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CONTACT FORCE DETERMINATION IN ABRASIVE WEAR TEST

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Abstract

Micro-abrasive wear test (Calowear) is used in tribological experiments for quality evaluation of superficial 1 to 100 μm thick coatings. One of significant quality indicators is the abrasion rate. During the abrasive wear experiments it is necessary to know the contact force F between the rotating ball and the sample surface. A theoretical way to contact force determination can be very complex, demanding acquaintance with numerous additional experimental parameters. A simpler method is proposed in this paper for contact force measurement using a cylindrical spiral spring. Previous determination of friction coefficient is avoided as well as not-so-easy measurements of numerous additional parameters. The proposed procedure enables contact force measurements with a ±2.5% error.

Keywords: *Wear testing, abrasion rate, contact force*

1. INTRODUCTION

One of the development trends in contemporary technologies is oriented toward miniaturization of devices and systems and it is already resulting in enormous direct consequences in the fields of electronics, computers and telecommunications and in indirect ones in all other fields of industry. Within this trend, the development of the localized application of special materials like thin superficial films and coatings is taking place.

There is a long tradition in surface modification of materials in order to increase resistance to wear, corrosion and fatigue. One of the oldest procedures is applied in metal works – nitriding, introducing nitrogen into the superficial layer of steel. The obtained dispersion of alloying elements nitrides influences very beneficially the mechanical and other properties of the surface layers and significantly improves the functional properties of machine parts and tools.

While the effects of nitriding are felt in layers up to several hundreds of micrometers deep, during the last two decades technologies were developed to deposit significantly thinner micrometer or even sub micrometer coatings on different materials in order to obtain desired mechanical or optical properties. Very often these are titanium-based layers, TiN, (Ti,Al)N, TiC and others, with high hardness and optical reflectivity.

The introduction into use of ever thinner surface coatings, even of multilayer surface structures, demanded a development of novel fabrication procedures, but also of new methods for their characterization. The contemporary production technologies in this field are mostly based on the application of plasma [1], which offer the best controllability and the highest potentials to obtain the desired properties.

During the recent years the method of micro-abrasion of the surface by a rotating ball (Calowear test) has been used in investigation of tribological properties of surface coatings.

The method comprises one of the subsequently noted application possibilities of so-called Calotest, a procedure originally developed for thickness measurements of thin hard coatings deposited on steel substrate [2]. This test proved itself convenient for the wear resistance investigation of both the deposited or modified superficial layer and that of the basic material (substrate).

2. CALOWEAR TESTING METHOD

Micro-abrasive wear test with a ball (Fig. 1) was originally developed for the thickness measurement of thin surface coatings (Calotest). The rotation of a profiled drive shaft is transferred to the ball via two contact points; the ball presses against the sample surface in a third point and thus wears it during its rotation. The speed and the duration of the shaft rotation are controllable, as well as the inclination of the sample load cell.

The wear scare on the sample surface has a shape of spherical crater with a diameter a. In the case when there is a surface coating, after a certain wearing period the ball enters the substrate and an inner circle with a diameter b appears in the spherical hollow, defined by the bottom boundary of the coating. This case is shown in Fig. 2.

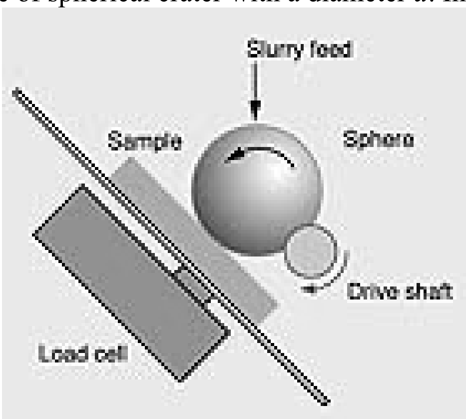

Fig. 1: *The principle of Calowear tester [2]*

An accurate measurement of the diameters a and b of the worn-out spherical hollow in the case of Calotest enables the determination of the surface coating thickness. Knowing the wear ball diameter $2R$ and using a simple measurement of geometrical parameters, the coating thickness is obtained by:

$$h = \frac{a^2 - b^2}{8R} = \frac{\frac{a+b}{2} \cdot \frac{a-b}{2}}{2R} = \frac{x \cdot y}{2R} \tag{1}$$

with a condition that (a, b) << R, (at least 5 times), which means that h << R, (at least 200 times).

The kind of the abrasive medium only influences the wearing duration, and thus the most often used abrasive medium is diamond paste, because of its efficiency.

Bearing in mind the properties of the micro-abrasive wear test, the possibility to apply it in the investigation of tribological properties of thin coatings within the so-called Calowear method [3] was quickly noticed. In this procedure the kind of the abrasive medium, the abrasive volume V, the contact force between the ball and the sample and the abrasion path S have all an important role.

One of the indications of the surface tribological qualities, with or without coating, is the abrasion rate $k = V/(F \cdot S)$. The abrasion volume *(V)* is defined by the diameter (a) of spherical crater formed after a way S slit by the rotating ball during abrasive wearing, while F is the normal component of the ball weight acting to the sample. The abrasion rate also depends on the normal contact force F and on the sliding friction coefficient (ball-sample) which is also connected with the kind of abrasive (or lubricant) used. Besides the possibility to determine the abrasion rate, the Calowear test offers the possibility to

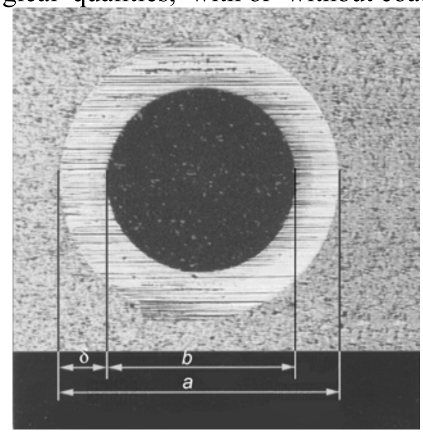

Fig. 2: *Top view of the worn out spherical crater if a surface coating is present*

draw a diagram of the abrasive wear as the change of abrasion volume (*V*) versus the wear way (*S*).

A theoretical explanation of the procedure for determination of normal component of the contact force was proposed by Rutherford and Hutchings [4]. According to our experience this procedure is not simple; it relies on precision measurement of several additional experimental parameters and thus is more prone to appearance of errors.

This paper presents a method for the measurement of contact force based on the use of cylindrical spiral spring as a simple sensor, utilized in the Laboratory of the Faculty of Electrical Engineering in Belgrade. It enables the measurement both of static contact force F_s between the abrasion ball and the sample and of dynamic force F during abrasion. To apply the method it is not necessary to perform a prior measurement of the sliding friction coefficient and of some geometrical parameters which are more complex to measure in micro-abrasive wear test.

3. SPRING AS A FORCE SENSOR

Our contact force sensor is a cylindrical spiral spring which reliably measures forces in a range of $F = (0.2 \div 1.5)$ N. The mechanical stiffness of the spring is $c = Q/f = 0.18$ N/mm. This was established by two experiments of the shortening under load:

$$1)\ Q_1 = 0.65\ \text{N} \rightarrow f_1 = 3.6\ \text{mm},$$
$$2)\ Q_2 = 1\ \text{N} \rightarrow f_2 = 5.55\ \text{mm} \qquad (2)$$

The spring cannot reliably measure contact forces in the range $F < 0.2$ N because of the decreased accuracy of the measurement of spring deformations, while the forces larger than 1.5 N do not appear in this method.

Chosen spring is made of plastic and has 7 coils with a flat ending (Fig. 3). Its mass is m = 0.47 g and it does not influence the accuracy of the contact force F measurement.

The unloaded spring length is 16.5 mm. A top view is that of an annulus with external diameter of 10 mm, and internal diameter of 5.7 mm. If the abrasion ball is placed on the spring the static shortening of spring appears:

$$f = L - L' = 3.5\ \text{mm (Fig. 4)}.$$

According to Figs. 3 and 4 it can be concluded that the ball weight is

$$W = c \cdot f = 0.18\ \text{N/mm} \cdot 3.5\ \text{mm} = 0.63 \qquad (3)$$

which was checked by an additional measurement of the ball weight by a precision scale. There is an inherent spacing between spring coils of t = 1.7 mm (Fig. 3) and the whole spring is shortened by

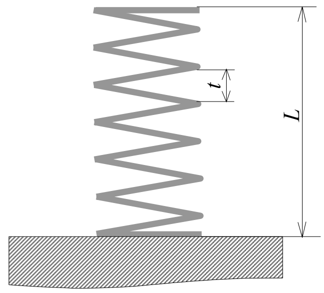

Fig. 3: *Appearance of unloaded spring-sensor*

9 mm under a load of Q = 1.62 N. The length of the blocked spring is 7.5 mm.

After the geometrical and mechanical characteristics of the spring-sensor itself were determined, an experimental investigation was performed of its behavior when measuring of static and dynamic force at the location of micro-abrasion. A sample ∅15x18 mm was fixed to the micro-abrasive wear test at an angle of $\varphi = 65^o$. The sample was then removed and the spring-sensor was placed in its place, in the identical position. A circular pad of hard rubber was placed under the spring, ∅25, thickness 3.5 mm, with a large sliding friction coefficient ($\mu \geq 0.4$). The abrasion ball was pressed to the other end of the spring, which shortened the spring by f = 2 mm and thus the ball assumed the position as if placed on a sample with a height of 18 mm (Figs.5 and 6)

According to the above quoted shortening of the spring it was concluded that the static force was

$$F_s = c \cdot f_s = 0.36\ \text{N} \qquad (4)$$

The determination of the dynamic force was done using the rotating ball (micro-abrasion wear test on) under the conditions of dry friction with the front end of the spring. The spring started to oscillate with an amplitude of A = 0.4 mm, and the dynamic force changed within an interval of

$$F_{max} = F_s = 0.36 \text{ N} \quad \text{to} \qquad (5)$$
$$F_{min} = c(f_s - A) = 0.18 \text{ N/mm} \cdot 1.6 \text{ mm} = 0.29 \text{ N}$$

The change of the contact force with sliding friction coefficient in the range under consideration is shown in Fig.7. In our experiment

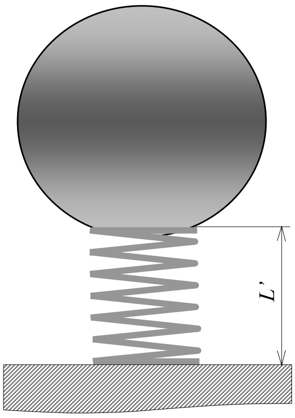

Fig. 4: *Static shortening of the spring*

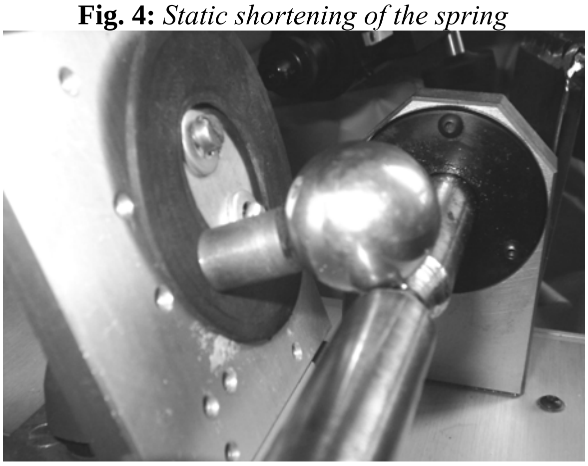

Fig. 5: *Sample position in experimental setup*

the sliding friction coefficient had a value of μ = 0.12 for a lubricated sample (nitrided or non-nitrided), while in the case of dry abrasion the value of this coefficient was 0.18 for the non-nitrided sample and 0.22 for the nitrided one.

It was assumed that the dynamic force was equal to the mean value, F = 0.33 N, from the above given range of sliding friction coefficient values.

A vernier with an accuracy of 0.05 mm was used to measure lengths. The accuracy of the force measurement was ± $c \cdot 0.05$ mm = ± 0.01 N, i.e. 2.5% of F_{max}.

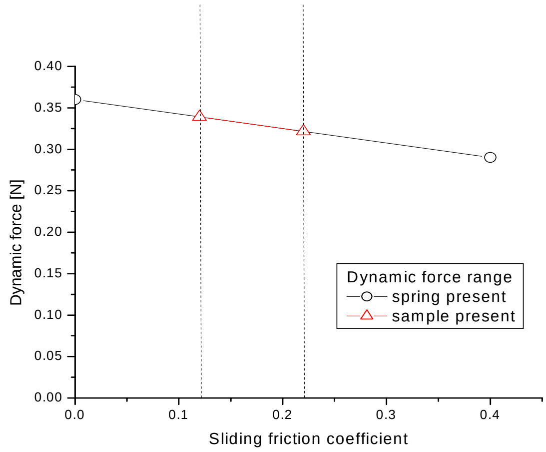

Fig. 7: *Contact force versus sliding friction coefficient*

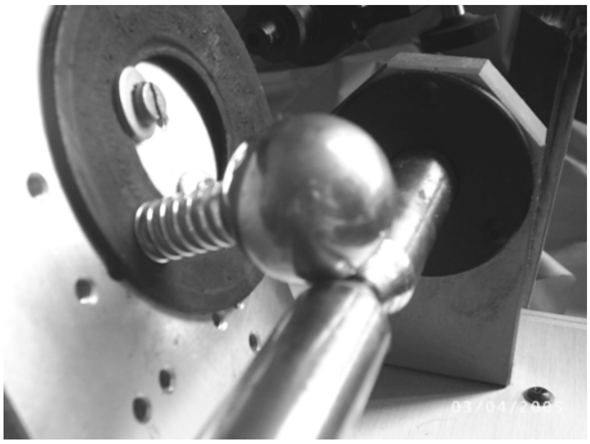

Fig. 6: *Spring position during force measuring*

4. CONCLUSION

1. The determination of the abrasion rate $k = V/(F \cdot S)$ requires a good knowledge of the contact dynamic force between the abrasive ball and the sample. This force can be experimentally measured by simple sensor – a cylindrical spiral spring whose mechanical stiffness can be easily determined (in our experiment c = 0.18 N/mm). Measurement accuracy was ± 0.01 N, or 2.5% by using a vernier with an accuracy of 0.05 mm.

2. Static contact force was determined by the sensor placed in position equivalent to that of the sample in experimental setup (Figs. 5, 6).
3. If the sliding friction coefficient were very small, $\mu \sim 0$, then the dynamic force would be equal to the static force, $F = F_s = 0.36$ N.
4. For the realistic values of sliding friction coefficient μ of about 0.12 in lubricated to 0.22 in dry state the dynamic force varies in an interval from 0.34 N for lubricated to 0.32 N for dry state, thus its mean value of F = 0.33 N can be utilized (Fig. 7)
5. The results of the described experiments agree with other authors [4] who used more complex methods and a more accurate sensor (precision ± 0.005 N).

5. ACKNOWLEDGEMENT

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6. REFERENCES

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