The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2063-11

ICTP/FANAS Conference on trends in Nanotribology

19 - 24 October 2009

Influence of sliding speed and surface properties on adhesion and friction forces

MAZERAN Pierre Emmanuel

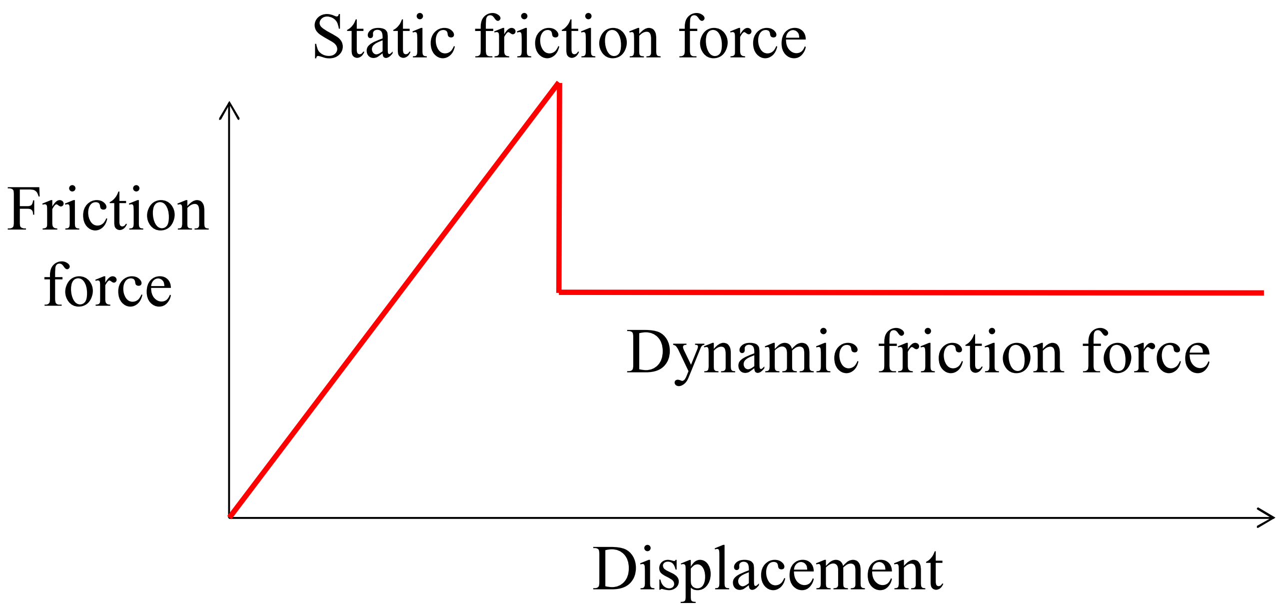
Universite de Technologie de Compiegne
Genie des Systemes Mecaniques
Laboratoire Roberval UMR CNRS UTC 6253
Rue Personne de Roberval
BP20529 60205 Cedex Compiegne

Influence of Sliding Speed and Surface Properties on Adhesion Force

Pierre-Emmanuel MAZERAN
Mechanic of Surfaces Group, Laboratoire Roberval, UMR 6253, Université de Technologie de Compiègne, France

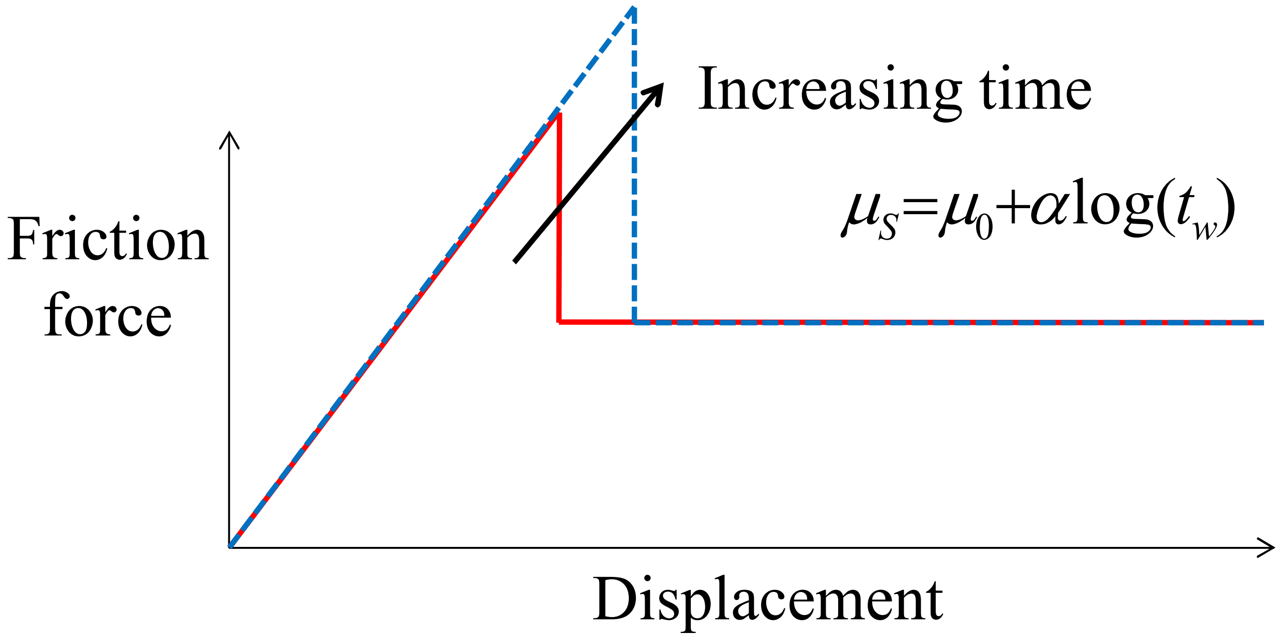
Hussein NASRALLAH, Olivier NOEL
Molecular Landscapes & Biophotonics Group, LPEC UMR 6087, Université du Maine, Le Mans, France

INTRODUCTION



- At the macroscopic scale, the static friction coefficient is higher than dynamic friction coefficient
- Static friction force is time dependent, adhesion is involved in this phenomenon

INTRODUCTION



- At the macroscopic scale, static friction coefficient is higher than the dynamic friction coefficient
- Static friction force is time dependent, adhesion is involved in this phenomenon

INTRODUCTION

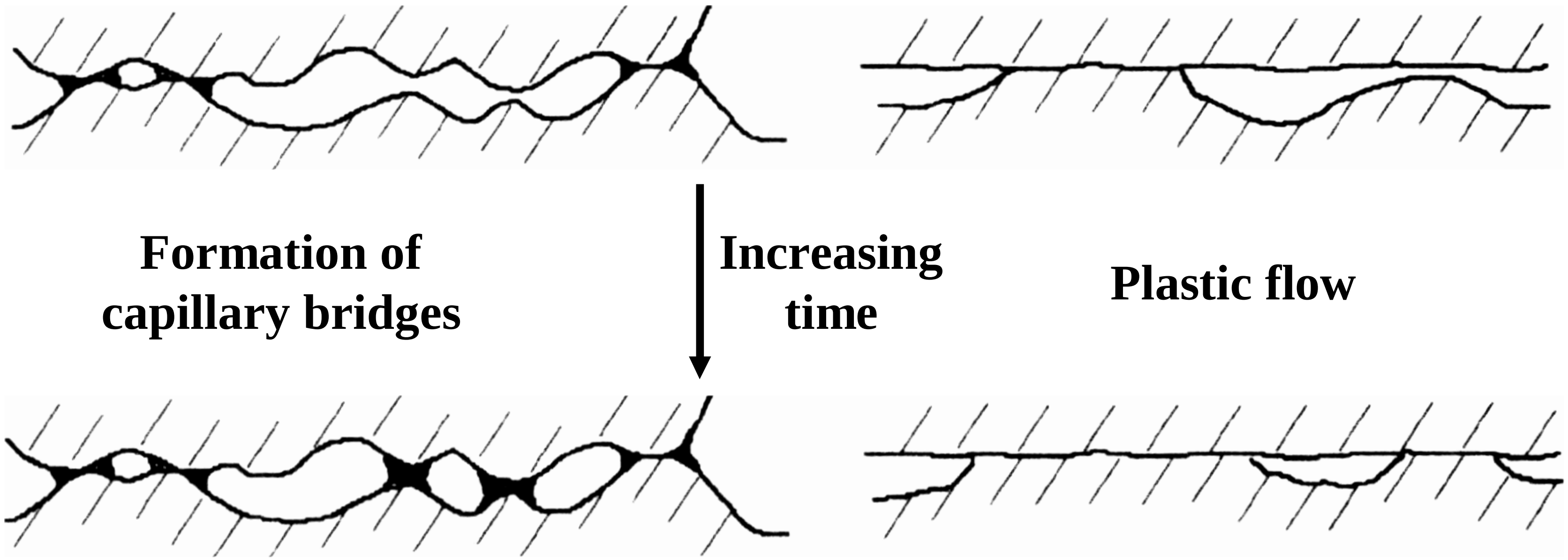
- Hydrophilic surfaces: Capillary adhesion in gaps between bodies in contact
- Metals: Solid-solid adhesion between asperities due to plastic flow

T. Baumberger, *Solid State Comm.* 102 (1997) 175–85

L. Bocquet & al. Nature 396 (1998) 735-737

B.N.J. Persson & al., Wear 254 (2003) 835-851

INTRODUCTION



- Hydrophilic surfaces: Capillary adhesion in gaps between bodies in contact
- Metals: Solid-solid adhesion between asperities due to plastic flow

T. Baumberger, *Solid State Comm.* 102 (1997) 175–85

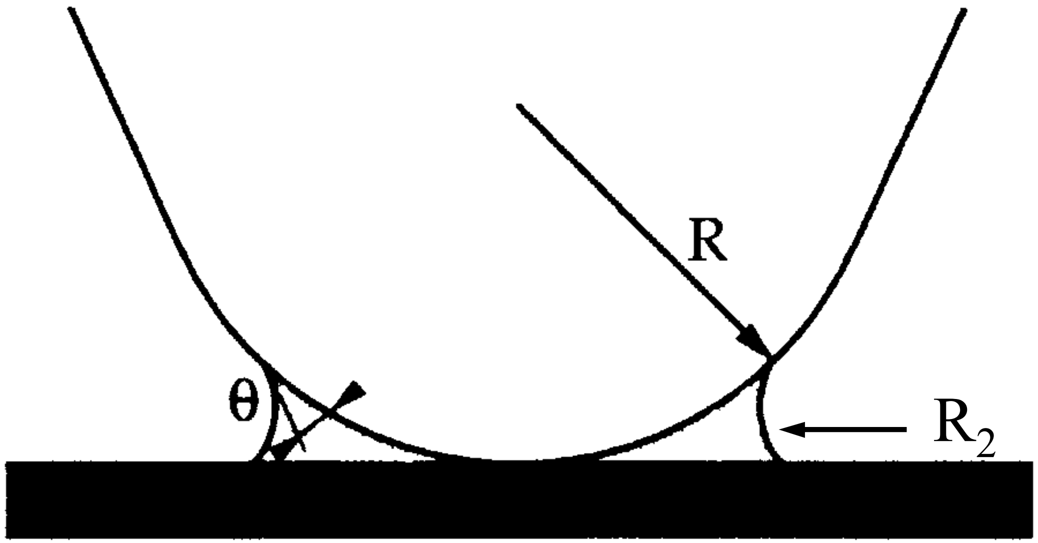
L. Bocquet & al. Nature 396 (1998) 735-737

B.N.J. Persson & al., Wear 254 (2003) 835-851

STATE OF THE ART

$$R_2 \approx R_K \approx 1-2\,nm$$

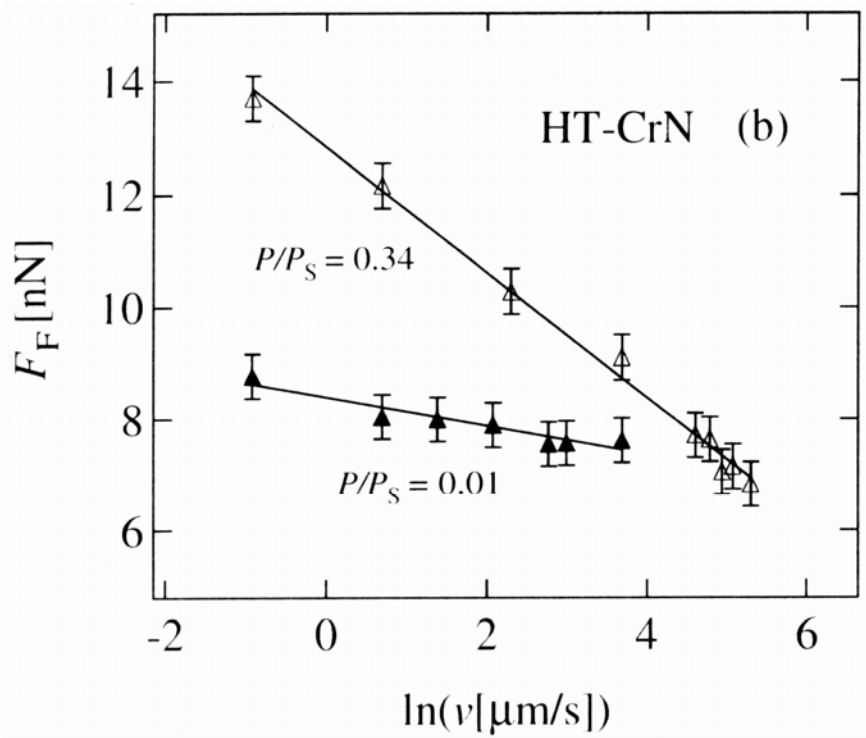
$$F_{Cap} \approx 4\pi R\gamma_{LV}\cos\theta$$
$$\approx 10-50\,nN$$



- For AFM experiments in wet air, capillary condensation occurs for hydrophilic surfaces
- The capillary meniscus generates a capillary force that adds to the normal load
- The formation time of the meniscus is of the order of a few ms (R. Szoszkiewicz & E. Riedo, Phys. Rev. Lett. 95 (2005) 135502)

STATE OF THE ART

- Friction force is velocity dependent
- For hydrophilic surfaces, friction force decreases with an increasing sliding speed
-This decrease is more important for high relative humidity
-This decrease of friction force is related to a decrease of capillary force



E. Riedo et al. Phys. Rev. Lett. 88 (2002) 185505

L. Sirghi, App. Phys. Lett. 82 (2003) 3755-3757

AIM

- ANR project 08-JCJC-0051-01 (2008-2011): PENELOPE Par MEDEE, H. Nasrallah PhD thesis

- Get direct evidence of the decrease of capillary forces with an increasing speed
- Describe the influence of sliding speed on capillary force as a function of contact properties (hydrophilic, roughness, tip radius, etc…)
- Describe the mechanism involved (thermodynamic, kinetic…)
- Establish relationships between the decrease of friction force and capillary force

EXPERIMENTAL SET-UP

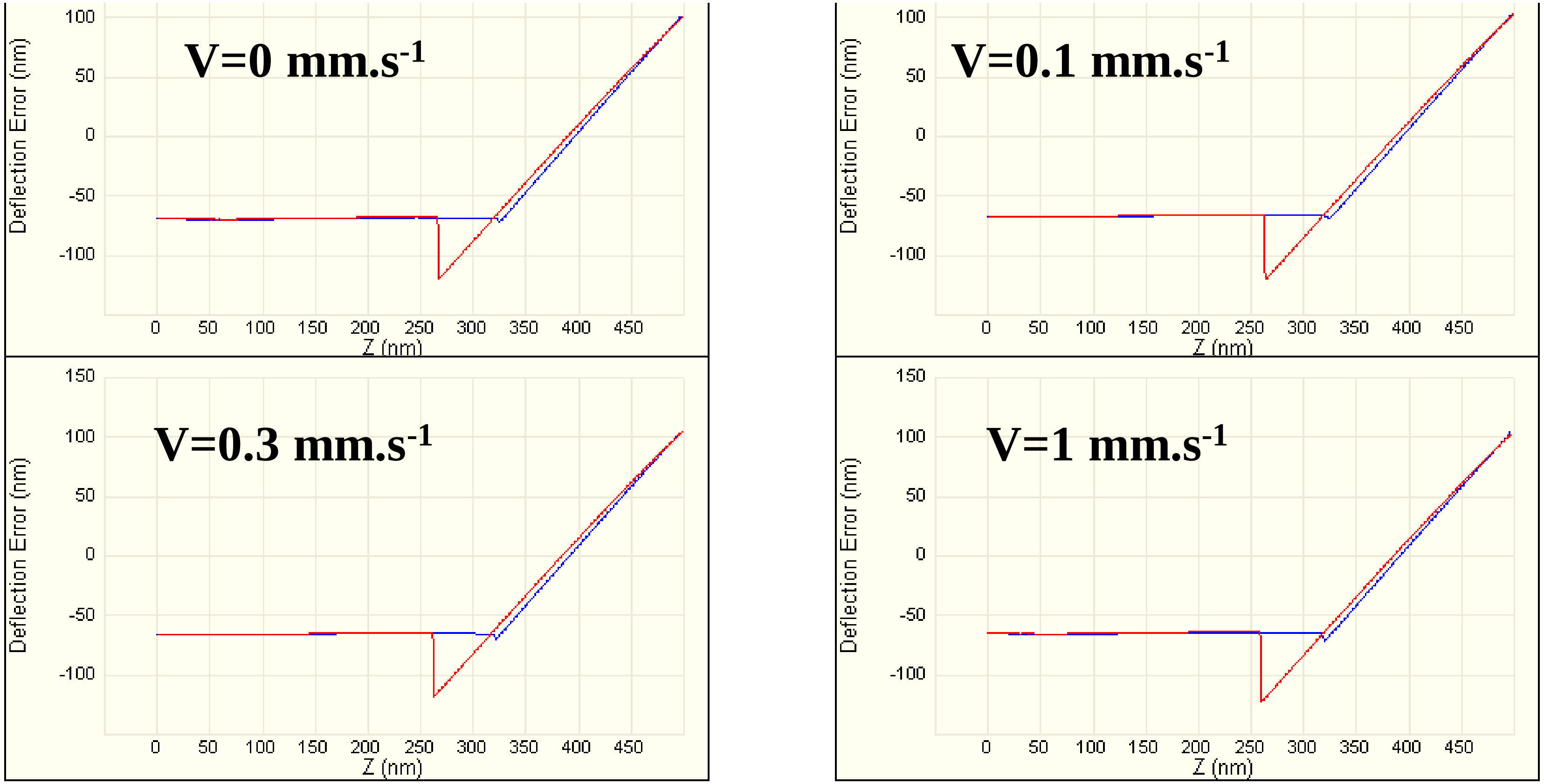
- Allows measuring of adhesion and attractive forces by means of force spectrum method while having a contact displacement with constant sliding speed

- Understanding the effects of surface (wetting properties, morphology…) and tip properties (probe nature, curvature radius…)

- Influence of relative humidity at ambient temperature

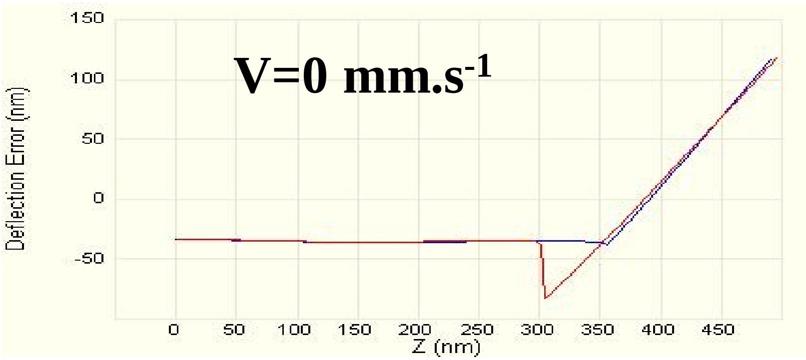
- Si_3N_4 AFM tip k=0.58 N/m

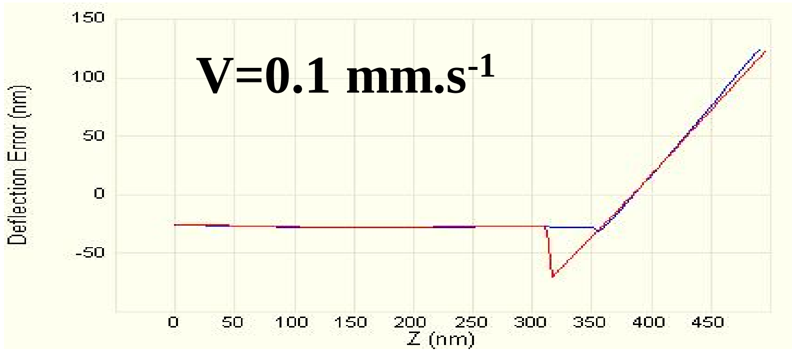
TIP SLIDDING ON HYDROPHOBIC SURFACE

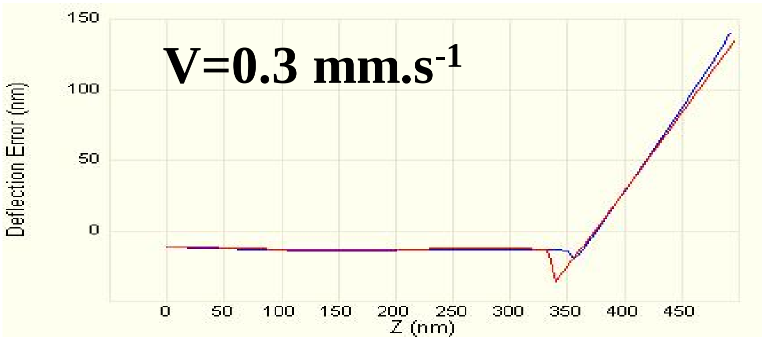


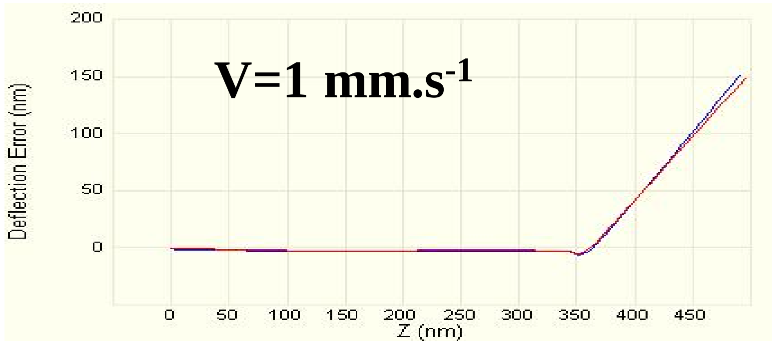
- According to contact angle of HOPG (θ=110°), no capillary condensation should occurs
- Adhesion force is constant whatever the sliding speed

TIP SLIDDING ON HYDROPHYLIC SURFACE





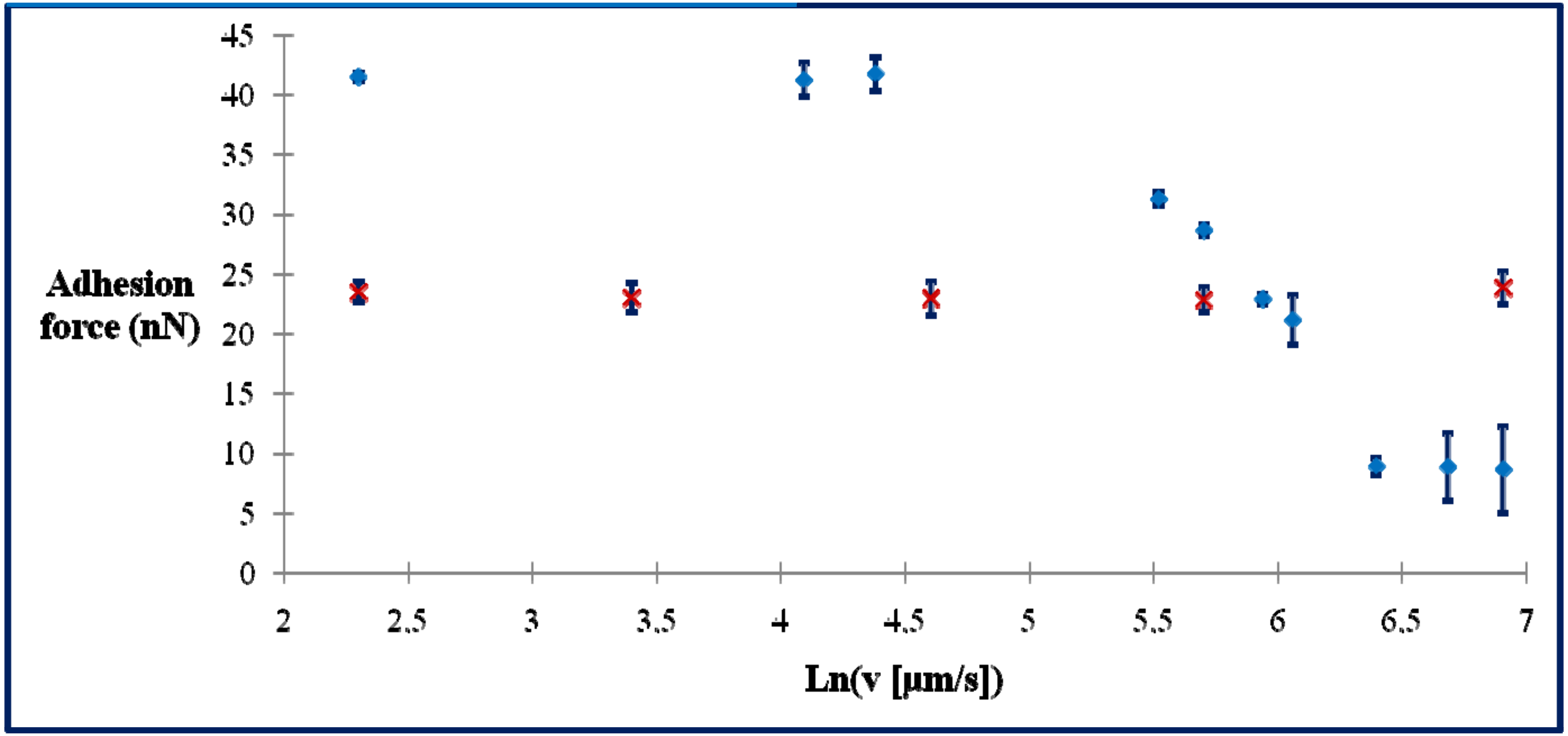




- Adhesion force is decreasing with an increasing sliding speed on hydrophilic surfaces (Gold θ=55°)
- At high sliding speed, the adhesive force is equal to the attractive force, the capillary force has vanished

HYDROPHILIC/HYDROPHOBIC BEHAVIOR

Experiments show that the variation of the adhesion force is linked to the hydrophilic properties of the surface



Hydrophilic

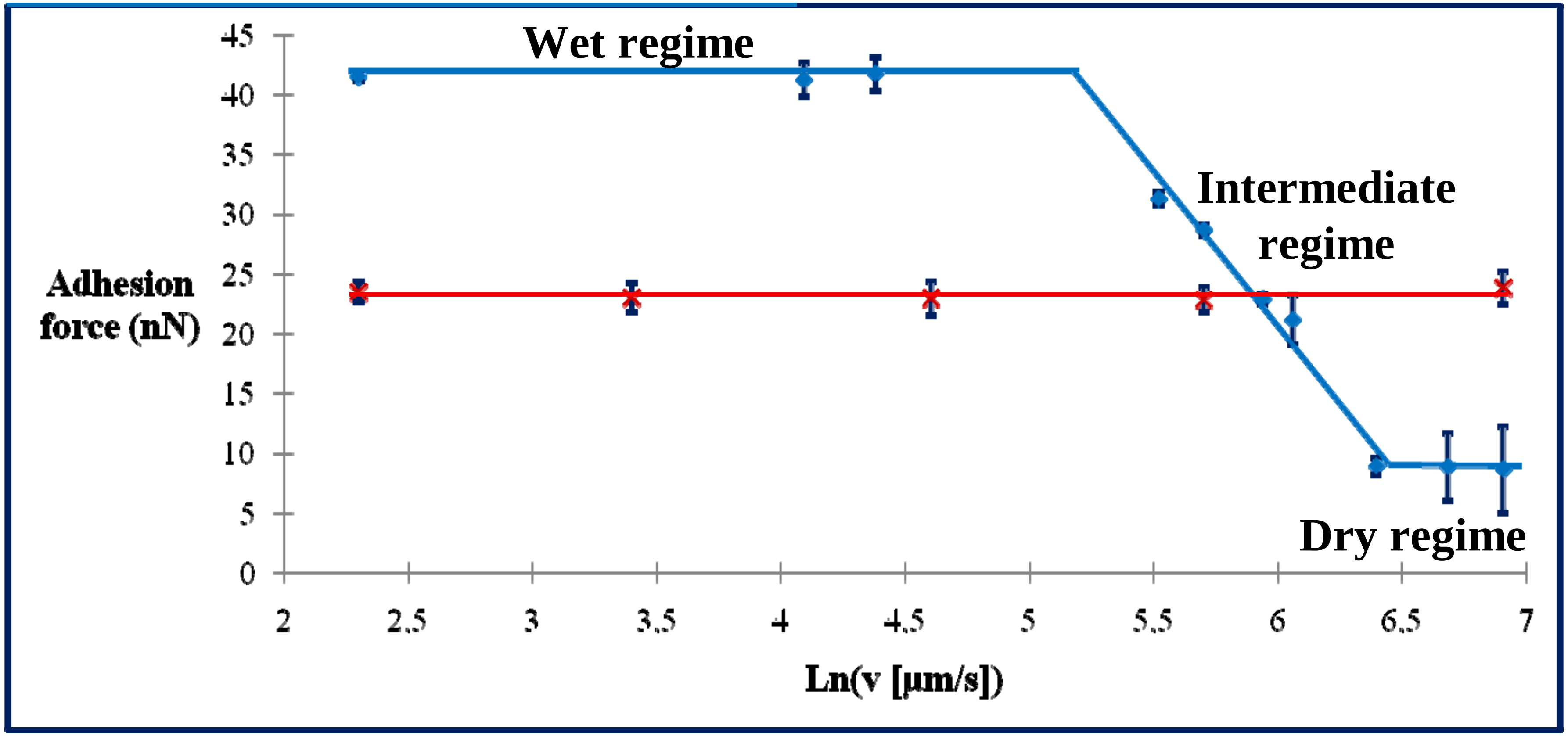
(Gold sample θ = 55°)

Hydrophobic

(HOPG sample θ = 110°)

HYDROPHILIC/HYDROPHOBIC BEHAVIOR

Experiments on adhesive force are similar to those observed for friction force



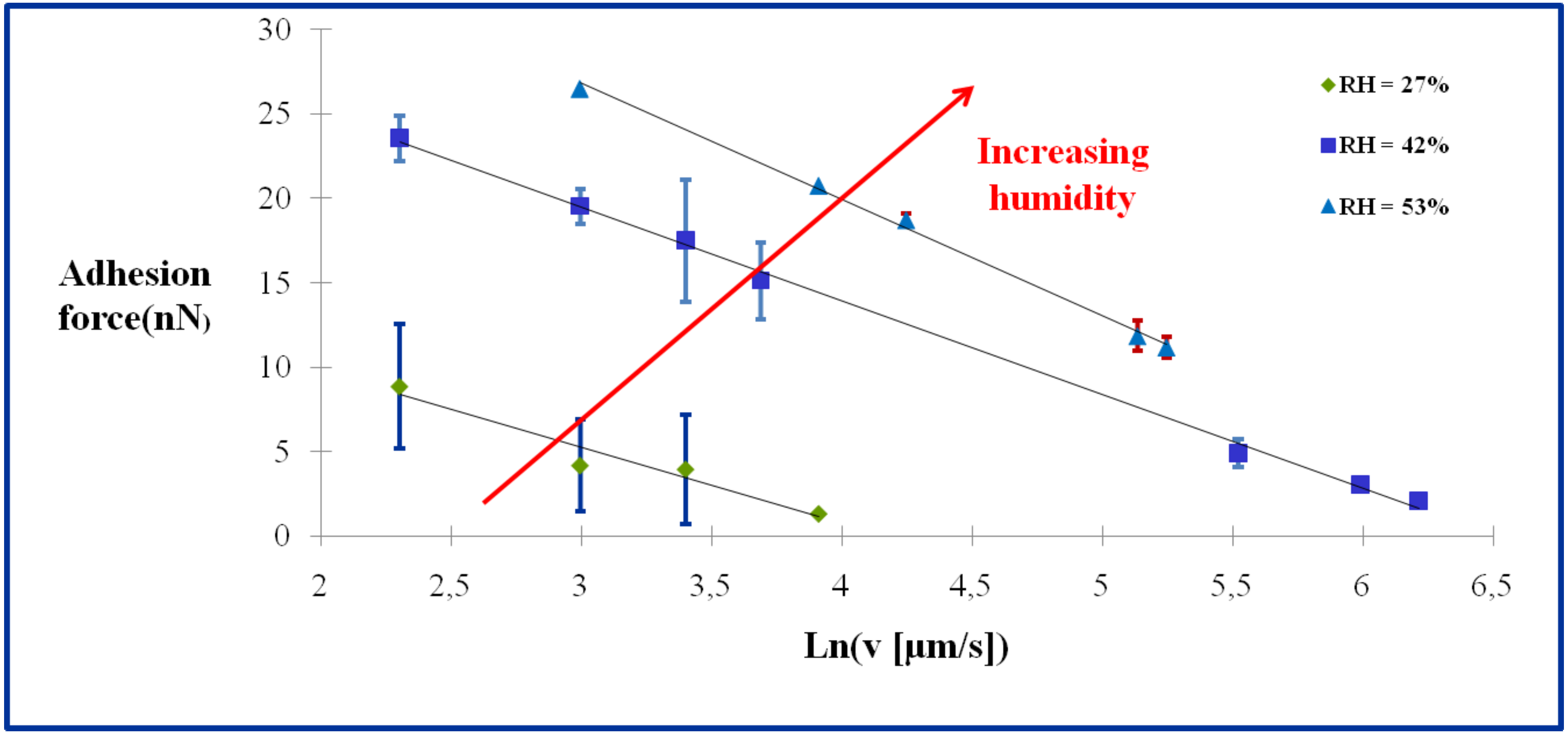
Hydrophilic

(Gold sample θ = 55°)

Hydrophobic

(HOPG sample θ = 110°)

EFFECT OF HUMIDITY

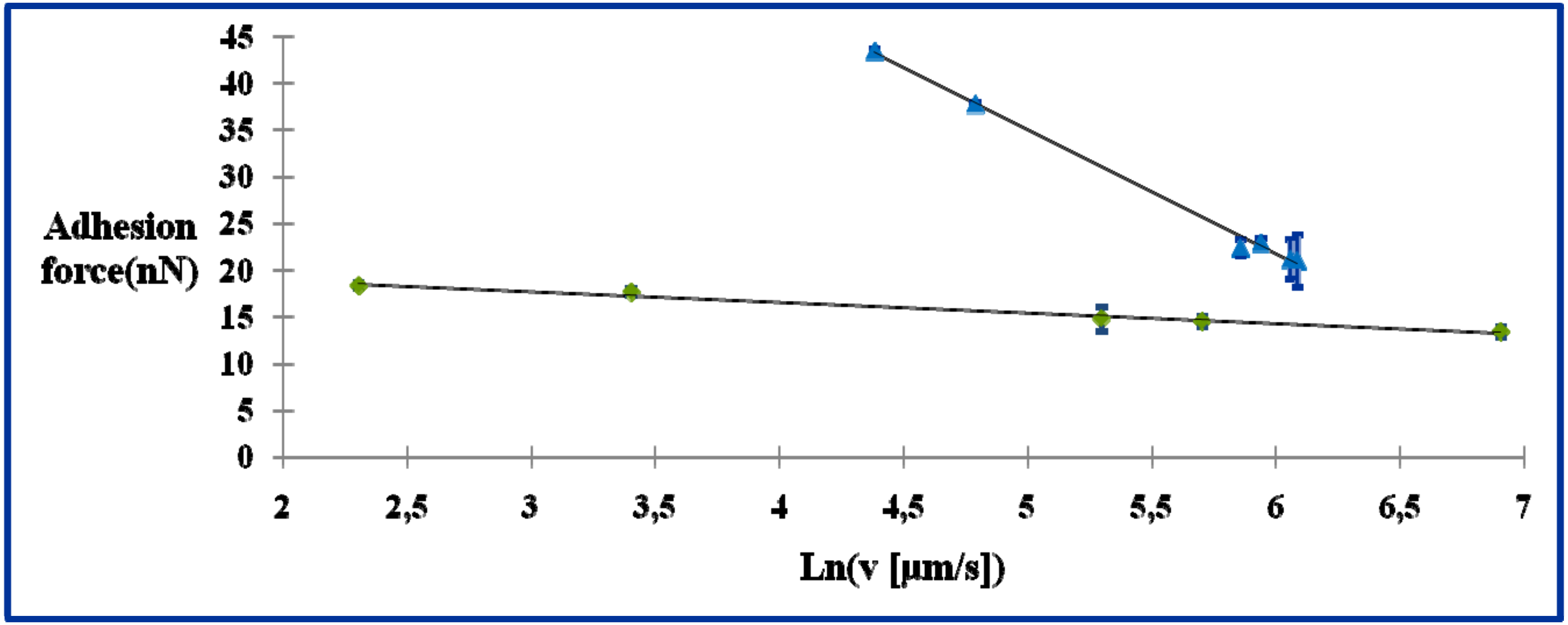


Mica

- Static contact angle ≈25°

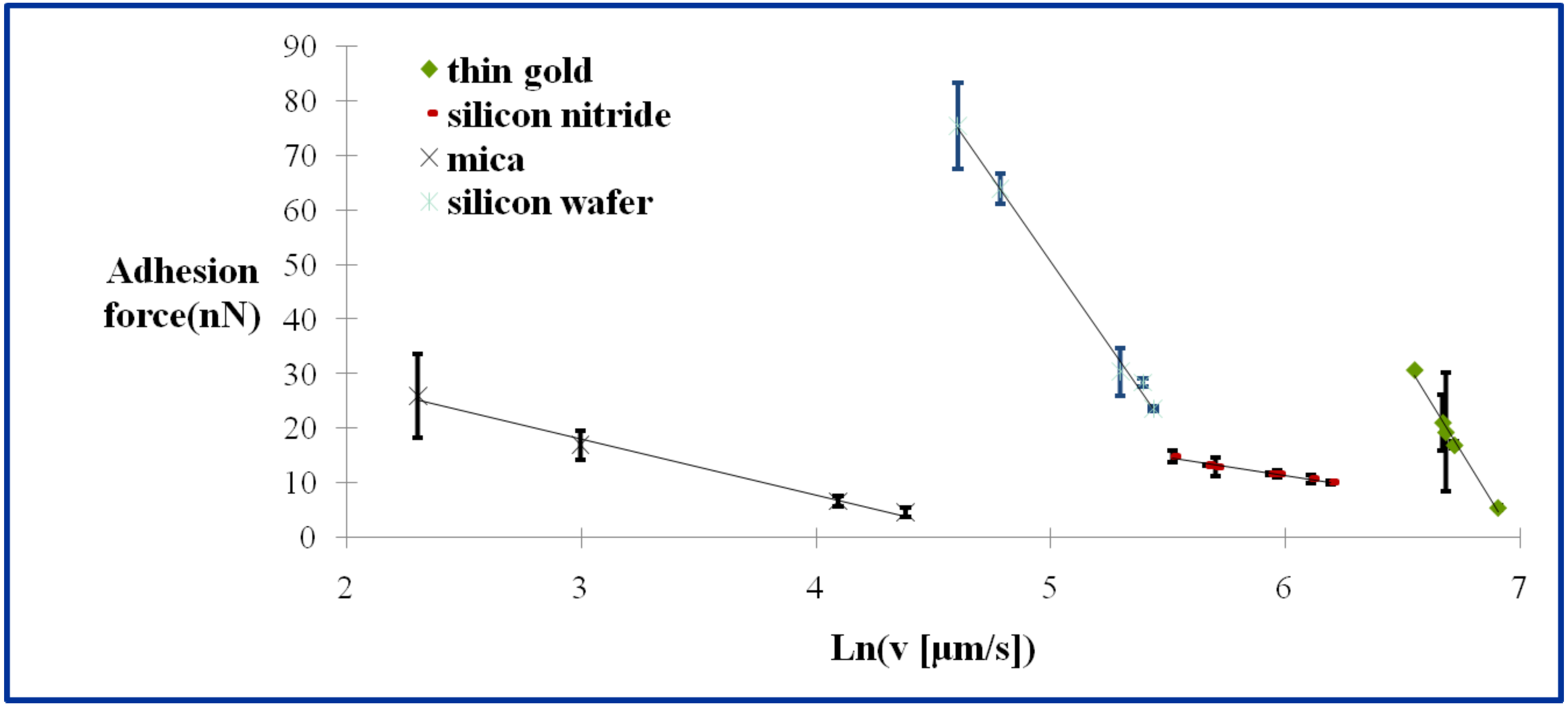
- Tip (silicon nitride, R≈30 nm)

EFFECT OF TIP RADIUS



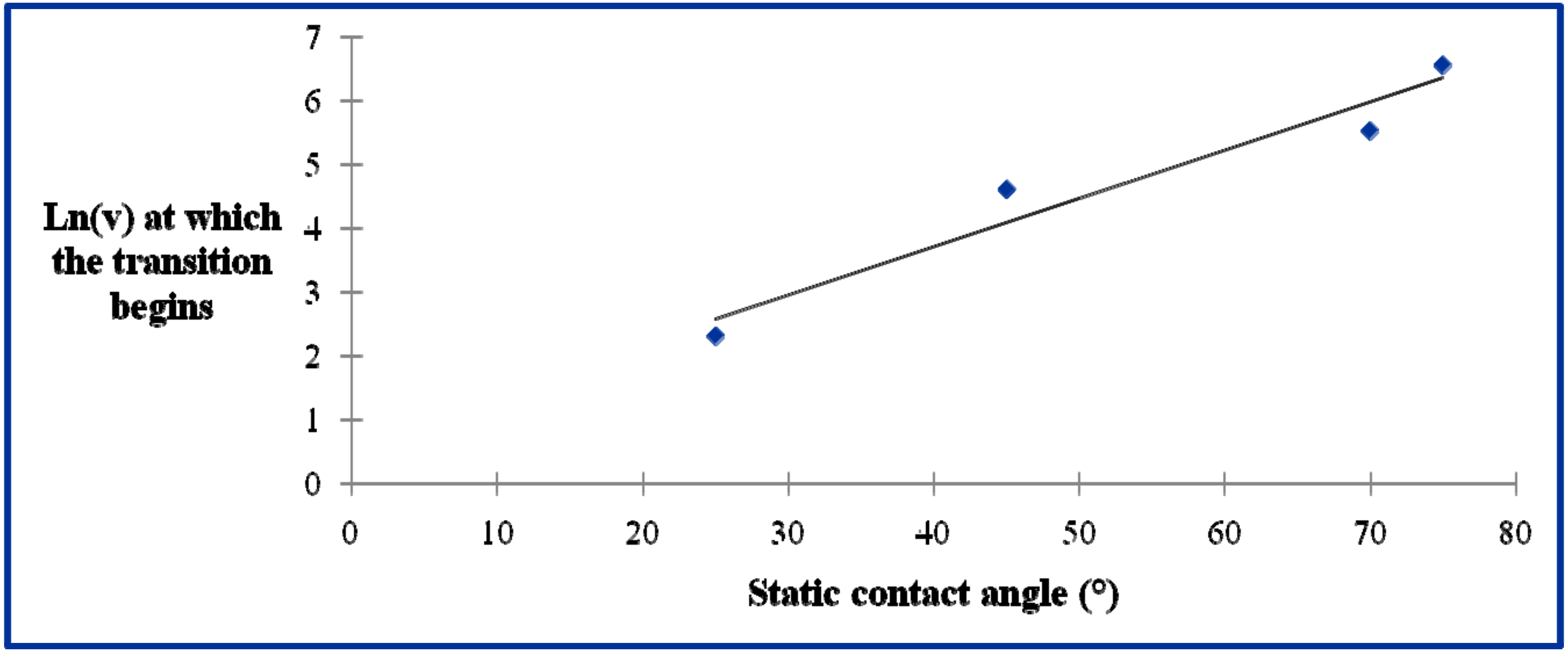
- Intermediate regime for small tip radius (15 nm-green points) and large tip radius (50 nm-blue triangles) at 50% humidity
- Adhesion force is proportional to tip radius
- The intermediate regime starts earlier for tip with smaller radius.

INTERMEDIATE REGIME FOR DIFFERENT SAMPLE



- Different samples : Different chemical properties and different roughness
- Same tip (Si_3N_4, R≈50nm) and same humidity (48%)

INTERMEDIATE REGIME



The beginning of the intermediate regime increases linearly with the static contact angle with water

Contact angles: *Mica 25°, Silicon wafer 45°, Silicon nitride 70°, Gold 75°*

CONCLUSION

- 1 regime for hydrophobic surface, 3 regimes for hydrophilic surfaces (wet, intermediate and a dry regime)

- Wet regime, adhesion force corresponds to capillary force

- Dry regime, adhesion force corresponds to attractive force

- In intermediate regime, the adhesion force decreases linearly with the logarithm of the sliding speed.

- Effect of tip radius, humidity and surface morphology on the borders of the intermediate regime

- We observe that the sliding speed, at which the transition regime starts, increases with the static contact angle measured with water for the different studied substrates

For this work see Noël et al. To be submitted to Langmuir

ACTUAL WORKS AND PERSPECTIVES

- Enlarge the experiment database with different experimental conditions to fix the general trends

- See if the morphology (local curvature change) of the surface has an influence on the intermediate regime

- Build a model that could explain experimental results

- Role played by capillary force on friction :

1) Does the capillary force act only as an additional force ?

2) Is the friction coefficient constant ?

For the curvature of surface, see Mazeran et al, Surf. Scie. 585 (2005) 25-37)

H.Nasrallah, P.-E. Mazeran, O. Noël