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In-situ observation of crack propagation in silicon nitride ceramics

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Abstract

Using the four point bending inside scanning electron microscope (SEM), the *in-situ* visualization of crack propagation in silicon nitride ceramic under monotonic and cyclic loading was performed with notched specimens of prismatic shape. In the monotonic loading experiment the study focused on the visualization of inter- vs. trans-granular crack propagation and on the analysis of the material resistance to cracking in terms of *R*-curve. In the cyclic loading experiment the test was done under high load regime, sufficient for crack initiation and visible propagation within few cycles.

Keywords: Silicon nitride; hybrid bearing; structural ceramics; inter- trans-granular crack propagation; *R*-curve; cyclic loading

1. Introduction

Silicon nitride (Si_3N_4) ceramic is nowadays the state-of-the-art material for rolling elements in hybrid bearing due to superior mechanical properties (Wang et al. (2000)), as high hardness, stiffness and low weight. Other physical properties, like good resistance to corrosion and hydrogen embrittlement, thermal stability and high electrical insulation make ceramics to be superior over full steel bearings for special applications. The SKF hybrid bearings

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comprise of steel rings and Si_3N_4 rolling elements (see Fig. 1). High hardness of ceramics however, has “another side of coin” and this is relatively low toughness inherent for these materials. Therefore ceramic components of bearings are less resistant to crack initiation and propagation in rolling contact fatigue than the components made of steel.

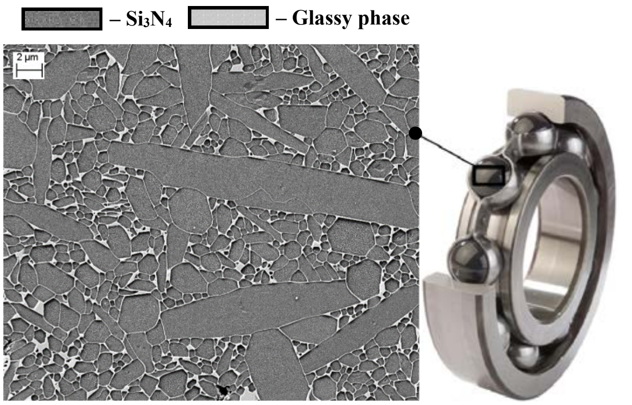

Figure 1: Micrograph of the engineering ceramics Si_3N_4 used for rolling elements in hybrid SKF bearings.

Nevertheless, there exist some toughening mechanisms for Si_3N_4, like crack kinking and arrest caused by the texture of sintered ceramics (see e.g. Xu et al. (2003)) and by the grain bridging (see e.g. Fünfschilling et al. (2011)), which is a potential toughening mechanism under cyclic loading (Greene et al. (2014)). The fracture resistance can be quantified in terms of the so-called R-curve, i.e. a material property relating a size of a crack to the crack propagation resistance. The size of propagating crack can be obtained by the compliance method, or by the direct measurement of crack length *in-situ* conditions (Fünfschilling et al. (2011)). It is rather complex and expensive to use the compliance method, because it requires high-precision equipment and calibration, so in the current work the crack extension is measured by the Scanning Electron Microscope (SEM). In addition to the crack size determination it can also provide the *in-situ* complex morphology of the crack propagating in a polycrystalline structure of Si_3N_4. As known, this material is sintered from hard Si_3N_4 grains (crystals) “glued” to each other by a glassy (amorphous) phase (see Fig. 1). This means that crack can propagate by the two different modes: through the Si_3N_4 grain (trans-granularly) or along the glassy phase at grain boundaries (inter-granularly). Typically, a crack path in the Si_3N_4 ceramics consists of trans-granular and inter-granular segments, and the mode of crack propagation depends on the fracture properties of these two phases and the orientation of an incident crack relatively to grain boundaries (Taheri Mousavi et al. (2015)). The incident crack approaching to the grain boundary, can either penetrate into the new grain or deflect and propagate along the boundary. In the current work the crack path is depicted within the granular structure of Si_3N_4, which allows to visualize the trans-granular and inter-granular segments of a propagating crack at the sample surface. Si_3N_4 ceramics with different microstructures were tested in the current work under monotonic load and the material resistance to the crack propagation was compared in terms of R-curves. The fracture experiment was also done under cyclic load, visualizing the crack propagation in very low cycle fatigue regime.

2. Experimental procedure

The equipment used in the current study combines a bending test apparatus (Kammrath & Weiss bending module) with SEM providing sufficient magnification to be able to observe a propagating crack on the scales of the granular morphology presented in Fig. 1. The loading of specimen is performed in the four point bending test presented in Fig. 2a. The ceramic specimen has a prismatic shape and the external force, F, applied to the specimen, is equally