Effect of Ultrasonic Surface Treatment on Giga-cycle Fatigue Properties of a Rolling Stock Axle Material

B. C. Goo¹*, and I. S. Cho²

¹New Transportation Department, Korea Railroad Research Institute, Uiwang, Korea
²Mbrosia Co., Ltd., Asan, Korea

*Corresponding author: bcgoo@krri.re.kr

1. Introduction

In the past, components under fatigue loading were designed by using an S-N curve and endurance limit according to very high cycle fatigue tests [1-3], fatigue strength to failure at a given life decreases as loading cycles increase. In other words, endurance limit is not observed for most materials, which is true for axle materials for rolling stock. An axle is one of the key components for structural safety of rolling stock. Failure of an axle may lead to derailment, fatal accidents, property loss, etc. During the lifetime of a railway vehicle, about $3 \times 10^6$ km mileage, an axle installed in the vehicle experiences very high cycles of fatigue loading (1.0~1.2 giga cycles). However, giga-cycle fatigue properties of axles have not been studied much owing to the restrictions of test time and costs. In this study, an ultrasonic fatigue test equipment with a piezoelectric actuator of frequency of 20 kHz was developed. By using the newly equipment, the effect of ultrasonic surface treatment on the fatigue behavior of an axle material was examined in giga cycle range. Failure mechanism was observed and fatigue strength in giga-cycle range was obtained. It was found that the ultrasonic surface treatment could improve the fatigue strength of the axle material by more than 10 %.

2. Specimen Preparation and Fatigue Test

The test equipment was designed and manufactured by referring to ASM Vol. 8 [4]. Fig. 1 shows the schematic diagram of an equipment. Fig. 2 presents the shape of the fatigue specimen. The minimum and maximum diameters of the specimen are 4 and 16 mm, respectively. The chemical composition of the axle material is 0.35~0.48 wt.% C; 0.15~0.40 Si, 0.40~0.85 Mn, and Fe. The measured tensile strength was 650 MPa. The surface was polished by lapping. The specimens were extracted from a real commercial axle for railway vehicle.

Ultrasonic surface treatment is a method of metal improvement that utilizes ultrasonic energy. In this process the tungsten carbide ball is attached to the ultrasonic device. The ball with the total force ($P_t = P_{st} + P_{dy}$) strikes the surface of the workpiece 20,000 to 40,000 times per second and at 1,000 to 4,000 shots per square millimeter. These strikes generate thousands of micro-dimples on the workpiece surface. This process causes severe plastic deformation of the workpiece surface, induces fine structures, and improves the fatigue strength [5]. Table 1 describes the principal parameters of UST technology for the treatment of the test specimens. The parameters were carefully controlled for optimal surface treatment.

<table>
<thead>
<tr>
<th>Amplitude (µm)</th>
<th>Load (N)</th>
<th>Speed (m/min)</th>
<th>Feed (mm/rev)</th>
<th>Tip Diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>60</td>
<td>30</td>
<td>0.07</td>
<td>2.38</td>
</tr>
</tbody>
</table>

Table 1 UST treatment parameters

<table>
<thead>
<tr>
<th>Loading frequency (kHz)</th>
<th>Stress ratio</th>
<th>Stress (MPa)</th>
<th>Test atmosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>R=-1</td>
<td>320~380</td>
<td>Room Temp.</td>
</tr>
</tbody>
</table>

Table 2 Conditions of ultrasonic fatigue test

Ultrasonic fatigue test was performed on the newly developed piezoelectric UFT system (see Fig. 1).
1) with the frequency of 20 kHz and stress ratio R=-1 at room temperature (see Table 2). The UFT system consists of a generator, a transducer, and a horn attached mechanically to the converter by a screw. The horn amplifies the axial vibration. A personal computer controls the generator and converter to impose a vibratory amplitude at the end of the horn, a photonic sensor to measure the longitudinal displacement at the horn end, and a cooler to keep the specimen at ambient temperature. UFT machine stopped when the fatigue cycles reached $10^9$ cycles for non-fractured specimens.

3. Test Results

Fig. 3 shows typical morphologies of plastic deformation produced in rolling stock axle (RSA) steel (a) before and (b) after UST treatment. It was found that UST process produced a plastic deformation up to about 200 μm in thickness from the surface of RSA steel. The surface hardness was improved from 200 to 280 Hv in the UST treated specimen. The precipitates were located along the grain boundaries in the plastic deformation.

![Fig. 3 Optical micrographs showing the effect of UST treatment on the plastic deformation in the surface layer.](image)

4. Discussion and Conclusions

Some results obtained from the fatigue tests of the UST-treated and untreated specimens made from RSA steel are as follows:

- Fatigue strength of the UST specimens was increased by about 10% compared with that of the untreated specimens. The slope of the S-N curve of the UST specimens was more steeper in the high cycle regime. The fatigue strengths of the UST-treated and untreated specimens continue to decrease with the number of cycles to failure. Conventional fatigue limits were observed near $10^8$ cycles for the untreated specimens and $10^9$ cycles for the UST specimens, respectively.

- The improvement of the surface hardness and fatigue strength seemed to result from the developed fine-structures in surface layer produced by UST.

According to SEM micrographs, there was no significant difference in microstructures of the fractured surfaces of the UST specimens and untreated specimens.

Acknowledgments

The authors are grateful to the Korea Railroad Research Institute for the support of this research.

References


