Tribology International (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Tribology International

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

Numerical analyses of stress induced damage during a reciprocating lubricated test of fecmo sps sintered alloy

N.K. Fukumasu[a,*], G. Boidi[a], V. Seriacopi[a], G.A.A. Machado[b], R.M. Souza[a], I.F. Machado[a]

[a] Polytechnic School of the University of Sao Paulo, Sao Paulo, Brazil
[b] Fiat Chrysler Automobile Group, Minas Gerais, Brazil

ARTICLE INFO

Keywords:
Sintered materials
Finite Element Method
Pores
Contact fatigue

ABSTRACT

Contact-induced stresses during reciprocating movement may lead to surface/subsurface damage. Sintering processes may be used to produce advanced materials with improved wear and friction behavior, but the volume fraction of pores may compromise structural integrity under high loads or fatigue conditions. In this work, the Finite Element Method (FEM) is applied to analyze contact-induced stress distributions produced by surface and inner pores on boundary lubrication condition during reciprocating tests. Material microstructure and mechanical properties are based on sintered FeCMo produced by Spark Plasma Sintering (SPS) process. Results indicate different behavior of surface pores with the increase of contact pressure. It was also observed that pores close to the surface promote a shift of high stress towards the surface, which may improve pitting resistance.

1. Introduction

The pursuit for advanced materials with improved wear and friction performance, low weight and low production costs is usual in many industrial applications. In this search, conventional sintering processes are pointed as an alternative that provides low component weight, low production costs and the possibility of working with advanced alloys. The main drawback of this process is the level of porosity that results from the sintering process, which may reduce the mechanical properties and lead to lower lifetime of the components.

The Spark Plasma Sintering (SPS) process, developed by Tokita [1], allows a better control of pore size and distribution. As indicated by Chen et al. [2] and Orrú et al. [3], SPS leads to the production of materials with improved densities and consolidated zones at reduced times and temperatures, when compared to those of conventional sintering processes.

Literature [4–7] reports that pore morphology, volume fraction and spatial distribution have a significant influence on bulk Young's modulus and on the overall yield strength of components, affecting fatigue and fracture behaviors.

Sinha and Farhat [8] analyzed the indentation hardness of porous samples using instrumented indentation with 100 mN normal load. These authors found a significant influence of porosity on the results, indicating that an increase in porosity led to lower sample hardness. Also, using a reciprocating ball-on-disk configuration, these authors reported an increase in coefficient of friction (COF) with the increase of porosity and significant wear of the surface. Such wear was promoted by debris formation, due to crack nucleation at the edges of the pores.

Zhu et al. [9,10] indicated that surface texturing may result in significant wear of the contact surface when materials with significant difference in hardness are used. In this case, dimples were produced at the surface and, instead of increasing the load carrying capacity, they acted as anchor points promoting severe plastic deformation and crack propagation on the lower hardness material.

Mazahery and Shabani [11] also observed that surface porosity may promote lower wear resistance for sintered materials. On the other hand, works including [12,13] indicate an improved performance of systems with texturized surfaces (e.g.: with dimples), which may improve lubrication conditions and reduce friction and wear.

In general terms, the wear of porous surfaces is associated with debatable positions depending upon system configuration. The porosity can lead to lower wear performance, as presented by Sinha and Farhat [8], Zhu et al. [9,10] and Mazahery and Shabani [11]. Nevertheless, improved wear and friction performance was observed by Babakhani, Haerian and Ghambri [12], for whom lower wear rates were obtained with porous materials, since pores acted as traps for debris produced during lubricated sliding.

In some cases, in which surface pores are closed by plastic deformation, the abrasion of the surface may change, leading to an improved load carrying capacity of the surface. Similar results were reported by Li, Sosa and Olofsson [13], who indicate that closed pores in sintered steel influence the fatigue endurance limit, leading to the

* Corresponding author.
E-mail address: newton.fukumasu@gmail.com (N.K. Fukumasu).

http://dx.doi.org/10.1016/j.triboint.2016.12.025
Received 21 July 2016; Received in revised form 8 December 2016; Accepted 13 December 2016

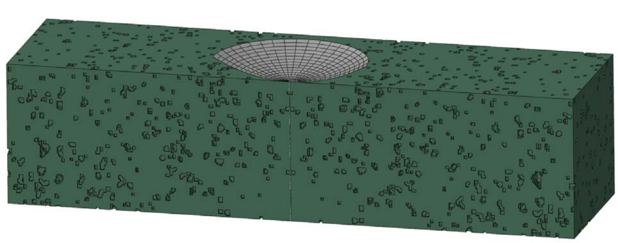
production of new structural components that support large loads, such as gears and cams. Additionally, pores can also act as oil reservoirs under lubricated contact conditions, but Li and Olofsson [14] indicate that such condition is speed and load-dependent, in which higher speeds and/or lower loads improve the condition of the pores as small reservoirs.

In this work, the Finite Element Method (FEM) was applied to analyze the behavior of a porous material subjected to contact loads during lubricated ball-on-disk reciprocating tests. A microscale system is analyzed to allow the simulation of realistic pore geometry obtained by X-ray tomography of a sintered material. A numerical model, based on the Stribeck curve, was implement on the comercial Abaqus® solver to consider the effect of a lubricant on the COF at the contact region.

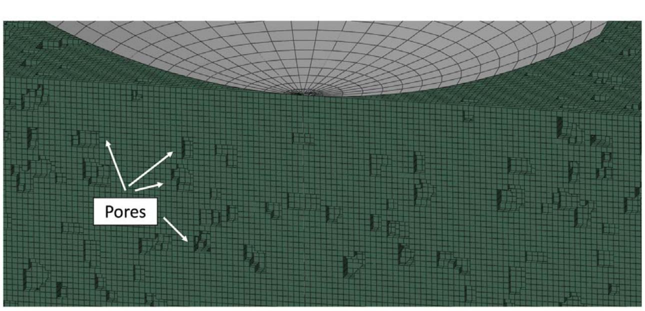
2. Numerical and experimental procedures

The Finite Element Method (FEM), using the Abaqus® comercial code, is used to build a 3D realistic representation of a porous sintered material in a lubricated reciprocating test. This system allows the analyses of pore dynamics under different contact loads. An explicit time integration algorithm was applied to consider time derivatives and inertial loads. All material constitutive models are provided by the Abaqus® simulation package. In this analysis, the computational domain, presented in Fig. 1a, is composed of a rigid sphere with diameter equal to 200 µm, which is in contact with a rectangular counterbody with 400 µm in length, 100 µm in width and 100 µm in height. The pores are assumed to be regions without material and, therefore, they were simulated as regions without elements, as presented in Fig. 1b.

The real porosity distribution and morphology of a FeCMo specimen sintered by the SPS process is included into the numerical domain. The powder, produced by Höganäs AB, has a composition of 0.85% Mo, 0.3% C and 98.85% Fe, presenting an average particle size between 45 and 150 µm. The sintering process, described by Machado et al. [15] and Bertolete et al. [16], consisted of a holding temperature of 1000 °C for 5 min under vacuum and constant pressure of 70 MPa. To increase the hardness, after the sintering process, the sample is water quenched after austenitizing at 850 °C for 30 min and then tempered at 200 °C for one hour. The real distribution and morphology of pores in the sintered specimen are analyzed by X-ray tomographic reconstruction technique, applied using a XRadia Versa XRM-510 from Zeiss Inc.. This system presents a maximum spatial resolution of 0.9 µm. The Avizo Fire v9.0 from Fei Inc. is used to extract pore morphology and to generate the numerical mesh of Fig. 1. From the tomographic analyses, pores present diameters with a gaussing distribution centered on 20 µm. Therefore, to consider the geometry of the pores, a very fine mesh, with approximately 3.9 million C3D8 continuum hexaedral elements, was used.



a)



b)

Fig. 1. Computational domain for the reciprocating test analyses: a) system composed by an analytical rigid sphere (gray) and a plane counterbody (dark green); b) detail of the system indicating the porosity represented as small voids (regions without elements) in the numerical mesh. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

In Fig. 1, the bottom of the counterbody was constrained in all directions and a symmetrical plane was defined at the lateral of the system. The sphere is able to move only on the symmetry plane in a pure sliding configuration. The movement of the sphere was controlled to reproduce a sinusoidal displacement with a stroke of 200 µm in length. The normal load was selected to provide Hertzian contact pressures of about 1.7 GPa, 3.0 GPa and 4.0 GPa at the beginning of the analysis.

The mechanical properties of the porous material are obtained by nano-indentation tests of bulk consolidated sintered material, using a Ti950 tribometer from Hysitron Inc.. A Berkovich tip is used with a normal load of 0.7 mN, which minimized the effect of porosity on the measurements, in opposition to results obtained by Sinha and Farhat [8]. A total of 250 indentation marks are used to evaluate both Young's modulus and hardness. The constitutive model for this material is based on the elastic-perfectly plastic behavior, in which the Von Mises criterium is selected to indicate the onset of plastic deformation.

Even though the selected test conditions promotes boundary lubrication, a user-defined function was used to implement the calculation of the local coefficient of friction (COF) as a function of the Hersey number (H), according to a defined Stribeck curve (Fig. 2). The Hersey number is a function of relative velocity, contact pressure and the viscosity. In this work, the viscosity is considered constant and is implicitly accounted in the calculations. At the beguinning of each time step, the variable COF is calculated based on Fig. 2 for each contacting element and serves as input variable to the general contact algorithm, based on the penalty formulation, provided by the comercial code.

An experimental lubricated reciprocating test is carried out to evaluate the behavior of the pores at the surface of the sintered material. A SRV v4 reciprocating rig from Optimol Instruments Prüftechnik GmbH is used with the lubricated ball-on-disk reciprocating configuration. The ball material is ASTM 52100 bearing steel and the disk is produced by the SPS process using the FeCMo powder and the process parameters described above. The experimental setup is configured with a 1 mm stroke, 50 Hz ball movement and two normal loads: 160 N and 400 N. This configuration leads to maximum contact stress of 2.5 GPa (160 N) and 3.4 GPa (400 N), calculated by the ideal

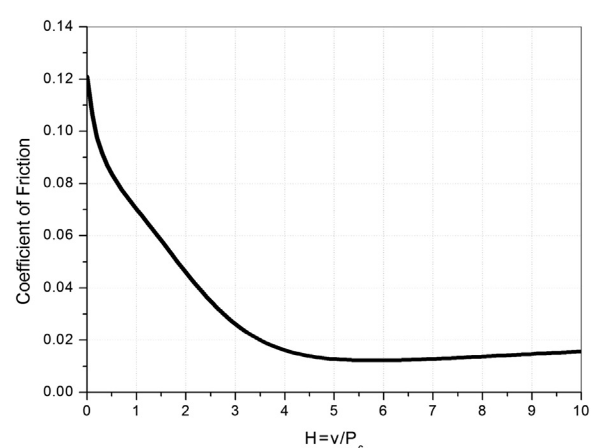


Fig. 2. Stribeck curve applied to calculate the variation of the coefficient of friction with the Hersey number (H) based on a constant viscosity.