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Measurement of temperature at sliding polymer surface by grindable thermocouples

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ABSTRACT

This paper is devoted to experimental study of capabilities and limitations of grindable thermocouples as applied to polymer materials sliding on metal. Chromel–alumel and chromel–copel grindable thermocouples have been developed and tested for wide ranges of contact pressure and sliding velocity. The background temperature of the sliding surface can be determined as the lower envelope of the signal from the grindable thermocouple. Steady and unsteady regimes of sliding have been investigated. For steady sliding, the accuracy of the temperature determination increases with measurement duration. In the case of unsteady sliding, accurate temperature determination requires multiple tests under the same conditions. The thickness of the thermocouple junction has been analyzed for correct comparison of experimental and calculated temperatures.

1. Introduction

It is well-known that temperature affects frictional behavior and failure of sliding components. Especially noticeable is its influence on properties of polymer materials which are widely used in brakes, clutches and sliding bearings. For example, the friction coefficient and wear rate of polymer/metal pair can change by several times within the range of working temperatures [1]. Therefore, temperature should be taken into account when predicting performance characteristics of polymer/metal friction pairs.

Generally, temperature is distributed in the sliding component non-uniformly. It reaches its maximum at the sliding surface and decreases with the distance. Polymers have low thermal conductivity, which results in a large temperature gradient at the sliding surface. For highly-loaded friction pairs, this gradient attains a magnitude of 0.1–1 °C/μm [2]. Consequently, for adequate description of thermal effects it is necessary to know the temperature of the surface layer not thicker than several tens of micrometers.

Different techniques have been developed to measure temperature of sliding surfaces [3]. The most commonly used methods are the infrared radiation technique and thermocouple technique. The infrared radiation technique is based on that the radiative power depends on temperature. Infrared detector is focused on the contact area through a transparent component [4] or at a surface close to the contact area [5]. The technique enables recording temperature with high sampling rate and spatial sensitivity. However, the requirement for at least one transparent sliding component is not practical in most cases.

The thermocouple technique is based on the Seebeck effect, i.e., the direct conversion of temperature to electric voltage. The common approach is installing a thermocouple in the stationary component as close as possible to the sliding surface. The smaller is the thermocouple junction, the higher is the measurement accuracy. Various miniature thermocouples have been developed. The smallest of them would probably be a thin film thermocouple with a junction of the order of 1 μm in the direction perpendicular to the sliding surface [6,7]. Miniature thermocouples provide reliable measurements, but their service life is short due to the microscopic distance between the junction and wearable sliding surface.

Another approach within the thermocouple technique is to use grindable thermocouples [8,9], also called contact thermocouples [3] or tape thermocouples [10,11]. Double-pole grindable thermocouple consists of two separate insulated wires embedded in the component with their ends exposed at the sliding surface. The frictional deformation and heating join the wires together into a junction. Thereby, the grindable thermocouple provides measurements under intensive wear conditions. In the case of a metallic component, the construction of the grindable thermocouple is simplified by eliminating one wire and using the component instead of it (single-pole grindable thermocouple [12]).

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Grindable thermocouples make a good alternative to infrared detectors and miniature thermocouples when applied to metallic friction pairs. They have been successfully used for measuring temperature of ground workpieces [9,12–16]. On the other hand, their application to non-metallic materials is considerably limited [17,18]. One of the main reasons for this is the dissimilarity in properties of non-metallic materials and metals. It has been testified [19] that the measurement error of the grindable thermocouple is dependent on the difference between the thermophysical properties of the sliding component and thermocouple wire; the more essential is the difference, the larger is the error. Moreover, the friction of the thermocouple wire on a counterbody differs qualitatively from the friction of non-metallic material on the counterbody. The involvement of the thermocouple in friction may cause distortion of the temperature field in the vicinity of the thermocouple junction. Thus, the problem of interpretation of the temperature signal from the grindable thermocouple should be resolved to expand the application of grindable thermocouples to non-metallic materials.

This paper provides an experimental study of characteristics of grindable thermocouples as applied to polymer materials. A special attention is paid to the issues of interpretation of the temperature signal and estimation of the measurement accuracy. The applicability of grindable thermocouples to temperature measurements is investigated for steady and unsteady sliding conditions.

2. Experimental technique

2.1. Grindable thermocouple tape arrangement

Two types of grindable thermocouples based on chromel–alumel and chromel–copel pairs are used in the experiments. Grindable thermocouple is manufactured from two wires of a small diameter. One end of each wire is flattened into a thin tape. The thickness h of the tapes is equal to 60 μm for chromel–alumel and 20 μm for chromel–copel. The tapes are trimmed, coated with thin insulation layer and sandwiched together, forming the tape arrangement, as shown in Fig. 1. The insulation material is polyimide for chromel–alumel and mica for chromel–copel. It is essential that the tapes are completely insulated from each other.

Friction sample represents a cube with a side of 1 cm. It is split into two equal pieces. The grooves are made accurately in the pieces, as depicted in Fig. 2. The tape arrangement is placed into the grooves. The cyanoacrylate adhesive is applied to the pieces (dotted areas in Fig. 2) and then the pieces are glued together under pressure. As a result, the tape arrangement is securely clamped in the grooves between the two pieces and its tip lies at the sample surface.

2.2. Experimental set-up

Fig. 3 shows a schematic of a friction machine developed. The sample is installed into a holder which is, in its turn, attached to a lever by use of a beam. The holder and beam are carefully leveled. The lever can rotate about a vertical axis. Friction disc is machined with high precision. Its friction surface is ground to eliminate waviness and distortion. It is mounted on a horizontally installed shaft together with an inertia disc. The shaft is driven by a rotor. By applying a force to the lever, the sample is pressed against the disc. The adjustable parameters of friction are the contact pressure p and linear velocity v of the disc at the average friction radius $r = 35$ mm.

Two beams with different stiffnesses are used to support the sample. The stiff beam (cross section 20×4 mm^2) allows conducting tests in the regimes of steady sliding and deceleration. On the other hand, friction-induced tangential oscillation of the sample is possible when using the pliable beam (cross section 16×2 mm^2).

The tangential displacement x of the sample is measured by a laser sensor with a resolution power of 0.2 μm. The laser spot, 70 μm in diameter, is focused on the polished upper face of the holder. The signals from the grindable thermocouple and laser sensor are processed by a data logger with a sampling rate f_s of up to 100 kHz. The data logger provides two modes of signal processing: no filter; low-pass filter with a cut-off frequency of 500 Hz.

2.3. Friction materials

Two polymer friction materials denoted as SFP04 and 145-40 are tested. SFP04 is used as brake pads in motor vehicles. It

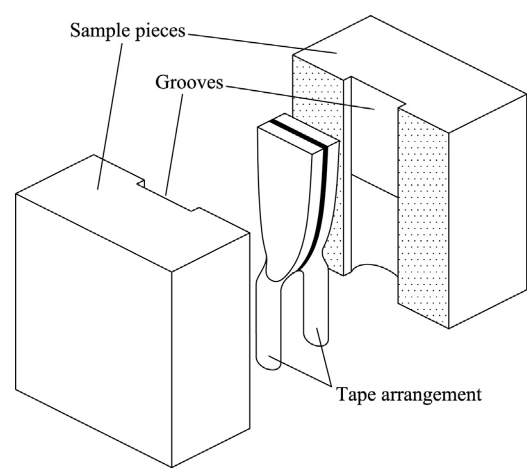

Fig. 2. Installation of tape arrangement into friction sample.

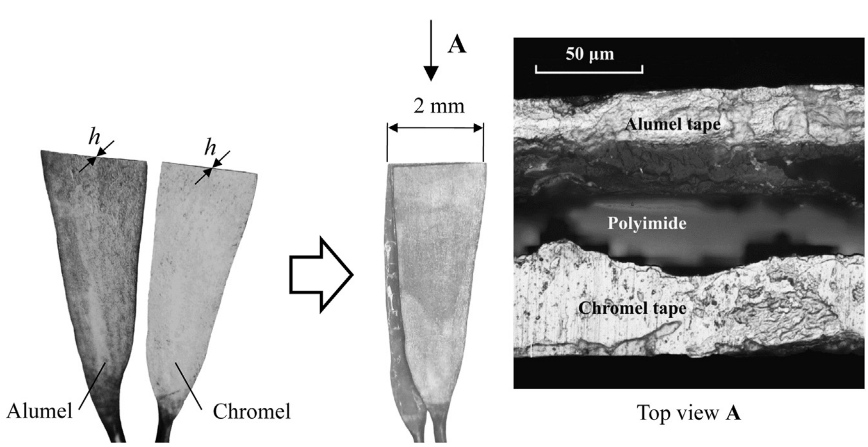

Fig. 1. Chromel–alumel thermocouple tape arrangement.