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Experimental and analytical investigation of effects of refurbishing on rolling contact fatigue

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ABSTRACT

In this study, the effects of refurbishing on rolling contact fatigue (RCF) in case carburized AISI 8620 steel were experimentally and analytically investigated. A thrust bearing test apparatus (TBTA) was designed and developed to simulate RCF. Initial RCF tests were conducted on AISI 8620 steel specimens to determine the baseline for pristine. Then new specimens were exposed to fatigue cycles equal to 90% of the L_{10} life of the pristine material. These specimens were then refurbished to the depths of 0.13b and 1.27b (b is the half width of Hertzian contact). The refurbished specimens were then subjected to RCF cycles in the TBTA until a spall appeared on the surface. The experimental results of refurbished specimens indicated a significant amount of fatigue life after refurbishing for both grinding depths. Moreover, it was observed that the remaining useful life of the refurbished test specimens was extended by increasing the depth of the regrinding.

For the analytical investigation, a two-dimensional elastic-plastic finite element model was developed to estimate RCF life for pristine and refurbished specimens of case carburized steel. The characteristics of case carburized materials (e.g., variations in hardness and residual stresses) were incorporated in the 2D finite element model. In the present study, a continuum damage mechanics approach was employed to determine fatigue damage accumulation in original and refurbished domains. The results obtained from the experimental and FEA models for pristine and refurbished case carburized steel are in good agreement for both grinding depths.

1. Introduction

Rolling contact fatigue (RCF) is a major cause of damage in components such as rolling element bearings, gears and cam/tappet arrangements. It is characterized by crack initiation and propagation caused by the alternating stress field below the surfaces of the contacting bodies. Rolling contact fatigue is the primary damage mode in rolling element bearings (REBs) that are properly installed, lubricated and well maintained [1]. Surface-originated pitting and subsurface originated spalling are the most dominant RCF mechanisms in REBs [2,3].

Surface irregularities in the form of dents or scratches cause surface stress concentrations and lead to the formation of surface cracks. These surface cracks propagate downward in the material at shallow angles and cause a small volume of material to come loose, creating the damage mode commonly referred to as surface-originated pitting. On the other hand, subsurface-originated spalling occurs when micro-cracks originate below the surface at material inhomogeneities and propagate toward the surface, forming a relatively large spall. When bearings are operated under ideal conditions (e.g., clean lubrication and smooth surface finishes), the subsurface-originated spalling mechanism is dominant [2,3].

Surface-originated damage in components of REBs can be repaired. In the mid-1970s, the aerospace industry began restoring bearings by grinding the surfaces of used bearings [4–6]. Since that time, bearing repair and refurbishment has become prevalent and is the standard practice in commercial aircraft applications. The popularity of this method has grown not only in the aerospace industry, but also in heavy industries [7]. Bearing repair and refurbishment can be an effective way to extend bearing life. Moreover, there are significant cost savings, since bearing refurbishing costs approximately 60% of new bearing replacement costs. Another advantage of refurbishment is the reduction in downtime, especially for custom-made bearings [7].

There are four reconditioning levels for bearing refurbishing, based

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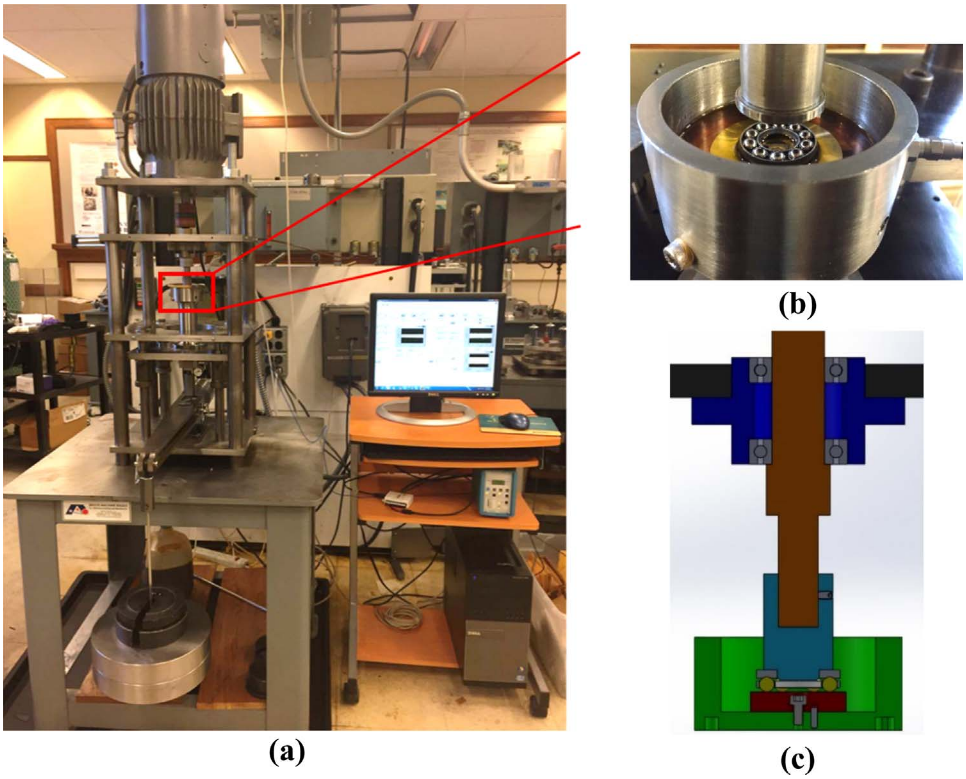

Fig. 1. Thrust bearing test apparatus for conducting the RCF test: (a) TBTA setup, (b) specimen holder, (c) CAD model.

on the amount of damage in the bearing components. The most basic case is category level I [8], where the corrosion is removed and the bearings are cleaned, reassembled and packaged to return for installation and service. At this level, no machining is required. At level II, the inner and outer rings are polished to remove the minimal damage on the raceways. In many cases, the raceways are heavily damaged and require level III repair, where the surfaces are ground to remove surface damage up to a depth of 0.015 in. (0.381 mm) [9]. In level III repair, the rolling elements are replaced in the bearing. When extreme material damage deeper than 0.015 in. is present, the rolling elements, cage or rolling bearing rings must be replaced with new parts. This is level IV repair. Among these four different levels of repair, level III repair is the most favorable, as it significantly enhances the fatigue lives of REBs with minimal cost. Another benefit of level III repair is to restore damaged surfaces that have defects caused by operating condition, which is a common industrial bearing damage mode [10]. This allows bearings to reach their critical damage mode and useful estimated life [11].

Few experimental and analytical investigations have been conducted on the effects of restoration on bearing life. In the past few decades, most of the experimental investigations have focused on determining the fatigue lives of pristine bearings rather than refurbished bearings. The majority of the experimental studies for repaired bearings have been done by specific industries for particular applications [12].

Analytical investigations of refurbished bearings have been quite limited. Coy et al. [13] modified the Lundberg-Palmgren equation to estimate the fatigue life of refurbished bearings as dependent on the previous service time and grinding depth of refurbishing [14]. Based on their model, the refurbished L_{10} life prediction could be between 74% and 100% of pristine L_{10} life. This model was then extended by Zaretsky [15] to include maximum shear stress criteria. In the new model, the fatigue damage of the outer race and the damage of the inner race and rolling elements were additionally considered. Kotzalas and Eckels [12] developed an analytical model using the ISO 281:2007 standard. This model includes the entire stress field instead of the simplified stress field employed by Lundberg-Palmgren [14] and Zaretsky [15].

One restriction associated with all the previous models is assuming a prescribed constant Weibull distribution of bearing failure. Paulson et al. [11] proposed a new modeling approach, which could calculate the Weibull parameter for a group of bearings. This model used microstructure topology coupled with damage mechanics to predict the fatigue lives of refurbished bearings [11].

In the present work, a thrust bearing test apparatus (TBTA) was designed and developed to experimentally investigate the rolling contact fatigue behavior of pristine and refurbished specimens. Case carburized AISI 8620 steel specimens were used in the experiments. First, RCF tests were conducted on the specimens to obtain the fatigue lives of pristine specimens. When the baseline L_{10} life (cycle) was determined, a second series of pristine specimens were tested in the TBTA up to 90% of the L_{10} life (cycle) of the pristine material. Some of the specimens were refurbished to a depth of 0.13b (b is the half contact width), and the rest were reground to the depth of 1.27b. The refurbished specimens were subjected to RCF until a spall was formed on the surface.

In the analytical part of this investigation, a model for predicting the fatigue life of refurbished RCF specimens was developed to incorporate the elastic-plastic material behavior of case carburized steel. A continuum damage mechanics approach was used to simulate material degradation due to fatigue. The effect of the carburizing process was included by varying the yield strength of the material linearly with the hardness and considering the residual stress distribution. In order to simulate the refurbishing process, continuum damage mechanics approach was employed to determine fatigue damage accumulation up to a specific number of contact cycles. Then a layer of the original surface up to the grinding depth was removed from the numerical domain, while retaining the initial accumulated damage prior to refurbishing. In order to validate the model, the analytical model was used to simulate the experimental conditions. However, the contact geometry between the balls and flat AISI 8620 steel is circular. Therefore, a sectioning approach was used to simulate the circular contact using the 2D RCF model. The results of the analytical model were corroborated with the refurbishing experiments.

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