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Finite element simulation for analysing experimental friction tests under severe conditions

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ABSTRACT

In this paper, a finite element model is proposed for analysing friction process derived from an experimental tribometer set-up able to reproduce severe contact conditions under dynamic loading. A pair of low carbon steel is studied when interacting for a sliding velocity varying from 15 to 82 m/s and a normal pressure of 50 and 200 MPa. The specificity of this device lies in the high-speed range with a maximum velocity close to 120 m/s. This high-speed range requires taking into account the dynamic phenomena due to fast loading and short transition time. The numerical simulations for the main objectives have to propose a support for the experimental signals analyse (inverse method) and to validate the calibration of the measuring device. The phenomena generated by the dynamic loading are highlighted and allows defining precisely the measurements and the physical quantities obtained during the tests. Therefore several recommendations are proposed to improve experimental data analysis considering structure effects related to the device.

1. Introduction

The growing need in productivity leads to increase rates of processes and use material under extreme conditions. Under high sliding speed, friction has to be considered with respect of energy consumption increase and lifetime of components. A precise knowledge of the friction factor becomes of crucial interest for designers. For this reason, it is essential to develop efficient devices to characterise and to measure the forces related to friction.

In recent decades, many devices have been proposed as tribometers to study dry friction. The most commonly used tribometers include a pin or a sphere loaded onto a test sample with an imposed normal force. Thanks to their simplicity of implementation in apparatus, a large domain of applications can be investigated from coating tests to railway braking [1–3]. Corresponding to a long time of interaction, wear and degradation mechanisms can also be suitably studied but generally under relatively low normal pressure. Other techniques that are more specific use a modified torsional Kolsky bar apparatus [4,5] or impact plates for applying high normal pressure [6,7]. These experimental techniques are most appropriate for studying initial mechanisms of friction. To reach very high speed (up to 800 m/s) other original devices based on rotating ball system with magnetic fields must be considered [8,9].

For each proposed devices, one of the most important characteristics is the specification of conditions under which friction is analysed. The phenomena involved in friction can lead to excessive energy consumption from the start that can modify rapidly the sliding conditions. Depending on the selected devices, the friction process must be differently analysed, when the contact takes place before or after a running phase. Another important challenge is to combine high sliding velocity with large normal pressure to have a better description of the processes studied and observed during real applications. Under these extreme conditions, the complexity of the phenomena encountered during friction is combined with independent dynamic phenomena caused by the use of high speed. For these reasons, it is essential to master the experimental tool to avoid missing valuable information from the friction phenomena itself because of improper filtering. As discussed above, a real challenge encountered by researchers is to develop optimised devices or tools available to characterise and to analyse faithfully the actual phenomena due to friction without artefact.

In this work, a specific experimental device is presented to combine high contact pressure and high sliding speed. Thanks to this set-up, the friction process is analysed during the initial phase (i.e. without running phase). A numerical study based on this device is conducted to validate the calibration and to propose a detailed analysis of the phenomena generated during the process of friction. From the numerical work, it is possible to estimate the perturbations caused by the device and the phenomena directly related to friction. Completed by previous results, friction experiments of a low carbon

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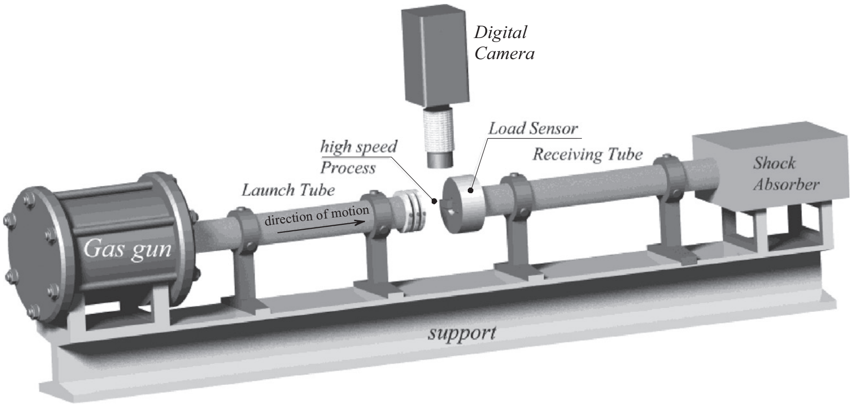

Fig. 1. Ballistic set-up used to analyse and study friction effects under dynamic loading [10–13].

steel tribo-pair are linked to a numerical analysis to improve the determination of the experimental friction coefficient intensity.

2. Experimentation

2.1. High sliding speed tribometer

A specific sensor for measuring forces generated during the friction was developed to combine the high sliding speed and high contact pressure [10–12]. This sensor is integrated on a ballistic bench able of reaching sliding speeds above 120 m/s. The ballistic device presented in Fig. 1 is composed of two coaxial tubes: the first one is the launch tube and the second one is the receiving tube leading to a shock absorber. This equipment was originally developed to study extreme cutting conditions and to reproduce perfectly orthogonal cutting conditions [13,14]. A pneumatic gas gun is used to propel the projectile at high speed into the launch tube. A sufficient tube length combined with an adjusted projectile mass (different geometries and different materials in order to have a suitable kinetic energy), provides almost a constant speed (less than 4% variation) to the projectile during the sliding process. At the end of the launch tube i.e. just before the friction process, a set of three lasers coupled to laser diodes allows to measure precisely the velocity and acceleration of the projectile during the friction phase. Assuming that the specimen remains in contact with the projectile during the test, the kinematics of the specimen is deduced from previous measurements. Initially, an additional set of measurement just placed after the friction process has confirmed that speed is maintained.

The load sensor shown in Fig. 2 is attached to the receiving tube and supports two plates labelled ***A***. A dynamometer ring allows applying the normal force F_N by elastic deformation for which the magnitude is imposed by the thickness of plates ***A***, the width of specimen ***B*** and the initial spacing of the dynamometer. The translation motion of the specimen ***B*** is caused by an inelastic collision with the projectile. The specimen ***B*** is caught by a shock absorber for post-mortem analysis of the rubbed surfaces. The tangential forces F_T generated by friction are deduced from the deformation of a thin component on which two sets of strain gauges are glued on both sides of the sensor.

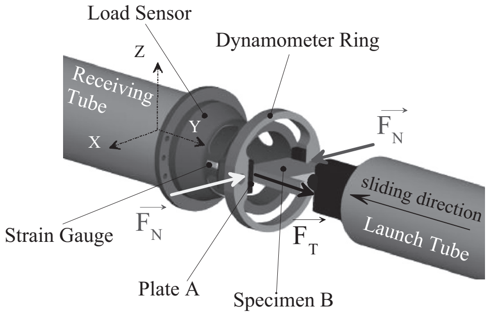

Fig. 2. Schematic representation of the load sensor fixed on the receiving tube.

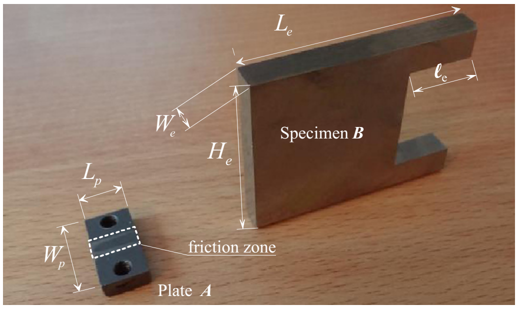

Fig. 3. Samples of friction tests: Plate ***A*** is fixed and specimen ***B*** is the moving part.

2.2. Sample characteristics

The samples shown in Fig. 3 consists of two parts: plates ***A*** and sample ***B***. The plates, which are fixed elements of the tribosystem, have a length L_p of 12 mm and a width W_p of 24 mm including the friction width of 10 mm relating the contact with the specimen ***B***. The specimen ***B*** which have a width W_e of 10 mm constitutes the mobile part and moves in translation along the length L_e (60 mm). A part with a length l_e of 15 mm is designed to guide the specimen after impact with the projectile. The surfaces, which will be in contact during the friction process, are prepared by grinding in the same direction than the rubbing movement (R_a=0.9 μm).

All the tests are carried out under dry friction conditions for a low carbon steel C22 (R_e=340 MPa) on itself. The chemical composition of the material used for the samples is listed in Table 1. Note that the friction tests are conducted with a single pass between two new surfaces (no running-in phase is performed). The main interest of a single pass rub [15] is to learn more about friction phenomena without being obstructed by wear.

2.3. Description of the recorded signal

Fig. 4 presents typical recorded signals from the two gauges glued on the device during dry friction of steel on steel at 40 m/s. The normal pressure P_N is deduced from the normal applied force F_N divided by the apparent friction surface W_e and L_e.