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Rolling contact fatigue and wear of two different rail steels under rolling–sliding contact

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ABSTRACT

Rolling contact fatigue and wear of rails are well-known problems. However, progress is not easy to predict because these problems interact with each other. Therefore, to reduce damage, the interactions between these two mechanisms must be clarified. In this study, the contact fatigue and wear of UIC 60 and KS 60 rail materials were investigated by twin-disc testing with various parameters. We found that ductility and fracture toughness are important factors on wear and contact fatigue. UIC 60 rail steel with higher ductility and fracture toughness than KS 60 rail steel has a higher resistance to contact fatigue but a lower resistance to wear.

1. Introduction

Rolling contact fatigue (RCF) and wear of rails are inevitable problems in railway operation due to the excessive wheel–rail contact stress. In the railway industry, higher traveling speeds and heavier axle loads have been achieved through advances in technology, but they result in higher traction power and contact stress than ever before, and progressive wear and RCF at the contact surface of both the rail and the wheel are accelerated. Research on the wear and RCF of rails has markedly progressed in recent years. Many studies [1–4] have focused on reducing wear. Moreover, contact fatigue damage on the surface of a rail such as squat and a head check have been raised as an important issue [5,6]. Generally, the contact fatigue of a rail is caused by the excessive contact stress between the wheel and the rail. Increased axle load and slip ratio cause increasingly excessive wear. Therefore, the initiation and propagation of the damage to a rail are influenced by both the contact fatigue and the wear [7,8].

Because the wear and the contact fatigue have a competitive relationship, if a crack does not have a sufficient growth rate compared to the wear rate, it will be worn away. In contrast, if the crack growth rate is higher than the wear rate, then the crack will continue to grow and cause a rail failure. Therefore, finding an optimal combination of wear and contact fatigue to prevent a crack from growing is the key to running on a safe and cost-effective railway. Research on the interaction between the wear and the RCF of rails has markedly progressed in recent years. Many experimental laboratory research works [9–11] have been carried out to study the occurrence and progress of wear and RCF. At the same time, many predictive models [12–14] have also been introduced to assess the competitive role of wear and RCF. Donzella et al. [15,16] suggested a model for evaluating rail wear and contact fatigue damage and they demonstrated the correlation between fatigue damage and wear. Wang et al. [17–19] investigated the track characteristics and studied the correlation between wear and inclined crack. Zapata et al. [20] studied the plastic deformation effect on the contact fatigue and wear of two different types of rail steels. Form the studies of previous researchers, we found that it is necessary to clarify the correlation between wear and fatigue crack to reduce rail damage. However, such a study has yet to be implemented in earnest.

Modeling the competitive interaction between wear and contact fatigue is crucial to predict the structural reliability of a wheel–rail interface in both the design and maintenance phases. However, the interaction is very complex, because the mechanisms of initiation and propagation of wear and contact fatigue rely on very complicated contact conditions between the wheel and the rail: the contacting geometry, applied load, lubricant on the surface, manufacturing characteristics of the material and chemical composition of the material etc. In this study, two types of rail steels were investigated. KS 60, which is well-known and generally used on the main line of the rail network in Korea, was investigated to determine the mechanisms of wear and contact fatigue. The results were compared to those of the well-known UIC 60 rail steel. The chemical composition, strength, and elongation of KS 60 rail steel and UIC 60 rail steel differ. The content of silicon in UIC 60 rail steel is higher than that of KS 60 rail steel, and the yield and tensile strengths of

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UIC 60 steel are higher than those of KS 60 rail steel. In contrast, the elongation of UIC 60 rail steel is significantly less than that of KS 60 rail steel. In this study, the wear and rolling contact fatigue characteristics of UIC 60 and KS 60 rail materials were investigated by focusing on the resistance capacity against the wear under rolling–sliding conditions. Various tests were conducted by changing the contact conditions in different ways to identify the interaction between the wear and the contact fatigue of rail.

Table 2
Mechanical properties of various specimens.

Steel	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Hardness (HV)
KS 60	481	887	15	292
UIC 60	528	923	11	310
Wheel	507	860	32	280

2. Experimental detail

2.1. Test apparatus

The rolling contact fatigue test was carried out with a specially designed twin disc tester. Fig. 1 presents the schematic diagram of the tester. The tester consists of two independent motors that control the rotating speeds of two pivoted driving shafts. The slip ratio can be controlled by adjusting the rotational speed of the shafts. The testing machine was designed to apply a normal contact load using a hydraulic actuator. A load cell is mounted beneath the hydraulic actuator, and a torque transducer is mounted to the one drive shaft as shown in the figure. The test conditions of applying load, rotational speed, and slip ratio are fully controlled by a computer, and all of the data collected during the test are saved.

2.2. Specimens

The test specimens were prepared by cutting the two different rails: KS 60 and UIC 60. Tables 1 and 2 show the chemical compositions and mechanical properties of the rail and wheel steels, respectively. The carbon content of UIC 60 rail steel is higher than that of KS 60 rail steel, and it also has higher strength, lower elongation and higher hardness values. The wheel specimens were cut from the rim of a wheel, and the rail specimens were cut from the head of a rail, as shown in Fig. 2. Fig. 3 shows the dimensions of the test specimen. Both the wheel and the rail specimens have the same size and shape, and the sizes of the outer diameter and thickness were 50 mm and 6 mm, respectively. A series of contact fatigue tests was conducted as a line contact in which the two specimens are contacted in a line. To reproduce the material and surface conditions of a real-sized wheel and rail in the small-sized specimens, and maintain the constant hardness around the specimen on the contact surface, a series of heat treatment processes was applied in three phases, which is the same as the manufacturing process of the wheel and rail: (1) heating at a temperature of 760 °C for 1 h, (2) quenching with the application of water for 6 min, (3) annealing at a temperature of 450 °C for 6 h. The contact surface was specially ground to be 0.3 μm to simulate the surface roughness of the rail.

2.3. Test condition and method

The initial load was applied while the rail and the wheel specimens were arranged to maintain in line contact, and the rotating velocity of the rail and wheel specimens was adjusted to reach the target slip ratio. The contact pressure P_0 and the slip ratio g were calculated from Eqs. (1) and (3) [21]. The friction coefficient μ was calculated from Eq. (4). All tests were carried out under the fully dry condition. The wear particles, which were encountered during the test and could influence the progress of wear in the wheel and the rail specimens, were removed by blowing air on the contact surface.

$$P_0 = 0.418\left[\frac{PE}{LR}\right]^{1/2} \quad (1)$$

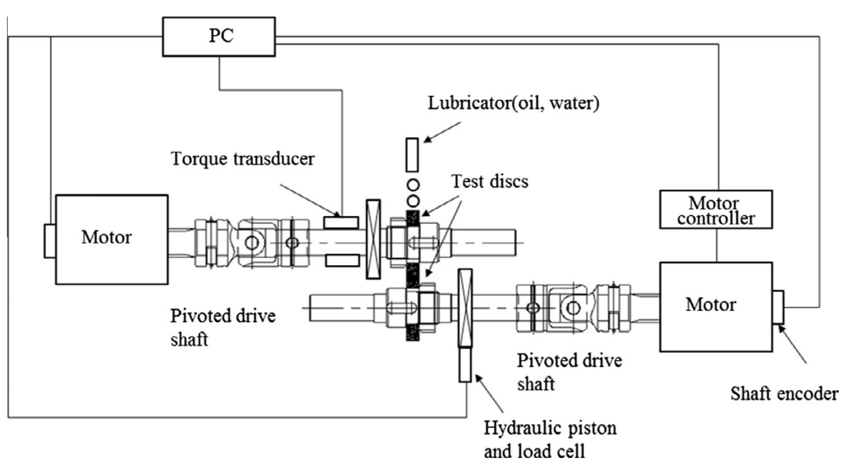

Fig. 1. Schematic diagram of the twin-disc tester.

Table 1
Chemical composition of rail and wheel specimen.

Steel	C	Si	Mn	P	S	Al	N	Cu
KS 60	0.63–0.75	0.15–0.30	0.70–1.10	0.030	0.025	–	–	–
UIC 60	0.65–0.82	0.13–0.60	0.65–1.25	0.030	0.008–0.030	0.004	0.009	–
Wheel	0.57–0.67	0.15	0.6–0.9	0.045	0.045	–	–	0.35