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Experimental investigation on the application of quick-hardening mortar for converting railway ballasted track to concrete track on operating line

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HIGHLIGHTS

- Converting technology developed to transform the existing ballasted tracks into concrete tracks.
- A quick-hardening cement mortar was developed that meets the functional requirements.
- Quick-hardening mortar was applied to a 52 m-long existing ballasted track of an operating line.
- Running stability of the train on the converted track was evaluated.

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ABSTRACT

The ballasted track system has been widely adopted on conventional railways due to its ease of construction, but its key shortcoming is its need for frequent maintenance. In recent years, with the growing demand for railway vehicles capable of higher speeds and capacities, the concrete track is becoming more popular due to its high rigidity and relatively low maintenance. A fast converting technology was developed in this study to transform the existing ballasted tracks into concrete tracks using the developed quick-hardening mortar, which has high fluidity and strength development at an early stage, such that it could minimize the interruption of train operation. To assess the applicability of the developed mortar in the field, durability, fluidity and strength development of the mortar were characterized. The developed quick-hardening mortar was applied to a 52 m-long existing ballasted track of an operating line, and structural stabilities under moving train loads were evaluated. Experimental results showed that the track conversion was successful with the quick-hardening mortar, and the concrete structures proved to have excellent performance compared to the existing ballasted track.

1. Introduction

A ballasted track system is the most widely used track system, and transports vehicle loads to sleepers and ballasts beneath the sleepers to reach the trackbed. The track system maintains its stability through the friction created in between gravel, while offering the sufficient rigidity needed for the smooth operation of the train. As the oldest type of track system in the history of railways, the ballasted track is beneficial in terms of having low investment costs in its early stage, and high elasticity. On the other hand, the use of crushed gravel causes dust and contamination, requiring regular cleansing [1], as well as track irregularity due to the repetitive loading of running trains [2]. In recent years, as train speeds have increased, with high-speed trains capable of traveling over 300 km/h, so has the burden of maintaining and repairing the ballasted track [3].

A new track system made of concrete that addresses these weaknesses of the ballasted track has become very popular in recent years [4–6]. Although the construction of the concrete track is expensive in terms of early investment and is a more highly sophisticated process, the concrete track is highly durable and resistant to track destruction, reducing the need for maintenance [4]. In addition, it will improve track regularity and reduce deformation while enhancing ride comfort for passengers [6].

The key measure to take to reduce maintenance with the ballasted track is to get rid of the ballast layer and construct new concrete tracks. However, changing an existing ballasted track into a concrete track requires a lengthy interruption of train operations. To tackle this problem, researchers have pursued a technology that transforms the track system by pouring fast-curing cement paste or mortar deep into the ballast layer during the interruption of

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train operation on a revenue service line [7,8]. This can be considered as a pre-packed concrete technique; however, since the mortar-filling work has to be done within a short period of time so that trains can resume operation thereafter, the material needs to have the property of curing at ultra-high speed, and at the same time a certain amount of working hours for the job are required.

The converted concrete track using quick-hardening mortar is an application method using pre-packed concrete, in which pre-placed aggregates are filled first, followed by the mixture of water and cement; while to form general concrete aggregates, water and cement are mixed together simultaneously. The suggested construction process is as follows: the existing gravel is replaced by the clean-washed gravel on top of sheets of geotextiles, and quick-hardening mortar is poured into the upper layer of ballasts beneath sleepers, which then becomes a solid slab structure. Fig. 1 illustrates the concept of converting a railway track using quick-hardening cement mortar. Accordingly, the ballast layer within the area from sleepers to where geotextiles are installed is converted into a single concrete slab layer by casting with pre-packed material. Furthermore, the existing crushed stone base could also work as a drainage layer in the converted concrete track system. Additional crossing culverts and/or a side water drainpipe could be installed for harsh environments.

This experimental research focused on the development of a quick-hardening cement mortar which meets the aforementioned requirements, along with tests to ensure the material's durability on a lab scale. Prior to its field application, tests on injection and strength were performed in an environment created that is similar to field conditions. In the final stage, field applicability of the new material was assessed using different types of measurements and analyses after the field test.

2. Development of quick-hardening mortar

The converted concrete track made of quick-hardening mortar is an engineering method of converting ballasted track into concrete track, and the construction usually is carried out at night during the hours in which there are no trains being operated, necessitating a speedy construction process. A quick-hardening mortar is developed in this section to come up with the most optimized mixture that meets chemical and physical requirements. The size of the aggregates used throughout this study was maintained at 22.4–63 mm, which is exactly the same as that of the gravel used for conventional tracks.

2.1. Raw materials and proportions of their mixture

Table 1 shows the proportions of the mixture used in this filling method that meet the requirements of high fluidity, fluidity-maintainability for over a certain period of time, quick hardening and high durability. Chemical proportions used for the mixture of rapid-hardening cement specially developed in this research are illustrated in Table 2.

2.2. Fluidity of the developed mortar

In terms of fluidity, it is important to secure substantial time in the injection process so that the material can flow deep down into the bottom of the structure. If the material becomes hardened within just a few minutes, it will have difficulty reaching the bottom of the ballast layer, causing the problem of insufficient filling. This approach also has the aim of offering methods of maintaining fluidity for the safe and efficient performance of mortar casting, while securing enough time for the work in the field. To satisfy the aforementioned requirement, the developed quick-hardening mortar is designed to maintain fluidity for over 20 min by using set-control agents, as can be seen in Table 1. Fluidity was evaluated by J14-funnel efflux time, based on JSCE F 541 [9]. Fig. 2 shows the results of the travel time of the developed mortar over time after the first chemical reaction starts. As can be seen from the graph, fluidity was maintained for more than 20 min, which was the target.

3. Durability tests of developed quick-hardening mortar

The durability of concrete railway tracks could be degraded by biological, chemical and physical factors, and for this reason it is critical to ensure durability to maintain long-term stability in

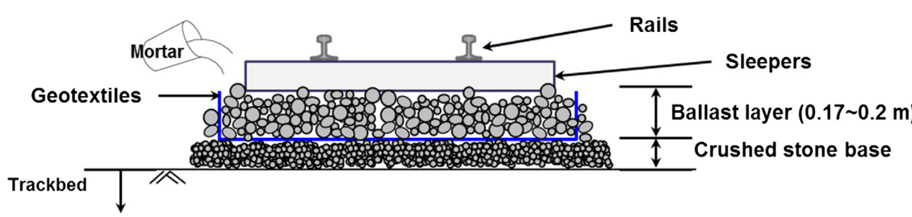

Fig. 1. Concept of converting railway track using quick-hardening cement mortar.

Table 1
Details of mix proportions (by mass).

Cement	Water	HRWRA[§]	Set-control agent	Sand A[†]	Sand B[‡]
1	0.40	0.027	0.0014	0.33	0.34

[§] HRWRA: High range water reducing agent.
[†] Maximum grain size = 1.2 mm.
[‡] Maximum grain size = 0.42 mm.

Table 2
Chemical composition of the cement.

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	LOI
Content (wt.%)	13.4	15.0	1.9	51.2	1.79	12.9	0.43	0.13	3.25