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Measurement of chemical and geometrical surface changes in a wear track by a confocal height sensor and confocal Raman spectroscopy

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ABSTRACT

Geometrical and chemical changes in the wear track can cause a drift in friction level. In this paper, chemical and geometrical surface changes in wear tracks are analyzed. For this, a setup with a confocal height sensor was developed to measure the local height changes on the wear track, combined with confocal Raman spectroscopy to determine the chemical changes at the surfaces. Pin-on-disc experiments were performed at room temperature and at elevated temperature (600 °C) to understand the material behavior between mild and severe wear regimes. The wear tracks developing between the two ceramics, alumina (Al_2O_3) and zirconia (Y-TZP), were analyzed using these techniques. The results of confocal height sensor showed significantly more geometrical changes in surface roughness at 600 °C compared to the test conducted at room temperature. The developed roughness in the wear track was approximately 250 times larger at 600 °C due to the higher degradation of the mechanical properties of ceramic. Further, material transfer was observed for the test conducted at 600 °C using Raman Spectroscopy. Material transfer at room temperature is difficult to observe because surface changes are less evident in mild wear regimes. The results show that the changes in the micro-geometry of the surface and the chemical compositions of the surface influence the friction level and wear processes. The confocal height sensor and Raman Spectroscopy were used to measure and understand the geometrical and chemical changes occurring on the surface of a wear track during sliding in a single setup.

1. Introduction

Friction and wear play an important role in the effective functioning of mechatronic systems where a precise positioning accuracy over a long working life is desired. The structure of two sliding surfaces, the operating variables and mechanical or chemical interaction of the components in the system influence friction and wear [1,2].

Ceramics are used in many applications, due to their low thermal conductivity and superior mechanical properties, chemical and electrical resistance. Alumina (Al_2O_3) and zirconia (ZrO_2) are widely used in industry as insulators in power transmission systems, optics, journal bearings, MEMS systems and so on [3].

Various measuring techniques are available to investigate the wear between ceramics. Optical methods based on light

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scattering are widely used to study the change in the surface topography [4,5]. Confocal microscopy can be used to analyze the micro-geometry of surfaces [6,7]. Miyake et al. [8] used confocal laser microscopy to determine wear by observing profiles of microgrooves in Al–Al_2O_3 composite surface. The advantages of using confocal microscopy are high spatial resolution together with a high accuracy and the possibility to be applied for different kinds of materials. In a confocal chromatic optical setup, the chromatic light is used to get complete parallelization of the depth scan, so the rough surfaces within the measuring range are measured [4,9].

Atomic force microscopy (AFM), energy dispersive microscopy (EDS) and X-ray photoelectron spectrometry (XPS) are common techniques to measure the presence of elements on the surface [10,11]. Sample pre-preparation is required for some of the mentioned techniques, which is a disadvantage to study the wear and surface changes. During the measurement there is a possibility of damaging the surface due to the test conditions. Raman spectroscopy is a non-intrusive technique, where sample preparation is not necessary. Confocal Raman spectroscopy is more suitable for ceramics, because of high spatial resolution and reduced fluorescence effect [11–13]. Many studies have been done on zirconia [14–16] and alumina [17,18] using Raman spectroscopy. For example, the structural phase transition of an alumina (Al_2O_3) was observed by Cava et al. [19]. The ability of the Raman spectroscopy to detect phase changes in the contact occurring due to mechanical stresses was demonstrated by authors [15–19].

The present research work in this paper focuses on the analysis of the wear track made by alumina (Al_2O_3) on zirconia (ZrO_2) at temperatures of 25 °C and 600 °C. A comparison between mild and severe wear regimes [12,15] indicates that at 600 °C material transfer is more evident between Al_2O_3 ball and ZrO_2 plate. In order to do this, a measurement setup composed of a fiber optics based confocal height sensor and a confocal Raman spectroscopy sensor has been developed. The latter was used to investigate the molecular composition of the wear track. The advantage of the setup is to measure the surface properties in a wear track. Further, it can be used in combination with tribological testers for an in-situ measurement. Wear tracks on ceramic contacts that have been operating respectively in the mild and severe wear regimes [20–22] will be analyzed and the surface changes will be compared.

2. Pin on disc tests

Friction measurements were carried out using a high temperature pin-on-disc tribometer at room temperature and at 600 °C. An alumina (Al_2O_3) ball with a diameter of 10 mm was sliding against a zirconia (Y-TZP) plate. A normal load of 5 N was applied with a sliding velocity of 0.1 m/s and a sliding distance of 1 km. Information of the sample preparation is described in our previous publication [10,23]. The properties of materials used in this study are summarized in Table 1.

The coefficient of friction measured as a function of sliding distance is shown in Fig. 1 for two temperature conditions. In both the cases, the transition from the initial to the steady state coefficient of friction was observed at the beginning of experiment. The average coefficient of friction obtained at room temperature was found to be 0.5 and 0.8 at 600 °C.

The difference in coefficient of friction is due to mechanical properties of ceramics and wear behavior described by Adachi et al. [20] and Wang et al. [24]. At high temperature conditions severe wear takes place and friction level is higher as compared to room temperature.

3. Surface measurement setup

A photograph of the experimental setup is shown in Fig. 2(a), and in Fig. 2(b) the schematic is shown.

The confocal height sensor (STIL CL1-MG210) is connected through an optical fiber to a controller (CCS Prima). The chromatic light from the controller is measuring the local surface height with a working distance of 3.3 mm and a nominal measuring range of 100 μm. The spot diameter of the sensor is 2 μm and the height resolution is 5 nm. Data acquisition is done by a computer. The Raman setup is composed of a laser (Ventus Laser) with wavelength 532 nm and power 50 mW. The green light from the laser is transmitted through optical fibers to a sensor (Horiba Super Head-532) with an objective lens of 50× (N.A. 0.5). Scattered light from the sample coming back through the sensor is sent to a

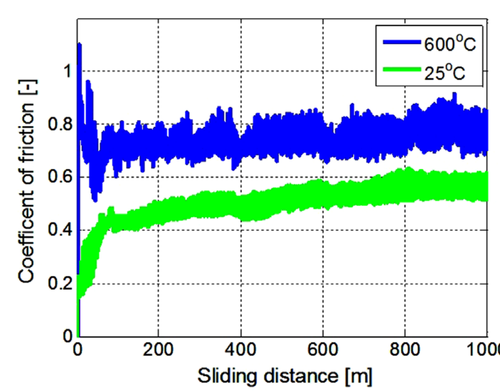

Fig. 1 – Friction level of 3Y-TZP sliding against Al_2O_3 at room temperature and at 600 °C.

Table 1 – Properties of material used in testing [22].

Material	Hardness (GPa)	Elastic modulus (GPa)	Bending strength (MPa)	Fracture toughness (MPa $m^{1/2}$)	Grain size (μm)	CLA surface roughness (nm)
Alumina	20±0.8	320	340	3.4±0.4	5	15
3Y-TZP	13±0.4	210	450±10	4.2±0.2	0.45	25