STRESS DISTRIBUTION IN THE MATRICES OF END FRICTION SEALS UNDER LOADING

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Abstract

The distribution of stresses generated in antifriction seal materials is considered. A photo of isochromes is presented when loading an isotropic material and a material containing solid inclusions. Isochromes when loading a material consist of solid inclusions of various shapes under a load of 120 kg. Photo drawings of the distribution in depth from a concentrated load of tangential stresses in an isotropic material are also presented. In a material consisting of solid inclusions of a round shape, the distribution of tangential stresses depends on the introduction of a "stamp" into the material. Isochromes are obtained when loading a material containing many inclusions.

Keywords: isochrome, shear stress, sealant, isotropic material, solid inclusion, concentrated load, matrix, particle.

I. Introduction

High-pressure end-face friction seals operate under very difficult conditions of high friction and wear loads. The development of new effective tribotechnical materials and the selection of friction pairs are associated with the improvement of testing methods and measuring output characteristics, as well as methods for assessing the performance of friction pairs. At the same time, the development of rational test cycles is one of the necessary conditions for the optimization and selection of friction pairs.

The development of tribology and tribotechnics has led to the need to develop models for optimizing complex systems. Successful solutions to complex problems that cannot be reduced to a single known algorithm are possible using various modeling, primarily based on system analysis. For some problems, physical modeling is still of great importance, allowing one to clarify the nature of phenomena, their mathematical description, and perform experiments with friction units that have no analogues. The greatest correspondence between the model and the original can be achieved using the basic provisions of adaptability, and with the accumulation of new statistically reliable data on the correspondence of the model to the original, it is necessary to consistently adjust the model parameters.

For friction and wear problems, methods of assessing the determining processes and phenomena through a model, rather than a natural experiment, the description and results of which are presented in criterial form, are of particular importance. The use of modeling methods with a correct and objective approach to their reliability and accuracy allows for a significant acceleration of the implementation of new technical solutions and a reduction in labor costs and expenses for scarce materials.

The purpose of this work is to create and select materials for end friction seals and implement the most rational design of this type of friction, which is possible only on the basis of a deep study of the processes of stress distribution in the matrices of materials under its loading.

II. Problem statement

There is a correlation between wear tests of composite materials, as well as the amount and distribution pattern of stresses in the surface layers [1, 2]. In works [3-5], an analytical definition of the amount of solid inclusions in composite materials of the filled matrix type is given, depending on the condition of transfer of contact loads to the matrix, the size of the areas of the solid component on the surface of the composition is calculated, depending on the contact conditions of the surface of the composite material and the counterbody, and an analysis of the dependence of the friction force on the composition and structure of the composite material is carried out using a friction surface model. It was found that in order to ensure high antifriction properties and load-bearing capacity of the material, it is necessary to fill it with wear-resistant solid inclusions exceeding the contact patch in size. Among these, inclusions with sizes from 0.35 to 2.0 mm are considered more optimal. However, this information is insufficient for the design of this type of antifriction materials. It is likely that not only the size, but also the shape and arrangement of the filler particles have a significant impact on the antifriction properties, wear resistance and strength characteristics of the composite. Depending on the listed factors, the solid filler inclusions take up the load caused by friction, and the composite matrix promotes a favorable distribution of stresses or, on the contrary, ensures the concentration of stresses in local areas, thereby reducing the fatigue strength of the material [6].

To select the optimal variant of the "structural design", it is interesting to study the stress state of an iron-cast iron composite containing cast iron inclusions of various shapes. These inclusions should be oriented relative to the direction of the load and significantly exceed (several times) the material matrix in strength characteristics.

III. Experimental methodology

Based on the methodology developed at the Kyiv State University named after T.G. Shevchenko, the stress state of structural anisotropic models was investigated using the polarization-optical method under conditions of static loading by normal tangential forces, which are formed depending on the shape and mutual arrangement of the structural elements. We made models from optically active material ED in the form of 5 mm thick plates. The technology for producing such a polymer was investigated in [7].

However, obtaining an optically sensitive polymer applicable to this class differs from generally accepted methods by the presence of high-modulus inclusions that differ in quantity and shape, as well as mutual arrangement in the material. Due to the need to acquire structures of non-uniform plates with different modules, the developed method consisted of the sequential implementation of two processes. The high-modulus polymer intended for inclusions was produced by thermal curing of epoxy resin FD (100 wt/h) with methyltetrahydrotalin anhydride (60 wt/h) in a stepwise heat treatment, the initial temperature of the polymer was 70 ^{0}C and the final temperature was 120 ^{0}C.

To obtain a relatively low-modulus structure of the model, ED-20 or ED-5 epoxy resin was used, fixed with L-20 polyamide in a ratio of 100:140 or 100:150. Before mixing, we heated the original components to 700 ^{0}C, and then mixed them at this temperature. The composition was kept for 5 minutes to evaporate the bubbles and poured into a mold, into which pre-prepared inclusions of high-modulus polymer were placed. The shape, location and number of inclusions varied.

The mould consisted of metal plates coated with organosilicon liquid K-21. Hardening was carried out at room temperature for 24 hours. The optics – mechanical properties (modulus of elasticity E, punch coefficient μ, relative optical coefficient C, size of the material strip) accumulated by forces along the diameter in compacted disks, as well as elementary tension of the rod were determined. Photographs of the strips were taken with a photoelastimeter of the GMB-57 type (Czech Republic), and the number of strips was designated by the letter n.

IV. Solution to the problem

We encrypted the obtained isochrome images using the strip method, which consisted of direct optical measurement of the order of the stripes at the points under study and determination of the difference in the main equations using Bertheim's formulas

$$\sigma_1 - \sigma_2 \tag{1}$$

Considering the moderation of the stress state at critical points, it is necessary to check the strength under contact stresses according to the third theory of strength.

$$\sigma_{ucl} = \sigma_1 - \sigma_2 \leq [\sigma] \tag{2}$$

As a strength criterion, we adopted the value of the greatest shear stress. It was assumed that, in general, the limit state occurs when the greatest shear stress τ_{max} reaches a critical value. According to the equation

$$\tau_{max}=\frac{1}{2}(\sigma_1 - \sigma_2) \tag{3}$$

the failure condition and strength can be expressed in terms of principal stresses.

Considering that dividing the principal stresses and obtaining individual components σ_x, σ_y, τ_{xy} is difficult, we presented the results in the form of distribution graphs for individual sections $\sigma_1 - \sigma_2 = 2\tau_{max}$ in the depth of the model, obtained from interference images of the bands (isochrome). The graph shows the distribution of maximum shear stresses in horizontal parts along the depth of the model, starting from the contour of load application. The influence of the particle strength shape and its location in the matrix in relation to the place of application of the normal load was studied using the example of single inclusions (Fig. 1 and Fig. 2). We selected similar linear dimensions of particles of different shapes. At a distance from the surface equal to 0.1; 0.3; 0.5; 1 to the linear parameter of particle a in the images of stripes, we selected the concentration coefficient τ_{max}. The distance between the axis of force application and the particle symmetry axis was 0.5; 1.2 according to the linear parameters of particle a.

Figure 1: *Isochromes under loading of an isotropic material (left) and a material containing solid inclusions (right). Load 150 kg;* $E_{ucl} = 46000$; $E_{max} = 16000$

a) *b*) *c*)

Figure 2: *Isochromes under loading of a material consisting of solid inclusions of various shapes under a load of 120 kg. a - E_{ucl} = 45000, E_{max} = 16000; b - E_{ucl} = 45000, E_{max} = 16000; c - E_{ucl} = 46000, E_{max} = 16000*

At a distance of approximately 1–1.2 times exceeding the characteristic linear size of the particle, the magnitude of the stress state depends significantly on the particle shape. At acute angles, in places of abrupt changes in the direction of the geometric shape of the particles, i.e. where the derivative of the geometric shape is prone to destruction, a sharp concentration of stress areas is observed. Probably, the stress function at the boundaries of the area under study has its own characteristics [8]. Large local deformation, naturally, leads to some relaxation of stresses and, at the same time, it was not possible to note the maximum jump in concentration. According to the images of the bands, a local stress concentration was noted that was 2–3.5 times greater than neighboring areas. According to the circumferential shape of the inclusions, the transition from the matrix to the inclusions occurs smoothly, with an insensitive concentration (Figs. 1–3).

At a distance of 1.3 times exceeding the characteristic linear dimension a from the particle surface, the stresses in the matrix are 0.5 – 0.8 stresses on the same area in an isotropic material. If the load is applied to inclusions at a distance of 0.5*a* from the symmetry axis, the particle itself takes the main load, reducing the stress area in the matrix by 5 – 5.1 times compared to local areas corresponding to an isotropic low-modulus plate. This is especially evident in the uniform distribution of the apparent load - "stamp" (Fig. 4). The difference in local coefficients of comparative concentration τ_{max} for the total force is 3 – 1.2.

In this case, inclusions are subject to loads at a distance of more than 1*a* from the axis of symmetry, the influence of the particle gradually decreases, and at a distance of more than 1.5*a* this influence becomes insignificant.

Thus, a solid inclusion affects the distribution of the stress field in the matrix along a radius equal to approximately 1.2 – 2*a*. To obtain a composite material with high load-bearing capacity and fatigue strength, it is necessary that inclusions resistant to strong wear are located in the matrix at a distance of at least 1.5 – 2*a*.

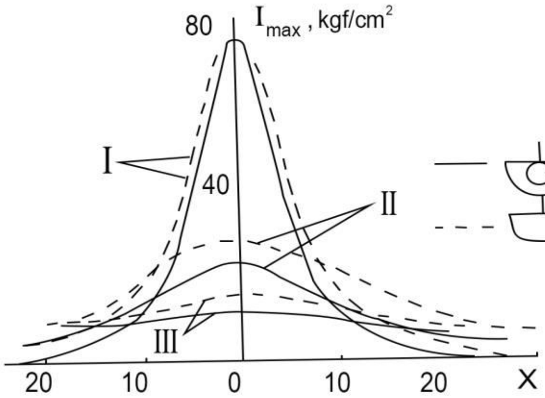


Figure 3: *Distribution in depth from a concentrated load of tangential stresses in an isotropic material with round solid inclusions. i..I-5; II-15; III-30 mm, p=150 kg*

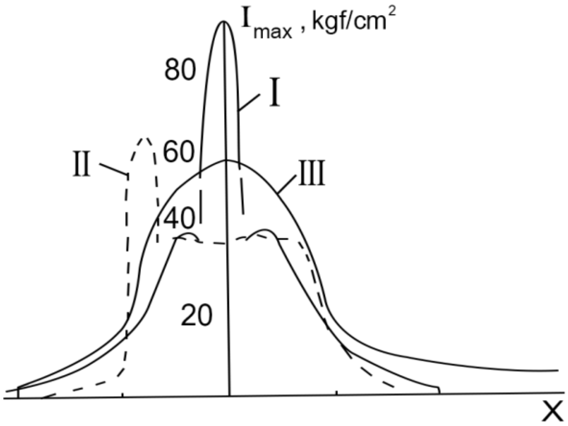
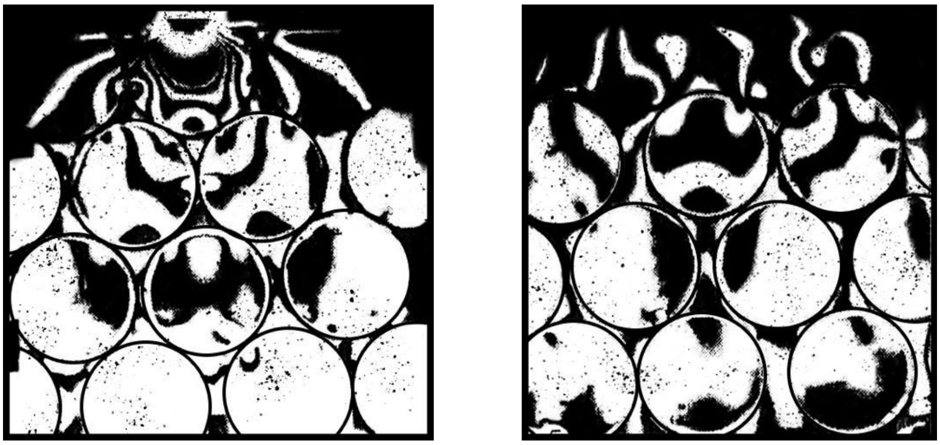


Figure 4: *Distribution of tangential stresses depending on the penetration of the "stamp" into the material containing a solid inclusion. p=120 kg, i=1.6 mm*

The study of the stress state of the model in most inclusions qualitatively complements the results obtained in the study of the stress state of models with homogeneous solid inclusions (Fig. 5).

Under the total load, the matrix particles (Fig. 5, a) are combined and experience the action of stresses, and it is clear that it is closed between two adjacent particles and creates greater stresses compared to the case of applying the total load of a homogeneous inclusion.

In the case of application of the "stamping" load in the surface layer of the matrix material, it is significantly lower than in the surface layer of inclusions. This occurs because the "stamping" load deforms both the matrix and the inclusions of the solid filler, but the elastic modulus of the matrix is three times lower than the elastic modulus of the inclusions, so the stress in the matrix is significantly lower [9].



a) *b*)

Figure 5: *Isochromes under loading of a material containing many inclusions. a) - total load 120 kg, E_{ucl} = 46000, E_{max} = 16000; b - "stamp", load 120 kg, E_{ucl} = 46000, E_{max} = 16000*

If we consider the conditions of contact of real composite surfaces with solid contact surfaces when analyzing images of models of most inclusions, then it is necessary to distinguish two qualitatively different variants of "die" load. One or another model corresponds to the conditions of loading of a single contact spot (in this case, solid inclusions have dimensions of about 1 – 10 microns) and the conditions of the outer contour of the nominal surface (for solid inclusions with linear dimensions of more than 30 microns). In both cases, the pattern of stress distribution is the same, but in the first case, the stresses are significantly greater, since contact loads, as a rule, exceed circumferential stresses by 100 times [10].

Thus, the concentration of stresses at the points of contact of solid inclusions is significantly less dangerous for compositions with large inclusions, since the load level is 100 times less.

III. Conclusions

1. The nature of the distribution and accumulation of stresses in antifriction powder materials of seals has been studied and the dependence of inclusions on their location and the dependence of their quantity on the shape, size of inclusions and matrix have been determined. This study has made it possible to select the optimal version of the "structural design" of the material. It has been established that in the compositions of composites containing large inclusions, the concentration of stresses at the points of contact of inclusions is significantly less dangerous, since in this case the level of load on the inclusion is significantly lower.

2. Regardless of the magnitude of the load and the method of its application to the surface, the optimal shape of solid inclusions in the composite material should be spheroidal or an ellipsoid of revolution. The characteristic linear size of the solid inclusion should be greater than the calculated diameter of a single contact spot.

3. To ensure high fatigue strength of the composite material, inclusions resistant to severe wear must be located at a distance of at least 1.6 – 2*a* (*a* is the characteristic linear dimension of the inclusion).

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