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Study of friction and wear mechanisms at high sliding speed

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ABSTRACT

The aim of this work is to propose an analysis of mechanisms inducing surface interaction by friction during high sliding speed. Specific devices including a ballistic setup were used to reproduce extreme sliding conditions combining high speed and high pressure. The titanium alloy/tantalum tribo-pair is chosen to investigate the frictional and material transfer mechanisms. The tangential force measurement is used to follow the evolution of the friction coefficient at a macroscopic scale. The evolution of the sliding surface was analyzed by confocal 3D microscope to evaluate material transfer and real contact surface area. Numerical modeling of micro-contact at the asperities scale is presented to illustrate the scenarii involved during friction. The energy needed to shear a junction is estimated and analyzed for several types of interaction. Different behaviors have been taken into account in order to investigate the global forces generated by the contact including strong and weak contacts. The analysis of energy is available to predict the global friction force in a large range of velocities. Correlations between experimental measurements and numerical predictions are used to validate the proposed approach. The results can be interpreted as following: (1) at lower velocity the main mechanism dominating the interaction between asperities becomes ploughing with large volume of plastic deformation (2) at higher velocity the main mechanism is shear localization requiring less energy and force for shearing the junctions.

1. Introduction

The interaction between solid surfaces is generally investigated through the friction factor such as described by the Coulomb's model. When the sliding speeds tend toward extreme conditions the evaluation of friction factors become crucial to correctly represent the physical phenomena for a wide range of problems including metal forming and machining. The tribological contact with two loaded surfaces in relative motion is nevertheless very complex. The combination of high pressures and high sliding speeds increases the difficulty of the determination of the friction factor. On the one hand, the experimental tests should reproduce the local conditions of high pressure and high speeds of the studied processes with the capability of the force measurement. These conditions were achieved in the present study with simple geometries of specimen mounted on a specific ballistic device and an hydraulic machine test (Arnoux et al., 2011; Kennedy, 1984; Sutter and Ranc, 2010). On the other hand, the contact modeling must take into account the entire physical phenomenon susceptible to occur during sliding (Kennedy, 1984; Molinari et al., 1999). Shearing of asperities is believed as one of the most important parameter controlling the force opposing to the sliding. A model at the level of micro-contacts of asperities is thus considered. The Finite element method, which is used to model the interaction, has the advantage to take into account most of physical parameters such as complex material behavior or damage

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consideration (Faulkner and Arnell, 2000; Jackson et al., 2007; Vijaywargiya and Green, 2007). Understanding the processes that occur at the asperities level when two rough surfaces are bought into contact has the main objective to evaluate the magnitude of shearing stress occurring during the junction evolution. The tangential contact force can be determined by summing the mean shear forces taking place at each asperity in contact. The knowledge of the real surface in contact during the friction process remains very important to predict the values of the friction forces and friction factors. Correlation with experimental observations of the surfaces in contact is then necessary in order to explain the evolution of the amplitude of the friction forces in the different studied cases.

2. Experimental at high sliding speed

The surfaces of bodies in contact were subjected to relative sliding velocities by using specific tribometer devices (Sutter and Ranc, 2010; Philippon et al., 2004). A specific load sensor (Fig. 1) is designed to be integrated on two different benches: (a) a ballistic setup (Fig. 1(a)) able to reach sliding speeds above 120 m/s and (b) a hydraulic dynamic testing machine able to perform sliding velocity under 3 m/s (Fig. 1(b)).

As shown in Fig. 2, two plates labeled ***A*** are fixed on a dynamometer ring which imposes a normal pressure between the plates and the specimen:

$$P_a = \frac{F_N}{S_a} \tag{1}$$

where S_a is the apparent surface corresponding to the area of a plate ***A*** in contact during the friction test (120 mm^2). The pressure magnitude P_a fixed to 50 MPa is calibrated by adjusting the dimensions between the two plates ***A*** and the dimension of the specimen ***B*** leading to the normal force F_N. A set of strain gauges records the axial component of the tangential forces F_T. The plates ***A*** are made up of tantalum whereas the plate ***B*** consists in a titanium alloy.

The friction factor μ is then defined through the tangential and normal forces by:

$$\mu = \frac{F_T}{F_N} \tag{2}$$

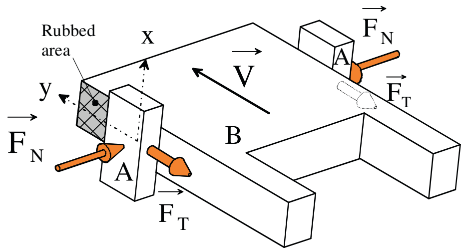

Fig. 2. Schematic view of the specimen and plates.

Illustrations in Fig. 3 show an example of evolution of surface on the specimen ***B*** for the case of the pair Ta6V4Al/Ta. The profile was obtained by 3D confocal microscope (Leica DM 3D). The surface roughness analysis shows that strong interactions have occurred between the peaks of the two materials. Material transfer with severe plastic deformation mechanisms is essentially from titanium alloy to tantalum as observed in previous works and other observation methods (Sutter et al., 2013).

3. Micro-contact model

3.1. General consideration

To investigate frictional forces it is necessary to examine in detail the mechanical behavior of typical junctions. Indeed, the knowledge of the shear stress τ_k needed to shear the junctions and the local pressure p_k supported by each couple of asperities (k) in contact should allow the determination of the total frictional force F_T and the normal force F_N by the simple relationships:

$$F_T = \sum_{k \le n} \tau_k S_k = \sum_{k \le n} (F_T)_k \tag{3}$$

$$F_N = \sum_{k \le n} p_k S_k = \sum_{k \le n} (F_N)_k \tag{4}$$

where n is the total number of pairs of asperities in contact and S_k the surface area of this contact. The real surface area S_r of the global contact is given by:

$$S_r = \sum_{k \le n} S_k \tag{5}$$

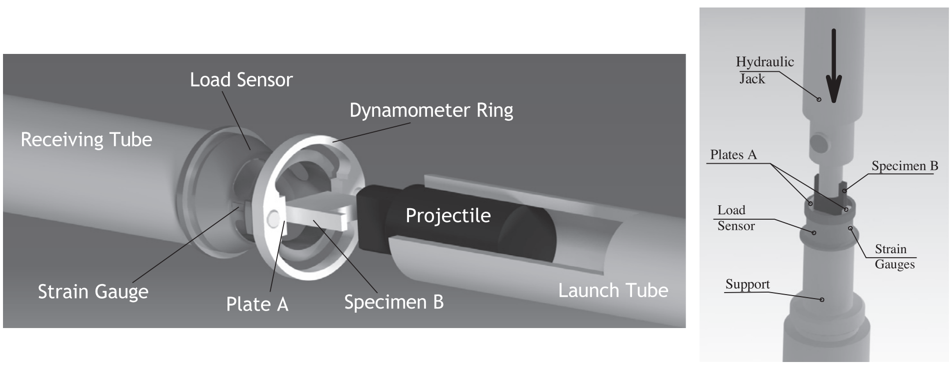

Fig. 1. Specific devices for friction tests (a) ballistic set-up; and (b) hydraulic machine.