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In situ X-ray analytical study on the alteration process of iron oxide layers at the railhead surface while under railway traffic

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ABSTRACT

This paper describes an experimental investigation of in situ X-ray diffraction analysis of iron oxides on the railhead surface, which have an influence on various wheel/rail rolling contact phenomena, e.g. the adhesion between wheels and rails, which can cause rail corrugations. The X-ray analysis using portable X-ray diffractometer installing XRF called "XRDF" was carried out for the preliminary laboratory experiment and the field test. For the laboratory experiment, the rail specimen samples on which rust was generated by scattering salt water mist and moisture vapor alternately were analyzed. The different rust types generated under the different environmental conditions were identified. For the field test, XRDF analysis was applied to the corroded test rail after the test vehicle passed over it several times. As a result, it can be concluded that the decreased proportion of rusts due to passage of the vehicle depends on the track alignment, the location where rails are installed, and the positions across the rail head such as top of rail in tangent track or gauge corner of the high rail in curved track, and also depends on the vehicle running conditions, i.e. free-rolling, driving or braking. Finally, we confirmed the effectiveness of applying XRDF analysis to track site measurements to obtain some important suggestions for understanding the wheel/rail rolling contact phenomena on which rail surface substances have great influence.

1. Introduction

It is well established that various phenomena caused by wheel/rail adhesion or friction depend on the interfacial substances and/or surface oxide layers produced by the train operation and environmental conditions. Especially, iron oxides (so-called "rusts") have many opportunities to be present at the rail surface through contact between wheel and rail; hence, many researchers have had much interest in their effects on the adhesion between wheels and rails, and in their conductivity [1–4].

One very interesting wheel/rail rolling contact phenomenon is the rail corrugations generated on the top of rail in tangent track in submarine railway tunnels [1,2]. In this case, corrugations were generated only in ascending slopes, where the wheels of the vehicle are driving, but not in descending slopes, where the wheels are free-rolling. There are some types of rail corrugations which are a kind of rail surface irregularity formed by wear and/or plastic deformation at the rail crown [5,6]. According to some field investigation, one of the main causes of generation of rail corrugations is the slight longitudinal roll–slip oscillation that takes place between wheel and rail when trains run on a rail surface having an uneven distribution of iron oxides and oxyhydroxides with various coefficients of friction [1,2]. Generally, the red rusts that are commonly found on the rail surface are iron oxyhydroxides with different types of crystal structures and characteristics, that is, α-type (α-FeOOH), β-type (β-FeOOH), γ-type (γ-FeOOH), amorphous type and so on. According to some sliding tests, it has been shown that β-FeOOH generated under the moist environment with chloride ion (Cl^-) or fluoride ion (F^-) such as submarine railway tunnel has a lower coefficient of friction than those of α-FeOOH and γ-FeOOH, which are generated under only a moist environment [7]. The further experimental results of extremely low coefficient of friction under the condition that water coexists with β-FeOOH and amorphous FeOOH can be correlated with the generation of rail corrugations.

In order to interpret these wheel/rail rolling contact phenomena caused by rusts with various characteristics, some information about types of rust adhering to the running band of rail before and after vehicle passing is indispensable. According to the conventional method, the rusts are scraped away from rail running surface by hard-edged tool and are analyzed by infrared absorption spectroscopy (IR), X-ray diffraction analysis (XRD) and other applicable methods in the laboratory; however, some sort of rusts, especially, β-FeOOH tends to transform when exposed to moisture and oxygen. Additionally, this method has no ability to analyze the variation

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with time of rust types and amounts at the same spot. Therefore, it was expected that an in situ analysis method would provide some important information of the rust at the specific positions on the rail surface along the rail crown.

Previously, we have reported on possibility of IR and Raman scattering spectroscopy (RAMAN) to be applied to in situ analysis [8]. The rail samples placed by the side of a track for a half-year in the mountain tunnels, where the rail corrugations were not generated, and in the submarine tunnels, where the rail corrugations were generated, were analyzed by the portable RAMAN spectrometer, and we reported that different kinds of iron oxyhydroxides were generated in the railway tunnels with different environments. We also reported that in situ RAMAN analysis would be applicable to an investigation of lubricating oil or grease, applied between wheel and rail in order to reduce lateral forces and wear caused by railway vehicle negotiating curved track.

In this study, we focused on the possibility of applying X-rays to in situ analysis of adhesive substances on the rail surface. Generally, XRD analysis can identify mainly crystal structures of inorganic substances, e.g. rusts and sand grains, more sensitively than IR and RAMAN; however, general X-ray analyzers are too large-scaled to be applied to the track site in railway line. Then, we adopted the portable X-ray diffractometer installing X-ray fluorescence (XRF) called "XRDF", which was originally developed for the purpose of non-destructive testing of ruins and cultural assets such as Pyramid in Egypt [9]. The portable XRDF would provide more reliable information than before by performing multiple analyses consisting of crystallographic analysis by XRD and elemental analysis by X-ray fluorescence (XRF) at the same locations (2–6 mm for X-ray beam diameter). In addition, since there are few limits to size and shape of the examination object, the XRDF analysis is very suited to analyzing the adhesive substances at the actual track.

First, the X-ray analysis using portable XRDF was carried out for rail samples on which rust was generated by scattering salt water mist and moisture vapor alternately for the preliminary laboratory experiment. For the field test on RTRI test track, XRDF analysis was applied to the corroded test rail after the test vehicle passed over it several times under various running conditions. The decreased proportion of iron rusts as the railway vehicle passes by under different conditions, which is considered as one of the most important factors influencing rail corrugations in the submarine tunnels, was investigated.

2. Experiments

First, as the preliminary laboratory experiment for the field test, XRDF analysis of rail samples on which rust was generated was carried out. We prepared two rail samples of 50 mm length: WR-5 on which rust was generated under a moist environment imitating the inside of the mountain tunnel, and SR-5 on which rust was generated under a moist and salty environment imitating the inside of the submarine tunnel. The top of the rail fragment cut from the rail used actually in the revenue line was ground by abrasive paper and then deoiled by normal hexane. The rail specimens were exposed in a weathering test apparatus (Suga test instruments DPWL-5L) for five cycles. As for WR-5, one cycle consisted of the one exposure in air for 2 h at 40 °C and RH (relative humidity) > 90%, and then another exposure in air for 6 h at 40 °C and RH < 30%. As for SR-5, one cycle consisted of the first exposure in air for 0.5 h at 40 °C and RH > 90%, the second exposure in air for 0.5 h with 1% NaCl solution spray at 40 °C and RH > 90%, the third exposure in air for 1 h at 40 °C and RH > 90%, and then the fourth exposure in air for 6 h at 40 °C and RH < 30%. Then, the XRDF analysis using Cr X-ray tube was carried out for top and gauge corner of each rail sample.

Fig. 1. Appearance of the portable XRDF system installed on the rail, performing analysis for (a) rail top in tangent track and (b) gauge corner of the high rail in curved track.

The field test to demonstrate applicability of XRDF (RIKEN KEIKI CO., LTD.) to the track site in railway line was carried out on the RTRI test track, of which the entire length is about 1 km and the stipulated maximum speed is 45 km/h. We prepared four rail samples: R-0, R-1, R-2 and R-3. R-0 was the initial state at the rail track, and the other three were the rail samples on which rust was generated by spraying of 3% NaCl solution for 20 min continuously onto the top of the rail in tangent track under three pre-processing conditions. As for R-1, salt water was sprayed without any pre-processing. As for R-2, the rail top was ground by abrasive paper and then deoiled by normal hexane to remove an oxide layer and other surface contaminations completely before salt water spraying. As for R-3, the rail top was ground by abrasive paper lightly in order to leave a partial oxide layer before salt water spraying.

Then, the XRDF analysis was carried out for these rusted sample rails. In order to analyze rails installed in actual track, we prepared the fixture to set the XRDF head just above the rail top. The fixture consists of 500 mm × 820 mm × 8 mm aluminum alloy plate to set the XRDF head and steel support structure to hold up the plate in a direction perpendicular to the track surface and to overstride the rail. Fig. 1 shows the portable XRDF system installed on the rail. As shown in Fig. 1(a), the portable XRDF system includes the XRDF head just above the rail top in tangent track with the fixture, a supply circuit and a controlling PC. For analysis of the gauge corner of the high rail in curved track, the XRDF head was inclined by 30° to the perpendicular direction, as shown in Fig. 1(b). Fig. 2 shows the close-up of XRDF head. The left attachment is an X-ray tube, of which the rated power is 35 W; the rated voltage, 35 kV; and the