ‘*Soft*’ sample is close to ‘*Panel*’ or ‘*Film*’ at small size, but a dramatic increase was found at large scale. The ‘*F3*’ sample has the largest surface roughness

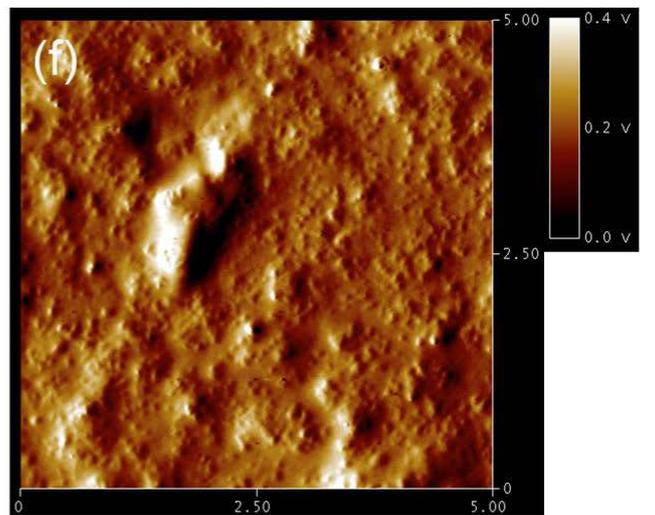
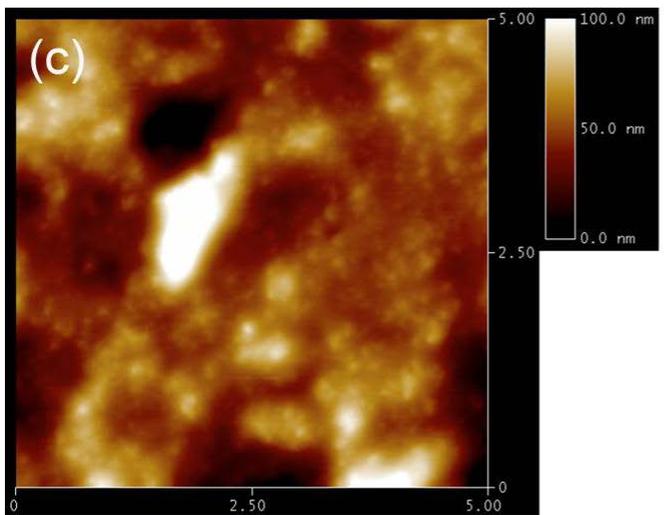
This level of roughness is of the same order as the surface of individual cotton fibres. A very smooth surface such as a silicon wafer would have a RMS roughness of around 2nm. A polished wooden surface, on the other hand, would be an order of magnitude rougher with values in the region of micrometres



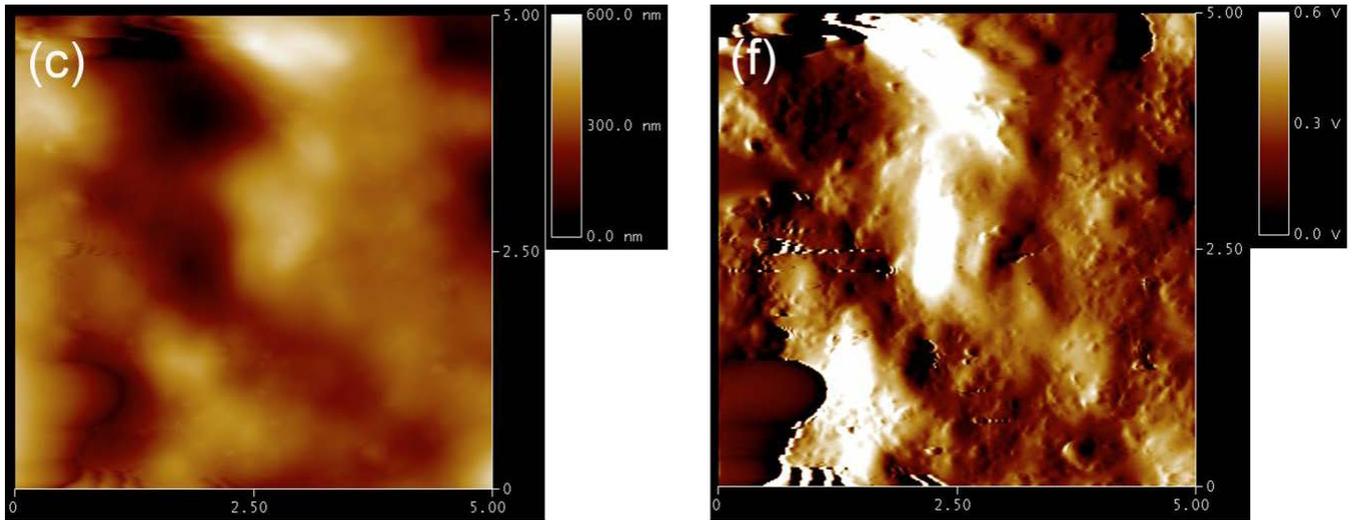
**Figure 1 (A) “Soft”**



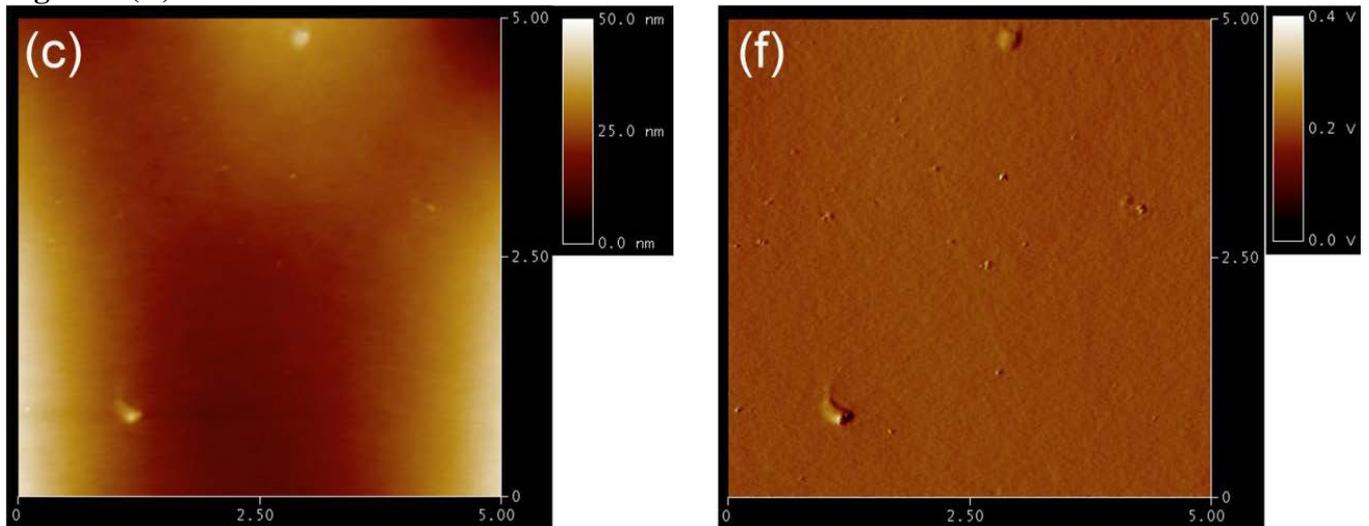
**Figure 1 (B) “Panel”**



**Figure 1 (C) “Film”**



**Figure 1 (D) “F3”**



**Figure 1 (E) “Nanocleen”**

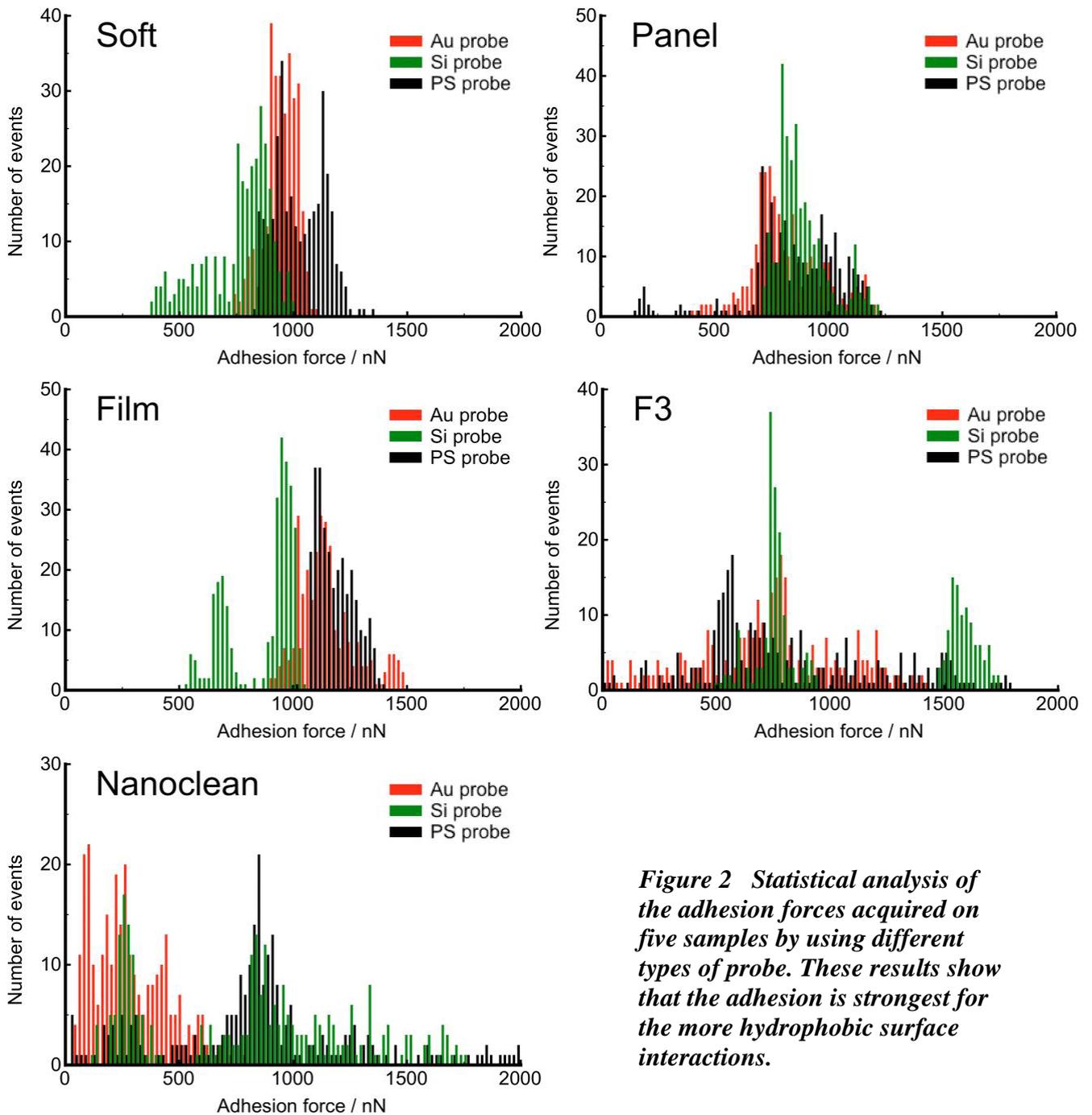
**Figure 1. Height (Left) and corresponding amplitude (Right) images of samples, acquired under intermittent mode at scan scale of 5  $\mu\text{m}$ .**

## **(ii) Adhesion measurement**

Adhesion force was calculated based on the force-displacement curves by using Carpick’s toolbox, and averaged values are summarized in Table 2. Samples of the statistical analysis of the adhesion force are shown in Figure 2, which provides a complimentary understanding of the adhesion data shown in Table 2.

Type of Probe	Silica	Gold-coated silica	Polystyrene
Sample name			
<b>Soft</b>	752.08±147.06	951.87±69.48	1027.79±109.82
<b>Panel</b>	848.11±112.98	823.55±160.72	847.12±214.75
<b>Nanoclean</b>	803.08±443.79	285.14±161.34	1073.17±629.94
<b>Film</b>	866.80±144.75	1152.12±125.74	1177.89±81.77
<b>F3</b>	1076.98±420.92	746.64±329.49	813.09±393.31

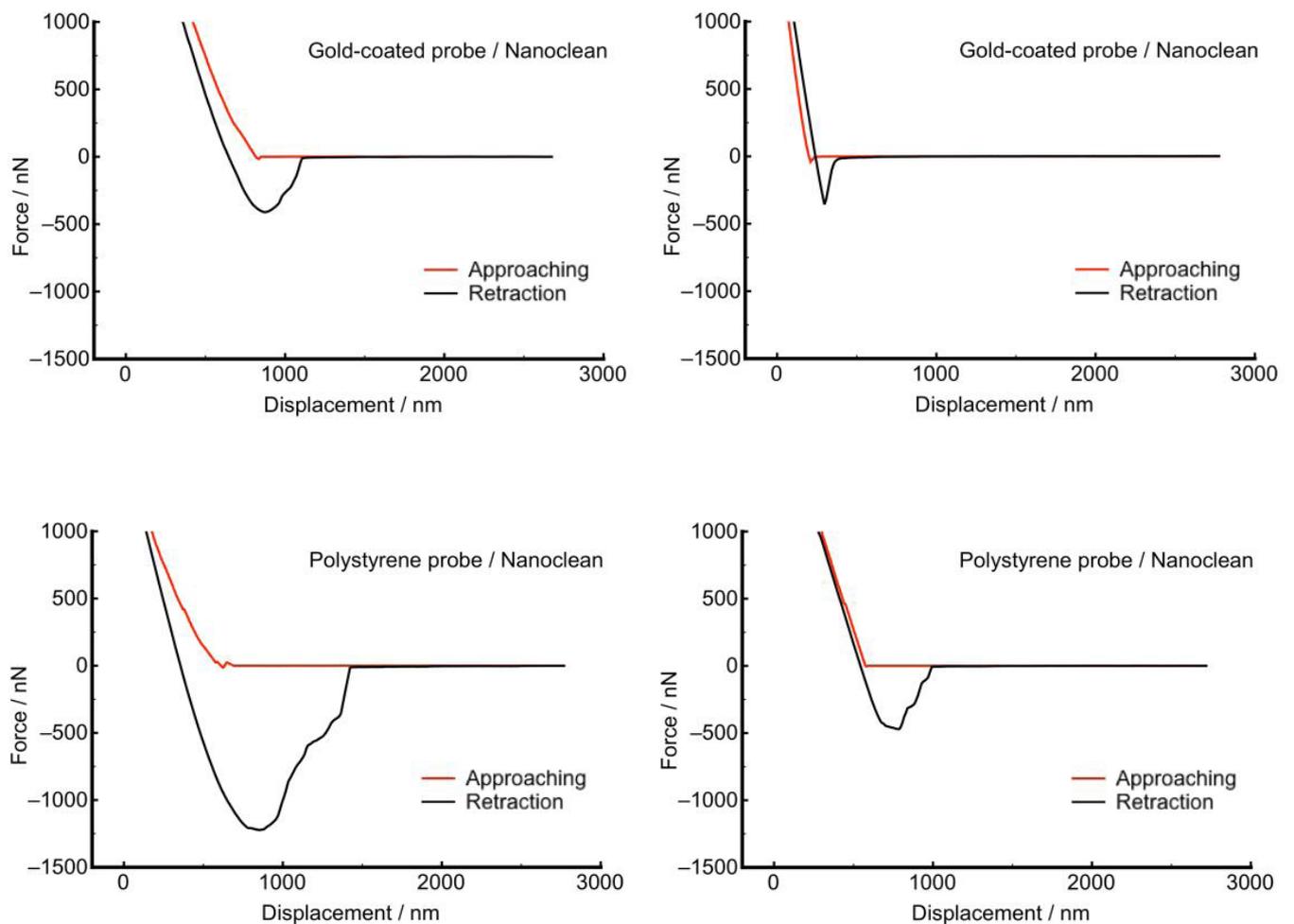
**Table 2:** Averaged adhesion force (nano-newton) of three types of probe (silica, Gold-coated silica, and polystyrene) on five different samples

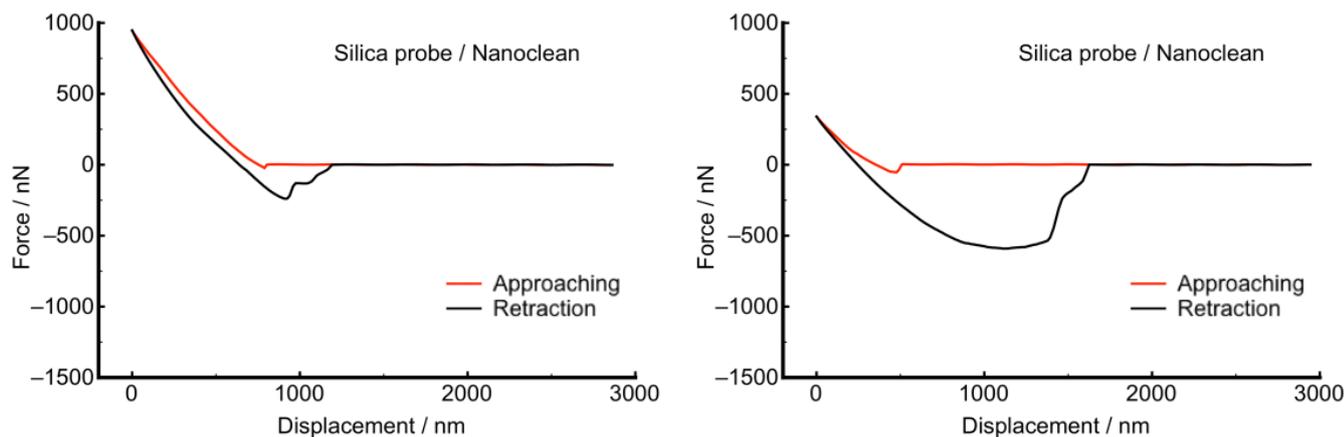


**Figure 2** Statistical analysis of the adhesion forces acquired on five samples by using different types of probe. These results show that the adhesion is strongest for the more hydrophobic surface interactions.

It was found that 'Soft' and 'Film' specimen have largest adhesion force with polystyrene probe, then gold-coated probe, and smallest with silica probe. The data indicate that hydrophobic particles adhere more strongly to these two samples in comparison to hydrophilic ones, although the difference is not huge.

For sample 'Panel', adhesion forces acquired by various types of probes are in a very close range; even the distributions of the adhesion forces follow a similar pattern. This suggests that sample 'Panel' has similar capabilities to attract particles of different surface properties. The adhesion force on sample 'Nanoclean' has a different trend to that of the 'Soft' sample; the polystyrene probe has the largest adhesion to the 'Soft' sample, whilst the gold-coated probe has the smallest adhesion. It is worth noting that there are two distinct groups in the distribution of adhesion forces acquired using the silica probe, which suggests that the adhesion between silica surface and 'Nanoclean' sample is not consistent throughout the surface, although the surface roughness of the 'Nanoclean' sample is the smallest compared to other samples. This is supported by the force-displacement curves acquired from different locations (See the typical force curves shown in Figure 3). Comparison between the three types of probes supports the conclusion that 'Nanoclean' sample could collect much more hydrophobic particles than hydrophilic ones.





**Figure 3** Typical Force –Displacement Curves

The adhesion forces on sample ‘F3’ is widely distributed for all probes, from tens of nano-newton up to thousands of nN, which results in large standard deviation values. Such a wide distribution is attributed to the large roughness of the sample surface.

## Conclusions

- 1 The chemistry of the elastomer has a significant impact on the adhesion force profile
- 2 Different types of contamination, with the same geometry have differing adhesion to the same elastomer.
- 3 Increasing surface roughness induces significant variations in the level of adhesion
- 3 Reaction to moisture changes the adhesion force

## Acknowledgements

Dr Zhenyu (Jason) Zhang and Professor Mark Geoghegan of the Polymer Institute at the University of Sheffield

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