ТЕЗИСЫ ДОКЛАДОВ

INTERNATIONAL WORKSHOP

**«Multiscale Biomechanics and Tribology
of Inorganic and Organic Systems»**

МЕЖДУНАРОДНАЯ КОНФЕРЕНЦИЯ

**«Перспективные материалы с иерархической структурой
для новых технологий и надежных конструкций»**

**VIII ВСЕРОССИЙСКАЯ НАУЧНО-ПРАКТИЧЕСКАЯ
КОНФЕРЕНЦИЯ С МЕЖДУНАРОДНЫМ УЧАСТИЕМ,
ПОСВЯЩЕННАЯ 50-ЛЕТИЮ ОСНОВАНИЯ
ИНСТИТУТА ХИМИИ НЕФТИ**

«Добыча, подготовка, транспорт нефти и газа»

DOI: 10.17223/9785946218412/17

ADHESIVE CONTRIBUTION TO FRICTION

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1990s were the years of a new birth of tribology. Among the most fundamental understandings of this time was the essential importance of *elastic instabilities*. If a tip of an atomic force microscope is forced to slowly move along an atomically flat surface, than the macroscopic force of friction, that is tangential force averaged over a macroscopic distance, is exactly zero, provided the cantilever of the AFM is stiff enough [1]. In other words, if the tip follows continuously the moving stage, there is no friction in the system. The situation changes qualitatively if the stiffness is smaller than some critical value. Then the tip does not follow the stage continuously any more but shows sudden jumps. These jumps, known as elastic instabilities, cause irreversible energy dissipation – in form of waves going away from the contact region.

Theoretically, the key importance of elastic instabilities was illustrated in the famous paper by Ludwig Prandtl [2-4]. He developed a very simple model explaining the mechanism of energy dissipation in the case when the system is purely elastic. Prandtl used this model as a model for plasticity and only mentioned briefly that it is even better applicable for describing friction. Many years later, the Prandtl model became a standard model in interpreting experiments on nanoscale friction between a tip of an atomic force microscope and atomically smooth surfaces such as graphite or mica.

The concept of elastic instabilities lead further to the concept of structural superlubricity. If two bodies with atomically smooth periodic surfaces are in contact, then final friction appears only if they have equal or similar periods. In the case of incommensurate lattice periods, the friction is vanishing. This is especially easy to illustrate by rotating one crystalline body relatively to the other one. In commensurate orientation, there is high friction. However, friction practically disappears if the surfaces are not oriented so that they match each other [5].

But exactly this fundamental understanding puts the question of what is the mechanism of friction in hard, amorphous, elastic smooth surfaces as we have e.g. in the contact of an DLC coating with another hard surface. The problem is that such surfaces are elastic, so that they show no plasticity and no viscosity, they are amorphous and thus intrinsically incommensurate to each others and they are smooth which is equivalent to high enough later stiffness of individual asperities for preventing elastic instabilities. Thus, there is no energy dissipation due to plasticity, no due to viscosity and no due to elastic instabilities. The friction should vanish, but in reality, final friction is observed.

In the present paper we discuss a contribution to friction which is present even in a contact of amorphous elastic bodies. This contribution is due to adhesion. Adhesive contacts show hysteresis due to "adhesive instability" even in the cases when the bodies are completely elastic [6]. The adhesion hysteresis does exist independently of whether the contacts are soft or very stiff. Measurements of adhesion forces with atomic force microscopes show that there exist "adhesion hysteresis" which manifests itself in different apparent specific work of adhesion in the phases of approach and detachment.

In the present talk, we report results of numerical simulation of adhesive contacts of rough surfaces using the full three-dimensional Boundary Element Method (BEM) [7]. Large-scale numerical simulations confirm the existence of the adhesion hysteresis and reveal a veil over the mystery of this effect [8]. The difference in apparent adhesion energies appears due to instable jumps of contact area, leading to irreversibility of the processes of both spreading and detaching adhesive contact. These instabilities on the nano-scale lead to effective force of friction acting on the boundary of an adhesive contact. Similar effects occur during tangential relative movement of two bodies in adhesive contact. The instabilities lead to appearance of friction force even if both bodies are elastic. The reported results not only provide new insights into fundamental mechanisms of friction but also may serve as designer rules for systems with hard elastic coatings with applications in nanomanufacturing.

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