

Theoretical prerequisites for improving durability of fixed rolling bearing joints restored with anaerobic

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Abstract. The paper presents the results of theoretical research of scientific works on determining the durability of fixed rolling bearing joints with restored anaerobic sealants, develops a scheme of angular mixing of the outer ring of the bearing at the deformation of the adhesive layer, and derives the analytical dependence of the absolute elongation of the adhesive layer in operating conditions.

1 Introduction

Restoration of rolling bearing seats with anaerobic sealants is performed by applying them to the parts to be joined with the following assembly of the joint and curing of the sealant. The durability of the resulting adhesive bond depends on its strength under static, dynamic, and cyclic loading. The strength of the adhesive bond depends on the adhesion and cohesion components.

Adhesion and cohesion strengths must ensure that the joints between the bearing rings and the housing, and the shaft do not move. The restored joints must absorb circular moments and axial and bending loads without fracture.

Currently, some several theories and views differently interpret the causes of adhesion. Molecular (adsorption), diffusion, chemical, microrheological and other theories of adhesion are known.

2 Methods

Molecular theory [1] studies the molecular interactions between the substrate and the adhesive, provided that they have functional groups capable of interacting. According to this theory, the formation of adhesion bonding takes place in two stages. In the first stage, substrate and adhesive molecules come into contact by transporting the adhesive molecules to the substrate surface. In the second stage, intermolecular interaction begins after the adhesive molecules come closer together at a distance of 5 Å. This process continues until adsorption equilibrium is reached. According to the molecular theory, adhesion is affected by all factors associated with the formation of adhesive contact (the adhesive's ability to wet the substrate surface and spread over it, rheological phenomena, surface diffusion) and

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determining its completeness (surface microrelief and its purity, the adhesive's viscosity, the duration of the adhesion process and its regime - pressure and temperature).

According to diffusion theory, adhesion occurs due to the mutual diffusion of polymers or other materials across the interface. Diffusion processes require mutual solubility and mobility of polymer macromolecules. At the same time, the diffusion duration, temperature, viscosity, molecular weights of the components, etc., influence the adhesion strength.

Based on the chemical [1, 2], to obtain a strong adhesive bond, the materials must interact with each other with the formation of covalent chemical bonds across the interface.

The essence of the microrheological theory [3] is that during the formation of the adhesive film, the depressions in the rough surface of the substrate are filled, which leads to an increase in the actual contact area and the number of bonds between the adhesive and the substrate.

One of the most important practical characteristics of an adhesive bond is adhesive strength.

Quantitatively, the adhesion strength of adhesive bonds can be described by the equation [4]

$$A_o = \frac{P_{tk} e^{\alpha}}{A_e I / R_{tk}} K_1 V_e I_A / R_{tr} \quad (1)$$

where A_o is the adhesive strength of the adhesive bond; P is contact pressure; R_{tk} is contact duration; α is viscosity parameter; I is activation energy of viscous flow; V_e is delamination rate of adhesive and substrate; I_A is activation energy of adhesive fracture; R_{tr} is delamination temperature; K_1 is coefficient, taking into account the nature of the adhesive and substrate.

The adhesion strength of adhesive bonds depends on the viscosity parameter, which depends on the degree of wetting quantified by the wetting angle.

The best wetting is achieved when the adhesive is applied in liquid form to a solid surface at a wetting angle close to zero.

The contact temperature plays an important role in creating a strong adhesive bond [5]. The increase in bond strength with an increase in temperature is associated with a decrease in the viscosity of the adhesive and complete contact between the adhesive and the substrate. In addition, an increase in the strength of the adhesive bond with an increase in temperature can occur due to increased mobility of the adhesive molecules. However, an excessive increase in temperature can reduce the adhesion strength due to polymer degradation processes.

As the contact time between the adhesive and the substrate increases, the strength of the adhesive bonds increases and stabilizes after a certain time.

With increasing time, the filling of capillaries, pores, and microroughness of the substrate with the adhesive increases.

The strength of adhesive bonds is significantly affected by contact pressure. A particularly noticeable effect of pressure when bonding porous bodies is when it contributes to the flow of the adhesive in the pores and microroughness of the substrate. As a result, the adhesive strength of adhesive joints increases significantly.

3 Results and Discussions

Thus, analysis of various adhesion theories shows that adhesive bonds with high adhesion strength can only be obtained if there is proper contact between the adhesive and the substrate. This contact should be ensured over as large an area as possible. In the case of liquid adhesives, maximum adhesion strength can be obtained by completely filling in the surface roughness depressions. To meet this condition, it is necessary to ensure maximum cleanliness of the substrate surface for bonding; the adhesive must be able to best wet the substrate and spread over its surface, have a low viscosity, and fill the hollows of the surface roughness well. With increasing pressure, temperature, and bonding time, the adhesion strength of the adhesive bond increases.

The adhesion strength of adhesive bonds depends on the rate and temperature of delamination. As the delamination rate increases, the adhesion strength of the joints increases. As the delamination rate increases, relaxation processes do not have time to occur in the adhesive. The adhesive works as a rigid material. More force is required to break the adhesion bond.

As the test temperature increases, the adhesion strength of the test decreases. The decrease in the adhesion strength of adhesive bonds with increasing temperature is due to an increase in the intensity of the thermal movement of the molecules and a decrease in the viscosity of the polymer.

Quantitatively, the cohesive strength of a bond is determined by the formula [6,7].

$$f_m = \frac{\xi}{\beta} - \sigma_{vn} \quad (2)$$

where f_m is the cohesive strength of the adhesive bond; ξ is molecular cohesion of the adhesive; β is stress concentration coefficient resulting from the microscopic heterogeneity of the solid body; σ_{vn} is internal stresses arising in the adhesive during its curing.

The cured adhesive is bound to the substrate surface by adhesive interaction; therefore, during shrinkage phenomena, it is stretched compared to its equilibrium state. As a result, internal stresses are formed in the adhesive bond [6].

To determine the internal stresses in adhesive joints, the following formula is proposed

$$\sigma_{vn} = \frac{E\varepsilon}{1-\mu} \quad (3)$$

where E and μ are the elastic modulus and Poisson's ratio of the adhesive; ε is shrinkage.

Internal stresses act against cohesive with adhesive forces. Therefore, they can be equated with a long-lasting load.

Internal stresses result in the detachment energy of the adhesive layer, which reduces the adhesion strength of the bond.

The intrinsic tear-off energy can be determined by the formula [7].

$$W_{vn} = \frac{\sigma_{vn}^2}{2E} S \cdot h, \quad (4)$$

where σ_{vn} is the internal energy of detachment; S is contact area of the adhesive with the substrate; h is thickness of the adhesive.

Substituting (3) into equation (4), we obtain

$$W_m = \frac{E\varepsilon^2}{2(1-\mu)^2} S \cdot h \quad (5)$$

Equation (5) shows that the internal energy of detachment increases with increasing shrinkage, elastic modulus, thickness, and area of the adhesive layer.

Therefore, to ensure a high adhesive strength of the adhesive bond, it is necessary to choose adhesives with low shrinkage and elastic moduli and limit the thickness of the adhesive bond.

The ultimate strength of the cured adhesive can be determined by the formula [8].

$$\sigma_p = K_1 V_1^p \exp \frac{I}{RT} \quad (6)$$

where σ_p is the ultimate tensile strength of the sample; I is potential fracture barrier; V_1 is tensile velocity of the sample; K and p are parameters determined by the nature of the material, dimensions, and shape of the sample; R is universal gas constant; T is absolute temperature.

However, dynamic stresses are more dangerous for adhesive joints. Dynamic stresses can be determined by the formula [9].

$$\sigma_g = K_g \sigma_{st} \quad (7)$$

σ_{st} – static stress.

where K_g is the ultimate tensile strength of the sample;

The dynamic coefficient depends on the rate of load application and static deformations Δ_{st} [10].

$$K_g = \frac{V}{\sqrt{g\Delta_{st}}} \quad (8)$$

where V is the velocity of the load application; g is acceleration of gravity.

Static stresses, in turn, are inversely proportional to the modulus of elasticity. Therefore, dynamic stresses in the adhesive bond can be reduced by using fixed adhesives with lower elastic moduli for reconstruction.

Under dynamic loading, the polymer's resistance to fracture can be estimated by the specific work of deformation to rupture [9].

$$a_p = \int_0^{\varepsilon_p} \sigma(\varepsilon) d\varepsilon, \quad (9)$$

where ε_p is the relative strain of the sample at rupture; σ is stress at relative elongation.

The specific work of tensile strain measures the serviceability of the material. The greater σ , the greater the impact load the material can absorb without rupture. Therefore, when restoring fixed rolling bearing joints, it is necessary to choose adhesives with high specific deformation work before tearing.

The durability of the cured adhesive under cyclic loading can be estimated by the number of deformation cycles to failure [9, 8, 10].

The formula can be used to determine the number of strain cycles to failure taking into account internal stresses

The formula can be used to determine the number of cycles of deformation before fracture, taking into account the internal stresses

$$N = \frac{2RT}{\Omega\chi E\varepsilon^2} \ln \frac{\sigma_p - \sigma_{in}}{\sigma_{max}} \quad (10)$$

where Ω is the coefficient showing the share of mechanical losses, going to the change in the potential fracture barrier; χ is the coefficient of mechanical losses; E is the dynamic modulus of elasticity; ε is the relative elongation.

The number of deformation cycles for fracture is determined by the ultimate strength under single static loading, maximum stress and internal stress, temperature, and modulus of elasticity. As the modulus of elasticity increases, the number of cycles decreases.

During operation, rolling bearing rings are subjected to three types of loading: local, circulating, and oscillating [11, 12]. In local loading, the radial load is continuously absorbed only by a limited area around the circumference of the raceway and is transmitted to the corresponding areas of the seating surfaces of the shaft and housing. The external load produces compressive stresses in the adhesive layer in contact with the loaded area of the ring and tensile stresses in contact with the unloaded area of the ring, which is added to the internal stresses.

Under circular loading, the radial load acting on the bearing is transmitted in series over the entire housing and shaft seating surface. Compressive and tensile stresses occur in the adhesive layer.

In oscillating loading, a constant radial load and a centripetal force act on the bearing. Depending on the radial centripetal force ratio, the bearing rings are subjected to either circular or local loading. The resultant force is variable.

In addition, the rolling friction force between the rolling element and the bearing ring and the sliding friction force between the rolling element and the cage are influenced by external loads. The total moment from these forces acts on the outer ring of the bearing. However, its magnitude is less than the friction torque between the outer ring of the bearing and the housing bore. Therefore, there is no rotation of the outer ring concerning the housing.

However, in the presence of non-parallelism of the bearing and shaft axes and other factors, the total friction torque increases significantly.

If the moment of rolling friction force M_r exceeds the moment of force holding the outer ring of the bearing, rotation of the outer ring of the bearing relative to the housing is observed. When bearing seats are rebuilt with anaerobic sealants, a layer of adhesive keeps the bearing ring from turning.

Tangential stresses occur in the adhesive layer

$$\tau = \frac{M_r}{2\pi R^2 B} \quad (11)$$

where τ is the tangential stress; M_r is moment of friction forces; R is radius of the outer ring of the bearing; B is width of the bearing.

As a result of angular displacement γ of the outer ring of the bearing under load (Fig.1), point B , which is on the surface of the outer ring, moves to point C . This deforms the adhesive layer without destroying it. Point A is on the seating surface of the housing part. The distance between points A and B equals the thickness of the adhesive layer. After deformation, the distance AC is greater than the distance AB by the value of DC , which corresponds to the absolute elongation of the adhesive layer Δh was determined using geometric and strain-gauge relationships from triangles ABD , BCD and OBC

$$\Delta h = \frac{2h \sin \frac{\varphi}{2} \sin \left(\frac{\varphi}{2} + \frac{\gamma}{2} \right)}{\cos \left(\varphi + \frac{\gamma}{2} \right)} \quad (12)$$

where Δh is absolute elongation, mm; h is layer thickness, mm; φ is shear angle, rad; γ is bearing displacement angle, rad.

Relative elongation of the adhesive as a result of deformation was determined by the formula

$$\varepsilon = \frac{\Delta h}{h} \quad (13)$$

Substituting (13) into (10), we obtain

$$N = \frac{2RT}{\Omega \chi E \left(\frac{\Delta h}{h} \right)^2} \ell n \frac{\sigma_p - \sigma_{\theta n}}{\sigma_{\max}}, \quad (14)$$

Changes in the angular displacement of the bearing outer ring when the adhesive layer is deformed

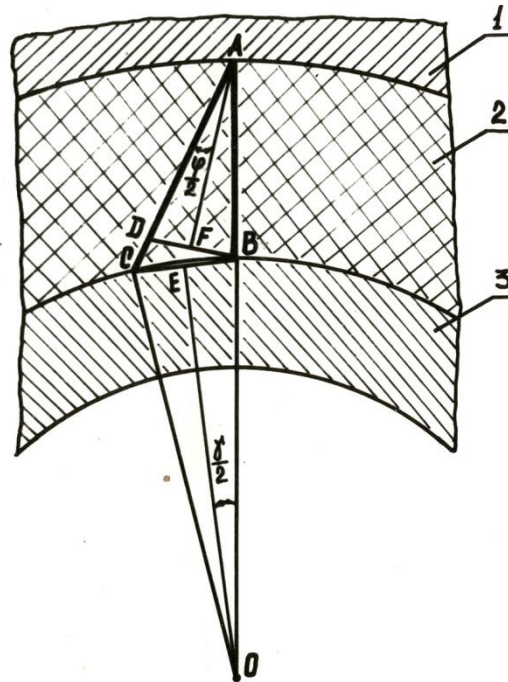


Fig. 1. 1 is hull; 2 is glue layer; 3 is bearing

4 Conclusions

To ensure the high durability of fixed joints restored with anaerobic sealants, it is necessary:

Use sealants with high wettability and the ability to contact the surface of the part over a maximum area have low curing shrinkage and modulus of elasticity and have high specific work of deformation before tearing.

Provide temperature, pressure, time, and cleanliness of the bonded surfaces to fill the surface roughness depressions as much as possible and create the maximum contact area with the part surface.

Limit the thickness of the adhesive layer, as increasing thickness increases shear strain and internal tear energy. As a result, the durability of fixed joints under circulating loading decreases.

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