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Possibility of in situ spectroscopic analysis for iron rust on the running band of rail

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ABSTRACT

Currently the surface characteristics of rail has been focused on to understand the coefficient of friction between wheel and rail because one of main causes of flange climb derailment and a kind of rail corrugations generated in a submarine tunnel can be considered to be the coefficient of friction. Then some of the influential factors of the coefficient of friction have been identified by findings obtained so far. However, the relation between oxide layer or contamination of rail surface and the coefficient of friction has not been clarified yet. Hence, in situ spectroscopic analysis can be a very strong tool to identify what kind of oxide layer and/or contamination coating the rail surface.

This paper describes the importance of the analysis for rail surface to understand the mechanism of rail corrugations generated in a submarine tunnel and the possibility of in situ spectroscopic analysis of the running band of rail.

1. Introduction

As a kind of rail surface irregularity there are some types of rail corrugations. Efforts have been made to understand the phenomenon [1,2]. Even on the ascending slopes of submarine railway tunnels, rail corrugations occurred on straight tracks, while they did not occur on that of mountain tunnels consisted of the same type rail, same kinds of vehicle, and same traffic frequency with the submarine tunnel. Therefore the cause of the rail corrugations was studied, but it was unidentified yet. As one of the main causes, not a large but a slight longitudinal roll-slip phenomenon due to a combination of a low friction and wheel load variation excited by trains passing on rail welds was suggested in the report [3]. To understand the friction between wheel and rail, coefficient of friction is very important. In addition, an uneven distribution of iron rusts with various friction properties on rail surface may have been another influence on the roll-slip phenomenon. The contribution of rust on wheel/rail problem has been suggested [4]. One of possibilities to understand the mechanism of roll-slip was considered to be the presence of β-FeOOH on wheel/rail interface, one of the iron oxides or oxyhydroxides which are kinds of rusts, generated on the rails installed in the tunnel. β-FeOOH is known to be generated under salty condition like a marine environment including submarine tunnels [5]. Therefore, the rust generated in the submarine tunnel should be studied in comparison with the rust generated in the mountain tunnel.

In the previous study, X-ray diffraction analysis (XRD) was carried out to find out β-FeOOH and/or some other substances to reduce the coefficient of friction, and observed some sorts of oxides and oxyhydroxides including β-FeOOH [3]. The specimens adopted in the analysis, however, were obtained from the surface of the running band of rail by scratching, so that an evidence of β-FeOOH existing actually on the surface of the running band of rail during train operation was not directly identified. At that time, many technical difficulties must have been solved. In situ analysis will help us to recognize the generating mechanism of corrugation in terms of the phenomenon originated in the top-of-rail substances especially iron rusts.

Rust normally accumulates on the running band of rail, on which trains are infrequently operated, and to date has not been analysed; surface rust is also removed by wheel/rail contact during normal train passages. In addition, compositions among the rust vary under different conditions; therefore, it is preferable to establish an in situ analytical method applicable directly on the rails installed in operational railway tracks instead of laboratory tests for specimens obtained from the running band of rail by scratching.

Various attempts so far made with certain techniques to identify some kinds of rust generated on the rail surface. However, any methods to satisfy the requirements have not been established as of yet. This is because it is very difficult to set up analytical devices on rails; surface roughness of rail surface, the diverse types of

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rust much different from those of specimens have been described. Water vapor in the atmosphere is also assumable as a barrier to obtain a definitive solution.

Miniature-size devices for analysis recently developed by technical innovation and in situ observation that are effective to identify the kinds of rusts, as example Fourier transform infrared absorption spectroscopy (IR) and Raman scattering spectroscopy (RAMAN) have become practicable. Both methods are useful to determine the functional group of unknown materials. In the case of rust identification, database established by accumulating data in the fundamental research clarified the durability of weathering steels with IR and RAMAN [6,7]. In particular, the database enables it easier to analyse IR spectra. On the contrary, in the case of RAMAN, the database is not as practicable as IR. However, it is advantageous that a visible laser beam is applicable to the analysis and an optical fibre is usable between a probe head and a main body of the device. Then, the main body can be safely placed slightly apart from the track and rails can be analysed with a probe head connected by an optical fibre. RAMAN seems more suitable for in situ observation than IR because water in the air has little influence on the analysis.

In this study, identification of rail contamination, especially the rust on rails, that may have adverse effects to the behavior of wheel/rail interface were carried out. In terms of applicability on in situ analysis, portable infrared absorption spectrometer and Raman spectrometer were taken on trial.

2. Sample and experimental apparatus

The rust was generated on steel plate specimens and rail specimens under artificial environments in the laboratory such as submarine tunnels and mountain tunnels.

Initially 40 mm × 60 mm × 2 mm steel plate specimens were made. These specimens were so small that could easily be analysed. On these specimens XRD analysis was carried out to verify the sorts of surface materials in terms of crystallographic structure. Then, IR and RAMAN were carried out to identify the sorts of surface rust with a focus placed on the chemical bonds. The results of these analyses were compared with those of XRD.

Next, rail specimens of 50 mm in length which were cut out of the rail used actually in a revenue line were arranged. Raman analysis was carried out on these rail specimens to evaluate the possibility of application for rail surface, namely, whether or not the surface with the curvature and the roughness like the real rail can be analysed.

For laboratory tests the surface of the mild steel plate specimens and the top-of-rail specimens were polished with emery paper, to remove oxides, and deoiled by n-hexane. Then the specimens were exposed in air for 1, 3 and 5 cycles. One cycle consisted of the exposure in air during 2 h at 40 °C and RH (relative humidity) >90% then during 6 h at 40 °C and RH < 30%, for the case of mountain tunnel condition. For the case of the submarine tunnel condition, one cycle consisted of the exposure in air during 0.5 h at 40 °C and RH > 90%, during 0.5 h 1% NaCl spray at 40 °C and RH > 90%, during 1 h at 40 °C and RH > 90% then during 6 h at 40 °C, RH < 30%.

Steel plate specimens were named S-1, S-3, S-5, W-1, W-3 and W-5 (S = submarine tunnel condition, W = mountain tunnel condition, the number refers the number of cycles), rail specimens were named WR-5 and SR-5 (R: rail).

At last, Raman analysis was carried out on the surface of rail samples placed aside track (not installed on track) in the mountain tunnel and the submarine tunnel for 6 months. Top surface of sample rails were also polished with emery paper and deoiled by n-hexane. This period was decided in consideration of the idea that top-of-rail would be sufficiently covered with rust. The exposure conditions in the tunnels were the temperature of 20-23 °C and the relative humidity of 60-90% on the days when the specimens were placed aside the tracks in the tunnels.

For the artificial conditions, weathering test apparatus Suga test instruments CY110 (in the case of steel plate specimens) Suga test instruments DPWL-5L (in the case of rail specimens) for the condition of RH > 90%, Suga test instruments CASSER-11L-ISO for 1% sodium chloride (NaCl) solution spray condition and Suga test instruments DPWL-5L for the condition of RH < 30% were employed, separately. Distilled water was used for the laboratory test; it was a little acidic because of carbon dioxide gas in the air. XRD patters of specimens were obtained with a Rigaku corporation RINT UltraX X-ray diffractometer using Cu Kα radiation. IR reflectance spectra were observed with PerkinElmer Spectrum One using fixed angle specular reflectance attachment. Raman scattering was observed with Kaiser optical systems Holo-Lab 5000 spectrometer using optical fibre between the main body and probe head, wavelength of the excitation laser was 532 nm. IR and RAMAN systems used in this study are both smaller than conventional apparatus and can be carried to the track side.

3. Results and discussion

3.1. Analysis of steel plate specimens

Fig. 1 shows the XRD patterns of W-1, W-3 and W-5. In the case of the mountain tunnel condition, γ-FeOOH (lepidocrocite) and α-

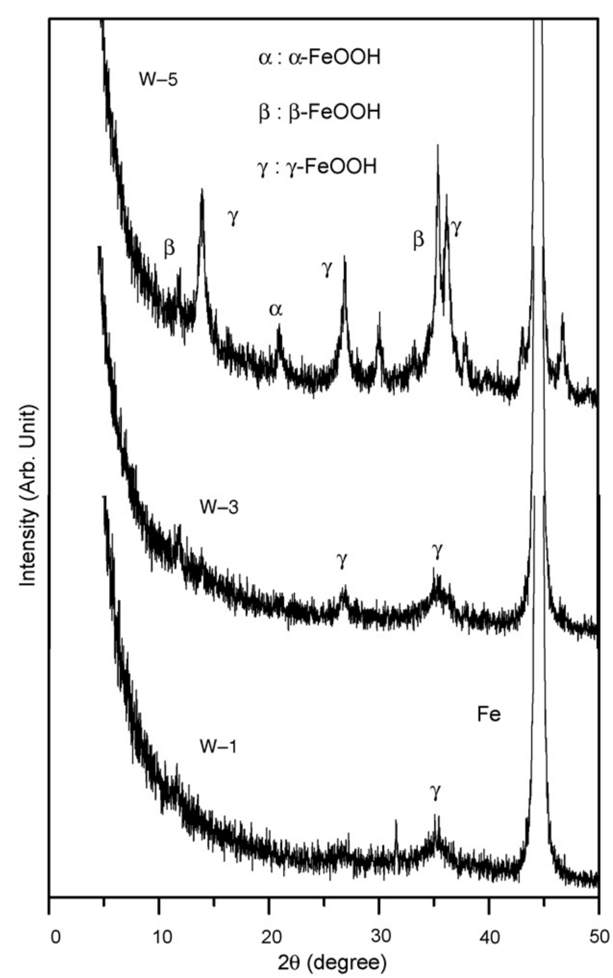

Fig. 1. X-ray diffraction patterns of steel plate specimens in the mountain tunnel condition.