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An experimental investigation of white layer on rolling contact fatigue using acoustic emission technique

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Abstract

Hard turning has being used to make various mechanical components. Under certain cutting conditions, a white layer (WL) may form on the machined surface that could drastically affect a component's service life. The presence of WL causes great concerns in machining industry just because the WL effects on component life are not yet understood. This study presents a novel real-time acoustic emission (AE) based rolling contact fatigue (RCF) testing system to study the WL effects on component life. AISI 52100 bearing steels were machined to generate two distinct surfaces: free of white layer (NOWL) and with WL. The real life loading of contact pressures and rolling speeds was applied to the test specimens. The applied load throughout the experiment was in-process monitored using a load cell which enabling the record of a Hertzian pressure history during rolling contact. It was found that the RCF testing system is simple and inexpensive, but very sensitive to fatigue crack initiation and propagation. Compared with AE count rate, AE parameters such as energy, RMS, and amplitude are more sensitive to fatigue crack initiation and propagation in rolling contact. The NOWL samples are more resistive to fatigue crack initiation/propagation and, therefore, have a longer life when compared to the WL samples with equivalent surface finish.

Keywords: White layer; Hard machining; Rolling contact; Fatigue; Acoustic emission

1. Introduction

Rolling contact is a phenomenon that occurs in many applications of precision-machined components, i.e. bearings, cams, shafts, etc., in the automotive, aircraft, aerospace, and other industries. It has been seen that the machining processes that manufacture these components produce a unique surface integrity. Surface integrity is classified as the quantitative as well as qualitative properties of the surface and subsurface of a machined component. These properties can be characterized by surface roughness, microstructure, micro-hardness, residual stresses, etc. Research has shown that the surface integrity of machined components has an effect on the fatigue life [1–7]. It can be presumed then that optimizing the surface integrity will have profound effects on the rolling contact fatigue (RCF) life of components.

Precision-machined components typically fall into two categories, hard turned and ground. Since the late 1970's hard turning, the turning of material with hardness greater than 45 HRC has become economically, environmentally, and technically competitive process when compared to grinding [8]. Hard turning has the advantage of a single cutting edge, capable of 'controlling' the surface integrity of the machined part through different machining parameters. With the capability of producing surface integrities at demand, manufacturers are able to design components that will have the optimal surface for their application. But to be able to 'optimize' for application, one must fully understand the effects of surface integrity on component life. Hard turning may induce a phase-transformed layer of material on component surface, commonly referred to as 'white layer' because of its white appearance under an optical microscope. The white layer has an increased hardness when compared to the bulk material, and is often associated with tensile residual stresses.

Although, it is often presumed that white layer is detrimental to RCF life, however, no research has been conducted to study the true effect of the hard turned white layer on component life, especially in rolling contact. The presence

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of white layer causes great concerns in machining industry just because the effect of white layer on component performance such as fatigue life has not been clarified or well understood yet at present. In order to clarify this compelling problem and increase the confidence on hard turning, it is, therefore, imperative for machining industry to understand how the white layer affects component life.

The objectives of this study are to: (1) present a novel RCF testing system with real-time AE monitoring capability; (2) investigate the sensitivity of AE signals to fatigue initiation and propagation; and (3) compare fatigue life of two types of machined surfaces with distinct surface integrities. This investigation will provide an insight on the role of white layer on component life and contribute to the knowledge base of hard machining.

2. Literature review

2.1. RCF testing system

An effective RCF test system allows the testing of materials in a controlled environment to determine the service life of bearings and other rolling contact applications. Full-scale fatigue tests give the best results, but the time and cost needed to conduct such tests would not be viable in lab scale. There are some considerations to look at when determining an appropriate test system, but one thing is certain: the test rig must be designed to analyze, a sample's RCF life at a time much shorter than the service life of an actual machined part. To do this, the test rig must be able to apply a reasonable load to the sample, operate at a rolling speed that encountered in real service, and be able to detect the failure in situ. The test rig can influence the results of the RCF test [9] and, therefore, should be given careful consideration.

A literature review [10] of some of the most common RCF testing systems [11–14] revealed two compelling issues, load/stress monitoring and fatigue monitoring. These testing systems typically apply a load either through a dead weight or compression springs. The applied load is then calculated based on statics and mechanics of materials. Though without some sort of strain gage, load cell, etc., the precise load at all times is only theoretical and not in-process monitored. The predominant method of fatigue detection is vibration monitoring, which is only capable of detecting surface defects in a component, while subsurface fatigue damage or surface pitting may go unnoticed. It is imperative that an effective method be developed that will detect subsurface damage and pitting, because different surface integrities may introduce subsurface damage and pitting in different manners.

2.2. AE monitoring

A novel method of in situ monitoring fatigue damage is through acoustic emission (AE) signal. AE is the generation of elastic waves caused by the release of strain energy when a material is subjected to stress. A literature review on fatigue monitoring revealed that AE offers significant benefits over vibration monitoring. Yoshioka and Fujiwara [15] compared AE to vibration in RCF and found that AE signals warned of failure earlier than vibration monitoring. They noted that the AE parameter, count rate, increased significantly before failure occurred. Also a significant development was their AE system capable of detecting AE sources [16]. Not only could AE be used for monitoring of the early development of fatigue, but also the source could be found and investigated. With AE signals, Yoshioka was then able to measured the propagation time of a crack, which in general was the time from significant AE signal generation to the time surface damage was detected [17]. Choudhury and Tandon [18] tested roller bearings with and without simulated defects to observe and determine the beneficial AE parameters. They concluded that the distribution of AE parameters counts and peak amplitude, were suitable measure for determining defects in bearings. Though not in rolling contact, Roberts and Talebzadeh [19] utilized an AE system in compact tension test samples to explicitly monitor the fatigue crack propagation and found a similar relationship between crack propagation and count rates. It indicates that sensitive AE signals may offer an advantage to fatigue monitoring than the traditionally used method of accelerometers.

2.3. White layer effect

The role of white layer on component life is a very controversial subject in academia and industry. It has reported that white layer would reduce fatigue strength [20–22]. In contrast, hard turned steels may have greater fatigue strength than ground steels [4,23], despite white layer occurrence. It was also assumed that white layer might not have a negative impact on fatigue life. However, these data are only limited to tension or compression fatigue. There is little experimental and theoretical work on the effect of white layer on RCF life. Therefore, it is not clear how white layer affects RCF life.

3. Experimental procedures

3.1. Test sample preparation and characterization

Work samples were cut from 76.2 mm diameter AISI 52100 steel bar at 19.05 mm thickness. All workpieces were

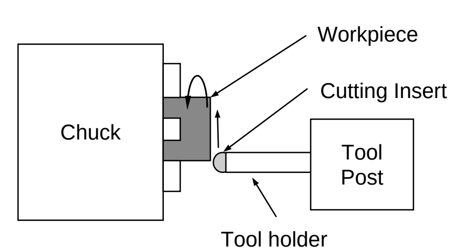

Fig. 1. Schematic of the cutting experimental set-up.