The analysis of the influence of the material antifrictional layer frictional properties on the parameters of the spherical bearing contact zone

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Abstract. The paper presents data on the influence of the frictional properties of a material antifrictional layer on the parameters of the spherical bearing contact zone. The dependences of the friction coefficient from the load were obtained as a result of the study. Series of numerical experiments were conducted to investigate the frictional properties of a materials contact pair in the work. Regularities of the relative contact pressure and relative contact tangential stress were obtained for seven variants of the load-friction coefficient for the spherical bearing with a layer of modified fluoroplastic. The study puts emphasis on the fact that that adhesion area of the contact surface is reduced and the load is increased taking into account the fact that the friction properties of the layer has been fixed in the study.

1. Introduction
The contact units with antifrictional coatings and layers are widely applied in engineering, construction, medicine and other industries. These designs are costly. It is difficult to repair them. High requirements with respect to durability, reliability and service life are characteristic of them. Such contact units are working within the contact mechanics. The stress-strain state of units has a complex three-dimensional character, and the design may include more than one sliding surface. The bearing bridges belong to these constructions [1, 2]. The modern antifrictional polymer materials are used in these designs as coating and layers materials. Modified fluoroplastic refers to these materials. A special topic of research is determined physical and mechanical, frictional and performance properties of the antifrictional interlayer materials. Research of the influence of material properties on contact area parameters within the contact mechanics is also a separate scientific topic.

It is worth mentioning that the fundamentals of contact mechanics were found by several scientists. They considered a one-way contact or contact bodies of canonical form [3]. Works on the study of contact interaction of the bodies with coatings and layers are also exist [4, 5]. The bodies of the canonical form, space and half-space are considered in these works. The analytical and semi-analytical solutions methods are mainly used in these studies. Effective numerical approaches to solving contact problems are also exist, these include the finite element method and the boundary element method [6]. These methods are applicable to the implementation of contact interaction of the bodies with coatings and layers. There is not enough information about the complex mathematical description of the contact status for bodies with coatings and layers having multiple sliding surfaces and a complex spatial configuration, and numerical methods require highly skilled researchers and multiprocessor
computers.

The contact interaction of spherical bearing elements through the antifriction layer is made within the study. The influence of mechanical and frictional properties of material layer on the parameters of the contact zone is considered in the work.

2. Mathematical statement, materials and methods

The general mathematical problem statement of contact between two elastic bodies through the antifriction layer is made in the work (Figure 1). Deformation plasticity theory is selected to describe the behavior of the material layer [2].

![Figure 1. The model of the bearing, where 1 – the top plate with a polished spherical segment; 2 – the bottom plate with a spherical cut; 3 – the interlayer from antifriction material.](image)

The contact boundary conditions applied to the surface are \( S_K = S_{K_1} \cup S_{K_2} \cup S_{K_3} \). Wherein the two bodies are in contact under \( S_K \) and which have conditioned numbers 1 and 2. The types of contact interaction that are implemented in the problem are given below:

- sliding with friction (friction of rest): \( \vec{u}^1 = \vec{u}^2, \sigma^1_n = \sigma^2_n, \sigma^1_{n_{11}} = \sigma^2_{n_{11}}, \sigma^1_{n_{12}} = \sigma^2_{n_{12}}, \) wherein \( \sigma_n < 0, |\sigma_n| < q(\sigma_n)|\tau_2| \);

- sliding with friction (sliding friction): \( u^1_u = u^2_u, u^1_{\tau_1} \neq u^2_{\tau_1}, u^1_{\tau_2} \neq u^2_{\tau_2}, \sigma^1_n = \sigma^2_n, \sigma^1_{n_{11}} = \sigma^2_{n_{11}}, \sigma^1_{n_{12}} = \sigma^2_{n_{12}}, \sigma^1_{n_{22}} = \sigma^2_{n_{22}}, \) wherein \( \sigma_n < 0, |\sigma_n| = q(\sigma_n)|\sigma_n| \);

- noncontact: \( |u^1_u - u^2_u| \geq 0, \sigma_{n_{11}} = \sigma_{n_{22}} = \sigma_n = 0; \)

- adhesion: \( \vec{u}^i = \vec{u}^2, \sigma^1_n = \sigma^2_n, \sigma^1_{n_{11}} = \sigma^2_{n_{11}}, \sigma^1_{n_{12}} = \sigma^2_{n_{12}}, \sigma^1_{n_{22}} = \sigma^2_{n_{22}}, \) wherein \( q(\sigma_n) \) – the friction coefficient, \( \tau_1, \tau_2 \) – axes designations which lie in a plane tangent to the contact surface, \( u_u \) – displacement along a normal to a corresponding contact edge, \( u_{\tau_1}, u_{\tau_2} \) – displacement in a tangential plane, \( \sigma_n \) – stress along the normal to the contact boundary, \( \sigma_{n_{11}}, \sigma_{n_{12}}, \sigma_{n_{22}} \) – tangential stresses at the contact boundary, \( \sigma_{n_{12}} \) – the value of vector tangential contact stresses.

The mathematical formulation is complemented by kinematic boundary conditions on surface \( S_z \): \( u_z = 0, \sigma_{rz} = 0, r \in S_z \), and also by static and kinematic boundary conditions on surface \( S_i \):
\[ p \cdot dS_i = -Q_z, \quad u_z(r, h) = U = \text{const}, \quad \sigma_{zz} = 0, \quad r \in S_1, \] where \( Q_z \) – the vertical force applied to \( S_1 \), \( U \) – the unknown quantity and the remaining outer surfaces are free of load.

The defining relations of the model of modified fluoroplastic were verified in the framework of a numerical experiment. The numerical experiment was implemented as a deformation of cylindrical samples by the plates of a press in the framework of contact mechanics. It was found that the numerical calculation with the selected defining relations provides a good quantitative agreement between the experimental results obtained at the Continuum Mechanics Institute. Determination of the frictional properties of antifriction polymeric materials is the next stage of the study. Special equipment has been developed and a multi-stage experimental program was made by professor of Continuum Mechanics Institute AA Adamov for conducting the experiment to determine frictional properties of the layer material. The dependences of the friction coefficient on the specific pressure on the sample were obtained from the experiments for two variants of the contact interaction: without lubrication and with lubricant. The numerical experiment program has been selected for two variants of contact interaction for analysis of the friction coefficient influence on the contact parameters in the design of the spherical bearing. The experimental results are presented in table 1 for a modified fluoroplastic.

| №  | Contact without lubrication | Contact with lubrication |
|----|----------------------------|--------------------------|
|    | Friction coefficient | Pressure, MPa | Friction coefficient | Pressure, MPa |
| 1  | 0.037         | 4               | 0.022         | 3               |
| 2  | 0.033         | 9               | 0.02          | 5               |
| 3  | 0.029         | 12              | 0.016         | 10              |
| 4  | 0.025         | 15              | 0.012         | 15              |
| 5  | 0.021         | 25              | 0.01          | 25              |
| 6  | 0.017         | 35              | 0.009         | 35              |
| 7  | 0.015         | 45              | 0.007         | 40              |

The solution is implemented by using the theory of elastic-plastic deformation in the software ‘ANSYS’. The convergence of the numerical solutions has been considered in [2] under deformation of the spherical bearing with the antifrictional layer made of the modified fluoroplastic with a constant friction coefficient. It is established that eight elements throughout the thickness of a layer is enough to ensure quality solutions in axisymmetric formulation, this corresponds to a finite element model with two hundred thirty five thousand nodal unknowns. The implementation of the contact boundary conditions for the tangential contact was checked, a displacement and deformation path in the main space of deviatoric strain values are considered in the design.

### 3. Results and Discussion

Series of numerical experiments were realized to study the influence of the impact of antifrictional properties of the friction material layer on the contact zone parameters. The field distribution relatively contact pressure (Figure 2a and 2b) and relatively tangential contact stress (Figure 2c and 2d) at contact without lubricant and with lubricant were obtained by solving the problem. They are shown on contact surface \( S_{k} \), at which the rotation of a spherical segment of the top plate was realized. The friction coefficient is decreased when the load acting on the contact unit is increased.
The relative contact pressure (a, b) and the relative contact tangential stress (c, d) on contact surface $S_{K_i}$: (a, c) contact without lubrication and (b, d) contact with lubrication, lines 1-7 are the result of numerical experiment № 1-7, respectively.

The level of the maximum relative contact pressure depends only slightly on the load and the friction coefficient. The relative contact tangential stress is the most sensitive to changes of the friction coefficient. The tangential stress level is decreased as the load grows. And the distribution of the relative contact tangential stress is becoming more uniform. It is more pronounced by contact with lubricant. The value of the relative tangential stress increases in the trapping zone. Its maximum value is observed in the transition contact zone from the adhesion state to the sliding state.

The dependences of maximum relative contact pressure and maximum relative contact tangential contact stress on the load are shown in Figure 3.

Figure 2. The relative contact pressure (a, b) and the relative contact tangential stress (c, d) on contact surface $S_{K_i}$: (a, c) contact without lubrication and (b, d) contact with lubrication, lines 1-7 are the result of numerical experiment № 1-7, respectively.

Figure 3. The dependence of maximum relative contact pressure (a) and maximum relative contact tangential stress (b) of $p_z$: 1 – without lubrication, 2 – with lubrication.
The dependences of maximum relative contact pressure and maximum relative tangential stress of the load were set in the framework of a series of numerical experiments:
- maximum contact pressure is increased with the increasing load and the decreasing friction coefficient in all variants of contact interaction, the contact pressure is greater in the case of contact with lubricant;
- the antifrictional properties of material are observed in the case of relative contact tangential stress: its maximum value decreases as the load grows;
- the maximum value of the relative contact tangential stress is much less in contact with lubricant at an identical load level.

The decreasing adhesion area of the contact surface has been registered, as shown in Figure 4.

![Figure 4](image_url)

**Figure 4.** The percentage of the contact surface area being in a state of adhesion: 1 – without lubrication, 2 – with lubrication.

The tendency towards the reduction of the adhesion area of the contact surface has been registered. The friction coefficients are very different for models without lubricant and with lubricant at the same load level, it influences the adhesion contact area:
- about ninety percent of the contact surface is in the state of adhesion if the bearing of minimum load is deformed by the contact without lubrication, and less than fifty percent of the contact surface is in the state of adhesion if the bearing of the minimum load is deformed by the contact with lubrication;
- about fifty percent of the contact surface is in the state of adhesion if the bearing of the maximum load is deformed by the contact without lubrication, and less than fifteen percent of the contact surface is in the state of adhesion if the bearing of the maximum load is deformed by the contact with lubrication.

### 4. Conclusion

Some results of solving the task can be formulated as the conclusions:
1. The mathematical problem statement of the contact interaction of two elastic bodies with antifrictional layer was made in the work.
2. The defining relations behavior model of the modified fluoroplastic was verified in the framework of a numerical experiment. The good qualitative and quantitative agreement between the results of experiments and numerical experiments was established.
3. The problem of the contact interaction of elements of spherical bearing with antifrictional polymer layer in axisymmetric and three-dimensional productions was performed at a constant friction coefficient equal to 0.04: convergence of the numerical solution was installed, distribution of contact zones was obtained, nature distribution of contact pressure and contact tangential stress was set.
4. Dependences of the friction coefficient on specific pressure were obtained for the modified fluoroplastic for the contact without lubricant and with lubricant. The numerical experiment program was based on the results of the field experiment.
5. The comparative analysis of the deformation behavior in the contact assembly with the antifrictional layer from the modified fluoroplastic with different ratios of the load and the friction coefficient was made.

6. Dependences of the maximal values of relative contact pressure and relative contact tangential stress on the load acting on a spherical bearing were set (its own friction coefficient corresponds to each load).

7. The tendency towards reducing the adhesion area was set when carrying out numerical experiments: the area of adhesion for contact without lubrication is by 35-40% less than for contact with lubricant at the same load level.

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