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

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MECHANICS OF ADHESIVE CONTACTS: EXPERIMENT AND THEORY

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Adhesion is both important and intriguing phenomenon in tribology. Despite studying of adhesion since many years, we are still far from complete understanding of this phenomenon. There are several classical theories and mathematical models of adhesion: the JKR theory [1] which is valid in the limiting case of very short range adhesive interactions, DMT theory [2], applicable in the contrary limiting case of long range adhesive interactions, as well as the theory by Maugis [3] considering arbitrary range of interactions, however, using a simplified interaction potential. The JKR and DMT theories are included in the Maugis theory as limiting cases. However, there are many problems, which wait for their solution. Thus, adhesion of rough surfaces is still discussed very controversially; the acceptable theory of adhesion of viscoelastic materials is practically absent. Even more complicated and controversial is adhesion in presence of tangential load, in particular the interrelation between adhesion and friction.

In [4], experimental equipment for investigation of flat-ended indenters during normal motion was designed and described. Authors developed numerical simulation procedure based on the Boundary Element Method (BEM) and used it for simulation of adhesion of complex shaped indenters. They validated the results by comparison with experiments. In the present work, we improved the equipment, described in [4]. The main difference of our experimental setup is the presence of possibility of both normal and tangential motions. Extensive parameter studies with flat and rough surfaces, parabolic and cylindrical indenters, were carried out. One of the effects, which we were concentrated on, was the difference in force-displacement relations on the stages of indentation and detachment. This is very well-known effect, which even have been observed on the nano scale – in AFM experiments [5]. Also, we investigated adhesion properties of flat indenters. Results of experiments are showed in Fig. 1.

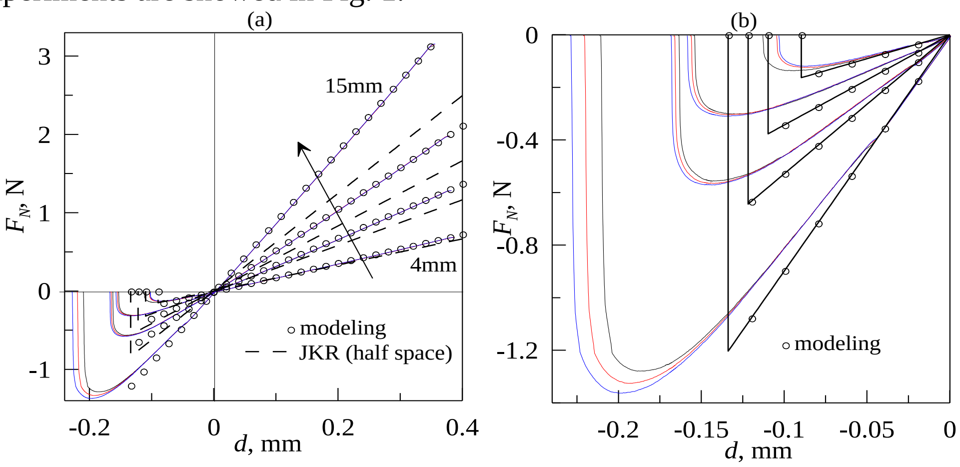

Fig. 1. (a) dependencies of normal force F_N vs. indentation depth d for indentation of steel cylindrical indenters with diameters of 4, 7, 10 and 15 mm in a flat layer of rubber TARNAC CRG N3005 with thickness h=25 mm (symbols). Dashed lines – theoretical predictions in the framework of JKR model for half-space approximation. Solid lines – simulation with BEM for layered systems; (b) Part of $F_N(d)$, depicted in fig. 1a, in the area of detachment, without showing of JKR approximation.

In all experiments, cylindrical indenters with different radii were indented in the rubber layer to maximal indentation depth d = 0.4 mm. Then indenters were pulled up to the moment of complete detachment. For each indenter, experiments were repeated 3 times, all three results are shown in fig. 1. In the fig. 1a, by dashed lines results, obtained in the framework of JKR theory in the half-space approximation are shown. Figure shows rather good comparison between JKR theory and experiment only in the case of the indenter with diameter 4 mm, because for half-space approximation diameter of indenter must be much smaller than thickness of the rubber. Solid lines represent the results obtained by BEM adapted for layered systems [6]. For simulation we used experimentally obtained parameters: elastic modulus of the rubber E = 0.324 MPa, surface energy $\gamma_{12} = 0.326\ \mathrm{J/m^2}$ and Poisson number $\nu = 0.47$. Rubber was located on the glass surface (in our simulations it was undeformed material with infinite value of elastic modulus). In figure, one can see that the simulation results coincide with great accuracy only in the area of positive indentation depth. For adhesion area there is a relatively large difference (see fig. 1b).

Some of experimental details still could not be explained theoretically. First, in simulations we have sharp disappearance of the contact at one single critical displacement, but experimental results show rather slow detachment and several stable configurations of the contact (with area of the contact smaller than the radius of cylinder). Velocity of the indenter motion in the detachment area (fig. 1b) was only $0.1\ \mathrm{\mu m/s}$, at this velocity the viscosity could not be the reason for this discrepancy. We are inclined to think the reason is in a friction force in the boundary line of the contact. This fact must be investigated further, because in all experiments (both with flat and rough surfaces) we have observed the same behavior.

For example, fig. 2 shows results of indentation of spherical indenter in the rubber material as we used for obtaining of results shown in fig. 1.

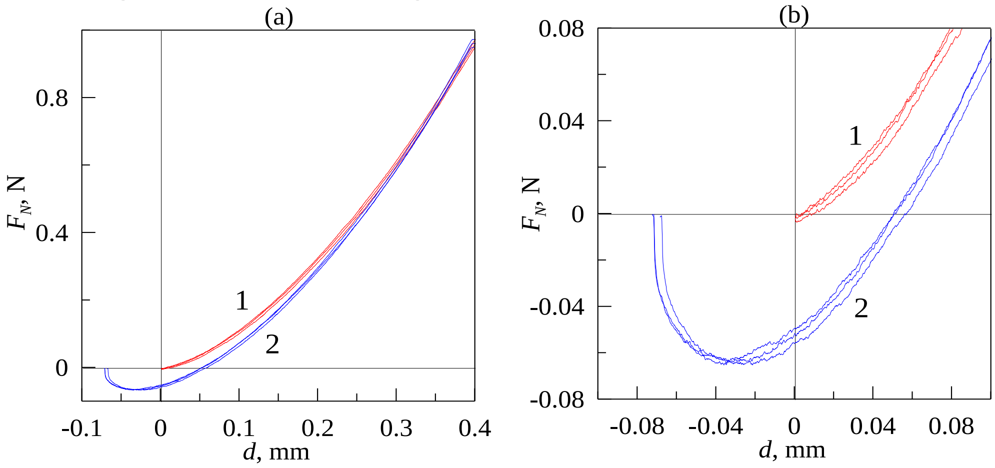

Fig. 2. (a) Dependencies of the normal force F_N vs. indentation depth d for indentation of steel spherical indenter with radii R=33 mm in a flat layer of rubber TARNAC CRG N3005 with thickness h=25 mm. (b) Enlarged fragment of the figure.

Here we also performed 3 experiments, and we can see good repeatability of results. At the stage of indentation these dependencies (curves 1) started from the point of origin at zero normal force, but during opposite direction normal force goes well below zero, because of adhesion interaction and presence of adhesion neck. We found, that curves 1 at indentation are well described by Herz [7] contact model, without adhesion. For the stage of detachment, much better approximation is JKR model [1, 3].

1. Johnson K. L., Kendall K., Roberts A. D. Surface Energy and the Contact of Elastic Solids // Proc. Royal Soc. Lond. A, 1971, V. 324. P. 301–313.
2. Derjaguin B. V., Muller V. M., Toporov Yu. P. Effect of Contact Deformations on the Adhesion of Particles // J. Colloid Interface Sci., 1975, V. 53. P. 314–326.
3. Maugis D. Adhesion of Spheres: the JKR-DMT Transition using a Dugdale Model // J. Colloid Interface Sci., 1992, V. 150, P. 243–269.
4. Popov V. L., Pohrt R., Li Q. Strength of Adhesive Contacts: Influence of Contact Geometry and Material Gradients // Friction, 2017, V. 5. P. 308–325.
5. Buzio R, Valbusa U. Interfacial stiffness and adhesion of randomly rough contacts probed by elastomer colloidal AFM probes // Journal of Physics: Condensed Matter, V. 20. P. 354014: 1–9.
6. Li Q., Pohrt R., Lyashenko I. A., Popov V. L. Boundary element method for nonadhesive and adhesive contacts of a coated elastic half-space // Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 2019, https://doi.org/10.1177/1350650119854250
7. Hertz H. Über Die Berührung Fester Elastischer Körper // Journal für die reine und angewandte Mathematik, 1882, V. 92. P.156–171.