DETERMINATION OF THE SHEAR STRENGTH OF THE
METAL-PLASTIC ADHESION BOND AND ITS
RESPONSE TO LUBRICATION

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A new method of determining the shear strength of the metal-plastic adhesion bond is considered. Experimental data on its dependence on load and indenter dimensions are presented for various types of plastics under different conditions.

Plastics are being used on an ever-increasing scale as bearing materials. Sliding bearings, in which plastics are employed, usually operate without or with only partial lubrication. In order to calculate the losses it is necessary to know the experimental value of certain parameters characterizing the external friction process. The sliding interaction of solids is a twofold effect [1, 2]. The force required to make two bodies slide is determined by the deformation of a thin surface layer on one of the bodies by the more rigid asperities of the other and the destruction of the adhesion joints at the points of true contact. The formation and destruction of adhesion joints take place at the interface.

In the general case, on the basis of the adhesion-deformation theory, for the coefficient of friction we obtain [3]

\[ f = f_{\text{adh}} + f_{\text{def}} = \frac{\tau_n}{P_c} + \alpha h \sqrt{\frac{h}{R}}, \]  

where \( \tau_n \) is the shear strength of the adhesion bond; \( P_c \) is the real contact pressure; \( \alpha \) is the hysteresis loss factor (for plastic contact \( \alpha = 1 \)); \( h \) is the depth of penetration or interlock; \( R \) is the rounding radius of the asperities; \( k \) is a coefficient.

It is clear from Eq. (1) that the external friction coefficient is directly proportional to the shear strength of the adhesion bond. Whereas the deformation component of the external friction coefficient can be calculated using continuum mechanics, it is very difficult to calculate the adhesion component, which must therefore be determined experimentally.

Methods of determining the normal adhesion are available [4, 5], but there is no direct method of evaluating the shear strength of an adhesion bond under normal load in external friction. The results of an investigation of the normal adhesion cannot be applied to the external friction process. First, under normal load some of the joints are destroyed owing to elastic recovery, while, second, in external friction there is shearing of the joints, still in the presence of a normal load. Accordingly, the optimal method of determining the shear strength of the adhesion bond is one in which the adhesion joints are sheared in the presence of normal stresses. In this case the state of stress in the contact zone coincides with that at the points where the solids touch, and the normal stresses in the contact zone of the solids in friction are equal to the normal stresses compressing the adhesion bond in the experimental apparatus. A closer approach to this model is obtained when a hard spherical indenter between two flat specimens of the test
material is subjected to a normal load and then rotated (Fig. 1). The axis of rotation should coincide with the vertical axis of symmetry. The load acting on the spherical indenter is selected according to the type of deformation in the zones of actual contact. The advantages of this method are as follows: first, the mean normal stresses coincide with those in the contact zone of sliding bodies; secondly, the use of a spherical indenter eliminates the problem of misalignment. For indenters with a smooth surface and regular geometry the force necessary for rotation is determined by the shearing of the adhesion joint at the indenter-specimen interfaces. In view of the high degree of surface finish, the deformation of the material of the flat specimens as a result of the interlocking action of the asperities of the spherical indenter can be neglected. Corresponding calculations have shown [6] that (for the indenters with class 12 finish used in our experiments) the deformation component of the force of friction is 2-3% of the adhesion component. In many cases, when plastics are subjected to friction, plastic deformations develop in the actual contact zones. Accordingly, the loads on the spherical indenter were so selected that plastic deformation occurred at the contact point.

We assume that contact between the sphere and the flat specimens extends over the entire geometric surface of the indentation. In order to rotate the spherical indenter it is necessary to apply a torque (see Fig. 1)

\[ M = 2\pi\tau_{n}R^{3}\int_{0}^{\pi/2} \sin\theta d\theta, \]

where \( \tau_{n} \) is the mean shearing stress; \( r \) is the variable value of the indentation; \( R \) is the radius of the spherical indenter.

Integrating (2) after simple algebra we obtain

\[ M = \frac{4}{3} \pi r_{\text{ind}}^{3} \tau_{n}. \]

On the other hand, on the basis of experiment

\[ M = F_{\text{expt}}R_{\text{expt}}, \]

where \( F_{\text{expt}} \) is the (registered) force required to rotate the spherical indenter; \( R_{\text{expt}} \) is the radius of the indenter mounting. Equating (3) and (4), we obtain

\[ \tau_{n} = \frac{3}{4} \frac{F_{\text{expt}}R_{\text{expt}}}{\pi r_{\text{ind}}^{3}}. \]

From plastic-contact experiments it is possible to obtain values of the adhesion component of the coefficient of friction

\[ f_{\text{adh}} = \frac{\tau_{n}}{P_{r}}. \]

Since \( P_{r} = N/\pi r_{\text{ind}}^{2} \),

\[ f_{\text{adh}} = \frac{3}{4} \frac{F_{\text{expt}}R_{\text{expt}}}{N r_{\text{ind}}^{2}}. \]

On this basis we have developed [7] an instrument for directly determining the adhesion component of the coefficient of friction and the shear strength of the adhesion bond. This instrument is shown schematically in Fig. 1. The spherical indenter 1 is rigidly held in a special mount 2 with an annular external slot that receives a cable 3. The indenter is rotated by the pull exerted on the cable by a traction system 4. The force necessary for rotation is registered by a recorder 5, which receives its signal from strain gauges bonded to elastic elements 6. The specimens 7, which are first placed in special holders, are compressed by the normal load \( N \).

It is known from the theory of external friction [3] that in the presence of plastic deformation in the contact zone the shear strength of the adhesion bond is a constant quantity that does not depend on the load or the dimensions of the spherical indenter. It does depend on the materials forming the rubbing pair and on the operating conditions.