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Fatigue life prediction of a railway hollow axle with a tapered bore surface

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ABSTRACT

This paper aims to evaluate the fatigue life of railway hollow axles with tapered bore surfaces (hereinafter indicated as RATB) that have a different inner shape than the shape of existing hollow axles. The fatigue strength evaluation method is identified in accordance with European Standards EN13103 and EN13261; the fatigue strength is also evaluated by finite element analysis of a full-scale axle test piece by way of applying an S–N curve that was identified through fatigue tests of high strength axle materials. Furthermore, a fatigue life analysis of the wheel–rail contact force was conducted using dynamic simulation results of a Korean Electric Multiple Unit (K-EMU) multi-body dynamics model. As a result of the fatigue life evaluation, the RATB for metro vehicles satisfied the fatigue strength requirements of EN, and the fatigue life by wheel–rail contact force was predicted to be safe within a standard axle replacement cycle.

1. Introduction

Axles are one of the most important railway vehicle parts that support the weight of both vehicles and passengers. Axle failures during operating conditions may result in derailment or crash accidents causing heavy damage to the car and passengers; hence, a high strength design is required. However, the need to reduce axle weight is on the rise in a bid to improve the energy efficiency and mitigate possible rail damage. Lightweight axles of railway vehicles reduce the un-sprung mass that leads to enhanced running performance on curves and reduced vehicle system noise and vibration [1]. Thus, the number of studies on lightweight axles by applying hollow axles and high strength materials has been increasing.

When applying hollow axles to railway vehicles that support rotational bending cyclic loads, bending stress increases due to reduced cross-sectional area that exists in the solid axle. The stress causes a reduction of the fatigue life under the same axle loads [2]. Thus, studies on fatigue life and strength depending on the materials and shapes are required when developing new types of axles.

The studies on the fatigue failure of railway vehicles began at the early stage of railway vehicle systems in the 1830s [3]. Studies have recently been developed to examine the fatigue life and failure of hollow axles of high-speed railways. Hirakawa et al. [4] proposed the optimal design, thermal treatment and surface treatment for enhancing the fatigue life and preventing failure of the hollow axles of high-speed trains, Shinkansen and ICE (InterCity Express), in various ways (Fig. 1). Luke et al. [5] and Kwon et al. [6] identified the fracture mechanics characteristics through testing and analytical approaches from the viewpoint of the fatigue crack growth of high-speed train axle materials.

However, there are limitations to lightweight design because existing railway hollow axles (Fig. 1) are manufactured to a same bore shape in the axial direction. In machinery with rotation shafts such as automobile engines or electric motors, the studies on

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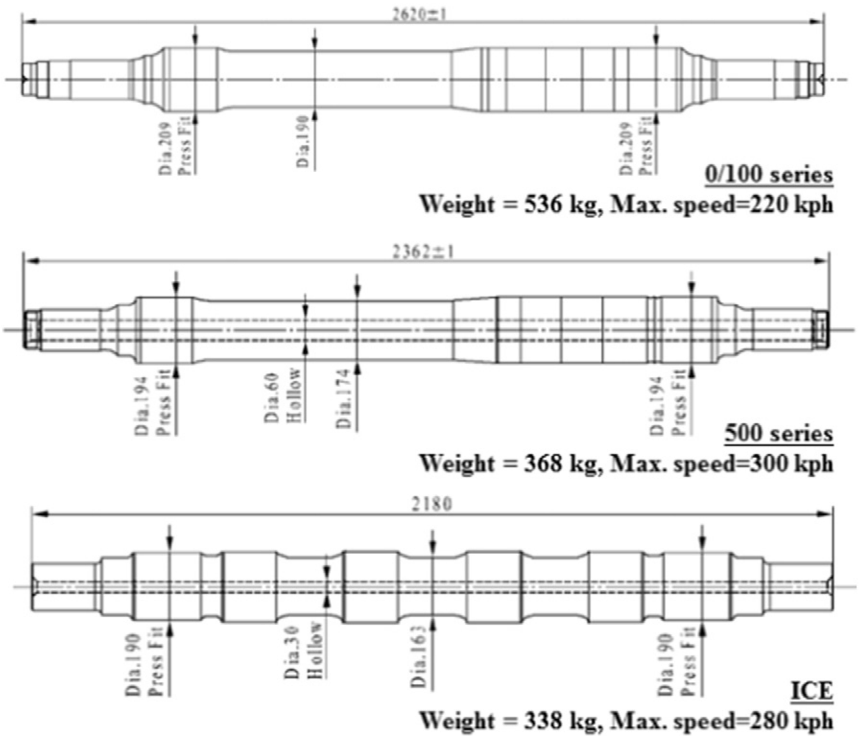

Fig. 1. Existing hollow axle designs for high-speed trains (Shinkansen and ICE) [4].

the design and manufacture of shafts with varying inner diameters depending on external diameter (Fig. 2) have been accelerated in an effort to reduce the shaft weight [7]. Despite the manufacturing studies, RATBs based on forging technologies such as radial forging and open die forging [8] with fatigue strength evaluations for application in railway vehicles still remain in the beginning stages.

The purpose of this paper is to predict the fatigue life of RATBs developed for the lightweight design of railway vehicles. Rotation bending fatigue tests of axle materials were used for new axles and were conducted for predicting the fatigue life in accordance with EN13261 [9]. The S–N curve was identified. The fatigue strength analysis of a full-scale axle test piece was also conducted to evaluate the dimensional appropriateness of an axle. Additionally, the wheel–rail contact force was analysed using a dynamic simulation of the Korean Electric Multiple Unit (K-EMU) multi-body dynamics model; then, the fatigue life of the RATB was predicted through a fatigue analysis under variable amplitude loading on the axle during operating conditions.

2. RATB design

The JIS [10] and European EN [9,11] standards are typically used for railway axle design and quality. In particular, EN 13103 [11] was adopted for the design standard and EN 13261 [9] was adopted for the evaluation standard in this study.

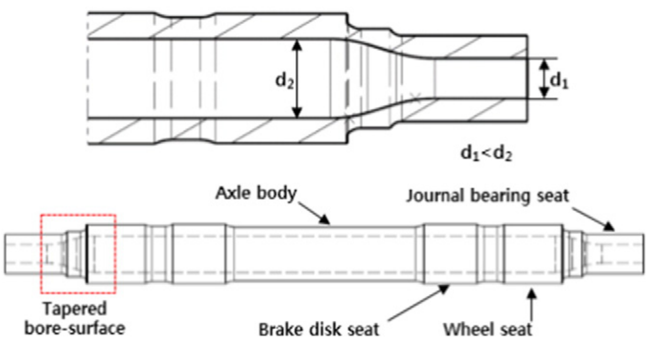

Fig. 2. RATB concept (Trailer car).