Non-monotonic friction due to water capillary adhesion and hydrogen bonding at multi-asperity interfaces

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SUPPLEMENTAL MATERIAL

Hysteresis in the relation between friction and humidity, as shown in Fig.S1, appears when the friction system is not fully dried before changing the humidity inside the chamber. Such hysteresis is believed to be due to the residual water trapped at the interface. This remaining water could enhance the capillary adhesion at the interface, thereby increasing the friction based on Amontons law as the capillary adhesion contributes an additional normal force and the friction force is proportional to the normal force. Once the residual water is removed by long-time nitrogen drying, the hysteresis could be eliminated as shown by point 10 in Fig. S1. What's more, the speed at which the CoF reaches a steady state in Fig. S2 also indicates the influence of residual water on friction: the CoF reaches a steady state faster after a small change in relative humidity when the sphere is kept in contact with the wafer. In contrast, the CoF could reach a steady state at almost the same speed with surface separation during drying.

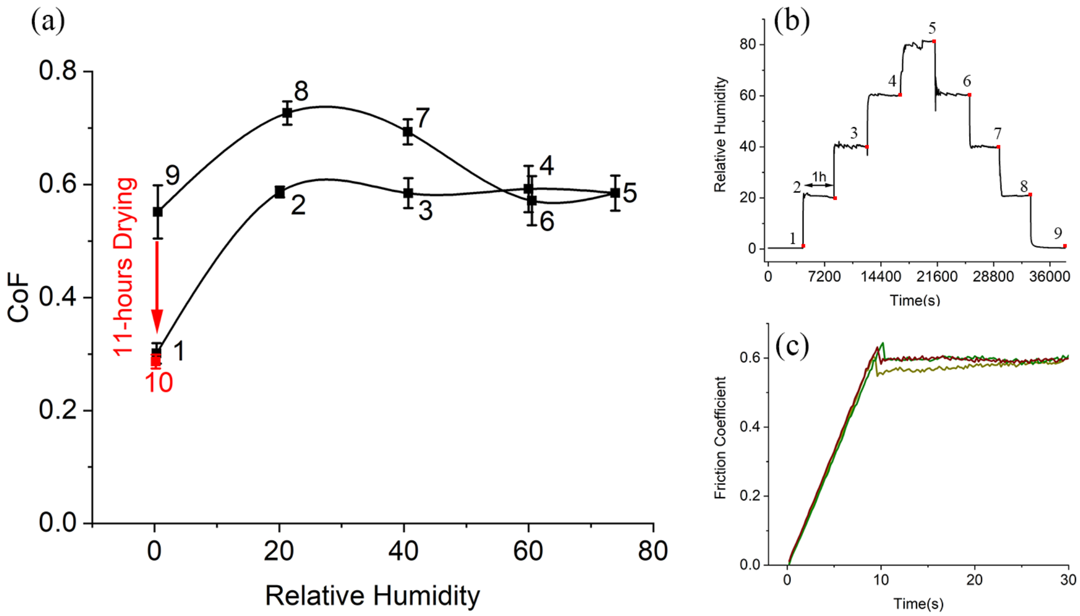

FIG. S1. Friction coefficient hysteresis loop as a function of relative humidity (a). In total ten sets of friction experiments were performed. The corresponding humidity-time curve and the times at which friction experiments were conducted are marked with red dots and numbers in (b). (c) is one example of how the friction coefficient is defined in the steady state at 20% humidity.

TABLE S1. Mechanical properties of the Si ball and the Si wafer.

Youngs modulus (GPa)	Poissons ratio	Hardness (GPa)
130	0.2	10

TABLE S2. Absorbed water film thickness and nucleation distance in various relative humidities.

Relative humidity	Given elastic repulsive force, $F_{elastic}$ (mN)	Thickness (nm)	Nucleation distance , D (nm)	Simulated capillary adhesion, $F^{adhesion}_{simulated}$ (mN)
10%	53.53	0.35	1.17	9.55
20%	56.24	0.55	1.47	10.25
40%	51.93	0.89	2.07	7.24
60%	53.81	1.23	3.12	6.50
80%	52.15	1.52	5.39	4.28

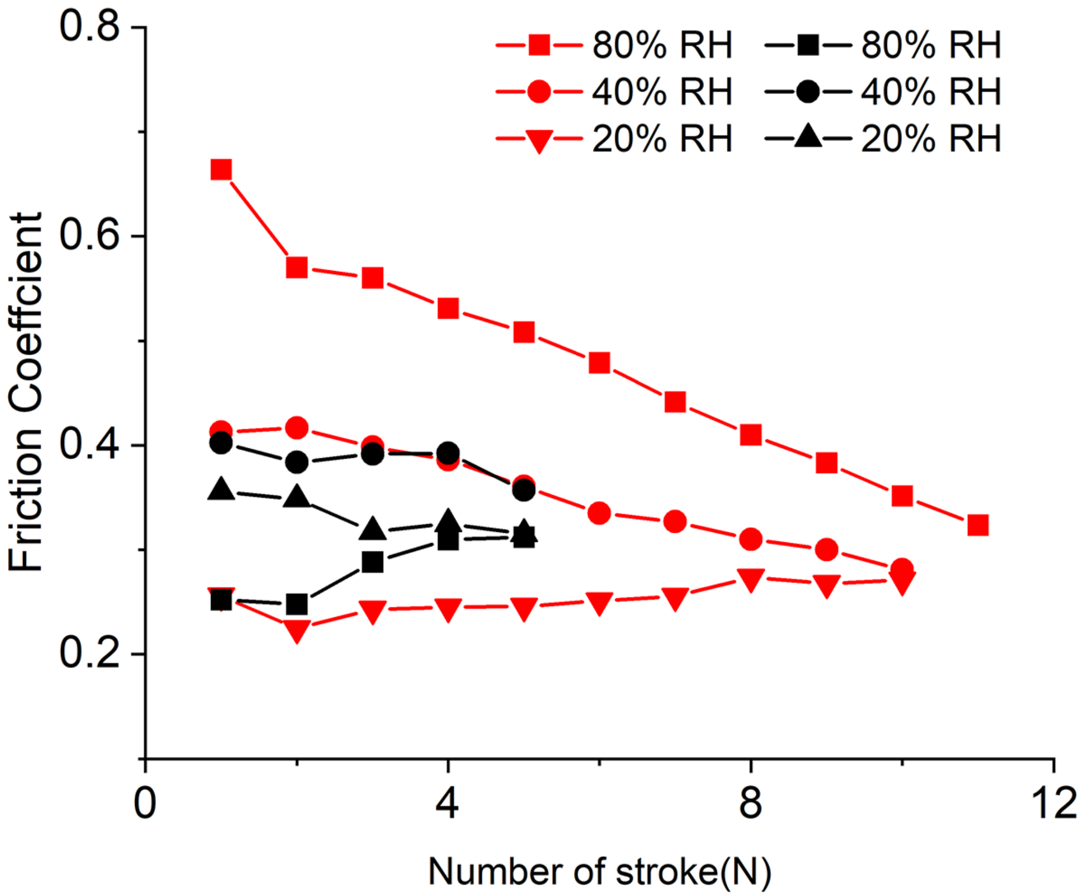

FIG. S2. Friction coefficient as a function of the number of strokes measured after drying the system for one hour. The black solid and red solid lines indicate the situation with (black) and without (red) contact separation after sliding in a specific humidity environment.

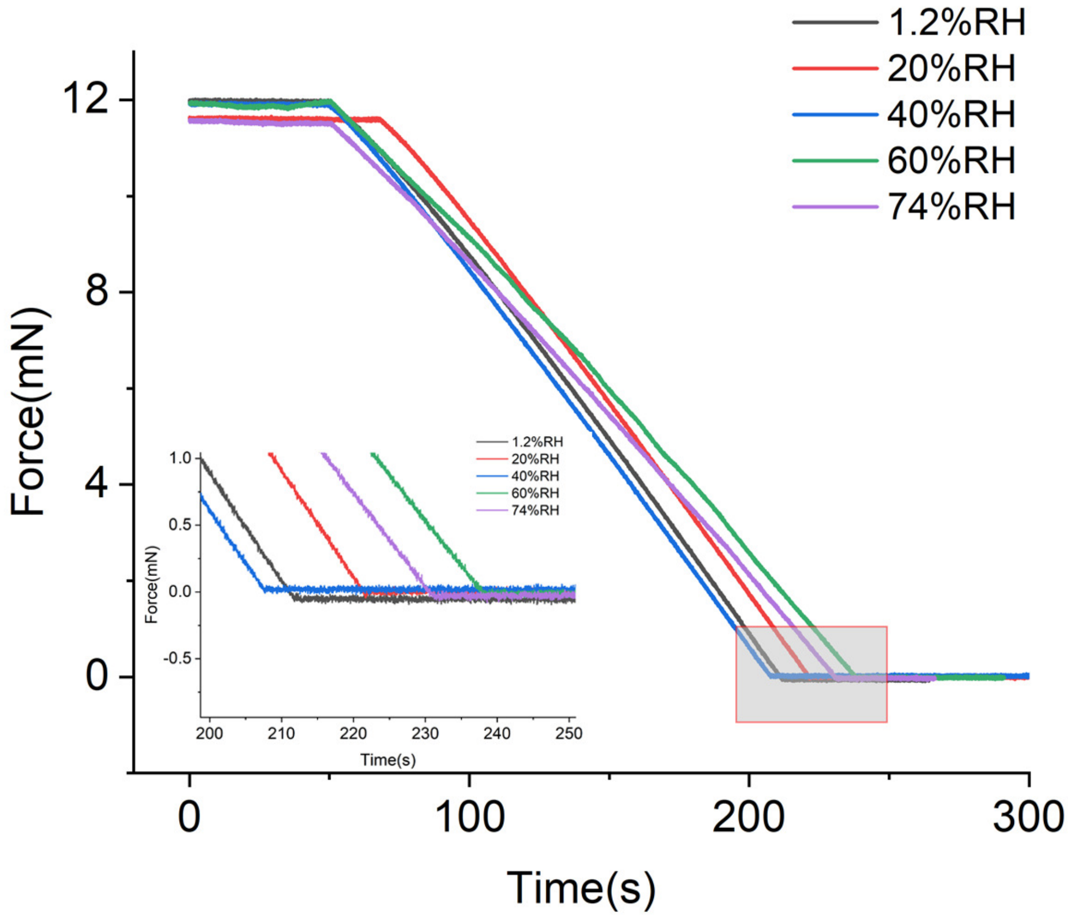

FIG. S3. Force as a function of time measured during the retraction of a sphere from a worn sphere at a speed of 77 nm/s till the surfaces were separated, the inset shows the force near the contact separation point.

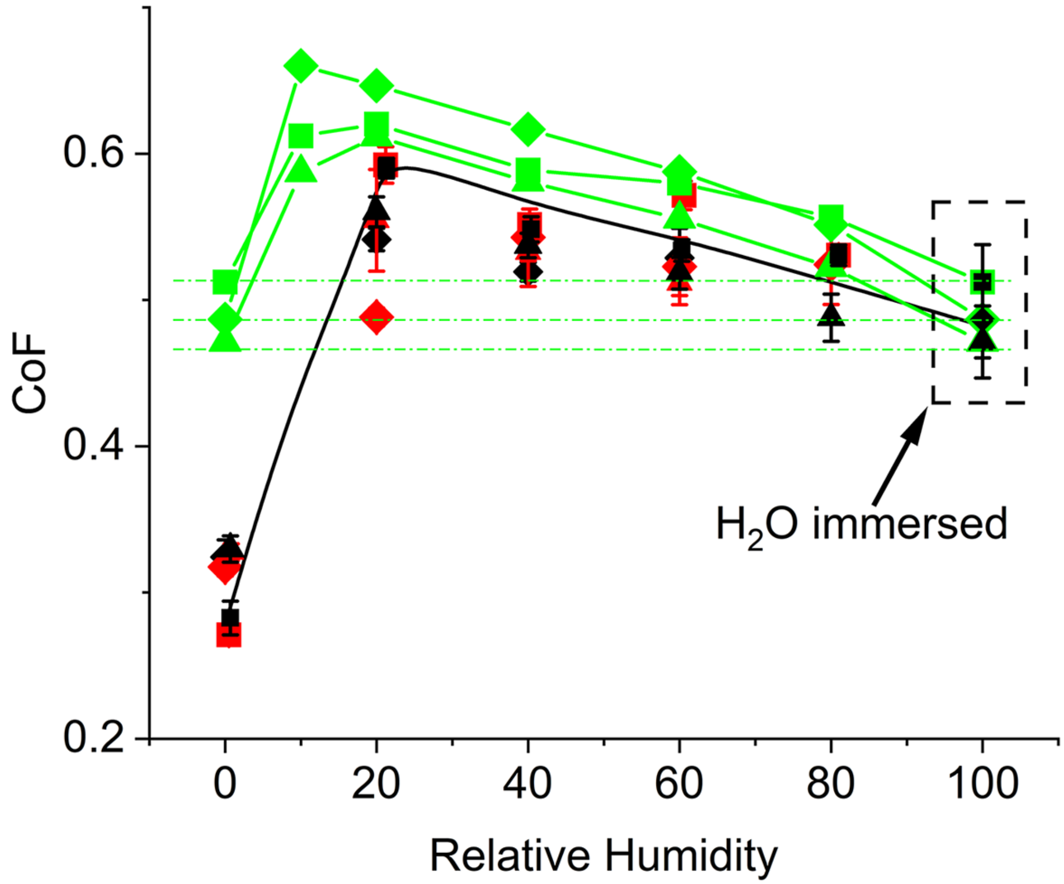

FIG. S4. Calculated and measured coefficient of friction as a function of relative humidity. The red and black symbols indicate friction experiments conducted at increasing (black) and decreasing (red) relative humidity varying from 0.6% to 80%. Squares, triangles and diamonds each correspond to an experiment conducted with a different sphere. The corresponding simulation results are represented by matching green symbols.