A STUDY OF STATIC FRICTION IN RECIPROCATING MOVEMENT OF SLIDING PAIR STEEL-EXPANDED GRAPHITE

BADANIA TARCIA STATYCZNEGO W RUCHU POSUWISTO-ZWROTNYM PARY ŚLIZGOWEJ STAL–GRAFIT EKSPANDOWANY

Key words:
static and kinetic friction, expanded graphite, reciprocating movement

Słowa kluczowe:
tarcie statyczne i kinetyczne, grafit ekspandowany, ruch posuwisto-zwrotny

Abstract

The paper presents the results of coefficient of static and kinetic friction depending on the load. During the study, the sample in the form of a pin with expanded graphite, mounted in a holder, was forcibly pressed the Fn to the steel countersample. The device on which the tests were carried out research

* Poznan University of Technology, ul. Piotrowo 3, 60-965 Poznań, Poland, e-mails: aleksandra.rewolinska@put.poznan.pl, karolina.perz@put.poznan.pl, marta.paczkowska@put.poznan.pl.

** Wroclaw University of Science and Technology, Wybrzeże Stanisława Wyspiańskiego 27, 50-370 Wroclaw, Poland, e-mail: piotr.kowalewski@pwr.edu.pl.
allows sliding friction in reciprocating motion. It has been found that there is a noticeable difference between the coefficient of static friction and kinetic for both fixed and different pressures. In the field of applied pressure, there were no significant their impact on the coefficient of friction; applied force was not sufficiently high which may have contributed to this state. The study had a distinctive character.

INTRODUCTION

Static friction plays a significant role in the operation of the machines. It is the characteristic friction for the reciprocating movement, e.g., seals working in valves. However, most of the tribological research focuses on the analysis of kinetic friction and downplays the phenomenon occurring in the initial phase of friction, while it is a phenomenon that can significantly affect the operation of machinery and equipment, especially those working in a motion-rest system. This influence may be disadvantageous, e.g., if it is the cause of vibration disrupting the movement of friction elements, the so-called “stick-slip” phenomenon [L. 1]. In addition, start-up of the machine can be difficult, especially if the contact time between the mating surfaces is increased. Then the processes of atom diffusion on the elementary contact surfaces are intensified, thereby increasing adhesion connections strength with the passage of time [L. 2]. This phenomenon may be due to an inappropriate choice of materials for the mating surfaces.

The literature shows a number of studies on the phenomenon occurring in the tribological combination polymer-steel [L. 3–5]. In these studies, graphite is often in the form of a polymer additive that is introduced in various forms and quantities [L. 6, 7]. Generally, the published research results indicate [L. 8–10] that graphite improves the wear resistance of the mating material, lowers the temperature of the friction pair, stabilizes the friction coefficient, and reduces the noise. However, there are no studies on the operation of expanded graphite - steel combination. On the other hand, the use of expanded graphite in seals is very common, e.g., in a ring-pin/shaft in valves or pumps. Therefore, the phenomenon of static friction occurring in that combination should be recognized. Another factor pointing to the need for these studies concerns the problems associated with the start-up of a steel-graphite combination, as mentioned by the producers and users of seals. Knowledge of the above issues will allow for better design and the selection of the seal for particular applications, which will limit the losses arising from the negative manifestations of friction and have other advantages.

The aim of this study is to determine the value of the coefficient of static and kinetic friction depending on the load. The study had an exploratory character.
MOTION STUDIES ON EXPANDED GRAPHITE-STEEL COMBINATION

The object of testing

A photograph of the stand and a schematic of mating steel-expanded graphite combination are shown in Fig. 1.

![Schematic and photograph of the stand](image)

**Fig. 1.** A photograph of a testing stand for the research of a static friction in case of a reciprocating movement [L. 11]: a) kinematic scheme of the testing, b) real view; 1 – lower platform, 2 – upper platform, 3 – friction force sensor, 4 – sample (expanded graphite pin), 5 – counter-specimen (metal plate) $F_n$ – pressure force, $F_f$ – friction force, $V_s$ – average speed.

Rys. 1. Stanowisko badawcze zastosowane do wyznaczania siły tarcia statycznego w ruchu posuwisto-zwrotnym [L. 11]: a) schemat, b) widok; 1 – wózek dolny, 2 – wózek górny, 3 – czujnik siły tarcia, 4 – próbka (trzpien grafitowy), 5 – przeciwpróbka (płyta metalowa), $F_n$ – siła nacisku, $F_f$ – siła tarcia, $V_s$ – średnia prędkość

The device on which the tests were carried out allows sliding friction testing in reciprocating motion. During the tests, the sample in the form of a pin of expanded graphite, mounted in a holder, was pressed with $F_n$ to the steel counter-specimen. Samples made of expanded graphite had a diameter of 14 mm. The roughness of the steel counter-specimen was $Ra = 0.98-1.12$ μm. Counter-specimen motion system consisted of two bearing platforms placed on one another so that they could move in the same direction. The force causing the slip $F_f$ (t) was recorded at a frequency of 100 Hz. Based on changes in the course of the friction force at the time of start-up, static friction values were determined, $F_{st}$, as well as kinetic friction values $F_{sk}$, and friction coefficients $\mu_{st}$ and $\mu_k$ were defined based on the above.

Testing conditions

Testing conditions were shown in Table 1. Before starting the specific measurements, the test materials pair was subjected to lapping until a sample of
the expanded graphite was in thorough surface contact with steel counter-
specimen. The lapping was carried out at a pressure of 25 N, the average speed
of 25 mm / sec for 60 minutes, followed by 30 minutes at an average speed Vs
= 3 mm / sec. The tests were carried out at different unit pressure p, at an average
friction velocity Vs = 3 mm / sec.

Table 1. Conditions for testing; s – rest, and – a movement
Tabela 1. Warunki przeprowadzania badań; s – spoczynek, r – ruch

<table>
<thead>
<tr>
<th>Phase</th>
<th>Time [min]</th>
<th>Pressure p [MPa]</th>
<th>Average speed [mm/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lapping</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>60</td>
<td>0.16</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td></td>
<td>3</td>
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<tr>
<td>Test at the constant pressure</td>
<td>s</td>
<td>0.5</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>r</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>s</td>
<td>0.5</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>r</td>
<td>15</td>
<td>1</td>
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<tr>
<td>Test at different</td>
<td>s</td>
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<tr>
<td>pressure values</td>
<td></td>
<td>0.5</td>
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<td></td>
<td>10</td>
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After a period of rest, the value of the coefficient of static friction \( \mu_s \) was
determined based on 1 motion cycle. For motion tests, the coefficient of kinetic
friction \( \mu_k \) was determined based on 4 motion cycles (30 s). The experiment
was performed with a 3-fold repetition. An example of the variation of the force
of friction for the tested friction pair at a unit pressure \( p = 0.75 \) MPa and
10 minute standstill is shown in Figure 2.

![An exemplary diagram of friction force during tests and 10 min of rest](image)

**Fig. 2.** An exemplary diagram of friction force \( F_t \) that shows how it changes in time.
Examined friction pair under unit load \( p = 0.75 \) MPa

**Rys. 2.** Przykładowy przebieg zmian wartości siły tarcia \( F_t \) zarejestrowanej na stanowisku ba-
dawczym przy nacisku jednostkowym \( p = 0.75 \) MPa
The ratio $\mu/\mu_{st}$ was determined for obtained values of the coefficients of static and kinetic friction. A smaller difference between the coefficients of static and kinetic friction for the conditions means a smaller susceptibility of the combinations of materials for the occurrence of stick-slip.

**Tests results**

According to the presented plan, the tests consisted of the tribological mating of steel counter-specimen with samples made of expanded graphite with a constant and with a varying load. Combination mating with a constant pressure of 0.25 MPa revealed differences in the coefficient of static and kinetic friction. The value of the coefficient of static friction is greater (0.22) than the kinetic coefficient (0.17). The value increases slightly (0.23) for the static coefficient when the system goes back to work after 15 minutes of rest (Fig. 3). However, the kinetic coefficient of friction remains constant during all the tests and amounts to 0.17.

![Graph showing static and kinetic friction coefficients](image)

**Fig. 3. The coefficients of static and kinetic friction for the pressure of 0.25 MPa and different times of rest**

Rys. 3. Współczynniki tarcia statycznego oraz kinetycznego dla nacisku 0,25 MPa i różnego czasu spoczynku

During the tests at different pressures (0.5, 0.75 and 1 MPa), differences in friction coefficients are smaller than for lower pressure (0.26 MPa). The coefficient of kinetic friction is, except for the pressure of 1 MPa, less than 0.2 (Fig. 4). On the other hand, the coefficient of static friction increases slightly with the pressure and the time of rest.
In addition, the tests show the impact of pressure on both the kinetic and static friction coefficient. At a pressure of 0.25 MPa static coefficient exceeds the value of 0.2 (Fig. 3). However, the coefficient was smaller at higher pressures (Fig. 4). No significant changes in friction coefficient depending on the time of rest of combination were observed. It can be argued that the selected times of rest of 5 and 10 minutes are too short to notice the changes. A 15-minute rest may suggest that the coefficient of friction increases, because the coefficient increase is observed for both constant and variable load; however, in the latter case, this value is within the error limit.

The ratio of kinetic to static friction coefficient $\mu_k/\mu_s$ during tests at constant pressure is on average 0.75. In addition, for a second test at different pressures, it is higher and amounts to an average of 0.92, which limits the potential for the stick-slip effect that causes vibrations in the system. In addition, the formation of a layer of graphite was observed on the steel counter-specimen (Fig. 5). This phenomenon is characteristic for steel-graphite combination [L. 12].
SUMMARY AND CONCLUSIONS

The results of tribological tests led to the following conclusions and observations:

- It was found that there is a noticeable difference between the static and kinetic friction coefficient for both constant and different pressures, which may be affected by material like expanded graphite, which supports the formation of stick-slip phenomena due to a layer created while moving to a mating surface.
- In the field of applied pressure, they had no significant impact on the coefficient of friction, since applied force was not sufficiently high, which may have contributed to this state. Information from literature on the impact of pressure on the coefficient of friction in combination steel–graphite is inconclusive.
- Tests conducted with different combinations of times of rest did not indicate its impact on the coefficient of friction, since the selected times of combination rests are too short and should be prolonged in subsequent studies.

REFERENCES


Streszczenie

W pracy przedstawiono wyniki badań wartości współczynnika tarcia statycznego i kinetycznego w zależności od obciążenia. Podczas przeprowadzonych badań próbka w postaci trzpienia z grafitu ekspandowanego, zamocowana w uchwycie, dociskana była siłą $F_n$ do stalowej przeciwciała. Urządzenie, na którym wykonano badania umożliwia prowadzenie badań tarcia ślizgowego w ruchu posuwisto-zwrotnym. Stwierdzono, że zauważalna jest różnica między współczynnikiem tarcia statycznego oraz kinetycznego zarówno dla stałych, jak i różnych nacisków.

W zakresie stosowanych nacisków nie odnotowano znaczącego wpływu na współczynnik tarcia; przyłożona siła nie była wystarczająco duża, co mogło przyczynić się do powyższego stanu. Przeprowadzone badania miały charakter rozpoznawczy.