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Observation of subsurface rolling contact fatigue cracks in silicon nitride and comparison of their location to Hertzian contact subsurface stresses

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Abstract

From lubricated rolling contact tests on silicon nitride rolling elements, genuine subsurface fatigue process from the Si3N4 microstructure was demonstrated and visualized for the first time by testing two different microstructure quality levels. Subsurface fatigue cracks initiating at microstructure features were found to be associated with local orthogonal shear stresses from the Hertzian stress field. All fatigue cracks displayed evidence of Mode II and III crack type propagation with an angle orientation that conformed to the shear stress direction.

Keywords: silicon nitride, rolling contact fatigue, subsurface fatigue cracks, rolling contact

1 Introduction

In the last twenty years, hybrid bearings, i.e. rolling bearings with silicon nitride rolling elements and steel rings, have become a common product that is readily available in many types and sizes in bearing manufacturers' catalogues. The use of ceramics as a bearing material was spurred on in the early sixties by the need for extreme temperature bearings for aero and space applications. Ceramic material purity, sintering technology and processes for super-finishing of silicon nitride ball surfaces were developed in the 80s and early 90s to levels that are required for bearing applications offering high performance Si3N4 based products. In the last few years, hybrid bearings have been increasingly used in many other applications with challenging environments. Early research [1] on ceramics rolling contact performance reported surface wear, spalling, pitting or fracturing at contact edges as failure modes. With improved processes and improved Silicon nitride materials [2, 3, 4], other research followed [5, 6, 7, 3, 2] on rolling element performance using component test rigs, with contact pressures in the range of 5.5 to 9 GPa. The main finding was that high quality Silicon nitride would require a much higher rolling contact pressure than the pressures used previously in order to fail, and the failure mode was by spalling in a non-catastrophic way and identical to that of bearing steel. Under these very high loads, shallow delamination and spalling were observed. Debates were raised on the initiation location [5, 6, 7]. In some cases the failure morphology suggested surface initiated, in other cases subsurface initiation. Some spalls could be associated with clear subsurface pores / inclusions, in other cases the spall origin was at the surface and at the contact path edges where high tensile stresses (maximum principal stresses) are present. A certain qualitative correlation between rolling contact performance, life time and the material microstructure and properties was reported [7, 3]. It was concluded that a duplex microstructure consisting of intermediate sized acicular grains with a high aspect ratio surrounded by smaller grains gave the best rolling contact lifetime. Larger grained structures gave poor bearing performance. A small amount of porosity degrades the rolling contact performance without affecting the material strength and hardness. However in other work [7], materials with high hardness, fine equi-axed grains and uniform, minimum secondary phases showed the best resistance to damage under rolling contact. In full scale hybrid bearing tests [8], a