Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 7 (2017) 468–475

Structural Integrity Procedia

www.elsevier.com/locate/procedia

3rd International Symposium on Fatigue Design and Material Defects, FDMD 2017, 19-22 September 2017, Lecco, Italy

Rolling Contact Fatigue Damage from Artificial Defects and Sulphide Inclusions in High Strength Steel

Taizo Makino[a]*, Yutaka Neishi[a], Daiki Shiozawa[b], Shoichi Kikuchi[b], Hitoshi Saito[b], Kentaro Kajiwara[c] and Yoshikazu Nakai[b]

[a]*Nippon Steel & Sumitomo Metal Corporation, 1-8 Fuso-Cho, Amagasaki, Hyogo, 660-0891, Japan*
[b]*Department of Mechanical Engineering, Kobe University, 1-1, Rokkodai, Nada, Kobe 657-8501, Japan*
[c]*Japan Synchrotron Radiation Research Institute (JASRI), 1-1-1, Kouto, Sayo-cho, Sayo-gun, Hyogo 679-5198, Japan*

Abstract

To clarify the effects of artificial defects and sulphide inclusions on rolling contact fatigue (RCF) in high strength steel, crack initiation and propagation behaviours from defects were evaluated by using synchrotron radiation computed laminography. Artificial defects and sulphide inclusions lead to RCF damage "flaking" through the same damage process, but considerably different crack initiation lives. Finite element analyses (FEA) for RCF simulated the different stress states between two kinds of defect. The FEA results suggest the reason for the different crack initiation lives in the RCF test.

Peer-review under responsibility of the Scientific Committee of the 3rd International Symposium on Fatigue Design and Material Defects.

Keywords: Rolling Contact Fatigue(RCF); Artificial Defect; Sulphide Inclusion; High Strength Steel; Synchrotron Radiation Computed Laminography (SRCL), Finite Element Analysis (FEA)

* Corresponding author. Tel.: +81-6-7670-5875; fax: +81-6-6489-5794.
E-mail address: makino.hb3.taizo@jp.nssmc.com

Peer-review under responsibility of the Scientific Committee of the 3rd International Symposium on Fatigue Design and Material Defects.
10.1016/j.prostr.2017.11.114

1. Introduction

In the rolling contact fatigue (RCF) test for bearing use under pure rolling contact and oil lubrication, it is believed that flaking failure results from crack initiation and propagation originating from non-metallic inclusions located in the internal region. Many researchers have studied the RCF damage originating from sphere-shaped inclusions, i.e., oxide inclusion and clarified its damage mechanism (Chen et al., 1991; Lewis et al., 2012; Unigame et al., 2007). In contrast, RCF damage originating from stringer-type inclusion has recently been reported (Nagao et al., 2005; Neishi et al., 2013). However, the damage mechanism has not been clarified.

To understand such RCF damage process in the internal region of the material, direct observation by non-destructive method is very helpful. Micro CT imaging using synchrotron X-ray is promising for the observation method. Its application to various objects, e.g., internal cracks by torsion fatigue (Shiozawa et al., 2014), internal fatigue cracks in aluminium alloy (Zhang et al., 2009), and internal inclusions (Stiénon et al., 2009) have already been reported.

The objective of this paper is to clarify the effect of artificial defects and sulphide inclusions on the rolling contact fatigue (RCF) property in high strength steel. Crack initiation and propagation behaviours from defects under rolling contact were evaluated by using synchrotron radiation computed laminography (SRCL) in SPring-8 (Super Photon Ring 8 GeV). Artificial defects and sulphide inclusions lead to RCF damage "flaking" through the same damage process, but considerably different crack initiation lives. Finite element analyses (FEA) for RCF simulated the different stress states between two kinds of defect. The FEA results suggest the reason for the different crack initiation lives in the RCF test.

2. Observation of RCF damage by synchrotron radiation computed laminography (SRCL)

We have evaluated RCF damage originating from artificial defects by using micro CT imaging (Nakai et al., 2012; Makino et al., 2014). However, the method requires the X-rays to penetrate the whole cross section of the specimen. The cross section of the specimen is restricted to a 0.5mm square shape. The shape of the specimen is too thin to conduct the RCF test. To solve the above problem, synchrotron radiation computed laminography (SRCL) (Moffat et al., 2010) was applied to direct observation of the RCF damage process.

2.1. RCF test for a material with excessively introduced inclusions

A material of high carbon-chromium bearing steels with high sulphur concentration was employed in RCF tests. Excessive sulphide inclusions were introduced in the material. The chemical compositions of the material were 1.01C, 0.33Si, 0.45Mn, 0.003P, 0.049S, 1.50Cr in mass%. Since the sulphur content was 0.049 %, the material is referred to as "S49" in this paper. The specimens were plate-shaped with W10 mm × L24 mm × t1.0 mm dimensions. They were cut from the material so that sulphide inclusions were orientated perpendicular to the rolling surface.

We developed a relatively small RCF testing machine that enables SRCL for plate specimens, and used it in this paper. A specimen is set on a linear guide. The linear guide is connected to an eccentric cam, and the rotating motion of the eccentric cam is converted to the reciprocating motion of the linear guide. Ceramic balls of 6.0mm in diameter (SiC, Young's modulus: 300 GPa) were used in the RCF test in this paper. The reciprocating distance was 3.0 mm. The vertical force was set so that the Hertzian stress p_{max} became 5.39 GPa. Then the half width (radius) of contact area a was 0.190 mm. We refer to the above test method as "reciprocating-type RCF test" in this paper.

2.2. Observation method of RCF damage by SRCL

Ultrabright synchrotron radiation is needed for observation of the above specimen with 1.0 mm thickness. BL46XU beamline of SPring-8 was employed, because the beamline was equipped with an undulator generating X-ray beam with high brightness. In SRCL, a plate specimen is penetrated at its central part by an X-ray beam with