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Microstructure variation and local plastic response of chrome molybdenum alloy steel after quasi rolling contact fatigue testing

Lechun Xie [a,*], Qinghua Zhou [b], Yan Wen [c], Liqiang Wang [a], Weijie Lu [a]

[a] State Key Laboratory of Metal Matrix Composites, School of Materials Science and Engineering, Shanghai Jiao Tong University, No. 800 Dongchuan Road, Shanghai 200240, PR China
[b] School of Aeronautics and Astronautics, Sichuan University, Chengdu 610065, PR China
[c] School of Physics and Optoelectronic Engineering, Nanjing University of Information Science and Technology, Nanjing, Jiangsu 210044, PR China

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ABSTRACT

This work presented the microstructure variation and local plastic response of chrome molybdenum alloy steel under quasi rolling contact fatigue (quasi-RCF) testing. The quasi-RCF testing means using the similar method of actual RCF to introduce obviously local plastic deformation and microstructure variation on surface layers of materials. After quasi-RCF testing, the microstructure were observed using optical microscope and scanning electron microscope (SEM) from both the top surface and cross section. Based on microstructure analysis, the deformation volume of materials after quasi-RCF testing were calculated. The local plastic response was demonstrated by the unique local strain-stress curve and strain hardening exponent obtained via experimental measurements and simulation prediction. One hand, the increase in the hardness of plastic zones due to quasi-RCF testing was measured by a Vickers indenter. The other hand, based on the virgin hardness and elastic modulus, some possible local stress-strain curves were obtained. Then according to the possible local stress-strain curves, finite element analysis was introduced to predict the increased hardness. Comparing the increased hardness obtained by experiments and prediction, the unique local strain-stress curve and strain hardening exponent of chrome molybdenum alloy steel were determined. All results were discussed in detail.

1. Introduction

Rolling contact fatigue (RCF) commonly appears in rotating mechanical components, such as bearings and gears, and is regarded as a main mode of failure if the rolling components are properly loaded, lubricated, installed, and kept free of foreign contaminants [1]. In order to improve RCF life of components, heat treatments for bearing steel are carried out, and the residual stresses are investigated together [2,3]. Meanwhile, surface modifications are introduced, such as carburizing, nitriding, and so on. About the RCF of steels, several types of important bearing and gear steels AISI M50, M50NiL, 52100 were studied and the RCF lives were tested, moreover, the sliding wear and spall propagation characteristics were also discussed [4–6]. Besides, RCF of other steels were studied, such as chromium steel, molybdenum alloyed steel, and so on [7–10]. Additionally, the variation of microstructure after RCF is a very important point which should be focused on. And some references have been related to the microstructure variations before and after RCF [7,10–14]. Even though, the studies on RCF of steels are still needed to improve, especially in the relation between microstructure variations and local plastic deformation, which is critical to improving fatigue properties. Therefore, investigation on the local plastic responses of steels under RCF is essential and significant.

Usually, plastic properties of materials are investigated by tensile or compression tests, but the results just reveal the average plastic responses. In order to get local plastic responses of materials, some available, simple or new methods are needed to be adopted to resolve this issue. Some developed methods, capable of utilizing the variation of hardness in plastic zone to predict the stress-strain response, become popular and can be adopted to study the local plastic responses [15–25]. Note that the local plastic response has a relationship with the hardness variation. Moreover, hardness measurements are relatively easy to perform and can be repeated multiple times on a relatively small sample. Therefore, Dao et al. [17] utilized two different indenters on strain hardening materials to predict the flow curves of plastic responses

* Corresponding author.
E-mail address: lechunxie@yahoo.com (L. Xie).

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Table 1
Chemical composition of chrome molybdenum alloy steel (AISI S7) (wt%).

Fe	C	Mn	Si	P	S	Cr	V	Mo	Ni
Balance	0.45–0.55	0.20–0.90	0.20–1.00	0–0.03	0–0.03	3.00–4.50	0–0.35	1.30–1.80	0–0.75

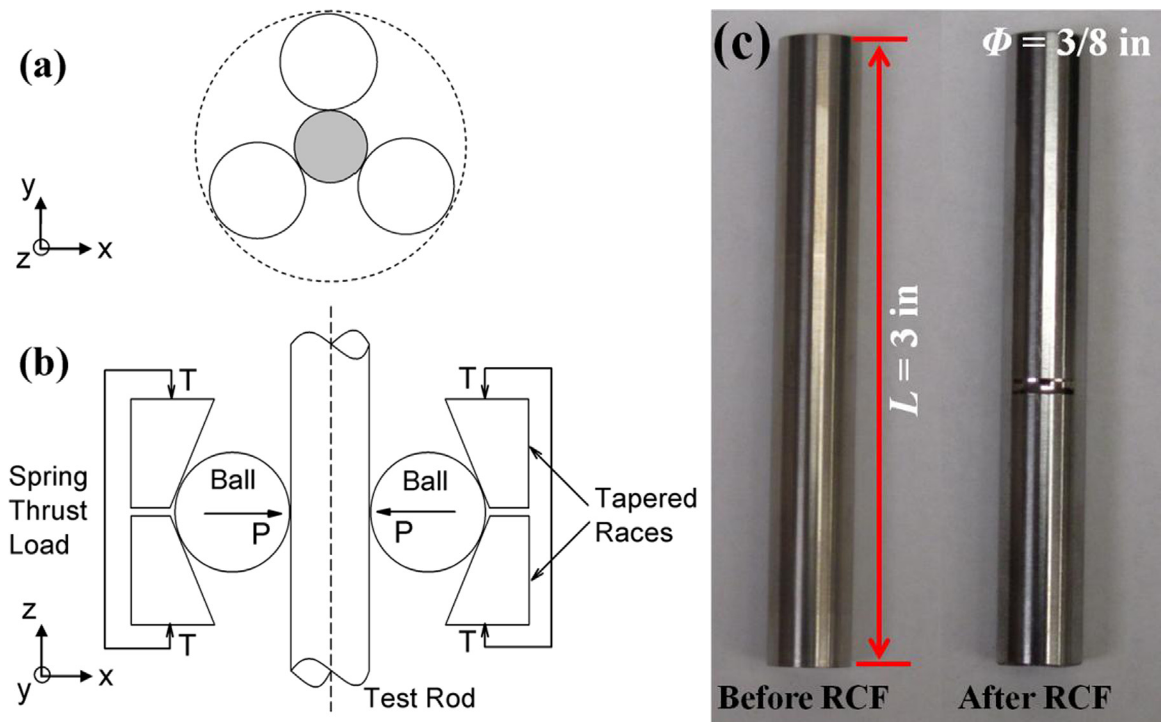

Fig. 1. Schematic diagram of quasi-RCF tester: (a) the top view; (b) the side cross-sectional view. The photographs of samples before and after quasi-RCF testing are shown in (c).

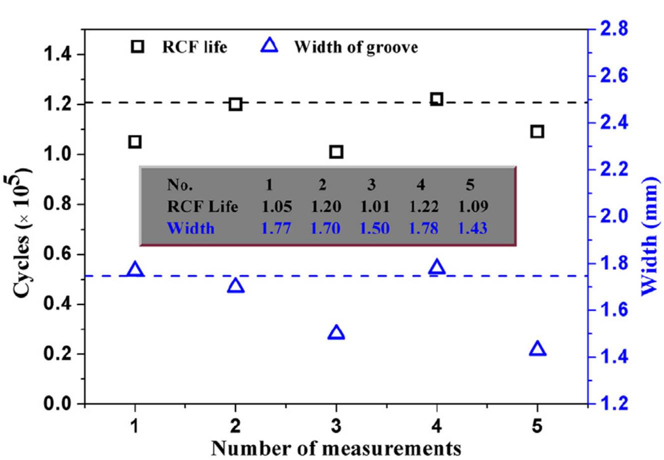

Fig. 2. Fatigue lives and groove width of five samples after quasi-RCF testing.

in 2001. Then in 2003, Bucaille et al. [24] extended the methods and used four different conical indenters to improve the accuracy of the reverse analysis. The reverse analysis means utilizing the indentation hardness measurements to predict the stress-strain response of a material [16–21]. Conversely, using the known plastic behavior of a material to determine the increment of hardness means a forward analysis [22,23]. After 2005, the method with a single indenter was proposed with given elastic modulus of material [20,21,25]. The methods have been extending [26,27], however, in all above work, plastic deformations are still introduced by indentation methods artificially.

Generally speaking, the RCF mentioned above is the actual RCF, which focuses on the improvement of fatigue lives, the failure of rolling components, and the practically industrial applications of materials on rolling contact fields, such as the applications on bearings, gears and rail wheels. However, in this work, the practical purpose of RCF testing is introducing the local plastic deformation, and the relatively soft material is chosen for RCF testing, which is different from the purpose of actual RCF testing. Therefore, the concept of quasi rolling contact fatigue (quasi-RCF) testing is defined and adopted, which means using the similar method of actual RCF to introduce obviously local plastic deformation and microstructure variation on surface layers of materials. Consequently, in this work, the method of introducing plastic deformation is improved and modified. And it is adopted to conduct quasi-RCF testing, which is different from previous execution processes [15–27].

In order to obtain obviously local plastic deformation and microstructure variation during quasi-RCF testing, the relatively soft material is chosen, moreover, the deeper groove and the obvious hardness variation can be obtained, which are beneficial to the following investigation on the plastic response. Thus the chrome molybdenum alloy steel (AISI S7) without hardening treatments is chosen as the experimental materials and limited information can be found on the local plastic response of this steel subjected to quasi-RCF. The local plastic response is demonstrated by the unique local strain-stress curve and strain hardening exponent.