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Experimental investigation of the friction coefficient between aluminium and steel

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The coefficient of friction for steel–aluminium contact surfaces has been determined. The test was conducted by using a testing machine active on the basis of the twist-compression test. A flat plate of aluminium was placed under pressure between two steel dies. One of the dies (the upper one) was capable of rotating while the other (the lower one) was stationary and attached to a load cell that was used for measuring the torque and force on the flat plate. By using a strain bridge data logger, the coefficient of friction can be found within 0.75-second intervals. The results show that the friction coefficient for steel-aluminium interfaces started at an initial value of 0.2, increased to almost 0.8 in the elastic region, and then decreased to the value of 0.6 in the plastic region.

Key words: *friction; coefficient; steel; aluminium*

1. Introduction

The coefficient of friction is one of the parameters describing the amount of resistance to the relative motion of two sliding objects. Historically, Leonardo Da Vinci (1508) showed that friction force was proportional to load [1], and Amonton (1700) formulated the relationship [2] that shear stress is proportional to normal stress by the coefficient of friction.

The earliest attempts to explain friction were based on interactions of surface asperities. It is now widely accepted, however, that although mechanical interactions play their part, the high coefficient of friction seen in clean environments may only be explained in terms of adhesion between contacting asperities. From this point of view,

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two well-known theories of friction have been introduced [3]: adhesive theory of friction and junction growth theory.

With the assumptions made by the adhesive theory of friction, the value of the coefficient of friction, μ, will be nearly equal to 0.2. Contaminant films will lead to even lower values of μ. In high vacuum conditions, experimentally determined values of the friction coefficient of six or more have been recorded, which clearly cannot be explained by a simple model. It is this discrepancy between experiment and theory that led to junction growth theory [3].

The principal error in the simple adhesive theory lays in the oversimplification of the laws governing plastic contact. The problem is essentially that of defining a yield criterion in a three-dimensional stress system, and may be treated within the classical plasticity theory. It is not acceptable to consider the normal and tangential stresses separately. The governing equation for the coefficient of friction in this theory is assumed to be:

$$\mu = \frac{\tau}{\sigma} = \frac{m_c}{\left[\alpha(1-m_c^2)^{1/2}\right]} \tag{1}$$

where τ is tangential stress due to friction, σ is normal stress at the area of contact, α is a constant determined by the asperity geometry and m_c is the friction factor. The relationship shows that any value between zero and infinity may be obtained merely by changing the value of m_c. For clean surfaces, m_c will tend to unity and μ to infinity.

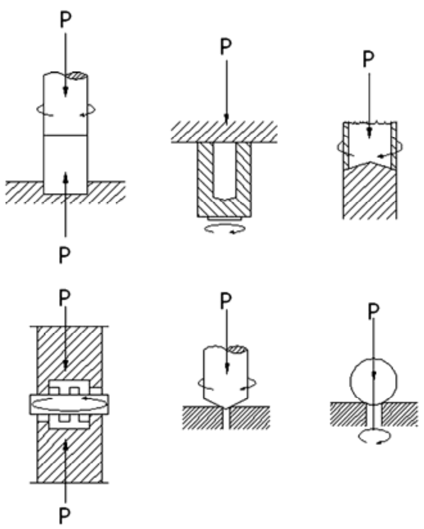

Fig. 1. Various types of twist-compression tests

Several types of experimental methods have been employed to find the friction coefficient, most of them [4] using pressure pins [5], pin on desk test [6] and twist-compression test.

In various forms of the twist-compression test [6] (Fig. 1), normal pressure is combined with continued sliding over the same surface area by rotation of a die or the specimen. Thus, the coefficient of friction is calculated by:

$$\mu = \frac{T}{rN} \tag{2}$$

where T is the torque applied, N is the normal force, and r is the mean radius.

In the following section, a new form of this test is introduced by a new, patented apparatus [7].

2. Experimental procedure

A new testing machine has been designed and made on the basis of the twist-compression test, as shown in Figure 2 [7].

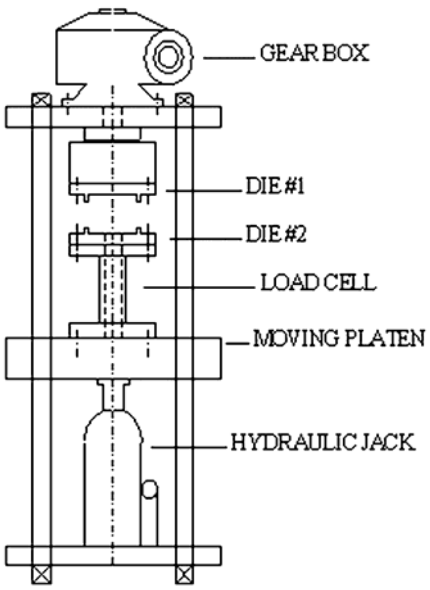

Fig. 2. Testing apparatus [7]

Although the basis of this testing apparatus is twist-compression, a new configuration of applying the load and torque are used (Fig. 3), which has not been introduced by the other configurations shown in Figure 1.

A flat aluminium plate 1 mm thick, with a yield stress of 210 MPa, is placed between two hardened steel dies (die #1 and die #2). Each die has an annular shaped edge 1 mm thick and with a mean radius of 30 mm. The aluminium plate is pressed between two dies by using a hydraulic jack. At the same time, die #1 is rotated by means of a gearbox, while the pressure is increased by the hydraulic jack and die #2 is rotationally fixed, and the load cell attached to it will measure the applied normal force and torque applied. The measured torque is certainly due to frictional load transferred from the upper to the lower die. Since the annular shaped edge has a diameter larger than 20 times its thickness, it is supposed that it will apply a uniform, normal, and shear stress on the aluminium plate. The torque is transferred by the plate to die #2 with almost no error, and its value is equal to the shear (friction) force multiplied by the mean radius of the annular shaped edge. Equation (2) can be used for computing the friction coefficient.

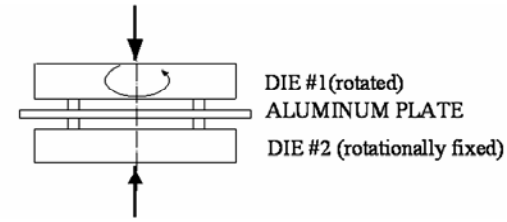

Fig. 3. Configuration of the applied torsional and normal load

Two 45 degree strain gauge rosettes are installed onto the load cell which can measure the load and torque applied to the plate. The load cell is connected to a strain-measuring device, TQ E31 strain bridge data logger which sends the measured strains to a computer by an RS232 connection. A complete strain read-out takes approximately 0.75 sec. The load cell was calibrated for the applied force and torque. By using a calibration curve and applying simple formulas, the normal and shear stress were found. The coefficient of friction is found by simply dividing the shear stress by the normal stress. It must be noted that both shear and normal stresses are apparent stresses. Before each test, the plate and dies were carefully cleaned and degreased with acetone. For preventing the error due to die pick-up after each test, the dies were smoothed with 400 grid abrasive paper in order to form a uniform surface.

3. Results

The results of shear stress versus normal stress and of the friction coefficient versus normal stress are shown for several tests in Figures 4 and 5, respectively. The stresses are obtained simply by dividing the load by the area of contact of the annular shaped edge. For calculating the friction coefficient, Equation (2) was used. The friction load was calculated by dividing the torque measured with the load cell by the mean radius of annular shaped edge.

It can be seen from Figure 4 that the shear stress dependence on the normal stress exhibits three regions. The first region (at low normal stresses) has a low slope which increases (region two) until the shear stress becomes constant (region three).

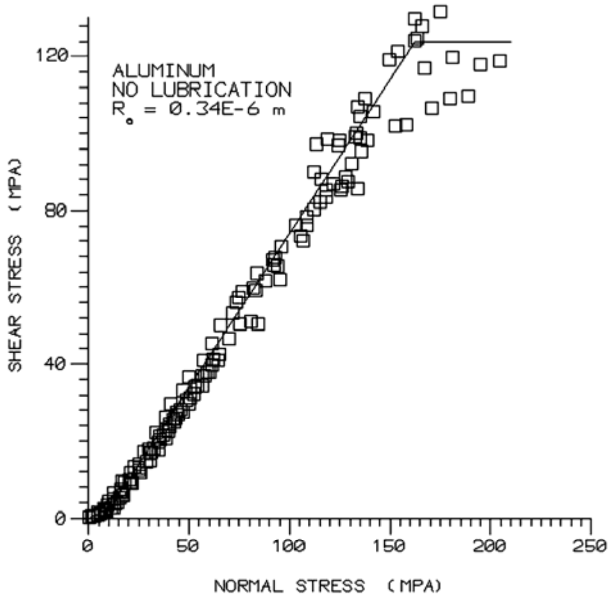

Fig. 4. Experimental results of shear stress vs. normal stress

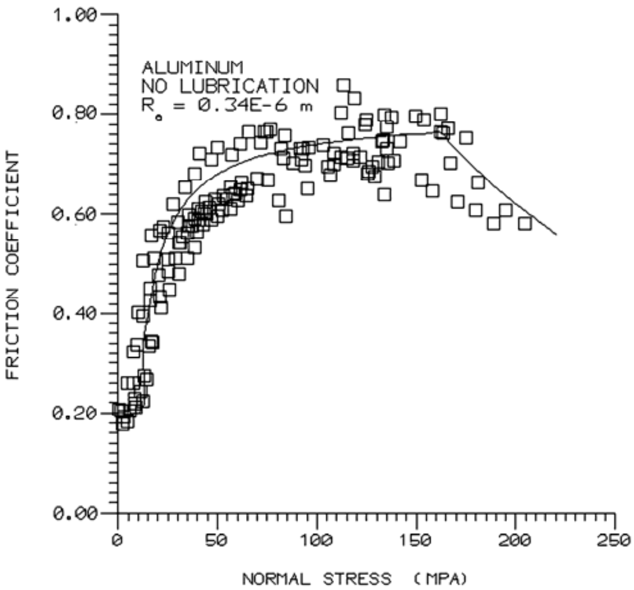

Fig. 5. Experimental results of the friction coefficient vs. normal stress

In Figure 5, it can be seen that the coefficient of friction starts with an initial value of 0.2, and then increases to a maximum of 0.8. After that, it decreases to 0.6 at the highest normal stresses applied in our experiments.

An initial value of 0.2 for the coefficient of friction has been reported by several researchers [8, 9], while a high value of 1.2 has been reported for steady state conditions [10]. The experiments showed that at low normal stresses the adhesive theory of friction can be used, while for higher normal stresses the junction growth theory must be applied due to a higher value of m_c.

For the third region, in which μ decreases, the coefficient of friction follows the formula:

$$\mu = \frac{k}{\sigma} \tag{3}$$

Although τ in Eq. (3) reached the value k, σ did not reach the yield stress. Therefore, when σ equals σ_y (yield stress), the coefficient of friction tends to 0.6. For higher normal stress, for instance $3\sigma_y$ at forging, the coefficient of friction reaches 0.2, in accordance with the data of Van Rooyen and Backofen [5].

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