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Quantitative Evaluation of the Flaking Strength of Rolling Bearings with Small Defects (Part 2: Evaluation of the Flaking Strength of Rolling Bearings with Small Drilled Holes, based on the Stress Intensity Factor)

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Abstract

Rolling contact fatigue (RCF) tests were conducted on rolling bearings, with holes micro-drilled at the mid-point of the tracks. In all of the RCF tests, fatigue cracks initiated at the edge, near the base of the drilled holes, later propagating by shear-mode. Even in the un-flaked specimens tested up to $N = 2\times10^8$ cycles, short fatigue cracks were discovered at the edges. Using the stress intensity factor (SIF) range, as calculated for the initial defect size, fatigue life data were uniformly gathered inside a narrow band, irrespective of the diameters and depths of the holes. In addition, it was determined that the crack-size dependency of the threshold SIF range, well-known for Mode I fatigue cracks, also exists for Mode II fatigue cracks, as produced after rolling contact. The values of the threshold SIF range obtained by the RCF tests were in good agreement with those obtained in the torsional fatigue tests under static compression.

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1. Introduction

Flaking, a typical fracture mode seen in rolling bearings, is a type of fatigue fracture associated with shear-mode (Modes II and III) crack-growth (Murakami, 1993). Therefore, it would be preferable if flaking strength could be handled as a crack problem, similar to the metal fatigue problems responsible for Mode I crack-growth. Furthermore, there is a need to develop a novel method to evaluate the rolling contact fatigue (RCF) strength of bearings, based on fracture mechanisms and crack-growth properties. In fact, many studies have been conducted in the last three decades in an attempt to establish this type of evaluation method (Murakami *et al.*, 1993; Otsuka *et al.,* 1994; Matsunaga *et al.,* 2009, 2011; Matsunaga, 2010; Okazaki *et al.,* 2014, 2017; Endo *et al.* 2015). However, the properties of crack-growth and crack-threshold during RCF still present many unsolved problems, chiefly because it is extremely difficult to make continuous observations, beginning with crack initiation, through crack-growth, up to final fracture. Given such constraints, a specimen with a crack-starter has been used (*e.g.,* small hole, groove, indentation, etc.), to enable a successive observation of the fracture process (Cheng *et al.,* 1993; Dommarco *et al.*, 2002, 2006; Fujii *et al.,* 2002; Kida *et al.,* 2004, 2006; da Mota *et al.*, 2008). The authors also conducted a series of RCF tests using a JIS-SUJ2 plate with various sizes of small drilled hole, in order to develop a method for evaluating flaking strength as a small crack problem (Komata *et al.*, 2012, 2013).

In this study, RCF tests were conducted on rolling bearings with small holes drilled at the mid-point of the tracks, for the purpose of establishing the evaluation method of RCF strength, based on fracture mechanics. The influence of the diameters and depths of the drilled holes on flaking strength was determined using actual rolling bearings. In Part 1 of this study, in order to quantify the RCF test results of rolling bearings with small drilled holes, the Mode II stress intensity factor (SIF) range of ring-shaped cracks, which emanated at the edges of the drilled holes after the passage of the rolling element, $\Delta K_{\mathrm{II,\,drill}}$, were analyzed using the finite element method (FEM). Based on the result of analyses, combined with an analytical solution for the SIF of penny-shaped cracks in an infinite body under uniform shear, an approximate formula was derived to obtain $\Delta K_{\mathrm{II,\,drill}}$ for various load levels and hole geometries. In this part of the research, the obtained formula was applied to the result of the RCF tests, thereby quantifying the impact of small defects on the flaking strength of rolling bearings as a crack problem.

Nomenclature

d	diameter of drilled hole
h'	depth of the edge of drilled hole
a	radius of penny-shaped crack in an infinite body
a'	length of ring-shaped crack emanating at the edge of drilled hole
F	Applied load on rolling element
$q_{\max}$	Maximum contact pressure
τ_{xz}	Shear stress in *x-z* plane
K_{II}	Mode II stress intensity factor
ΔK_{II}	Mode II stress intensity factor range

2. Experimental procedures

2.1. Materials

The rolling bearings used in the RCF tests were JIS-6206 and JIS-51305, produced from JIS-SUJ2, the chemical composition of which is provided in Table 1. All of the bearings were at first heat-treated at 1113 K for 60 mins, then subsequently oil-quenched and tempered at a temperature of 443 K for 120 mins. After heat treatment, the sizes