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Influence of axle–wheel interface on ultrasonic testing of fatigue cracks in wheelset

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ABSTRACT

For the ultrasonic testing at the wheel seat of railway axles, quantitative investigation of the reflection and transmission phenomena at the axle–wheel interface is important. This paper describes the influence of the axle–wheel interface on the ultrasonic testing of a fatigue crack in a wheelset by applying the spring interface model. The normal and tangential stiffnesses were identified experimentally for an as-manufactured wheelset at the normal incidence, and the reflection coefficient for the shear-wave oblique incidence was calculated. A parametric study was performed to clarify the influence of these interfacial stiffnesses on the incident-angle dependence of the reflection coefficient. The calculated reflection coefficient at the incident angle of 45° qualitatively explained the relative echo-height decrease due to the presence of a wheel observed experimentally for a wheelset in fatigue loading by rotating bending. The quantitative difference between the experimental and calculated results was considered to be due to the reduction of the effective interference of shrink fit by the wear at the axle–wheel interface during the fatigue loading as well as by the applied bending moment. For the estimated relative echo-height decrease to agree with the experimental results, the interfacial stiffnesses were found to be smaller than the values identified for the as-manufactured wheelset by a factor of 0.5–0.7.

1. Introduction

Railway axles are inspected periodically by a certain time interval or a certain running distance by means of the ultrasonic testing and/or the magnetic particle testing [1,2]. When the ultrasonic testing of a railway axle is performed, attentions are to be paid to the respective positions where the components such as a wheel, a gear, a bearing and a brake disk are fitted [3,4]. Among them, the position where a wheel is fitted, i.e. the wheel seat on the axle, is a potential site for the development of a fatigue crack initiated by the effect of fretting [5,6], which motivates the careful inspection at the wheel seat.

In the ultrasonic testing at the wheel seat, it is expected that a flaw echo might be affected by the contact between the axle and the wheel [7,8], since the axle–wheel contact interface transmits some portion of the ultrasound which reached the vicinity of a crack into the wheel. The behavior of the ultrasound in the testing with the shear-wave angle beam, whose incident angle is around 37–55° in most cases, is schematically shown in Fig. 1. It involves the reflection and transmission phenomena at the axle–wheel interface as well as at the faces of a possibly closed fatigue crack. Quantitative investigation of these phenomena is currently not sufficient, in spite of importance to understand the effect of a fitted wheel on the inspection accuracy.

In the previous report [9], it was clarified that the echo height of a fatigue crack at the wheel seat in the ultrasonic experiment was significantly reduced by the presence of a wheel. Therefore, in this paper, we discuss the influence of the axle–wheel interface on the ultrasonic testing of a fatigue crack in a wheelset in a more quantitative manner, by applying the spring interface model [10–12]. For this purpose, the normal and tangential stiffnesses of the axle–wheel interface are identified experimentally from the measurement of the reflection coefficient of longitudinal and shear waves for the normal incidence, by using a miniature wheelset having the dimensions similar to the one used for the ultrasonic experiment of the fatigue crack. With the identified interfacial stiffnesses, the reflection coefficient at the axle–wheel interface for the shear-wave oblique incidence is calculated theoretically as a function of the incident angle. A parametric study is performed to clarify the influence of the interfacial stiffnesses on the incident-angle dependence of the reflection coefficient. Based on the results of these theoretical calculations, we attempt to explain the relative decrease of the echo height of a fatigue crack by the presence of a wheel.

2. Ultrasonic test results for fatigue crack

First, we explain an overview of the ultrasonic testing of a fatigue crack in a miniature wheelset test piece as reported in Ref. [9].

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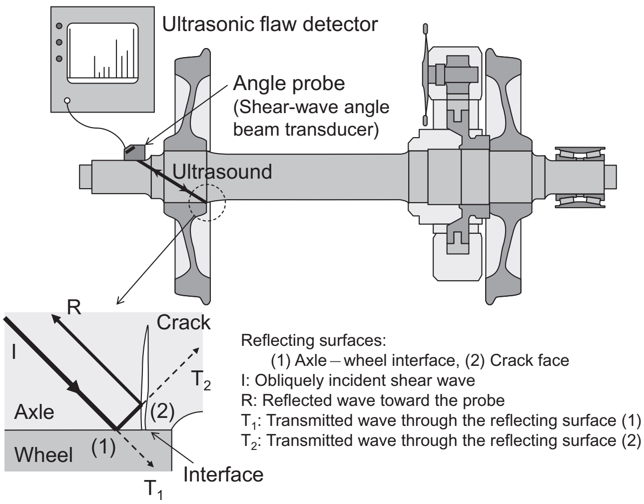

Fig. 1. Schematic view of the ultrasonic testing with shear-wave angle probes.

Although the experimental study described in this reference involved two types of ultrasound incidence (angled shear wave and grazing shear-horizontal wave) and two fatigue cracks with different depths, only the results pertinent to the present discussion are outlined here. A schematic view of the test piece and the test setup is shown in Fig. 2a. Both of the axle and the wheel were manufactured from carbon steel. The diameter of the wheel seat (fitting part) of the axle was 57 mm, and the wheel with the outer diameter of 87 mm was shrink fitted on the wheel seat. An interference set between the axle and the wheel generated the contact pressure of approximately 85 MPa, which was similar to that for full-sized wheelsets. According to the measurement of the surface roughness profile, the maximum height of profile at the surface of the axle was approximately 3 μm and that at the inner bore of the wheel was approximately 10 μm.

A fatigue crack was developed on the surface of the wheel seat by using a four-point rotating bending fatigue test machine. This fatigue crack was initiated by the effect of fretting at the axle–wheel interface and developed from the surface of the wheel seat as an ordinary fatigue crack under bending. A destructive measurement was performed after all the ultrasonic test menus mentioned below were completed. It was found that the fatigue crack had an actual depth of 3.5 mm and the distance of the crack from the edge of the wheel seat was around 0.7 mm.

A load cycle was applied to vary the nominal stress σ_n at the surface of the wheel seat in the order of 0, +165, 0, −165 and 0 MPa, where σ_n was calculated by the bending moment M and the diameter of the wheel seat d as $\sigma_n = M/(\pi d^3/32)$. The ultrasonic testing was performed to measure the flaw echo height in each state of the crack opening and closure. Two ultrasonic angle probes (shear-wave angle beam transducers) with the refraction angle of 45° were used, each of which had the nominal frequency of 2 or 5 MHz. Next, we removed the wheel by cutting it, and performed the same menus of ultrasonic testing for the axle without a wheel. The echo heights were normalized by the reflection at the corner of axle end face as shown in Fig. 2b.

The normalized echo heights of the fatigue crack are plotted in Fig. 3 against the nominal stress at the wheel seat in the process of increasing and decreasing σ_n. For each nominal frequency, the echo heights were compared between two cases, namely, the case 1 where the axle was fitted with a wheel and the case 2 where the wheel was cut off from the axle. The echo height saturated when the tensile stress was higher than approximately 50 MPa, since the state of the fatigue crack approached that of an open flaw. We calculated the relative decrease of the echo height from the case 2 (without a wheel) to the case 1 (with a wheel), in the state where the nominal tensile stress of +165 MPa was applied at the wheel seat to open the crack faces. As shown in Fig. 3, the relative decrease was 13.1 dB at 2 MHz and 9.2 dB at 5 MHz. This echo-height reduction was considered to be due to the contact between the axle and the wheel. Therefore, it is the aim of the present paper to examine it in a quantitative manner by applying a theoretical model to the axle–wheel interface.

3. Identification of interfacial stiffnesses by normal incident wave

3.1. Theoretical background

In this paper, we attempt to discuss the results of the echo-height measurement mentioned above by modeling the axle–wheel interface theoretically as a combination of normal and

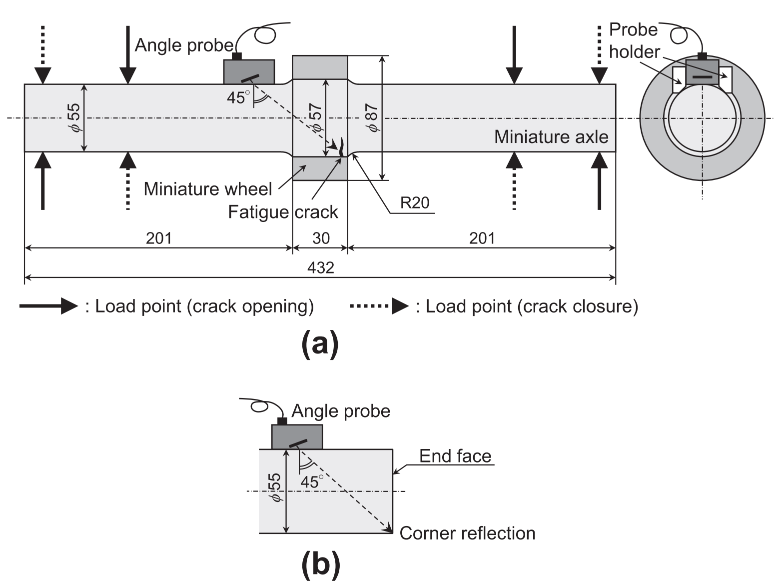

Fig. 2. Schematic view of (a) the test setup for a miniature wheelset and (b) the measurement of the corner reflection for the normalization of the echo height.