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Feasibility of Magnesium Phosphate Cement (MPC) as a repair material for ballastless track slab

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HIGHLIGHTS

- The feasibility of MPC as a repair material for Ballastless Track Slab was analyzed.
- The cracking resistance of MPC was found to be comparable to that of epoxy resin.
- The stress and strain properties of MPC repaired ballastless track were studied.

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ABSTRACT

Ballastless tracks are becoming more popular with their lower overall lifecycle costs and increased lateral load capabilities but cracking due to cyclic vehicle loads and temperature loads have known to cause cracking which has become a major problem for this kind of construction. Based on the needs of the repair material, Magnesium Phosphate Cement has been studied in this paper as a possibility. A finite element model of a stretch of ballastless track slab has been developed to study the stress and strain properties of MPC repaired ballastless track under different temperature conditions. Results have then been compared to that for epoxy resin which is currently the industry standard for these kinds of repair. The analysis revealed that stress concentration occurred at the end of crack and that the smaller the magnitude of this stress concentration, the more obvious its effects were. The cracking resistance of MPC was found to be comparable to that of epoxy resin, though not better than epoxy resin. However, MPC was concluded to be more suitable than epoxy resin practically because of its superior compatibility with concrete, lower coefficient of linear expansion, better stability to temperature changes and lower setting times.

1. Introduction

The utilization of ballastless track has received much attention in recent years because it improves the railway lifespan, allows for higher train speeds, increases lateral load capabilities which in turn reduce maintenance needs, high availability and thereby reduces total costs [1,2]. Ballasted track is more maintenance intensive, especially for high speed railways where churning up of ballast particles can lead to damage to the wheels and the rail, therefore, ballastless track can be considered as alternative for ballasted track due to the fact that it has several advantages over ballasted track which will be described later in this paper [3]. They have become essential in countries like China where the high speed railway network, which requires the use of ballastless slab, has grown over 10,000 km by 2013 [4].

Concrete plays an important role in construction of high-speed railways and concrete ballastless track slabs are built on a large scale worldwide [5]; However, concrete cracking has been widely observed in ballastless tracks in these kinds of systems [6]. Cracks can lead to the corrosion of rebar under the Cl^- or CO_2 environment that could result in reduction of the service life of ballastless track. Crack repair adds to the total cost of maintenance, which is already estimated at 30 million Euros per year for high speed railways of 500 km, excluding some extreme cases [7]. In addition, the maximum night time possessions are decreasing over time and there is an increasing pressure for reduced train delays, for higher level of service [8]. Their maintenance is therefore subject to a strict time constraints and the materials to be used to repair these cracks have to be strong enough to deal with the train loads and they must develop this strength in a relatively short time (i.e. it

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must have a lower setting time and high setting strength). These facts were the rationale behind suggesting Magnesium Phosphate Cement (MPC) in this study.

Magnesium Phosphate Cement (MPC) has been considered as suitable method to rapidly repair of concrete because it has been found to develop interfacial bond strength and compressive strength relatively fast [9,10]. Its coefficient of thermal expansion is similar to that of Ordinary Portland Cement making them more compatible. It has high volumetric stability making it less susceptible to drying shrinkage and subsequent shrinkage cracking. It is also highly resistant to abrasion and corrosion and provides good corrosion protection. MPC can also set in low temperature conditions and leaves a smaller carbon footprint during production [11,12]. However, only a few researchers have reported the use of MPC in order to repair of ballastless slab and its relative properties.

This paper presents a Finite Element Model of the CRTSII ballastless track slab which has been used to analyze the performance of MPC for different crack widths under temperature induced loads. In addition, MPC performance in cracking control has been compared to that of epoxy resin which is currently in use to perform repairs in ballastless tracks. Thus, the applicability of MPC for repair of ballastless track slab has been discussed.

2. Properties of repair materials for ballastless track slab repairing

Ballastless track slab repair requires the repair material to be quick acting, in other words the repair material must be capable of hardening extremely fast and the interfacial bond strength between the repairing material and the old concrete to be extremely high. In addition, since fixes are to be applied in the field, the repair material must be easy to work with under the environmental conditions of the site (i.e. it must have the right viscosity, good thermal performance and can be used flexibly under low temperature conditions). Table 1 compares some of the physical properties that will determine workability and durability of MPC and the normally used epoxy resin.

Table 1 indicates that MPC is better suited for site use as the bonding time for MPC is 5–30 min compared to the 240–1500 min for epoxy resin. MPC functions well at temperatures ranging from normal room temperatures to temperatures below freezing, with the rate of hardening increasing with the rise in temperature. The rate of setting is extremely high necessitating measures to reduce setting time when the temperature rises to 30 °C or higher [6]. On the other hand epoxy resin is more sensitive to low temperature (for every 10 °C drop in temperature the setting time increases by 60–120 min). It requires heat treatment at temperatures of 5 °C and below and further meticulous maintenance should also be given during construction as it adapts poorly to cold climate. In addition, MPC also has a longer service life (50 years) compared to that of epoxy resin. OPC and MPC also share similar moduli of elasticity and linear coefficient of expansion making them highly compatible as mentioned earlier.

3. Finite element modelling (with FEM)

In this study ABAQUS has been utilized to create a model of the longitudinal section of CRTSII ballastless track slab atop the subgrade. The model consists of rails, fasteners, sleeper, track slab, cement asphalt mortar (CA) layer and supporting base subgrade layer. The sleeper was assigned to be of the type CHN60, the rail spacing was set to be 1435 mm, each track board laying 20 sleepers, the spacing between the sleepers was taken to be 650 mm, the stiffness of fastener was taken to be 20 kN/mm, the total track slab dimensions were taken to be 6450 × 2800 × 200 mm which was constructed of reinforced cement concrete. The track slab was supported by a cement asphalt mortar (CA) layer of 30 mm thickness. The CA layer was laid over a supporting base subgrade layer; the total support plate dimension were taken to be 6450 × 2950 × 300 mm. The diameters of longitudinal and transverse reinforcing bars in support plate were taken to be 20 mm and 16 mm, respectively.

The material properties of each component are given in Table 2. T3D2truss elements were used to simulate the steel bars while C3D8I solid elements were used to model concrete of the track slab, support layer and mortar layer. The model used Vossloh300 type fasteners. The spring elements were utilized to simulate the fasteners and their stiffness was taken as by 20 kN/mm. In order to avoid problems due to stress concentration, coupling mode was used to simulate the connections between fasteners and sleepers. It has been assumed that track plate deformations are compatible with CA mortar layer and the deformations of CA layer is connected to the support layer, therefore the connections could be modelled by the tie model. The steel-concrete interaction is modelled by the embed model inbuilt in ABAQUS. This study mainly focuses on the mechanical properties of MPC as a repair material for ballastless track slabs, so the subgrade has been assumed to be an elastic foundation with subgrade surface stiffness 76 MPa/m in order to simplify the model.

Table 1
Physical Properties of MPC and Epoxy Resin.

Material	Setting time (min)	Setting Temperature (°C)	Dynamic Viscosity (mps)	Contraction Percentage (%)	Cohesional Strength (MPa)	Modulus of Elasticity (Mpa)	Thermal Coefficient (/°C)	Service Life (years)
MPC	5–30	−10 to 40	100–400	0.018–0.035	2–3	30,000–46,000	1.0×10^{-5}	50
Epoxy Resin	240–1500	5–40	3–300	2.0–6.0	1.5–3.5	1000–3000	5.0×10^{-5}	5–8

Table 2
Materials properties of CRTSII ballastless track components.

Component	Material	Density (T/m^3)	Modulus of elasticity (Mpa)	Poisson ratio	Coefficient (°C^{-1})
Steel rail	Steel	7.8E-09	2.10E+05	0.3	1.20E-05
Steel bar	Steel	7.8E-09	2.10E+05	0.3	1.00E-05
Slab	Concrete	2.5E-09	3.60E+04	0.2	1.00E-05
Mortar layer	CA Mortar	1.5E-09	9.00E+03	0.34	1.30E-05
Support layer	Concrete	2.5E-09	2.55E+04	0.2	1.00E-05
Repaired layer	MPC	2.5E-09	4.20E+04	0.2	1.00E-05
	Epoxy resin	1.20E-09	3.00E+03	0.38	5.00E-05