ARTICLE IN PRESS

Tribology International ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Wear behavior of high chromium sintered steel under dynamic impact-sliding: Effect of temperature

Maha Messaadi*, Philippe Kapsa

Laboratoire de Tribologie et Dynamiques des Systèmes, UMR CNRS 5513 ECL-ENISE, Ecole Centrale de Lyon, 36 avenue Guy de Collongue, 60134, Ecully Cedex, France

ARTICLE INFO

Article history:
Received 31 July 2015
Received in revised form
7 April 2016
Accepted 8 April 2016

Keywords:
Sintered steel
Contact temperature
Oxidation
Impact-sliding

ABSTRACT

The present research was carried out to study the combined aspects of impact and sliding failure mechanisms of high chromium sintered steel at different contact temperatures. The tribological behavior (mainly mass loss) was investigated both under reciprocating motion and with a dynamic impact-sliding loading. In case of reciprocating motion, the measured friction coefficient decreases as the contact temperature increases. The presence of oxides seems to be the key factor of this evolution. When for the combined impact with sliding, wear rate and damage mechanisms vary strongly with temperatures. Scanning electron microscopy observations coupled with EDX analysis were performed inside and outside of the wear track in order to understand the surface accommodation with temperatures.

1. Introduction

The use of sintered components seems to provide a relevant path to downsize mechanical systems. In automotive industry, sintered parts are employed as clutches, cams, valves seats, gears and bearings [1]. Wear behavior of these sintered elements is strongly dependent overall tribological system. For instance, valve seat inserts, adapted to be fitted in a cylinder head in automobile engine, are required to have a high wear resistance not only at room temperature but also at elevated temperatures. It should have high abrasion and corrosion resistance under the repeated impact-sliding loading and the cyclic heating-cooling regimes.

Regarding literature, Sato et al. showed that at high temperature, the amount of oxide formed on sliding surface of valve seat is closely correlated to the abrasion resistance [2]. Then, a high-density valve seat contains very small number of pores inducing a small amount of iron oxide on the rubbing surface. Adhesive wear occurs whereby the valve and valve seat are seriously worn. For low-density materials, microspores promote the formation of oxide, which prevents the adhesive wear and satisfactory abrasion resistance. In previous work, Kazuoka et al. recommended the use of sintered alloys having a density not less than 6.6 g/cm^3 [3]. Because if densities are less than the respective minimum values, it is difficult to produce a valve seat insert having a desired mechanical strength and resistance to repeated shock loads.

Therefore, sintered steel porosity plays an important role on surface accommodation for this application. Both beneficial and detrimental effects on wear resistance have been reported [4,5]. Most papers interested on the evaluation of valve seat materials or coatings use the tribometer reproducing the industrial wear conditions [6,7]. Only few works are looking for studying the material response under several loading conditions: reciprocating friction and impact-sliding. In this paper, the study aims to better understand the correlation between contact temperature and oxide generation on wear processes under impact-sliding loading. Approach consists on a comparison between the mass loss and mechanisms induced by reciprocating motion and dynamic impact-sliding loading at different temperatures.

2. Experimental details

2.1 Materials

Hoganas company have designed new sintered steel called OB1 [8]. Microstructure of OB1 workpiece is displayed in Fig. 1 at two magnifications in aim to point out carbide presence in steel matrix. Their advantages are:

– A high wear resistance because the presence of an extended fraction volume of carbides in his metallic matrix (see Fig. 1 on the right). The US Pat. No 8, 110, 020, B2 describes clearly the metallurgical powder composition and the manufacturing process [9].

---

* Corresponding author. Tel.: +33 164706655; fax: +33 160964346.
E-mail address: messadi.maha@yahoo.fr (M. Messaadi).

http://dx.doi.org/10.1016/j.triboint.2016.04.010
0301-679X/

Please cite this article as: Messaadi M, Kapsa P. Wear behavior of high chromium sintered steel under dynamic impact-sliding: Effect of temperature. Tribology International (2016), http://dx.doi.org/10.1016/j.triboint.2016.04.010

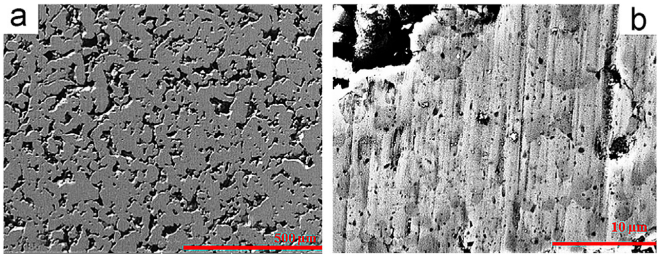

Fig. 1. SEM observations of OB1 microstructure at different magnifications.

- The use of chromium as the main carbide forming metal in order to facilitate the compaction of the product and then to have cheap manufacturing.

The OB1 steel density is 7.7 g/cm^3, equivalent to 21% of porosity volume. To characterize the surface porosity, f_{shape} and f_{circle} parameters are calculated [10]. The f_{shape} indicates the pore elongation, and f_{circle} the pore profile irregularity. Results show that OB1's porosities have a medium elongation and high irregular profiles. Fig. 1 left side shows clearly the morphology of surface porosity. Besides, the steel hardness is dependent on the temperature: at 25 °C, it is around 733 HV_{10} when at 400 °C, it is given in [9], the value is estimated to 299 HV_5.

2.2 Tribological tests

Before tribological tests, OB1steel specimens are polished until a surface roughness R_a less than 0.3 μm. Then, they are cleaned in ultrasonic with ethanol. Spheres of AISI 52100 steel have a surface roughness around 0.01 μm. OB1steel and the counter-body hardness are about 700 HV_1.

Temperatures of tests are similar to those encountered in an Internal Combustion Engine such as starting in ambient condition (25 °C) and in steady-state operation of inlet valve (180 °C) and exhaust valve (400 °C). Specimens are fixed on test benches, reciprocating and the impact-sliding tester, and heated until 180 °C or 400 °C. The heating system consists on a high power electrical resistance localized under the specimen holder. Then, a period of pre-heating is carried out while OB1 specimen is maintained until that instructed temperature is reached. To take into account heat dissipation, measurement of the contact temperature using thermocouple probes is performed during running tests. Tribological tests are carried out into two steps:

- Firstly, friction experiments are performed using a reciprocating ball-on-flat tribometer [11]. The ball slides reciprocally on a fixed specimen with a sliding velocity of 3 mm/s and a stroke length of 2.5 mm. The applied load for each test is 150 N corresponding to a maximum Hertzian pressure of 1.3 GPa. Friction experiments were run until 1000 cycles.
- Secondly, a series of wear tests are conducted under impact-sliding work conditions. The bench test is a modified version of these previously used by Ramalho et al.[12]. Experiments are performed at same impact energy (4 mJ/impact) and excitation frequency (16 Hz) in order to reproduce the same dynamic behavior of the machine test. Additional friction tests were performed (5000, 20,000, 40,000, and 100,000 cycles) in order to observe the evolution of the wear.

2.3 Analytical tools

At the end of tribological tests, wear scars are observed by optical microscopy. Wear scar profile is analyzed by a 3D optical interferometer and the mass loss is calculated using software. Scanning electron microscopy observations coupled with EDS analyses were also performed inside and outside of wear scar. Debris around the contact area were collected and characterized. Some cross sections are performed in order to understand the structure of the tribological transformation of the surface with temperatures.

3. Results

3.1 Reciprocating friction results

Evolution of friction coefficient in dependence of contact temperatures and running time are illustrated in Fig. 2. As temperature increases the friction decreases. Friction variation with time highlights a specific behavior at each temperature. At 25 °C, it seems to increase slightly but continuously with fluctuation. At 180 °C and 400 °C, friction signals display an initial transition period, of about 120 cycles, during which friction reaches a steady values. Similar high speed steels friction behaviours at high temperature are reported elsewhere [13,14].

At room temperature, friction coefficient is the highest. It is around 0, 62. This high value suggests a metal–metal contact. Then, it indicates that it is hard to shear the contacting surfaces. The scanning electron microscopic images, in Fig. 3, present rubbing areas of each contacting bodies at the end of the test. Ball rubbing area shows many grooves and local dark zones (see Fig. 3a). That evokes an adhesive wear process that can occur between metallic asperities. In OB1 workpiece rubbing area, less wear features are visible (see Fig. 3b). One can note presence of tribo-oxidation debris on wear scar edges indicating an oxidation and abrasion process.

The continual increase of friction and its fluctuation are probably due to a competition between adhesive, abrasion and tribo-oxidative wear mechanisms. Under atmospheric conditions and ambient temperature, high chromium steel forms thin oxide films, which are generated and delaminated periodically due to contact friction heating [15]. In this case, oxidation occurs during friction tests.

For high temperature tests, impacted samples are heated inducing the increase of contact temperature by conduction and radiation to the ball. During pre-heating period, the static OB1 specimen develops progressively oxides before the beginning of the tribological test: it is called pre-oxidized. It is wise to keep in mind that tri-oxidation is a different process from static oxidation [16]. Tribo-oxidative refers to oxidation occurring during contact

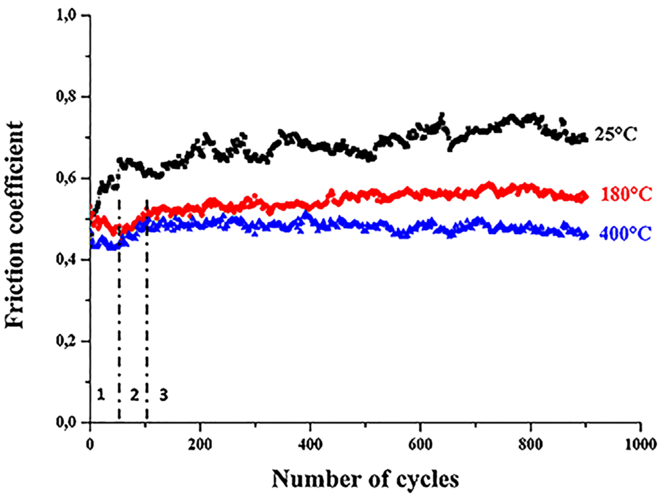

Fig. 2. Effect of sliding cycles on friction coefficient at 25 °C, 180 °C and 400 °C.

Please cite this article as: Messaadi M, Kapsa P. Wear behavior of high chromium sintered steel under dynamic impact-sliding: Effect of temperature. Tribology International (2016), http://dx.doi.org/10.1016/j.triboint.2016.04.010