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Tribology and ultrasonic hysteresis at local scales

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Abstract

Local adhesion hysteresis (AH) is difficult to measure using an AFM due to complications introduced by compliant cantilevers as they snap-in and snap-out to/from a sample surface. But, at ultrasonic frequencies well above the cantilever mechanical resonance, the effective stiffness can increase enormously. Therefore, ultrasonically vibrating a sample in contact with an AFM tip can probe the hysteretic cycle of tip–sample in- and out-interactions [Jpn. J. Appl. Phys. 32 (1993) 22; Acoust. Imag. (1996)] allowing AH to be investigated by measuring ultrasonic hysteresis (UH). For the first time UH is compared here with lateral force microscopy (LFM) data. The same kind of experiments is also implemented for a nanoindenter based setup. Thus, the *micro*- (nanoindenter) and *nano*- (AFM) scales are investigated. UH and friction of both length scales are found to be linearly related for surfaces differing widely in elasticity and adhesion.

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1. Introduction

For an insight into adhesive material properties, an AFM is usually applied with force modulation. There are, however, certain constraints due to cantilevers. Compliant levers are subjected to a large mechanical hysteresis [3], while the use of stiff cantilevers, with a few exceptions [4], decreases the sensitivity and overall contrast. To overcome these difficulties a family of techniques applying ultrasonic excitations was developed [2]. In this paper, ultrasonic force microscopy (UFM) is exploited to investigate relations between adhesion hysteresis (AH) and friction.

UFM takes advantage of inertial stiffness which adds to the elastic stiffness of the cantilever due to high frequency vibrations. When ultrasonic excitation with a given amplitude a is applied to the sample, the cantilever experiences an average force $\bar{F}(\delta)$ known as the ultrasonic force [1]. Such a mean force is determined by averaging over the force–distance curve between tip and sample for the entire vibration amplitude, where δ is an indentation and/or separation with δ_0 as the initial indentation value. Modulating the vibrations by a frequency at which the cantilever can readily respond (Fig. 1(a)) causes the lever to deflect from its initial position z_0 by an extra term $\bar{z}_t$ arising from the difference between initial and averaged tip–sample forces as

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