

FRETTING WEAR OF MATERIALS – METHODOLOGICAL ASPECTS OF RESEARCH

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Abstract: In this article, methodical aspects of studies on material fretting wear have been presented. The results of studies conducted on a “pin on disc” type device made at the Department of Materials and Biomedical Engineering of the Białystok University of Technology confirmed the decisive influence of the amplitude of oscillations and the load value on the course and nature of the process. At a constant value of load, the course of resistance to motion was dependent on the amplitude. Increasing the amplitude of oscillations caused a change in friction conditions: from static friction (elastic deformation of formed adhesive connections, without dislocation of cooperating elements) to kinetic friction (breaking of adhesive bridges and displacement with sliding). The increase of the load value at a constant amplitude value caused a change in the course and nature of resistance to motion from sliding friction to friction at-rest.

Key words: Fretting, Wear, Stainless Steel, Ferrite

1. INTRODUCTION

Fretting is the complex process of destruction of surface layers of cooperating elements having a normal force applied to them as load, moving relative to each other with tangential low-amplitude oscillatory motion. The complexity of fretting wear processes is the result of many interconnected physical and chemical phenomena occurring at points of contact of the cooperating surfaces. Among the many significant factors influencing the intensity and nature of fretting wear, the most important are: load, amplitude, duration, geometry of the contact area, properties of contacting elements (adhesive properties, resistance to corrosion, hardness, tensile strength, yield point, fatigue strength), as well as environmental conditions. There are several definitions of fretting which distinguish the term by specifying the course of the process or its effects. The Glossary of Terms and Definitions in the Field of Friction, Wear, and Lubrication (1969) define fretting as the phenomenon of wear present between two surfaces where there is a relative reciprocating sliding motion of a small amplitude.

The definition of fretting proposed by professor M. Hebda is as follows:

„(...) Fretting is a type of wear occurring during slight (on the order of a fraction of a mm) mutual movement of bodies that are in contact with each other. In its broad sense, the word fretting denotes the group of mechanical, thermal, chemical, and electric phenomena taking place at the places of contact of bodies that are moving slightly relative to each other with rotational or reciprocating motion as a result of vibrations, load pulsation, etc. Thus, this is wear occurring at places that are “nominally” immobile connections. (...)” (Hebda and Wachal, 1980).

The terms fretting and fretting corrosion were used for the first

time in 1927 by G.A. Tomlinson (Tomlinson, 1927) in order to specify characteristic damage to steel surfaces.

According to other definitions, fretting is also considered to be a special type of friction occurring under conditions of movement on the micro scale (Smith, 1998). Thus, it is justified to distinguish subordinate terms relative to fretting that are used in the literature. These are: fretting wear, fretting corrosion, fretting fatigue. Fretting wear is the change in mass or volume of the surface layer as a result of a process. Destruction that is mostly caused by the process of oxidation of the surface layer is called fretting corrosion. However, in the case of fretting on the surfaces of elements with applied variable loads, the influence of fretting is decisive for fatigue strength – fretting fatigue (Neyman, 2003).

Destruction of material surface layers through fretting takes place, e.g.: in close-fitted elements (e.g. axles of vehicle axle sets (Guzowski, 2003)); in joints that are screwed, keyed, riveted, or pinned; in non-operating rolling bearings, gear wheels; on the surfaces of electrical contacts in airplane elements, and also in biomedical implants (Guzowski, 2003; Hannel et al. 2001; Hoppner et al. 1994; Neale, 1995; Shanshan, 2010; Tristani et al., 2001; Waterhouse, 1972; Wierzcholski et al. 1999; Young et al. 2010).

1.1. Devices for fretting studies

Four basic systems can be distinguished among the devices for fretting studies:

- a fastening system for studied samples;
- a system for inducing relative oscillatory motion of samples;
- a system for applying load;
- a system for measuring displacements and resistance to motion (Neyman, 1993).

A basic property of the testing station is the type of sample contact. Focused contact is used most often: cylinder – cylinder, sphere – plane, cylinder - plane (Fig. 1 a, b, d). Such a type of contact facilitates identification and measurement of wear due to the existence of a single, central area of wear. In the case of distributed contact, e.g. two flat elements (Fig. 1 c), the wear areas are located at random on the nominal contact surface. This creates significant difficulties during wear measurement. Furthermore, the power of the device must be greater due to the much higher load necessary for creating the appropriately high contact stresses. Ensuring correct contact of cooperating surfaces is a significant problem in these types of stations.

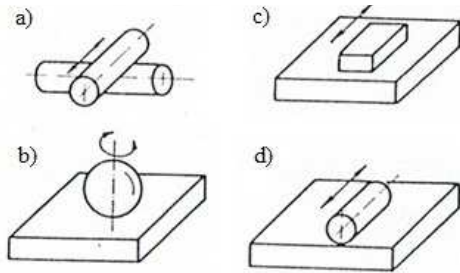


Fig. 1. Configurations of samples most often used in testing stations: a) cylinder - cylinder, b) sphere – flat element, c) flat element – flat element, d) cylinder – flat element (Neyman, 1993)

In testing stations, oscillatory motion can be induced by devices of the following types:

- Mechanical;
- Electromagnetic;
- Piezoelectric;
- hydraulic.

Each of these types of devices is characterized by specific pros as well as cons in terms of their fulfillment of the requirements of conducted tests.

The advantages of mechanical devices, usually operating on the principle of eccentricity, are: easy regulation of oscillation frequency and a constant value of the amplitude of oscillations. A disadvantage is the necessity of replacing the circular cam upon changing the amplitude of oscillations.

Electromagnetic devices ensure achievement of high frequencies and easy regulation of frequency and amplitude. The limitations in achievable values of frequency and amplitude are due to the lower power of these types of devices in comparison with mechanical devices.

Piezoelectric devices are characterized by easy and precise regulation of frequency and oscillation amplitude but have a significantly limited amplitude value.

The greatest load values can be obtained by using hydraulic devices, however they are decidedly the most expensive.

Analysis of contact conditions in a dependency on load and tangent displacements has been conducted by several authors, including O'Connor J. (1981). In the case of a sphere-sphere or sphere-flat element association, the contact area is a circle with radius a (Fig. 2).

If, during loading of the cooperating pair with normal force N , the applied, cyclically variable force T is not sufficiently large to cause relative sliding, then the conditions presented on Fig. 2 will be present. The normal force between spheres with a radius of R and an applied force of N , designated p , reaches its maximum in the center of the circular contact area and decreases

to zero on the edge of the contact area. If a tangential force of T is applied to one of the spheres, in parallel to the contact surface, unit tangential forces „ τ ” will be present. Unit tangential forces reach a minimum at the center of the contact area and increase in the direction of the boundary of the contact area, approaching infinity under the assumption that sliding in the macro scale is not present. Everywhere that elementary friction forces “ μp ” are greater than “ τ ”, local slipping (micro slips) does not occur, however where they are lesser, slipping does take place. Thus, the entire contact area is divided into two sub-areas: without slipping (a circle with a radius of a') and with slipping (a ring with an outside radius of a and an internal radius of a').

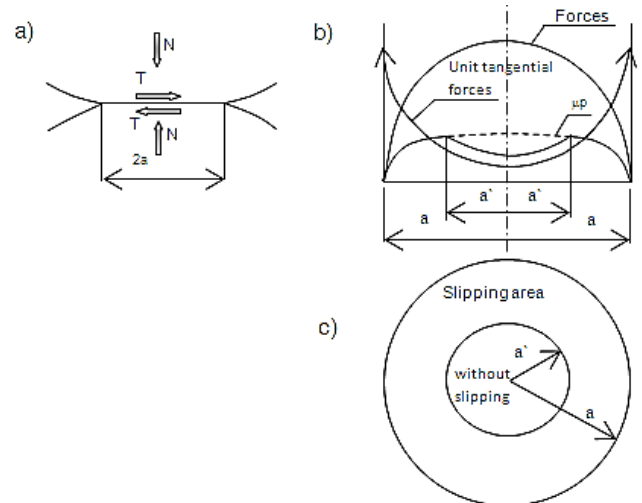


Fig. 2. Conditions of contact for a sphere-sphere association with a lack of full sliding according to (O'Connor, 1981)

Depending on the ratio of radius a' to a , three intervals of contact conditions are distinguished:

- $a'/a = 1$, a limit instance, contact without slipping (stick regime);
- $a' < a$, contact with slipping onto parts of the contact area (with micro slips) (partial slip regime);
- $a' = 0$, a limit instance between contact with slipping onto parts of the contact area and contact with slipping over the entire contact area (gross slip regime).

2. OWN PROPOSITION FOR RESEARCH METHODOLOGY

A prototype device for fretting studies with an eccentric oscillation inducer has been made at the Department of Materials and Biomedical Engineering (Fig. 3, currently in the process of patent application). Samples are applied in the pin on disc configuration, with a flat contact surface.

A series of experiments with various materials used in associations were conducted on this device. The influence of oscillation amplitude on the course of friction and wear processes was studied. Analysis of the obtained results made it possible to confirm the influence of load and amplitude described in the literature on the change in the nature of contact made apparent by a change in the course of friction forces.

The following association was subjected to tests: disc – H18N9T steel, pin – 315 steel. Contact surface $S=2 \text{ mm}^2$. Applied loads had a value of 14 N and the amplitude of oscillations

for instance a) 107 μm (Fig. 4a), and in instance b) 64 μm (Fig. 4b). The results of the courses of friction forces, displacements, and pressure forces after one hour of testing have been presented.



Fig. 3. Prototype of the device with an eccentric oscillation inducer

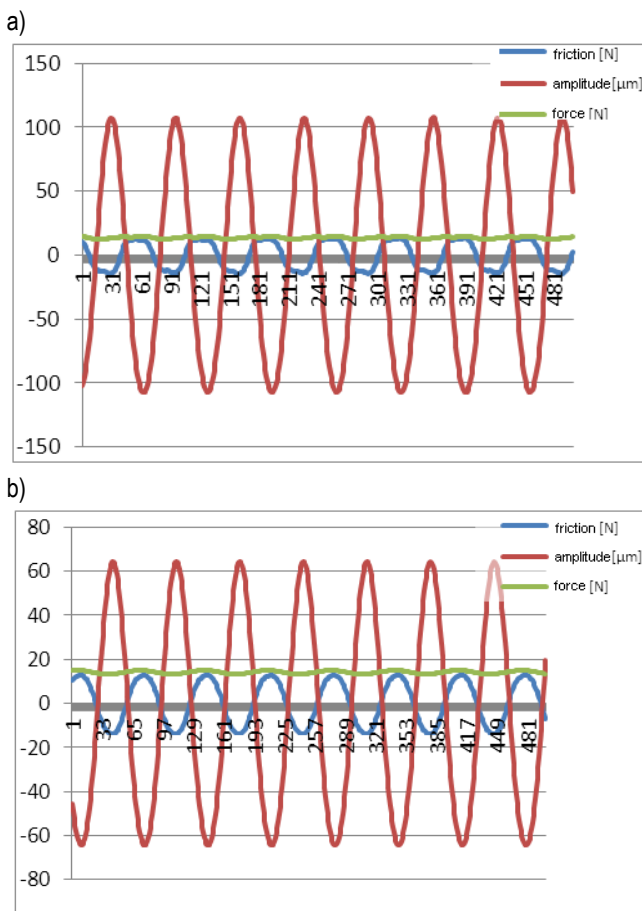


Fig. 4. Charts of the courses of friction forces, displacements, and pressure forces. Pressure force 14 N amplitude, a) 107 μm , b) 64 μm

From the presented photographs (Fig. 5) and on the basis of observations of the nature of the friction forces (Fig. 4), the following conclusions can be made: in the case of a greater amplitude of oscillations, adhesive connections are broken and sliding of contacting surfaces takes place. The material is subject to plastic deformation, and delamination and flaking of fragments

of the surface layer occur. On the photograph shown on Fig. 5a, successive stages of surface destruction during fretting are visible: plastic deformation of the material and material delamination, causing detachment of material fragments at places of material discontinuity and creating free wear products. At this time, kinetic friction conditions between contacting surfaces are present, and friction force courses have a trapezoidal nature (Fig. 4a and 5a-b).

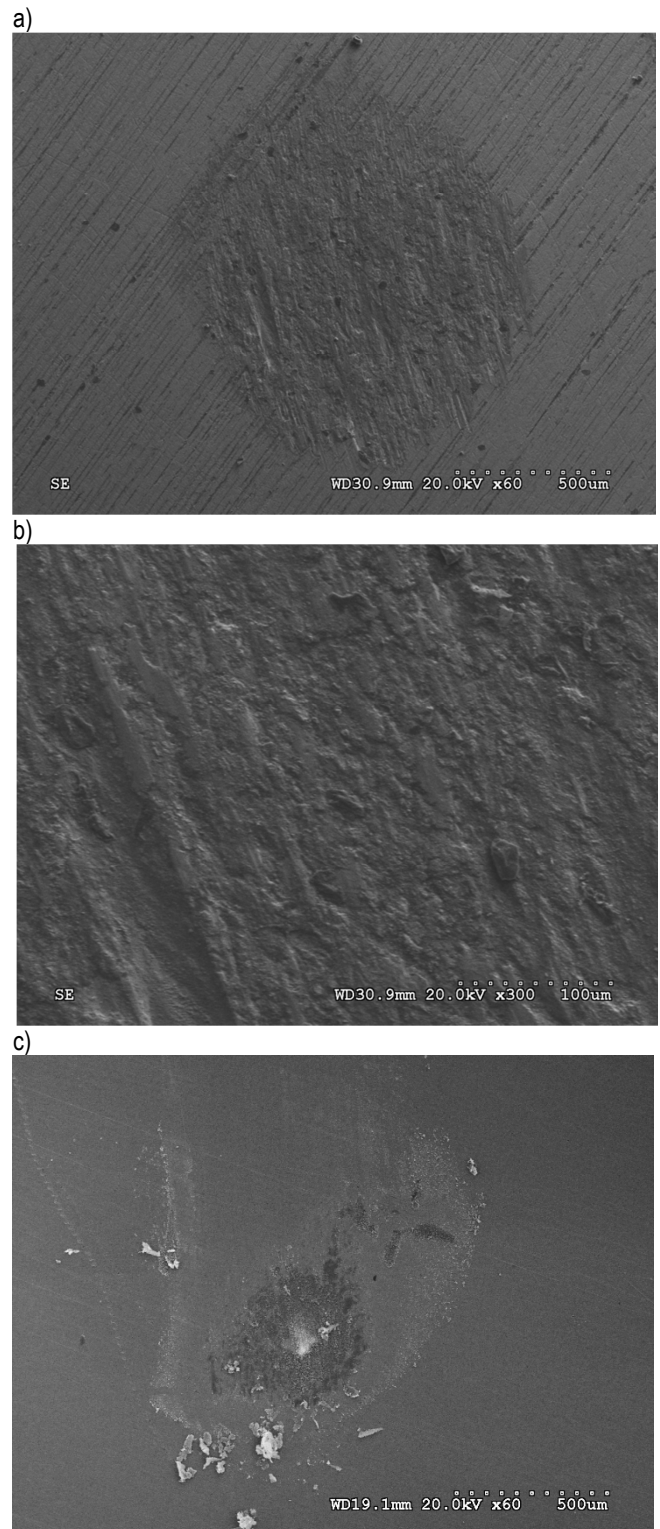


Fig. 5. Photographs from electron microscope. Pressure force 14 N amplitude, a) 107 μm , b) 107 μm , c) 64 μm

However, for smaller amplitude values, adhesive connections and compensations of tangential displacements through elastic deformation of connected peaks of surface irregularities take place. Friction has a static nature and the courses of friction forces have a sinusoidal nature (Fig. 4b).

3. CONCLUSIONS

Analysis of the results of tests confirms the decisive influence of the value of applied load and tangential displacement amplitude on the nature of contact and courses of friction forces. In the pin on disc sample configuration with two flat surfaces, for a constant value of applied load, the value of the amplitude of oscillations was decisive to the nature of friction forces. Increasing the amplitude value caused a change in friction conditions: from static friction (elastic deformation of formed adhesive connections, without dislocation of cooperating elements) to kinetic friction (breaking of adhesive connections and dislocation with sliding).

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