ADHESION FORCES BETWEEN MICA SURFACES IN AIR AND LIQUIDS

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INTRODUCTION

Adhesion forces between mica surfaces in the air and several kinds of liquid are measured with an apparatus composed of a flexible elastic stage driven by a piezo actuator. Cleaved mica has been used in many studies of surface interactions because of its wellknown surface characteristics, i.e., elastic and adhesive properties. In addition, the mica has molecularly smooth surface which is advantageous to the experiments in nano-scale. Liquids used as a medium between mica surfaces are *n*-octane, *n*-hexadecane, octamethylcyclotetrasiloxane(OMCTS) and PFPE oil. By comparing the results of the experiments with those in the past studies and those from van der Waals-Lifshitz theory, we found that the new apparatus detects surface interactions accurately, and that the adhesion forces are well described by considering mica-liquid-mica system and adsorbed films on the mica surfaces affect the interaction in the air.

EXPERIMENTAL

An apparatus used in this study is composed of three micro stages driven by DC motor for coarse movement, two elastic stages driven by piezo electric actuator for fine movement, a non-contact capacitive displacement sensor whose resolution is less than 1nm, and a double cantilever spring of constant k=314N/m supporting cylindrical mica surface whose curvature radius R is 1cm. The apparatus is put on air suspention and in clean booth where temperature and relative humidity(R.H.) are controlled to be constant. First, the mica surfaces in crossed cylinder geometry are made contact under initial contact load, then the load is decreased gradually. The two surfaces separate abruptly under negative load and we consider the negative pull-off load as adhesion force. ***Characteristics of mica surface*** are the following : reflactive index n=1.60, dielectric constant ε_0=2.56, absorption frequency ω=1.9×10^{16}rad/s, surface energy γ=60-72mJ/m^2, Young's modulus E=34.5GPa, Poisson's ratio ν=0.205, Vickers' hardness HV=1.43GPa, roughness Ra=0.048nm(by AFM). From the roughness data, we obtain the following contact parameters: curvature radius of asperity(1) β=18μm, standard deviation of asperity top distribution σ=0.048nm, the adhesion parameter(2) θ=0.0118-0.0174 which indicates the decrease of adhesion force by surface roughness will hardly exist, the plasticity index(1) ψ=0.0206 which indicates the contact will be almost elastic, the contact theory number(3) μ=101-115 which indicates JKR theory (4)is applicable to the present experiments carried out in the air and the Lifshitz theory(5) for those in liquid(6). According to G-W model (1), the plastic deformation begins when the load is 3.9mN, thus, the initial load must be lower than this value. ***Characteristics of four liquids*** are the following: OMCTS n=1.40, ε_0=2.30, ω= 1.60×10^{16}rad/s; *n*-octane n=1.39, ε_0=1.95, ω=1.88×10^{16}rad/s; *n*-hexadecane n=1.42, ε_0=2.05, ω=1.82×10^{16}rad/s; PFPE n=1.33, ε_0=1.78, ω=1.88×10^{16}rad/s.

THEORETICAL

When two mica surfaces(suffix 1) interact ***with the medium of liquid***(suffix 3), van der Waals force F between the surfaces is: $F = A_{131}R / 6D^2$ …[1] where D is the smallest distance between the surfaces and A_{131} is Hamaker constant which is a function of n, ε_0, ω of mica and liquid. D is called "cut off distance" whose value is about 0.165nm when two surfaces adhere(6). ***In the air***, the adhesion force is given by the following JKR equation: $F = 3\pi R\gamma = A_{11}R / 8D^2$ …[2]. In this theory, it is assumed that mica surfaces interact directly. But it is known by closer investigations that thin adsorbed film(suffix 2) exists on mica surfaces in the air. Characteristics of this film(7) are n=1.8, ε_0=3.24, ω=1.8×10^{16}rad/s and the thickness T=0.25-0.4nm. If we take the film effect into account, A_{11} in eqn.[2] is replaced with the following A_{eff}(7):

$$A_{eff} = A_{232} - 2A_{123}/\left(1+T/D\right)^3 + A_{121}/\left(1+2T/D\right)^3 \quad \ldots[3]$$

RESULTS

From measurements in the air, it is found that the adhesion force remains constant under 30% R.H. or less and is insensitive to velocity of surface separation, v, and initial contact load, P. So we decided experimental conditions as follows: R.H.<20%, v=5 μm/s and P<3.9mN to ensure an elastic contact. Table 1 shows the results of present experiments, calculated values from eqs.[1]-[3] and experimental values in the past studies. It is clear that these values agree well except the values from eqn.[2]. We conclude from these results that (i)this new apparatus we developed detects surface interactions accurately and (ii)the adsorbed film must be considered in case of the interaction in the air but surfaces interact directly in the liquids. We can predict the force between mica surfaces immersed in these liquids using the equation[1] with an excellent agreement. These results suggest that the adsorbed film on the mica surface in the air will dissolve in the liquids used in the present study.

Table 1. Adhesion Forces between Mica surfaces

	Exp. F(mN)	A(×10^{-20}J)	Th. F(mN)	Ref. F(mN)
Air	6.05-6.30	9.79[2]	4.49	5.65-6.78 (8)
		13.7-14.2[3]	6.29-6.52	
OMCTS	0.880-0.930	1.53[1]	0.935	0.854(9)
n-octane	0.649-0.685	1.15[1]	0.704	0.672(10)
n-hexad.	0.532-0.578	0.914[1]	0.559	0.612(11)
PFPE	1.05-1.12	1.84[1]	1.13	-

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