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Adhesion-Deformation-Hydrodynamic model of friction and wear

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Abstract

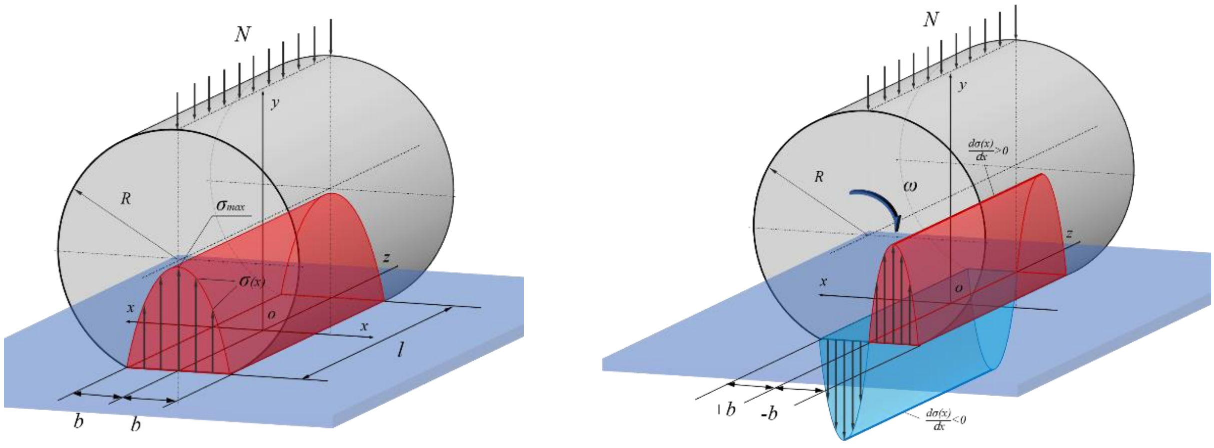
The proposed Adhesion-Deformation-Hydrodynamic model of friction and wear is based on the relationship of elastic-deformation processes in the surfaces of curvilinear contacts with hydrodynamic regular processes of extrusion and rarefaction in lubricating layers in tribocontacts, as well as with the processes of primary adhesion of friction surfaces and subsequent acts of adhesive wear. The proposed Adhesion-Deformation-Hydrodynamic model of friction and wear and its main provisions on the relationship between extrusion, rarefaction in lubricating layers and primary adhesion of friction surfaces of curvilinear contacts cover the entire load-speed range and all modes of lubrication of friction surfaces.

Keywords: model of friction, lubricating layers, contact pressure, adhesion

1. The main provisions of the Adhesion-Deformation-Hydrodynamic model

Wear of friction surfaces always occurs in elastically deformed areas of tribocontacts. It is clear that in areas, for example, in the gap of a radial plain bearing, where the surfaces are not elastically deformed and there is a gap, the surfaces do not wear out, since they do not contact.

Under static conditions, when the surfaces are compressed, all supramolecular layers flow into areas with lower pressure, that is, they are extruded in all directions from elastically deformed contact with mono- and multimolecular lubricant layers, as noted by O. Reynolds at the beginning of his well-known work [11]. Contact stresses are distributed axisymmetrically in the form of a semi-ellipse according to G. Hertz (Fig. 10(a)).



(a) (b)

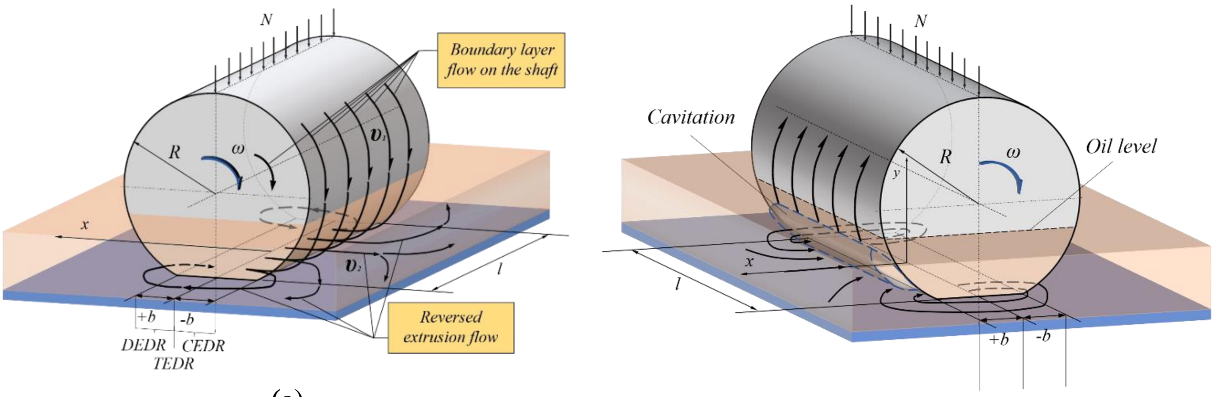
Fig. 1. Axisymmetric distribution of contact stresses.

Axisymmetric distribution of contact stresses $\sigma(x)$ from the applied load N under static compression in contact $2b$ of a shaft with radius R and length l with maximum values of $\sigma_{\max}$ in the ZOY plane in the form of a semi-ellipse according to G. Hertz (Fig 1, a) and a centrally symmetric distribution of the contact gradient stresses $\frac{d\sigma(x)}{d(x)}$ when choosing the friction direction along the OX axis (Fig1,b).

When one or two surfaces break off, in the direction of friction, in the entire elastically deformed area of the tribo-contact, characteristic areas immediately appear in the direction of friction of the shaft along the radial bearing (Fig. 1(b)): 1. First - Convergent elastically deformed area - with a positive gradient of contact stresses, which leads to the extrusion of lubricating layers in which the overpressure rapidly increases relative to the ambient pressure; 2. The second is the transition region, where the contact stress gradient is approximately equal to zero, and the pressure in the lubricating layer changes extreme from the maximum excess to the minimum rarefaction, passing through the pressure area equal to the ambient pressure (in laboratory conditions, this is atmospheric pressure P_0); 3. The third one is an elastically deformed divergent area with a negative contact stress gradient, which leads to a rarefaction of the lubricating layers, in which the pressure is less than the ambient pressure.

When friction in a given direction with a shaft rotation frequency ω in the convergent elastically deformed area of the tribocontact, the lubricating layers are compressed, which squeeze out all supra-monomolecular layers of the lubricant into the volume in accordance with the Hertz theory (Fig. 1(a)) and the Langmuir and BET adsorption theories, in an area with lower pressure (in laboratory conditions, this is the ambient pressure P_0) in accordance with Pascal's law along the shortest path, that is, the boundary layers are extrusion.

In the convergent elastically deformed region, the lubricating layers, under the action of a positive gradient of contact stresses (Fig. 1(b)), contracting, realize Extrusion and return flow in the region with lower pressure (since the pressure is even greater in front) along the shortest path (at the contact ends, the squeezed out fragments of the lubricant flow immediately outward, and in the middle of the contact, the most compressed fragments flow strictly in the direction opposite to friction), which is schematically shown in Fig. 2 (a)).



(a) (b)

Fig. 2. Scheme of the occurrence of extrusion and reverse flows in the convergent non-contact and elastically deformed regions (a) as well as rarefaction in the divergent non-contact and elastically deformed regions (b) of the tribocontact according to the Timken scheme

Here, in the convergent area of contact, the incoming boundary layers of the lubricant together with the shaft and the extrusion flows in front of and in the elastically deformed convergent area are directed towards each other, which, when colliding and braking, lead to the emergence of the so-called "oil wedge" (Fig. 2(a)).

In the transition region, the contact stresses reach their maximum values, and between the surfaces there is a minimum amount of lubricant remaining after extrusion in the convergent elastically deformed contact region. This very short region is characterized by an almost zero contact stress gradient (Fig. 1(a)), and the pressure in the residual lubricating layer is equal to the ambient pressure. Obviously, only in this region is the classical Newtonian viscous flow of mono- or multimolecular boundary layers of lubricant with a rectangular velocity diagram realized.

Then, from the transitional elastically deformed region, a part of the remaining small amount of lubricant, together with the shaft, enters the divergent elastically deformed contact region and enters the conditions of bilateral tension.

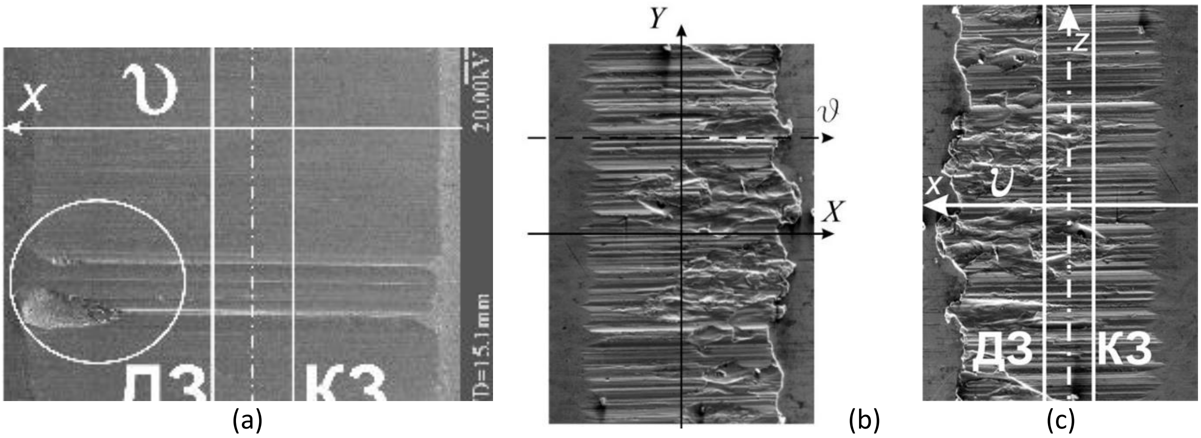
In the divergent elastically deformed region of the friction surface, from the maximum compressed state, relative bilateral stretching of the remaining fragments of the boundary layers is realized, which leads to their rapid rarefaction and a rapid decrease in pressure in them.

Under these conditions, rarefaction, evaporation and DESORPTION of residual adsorbed substances occur, then: nucleation of the vapor-gas phase: first in the form of cavitation nuclei, then to their merger and the formation of a cavitation cavity attached to the moving surface, which is schematically shown in Fig. 2(b)). Such an idea of the process of rarefaction of lubricating layers is in good agreement with the mechanism of desorption of mono- and multimolecular near-surface boundary layers of lubrication in accordance with the Langmuir and BET theories.

Mechanism of adhesive wear within the framework of the proposed Adhesion-Deformation-Hydrodynamic model.

In the divergent elastically deformed region of the tribo-contact, the residual boundary layers are under conditions of rapid rarefaction. They are desorbed, evaporate, and the areas of contacting oxide layers of the surfaces are under conditions of quasi-dry friction. Under these conditions, oxide films are easily removed by cracking, which leads to adhesion of juvenile areas of elastically deformed surfaces in the divergent contact area, i.e. to micro- and submicro-seizure of the surfaces, followed by tearing of the material from the friction surface of the bearing and neoplasm on the shaft.

Thus, during friction of surfaces with adsorbed layers of lubricant active substances, primary adhesion occurs precisely in divergent elastically deformed regions of curvilinear micro- and macrocontacts. The photographs of the worn friction tracks of the flat surface of the model bearing shown in Fig. 3 after friction on it with the model shaft confirm the correctness of the assumed adhesive wear mechanism and the Adhesion-Deformation-Hydrodynamic model of friction and wear.



(a) (b) (c)

Fig. 3. Primary adhesion in the divergent area of contact with a characteristic pull-out of a fragment of the bearing material (a) and the regular appearance of friction tracks (wear traces): in the direction of friction: at the exit from the shaft contact (in the divergent elastically deformed area) - characteristic pull-outs of the material of a model plain bearing (b, c), and at the contact entry (in the convergent elastically deformed area) there are characteristic risks of deformation microcutting. Friction conditions: steel ШХ-15 with HRC=59~62, Ra<0.02mkm, initial, design, maximum contact stresses 2000MPa, linear velocity 0.3m/s, friction device ПТИ ТРИБО-04

The above model of the occurrence of extrusion and rarefaction in an elastically deformed curvilinear contact is experimentally confirmed by the following regularities (Fig. 13), when with an increase in friction speed and load, the pressure in the lubricating layer in the convergent elastically deformed area of the tribo-contact always increases, and in the divergent area it decreases. In the convergent elastically deformed region, this is explained by the fact that with an increase in only the friction velocity at a constant load, the speed of the incident flows and return extrusion flows simultaneously increases, and with an increase in only the load and contact stresses, only the velocity of the return extrusion flows increases correspondingly to meet the boundary layers incident with the shaft. In the divergent region, a similar but reverse picture occurs: with an increase in the friction velocity and contact stresses, the extension rate and the gradient of negative stresses increase, which leads to an increase in the degree of rarefaction.

The lower part of Fig. 4 shows the schematic appearance of return flows as a result of extrusion in the convergent region of the elastically deformed contact and cavitation nucleation as a result of rarefaction in the divergent elastically deformed region of the contact. This scheme is fully consistent with the measured distribution of local pressure in the lubricating layers during sliding friction of a model shaft over a plain bearing in dynamics, which will be described in more detail in the following reports of the authors.

In this case, as can be seen in Fig. 4, the degree of rarefaction in the divergent region also increases with an increase in both the sliding speed and contact stresses. It is noteworthy that with an increase in the degree of rarefaction in the divergent region of the elastically deformed contact, in addition to an increase in the rate of desorption of the lubricating layers, the actual contact stresses in the microcontacts of the elastically deformed vertices will also increase, which will experience an additional load due to the suction effect. This further exacerbates the situation of the contacting quasi-dry tops of the surfaces and contributes to their more intense adhesive interaction and wear.

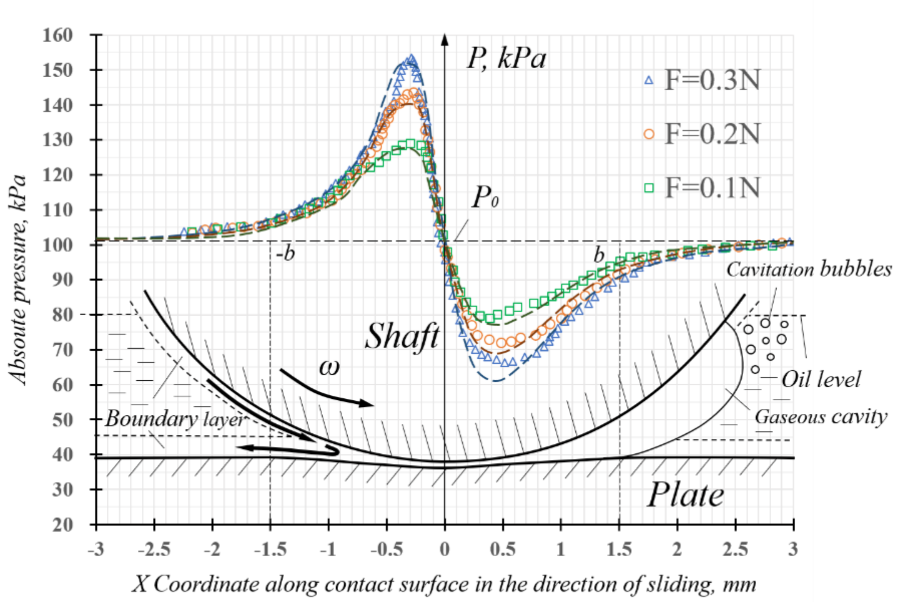


Fig. 4. Experimentally measured (solid lines) and calculated (dashed lines) values of local pressure in the lubricating layer during friction of a model shaft on a model flat bearing according to the Timken scheme within the width of the elastically deformed contact [-b;+b] at different axial loads (0.1N, 0.2N, 0.3N) and one stabilized speed of 0.251m/s.

2. Summary of the Adhesion-Deformation-Hydrodynamic model of friction and wear

The main provisions presented above find their experimental confirmation (Fig. 3, 4) and will be detailed in the following. Adhesion-Deformation-Hydrodynamic model of friction and wear in relation to a radial plain bearing. Previously, the main assumptions of the Adhesion-Deformation-Hydrodynamic model were given on the example of a plain bearing with the Timken scheme. With regard to the radial plain bearing Adhesive wear in conjunction with the hydrodynamic processes of extrusion and rarefaction in the boundary layers in the elastically deformed region of the Adhesion-Deformation-Hydrodynamic model of friction and the wear process is presented as follows (Fig. 5).

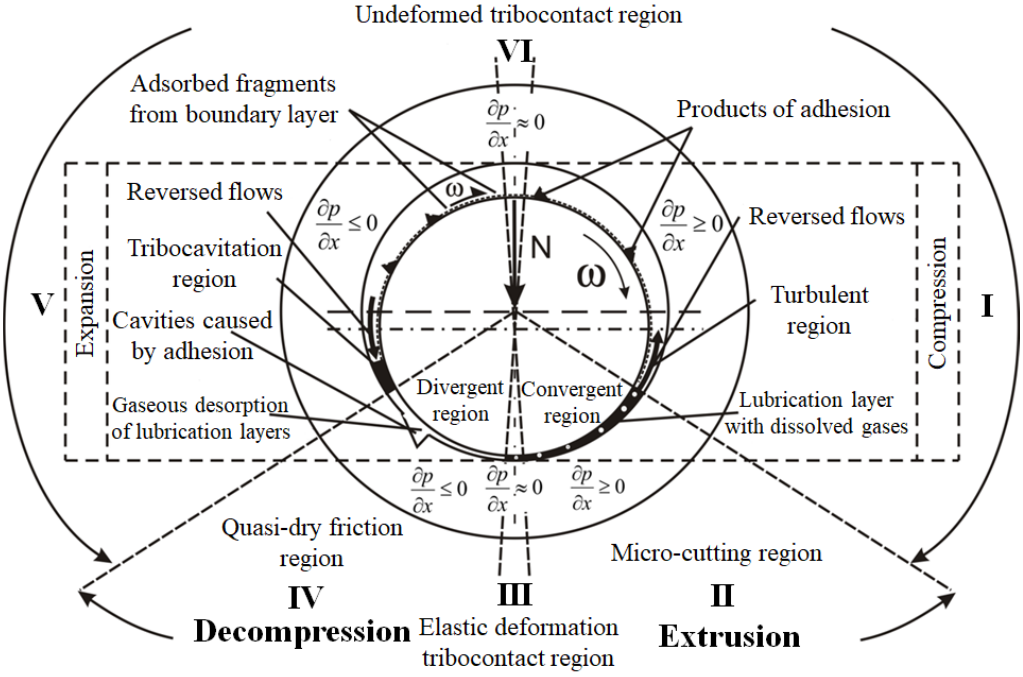


Fig. 5. Schematic representation of the physical friction model of a radial plain bearing with characteristic convergent, transition and divergent non-contact and elastically deformed areas, taking into account extrusion and rarefaction processes.

In the elastically deformed divergent region of the tribo-contact, rarefaction occurs in the boundary layers of the lubricant and their desorption. Desorption of lubricating layers leads to the appearance of conditions of quasi-dry friction and primary adhesion of friction surfaces (Fig. 5). Such local adhesion leads to tearing of a fragment of material from the bearing surface and neoplasm on the friction surface of the shaft. This neoplasm, in the case of a radial plain bearing, enters the convergent region, where, due to the increased radial dimensions of the initial shaft surface, it implements microcutting as follows: part of it is cut and carried out into the lubricant volume in the form of a wear product, and the rest implements microcutting, which is shown in the diagram (Fig. 5). This leads to a rapid change in the micro- and macro-geometry of the contact, which immediately leads to a redistribution of contact stresses and a change in all parameters of the initial contact both along and in the radial direction. After that, friction occurs, in fact, already in other newly formed elastically deformed - convergent and divergent areas. Then, new areas appear in elastically deformed contact with quasi-dry friction conditions in other new divergent contact areas, where adhesive micro- and submicro-seizure occurs. Then, pull-out in the divergent area, micro-cutting in the convergent area, and so on (Fig. 5).

Conclusions

1. The development of a new Adhesion-Deformation-Hydrodynamic model of friction and wear should be based on experimental and theoretical studies of hydrodynamic processes of extrusion and rarefaction of lubricating layers in characteristic elastically deformed areas of tribocontact in the entire range of loads and friction velocities. For this, it is necessary to establish the relationship 1 - the stressed state in the contact of elastically deformed surfaces, 2 - the structural-phase state of the boundary layers of the lubricant adsorbed on them, and 3 - the adhesion of friction surfaces.

2. The proposed Adhesion-Deformation-Hydrodynamic model of friction and wear and its main provisions on the relationship between extrusion, rarefaction in lubricating layers and primary adhesion of friction surfaces of curvilinear contacts cover the entire load-speed range and all modes of lubrication of friction surfaces.

3. To create a new Adhesion-Deformation-Hydrodynamic model of friction and wear, it is necessary to establish experimental patterns that directly or indirectly confirm the objectively occurring processes of extrusion and rarefaction in boundary layers in elastically deformed curvilinear contacts of highly elastic real and materials such as bearing steel ШХ-15 during friction, when the elastically deformed area is several tens of microns, in conjunction with the adhesive interaction of surfaces. In addition, it is required to develop and use new laboratory instruments and techniques, for example [2-4], which will allow observing Extrusion and Vacuum in lubricating layers, as well as scanning and metrologically measuring the local pressure in them as accurately as possible and other parameters of lubricating layers and tribo-contacts of model low-elastic and optically transparent materials during friction in dynamics.

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Олександр Стельмах, Хун'ю Фу, Іцяо Гуо, Сіньбо Ван, Хао Чжан, Олександр Диха. Адгезійно-деформаційно-гідродинамічна модель тертя та зношування

Запропонована адгезійно-деформаційно-гідродинамічна модель тертя та зношування базується на зв'язку пружно-деформаційних процесів на поверхнях криволінійних контактів з гідродинамічними закономірними процесами видавлювання та розрідження в мастильних шарах у трибоконтактах, а також з процесами первинного зчеплення поверхонь тертя і подальші акти адгезійного зношування. Запропонована адгезійно-деформаційно-гідродинамічна модель тертя і зношування та її основні положення про взаємозв'язок між видавлюванням, розрідженням у мастильних шарах і первинним зчепленням поверхонь тертя криволінійних контактів охоплюють весь діапазон навантажень-швидкісність і всі режими змащування поверхонь тертя.

Ключові слова: модель тертя, мастильні шари, контактний тиск, адгезія