Study on physical and mechanical properties of cement asphalt emulsified mortar under track slab

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Abstract

Purpose – During the construction process of the China Railway Track System (CRTS) I type filling layer, the nonwoven fabric bags have been used as grouting templates for cement asphalt (CA) emulsified mortar. The porous structure of nonwoven fabrics endowed the templates with breathability and water permeability. The standard requires that the volume expansion rate of CA mortar must be controlled within 1%–3%, which can generate expansion pressure to ensure that the cavities under track slabs are filled fully. However, the expansion pressure caused some of the water to seep out from the periphery of the filling bag, and it would affect the actual mix proportion of CA mortar. The differences in physical and mechanical properties between the CA mortar under track slabs and the CA mortar formed in the laboratory were studied in this paper. The relevant results could provide important methods for the research of filling layer materials for CRTS I type and other types of ballastless tracks in China.

Design/methodology/approach – During the inspection of filling layer, the samples of CA mortar from different working conditions and raw materials were taken by uncovering the track slabs and drilling cores. The physical and mechanical properties of CA mortar under the filling layer of the slab were systematically analyzed by testing the electrical flux, compressive strength and density of mortar in different parts of the filling layer.

Findings – In this paper, the electric flux, the physical properties and mechanical properties of different parts of CA mortar under the track slab were investigated. The results showed that the density, electric flux and compressive strength of CA mortar were affected by the composition of raw materials for dry powders and different parts of the filling layer. In addition, the electrical flux of CA mortar gradually decreased within 90 days' age. The electrical flux of samples with the thickness of 54 mm was lower than 500 C. Therefore, the impermeability and durability of CA mortar could be improved by increasing the thickness of filling layer. Besides, the results showed that the compressive strength of CA mortar increased, while the density and electric flux decreased gradually, with the prolongation of hardening time.

Originality/value – During 90 days' age, the electrical flux of the CA mortar gradually decreased with the increase of specimen thickness and the electrical flux of the specimens with the thickness of 54 mm was lower than 500 C. The impermeability and durability of the CA mortar could be improved by increasing the thickness of filling layer. The proposed method can provide reference for the further development and improvement of CRTS I and CRTS II type ballastless track in China.

Keywords CA mortar, Electric flux, Compressive strength, Density

Paper type Research paper

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1. Introduction

The slab ballastless track system has many advantages, such as better structural integrity and stability, lower maintenance requirements (Shigeru, Hideyuki, & Masao, 1998; Katsuoshi, 2001; Murata, 2003; Wang, Liu, Zhang, & Hu, 2012; Shao, Li, Wu, Wang, & Li, 2013; Wang, Liu, Li, Li, & Shao, 2016; Wu, Li, Jia, Wei, & Wang, 2021; Wu *et al*., 2022) and it can meet the requirements of construction and development for high-speed railway in China. CRTS I slab type ballastless track are composed of concrete base, CA mortar filling layer and track slab. With the characteristics of faster construction progress and easier maintenance, it has been widely used in the construction of high-speed railway in China (Wang, Liu, Wang, & Hu, 2008; He, Long, & Xie, 2009; Tian, Deng, Huang, & Liao, 2010; Peng & Yang, 2011; Wu *et al*., 2012; Zeng, Xie, & Deng, 2012). CRTS I type CA mortar is prepared by high-speed mixing of cement, emulsified asphalt, sand, water and various admixtures in a certain proportion, which is filled into the cavity (length 4,962 mm, width 2,400 mm and height 40–60 mm) between the track slab and the concrete basement (Wang, 2008; He, Long, Xie, & Liu, 2012; Song, Zeng, Xie, Long, & Ma, 2020). Therefore, the filling layer is the key structure and the CA mortar is the key material of filling layer for the slab ballastless track.

At present, the test and assessment of the performance of CA mortar are mainly based on the temporary technical requirements (Department of science & technology of China railway ministry, 2008), as the samples for the test of physical and mechanical properties, durability performance are in specified size (Wang, Liu, & Hu, 2010; Jia, Wei, Wu, & Li, 2013; Wang, 2013). However, in practical engineering, nonwoven bags that are permeable to air and water, have been used as templates for grouting CA mortar. In that case, the hardened CA mortar is different from the molding sample due to the expansion of aluminum powder in mortar during the harden process (State standard of the People's Republic of China, 2010; Wang, Jia, Li, Wei, & Li, 2016), a part of water will seep from the periphery of the nonwoven bag in practical engineering. Before the formal construction of CA mortar, the method of removing track board and inspecting the CA mortar can only avoid the phenomena such as mortar peeling and bubble layering, but the actual performance of CA mortar under the slap cannot be well monitored.

In this paper, the CA mortar under slab in practical engineering was evaluated by drills core samples from different raw material and under different working conditions. By testing the electric flux, the compressive strength and density of the CA mortar in different parts, physical and mechanical properties of CA mortar under slab were systematically analyzed. These results could provide valuable references for the material research and construction of the CRTS I type and other ballastless track slab.

2. Experimental

2.1 Raw materials, the composition and preparation

(1) Emulsified asphalt: cationic slow-breaking emulsified asphalt for CRTS I type CA mortar specially, 60% of solid content; (2) Dry-mixed powder: cement-based dry-mixed powder for CRTS I type CA mortar specially, the amount of particle size <0.075 mm about 33%, the experiments used two dry-mixed powder (1# and 2#) from different manufacturers and it referred to the 2# dry-mixed powder if the special note had not been made; (3) Latex: TD-08 polymer emulsion; (4) defoaming agent: organic silicon and (5) air-entraining agent: rosin.

Raw material ratio: dry-mixed mortar: emulsified asphalt: latex: water: defoaming agent: air-entraining agent = 3: 1.29: 0.11: 0.067: 0.0004: 0.004, dry-mixed mortar: 1,103 kg/m^3.

CA mortar was prepared by mortar mixing lorry of the South Road Machine Company, with the materials weighed automatically. Mixing process: the liquid materials, including water, emulsified asphalt, latex, defoaming agent, were added at first, with a stirring speed of 30 r/min; then, the dry-mixed mortar was added with a stirring speed of 80 r/min; next, the air-entraining agent was added with a high stirring speed of 120 r/min within 120 s; finally, the stirring continued for another 30 s with a low stirring speed of 30 r/min to complete the CA mortar preparation.

The test results of the performance of CA mortar were obtained from three parallel samples in the article.

2.2 Methods

When the CA mortar was assessed after removing the track slab in practical engineering, the samples were drilled core from different parts of the CA mortar. The size of samples for compressive strength and density was $\varphi 50$ mm × 50 mm. The size of samples for electric flux was $\varphi 100$ mm × 50 mm.

The compressive strength of CA mortar was measured according to the Chinese railway standard: CA mortar of CRTS I type slab ballastless track (Department of science & technology of China railway ministry, 2008).

The density of CA mortar was obtained by calculation, based on the test results of hydrostatic balance.

The expansion rate of CA mortar was measured according to the Chinese railway standard: CA mortar of CRTS I slab ballastless track (Department of science & technology of China railway ministry, 2008).

The electric flux of CA mortar referred to the test method for coulomb electric flux of concrete according to "*Standard for test methods of long-term performance and durability of ordinary concrete*" (State standard of the People's Republic of China, 2010).

3. Results and discussion

In practical engineering, samples of CA mortar under slab were tested. The trends of electric flux, strength, density and porosity rate of the mortar with different raw materials and different site were also analyzed.

3.1 Electric flux

As the CA mortar filling layer was influenced by uneven slab cavity, thickness of mortar filling layer was not uniform actually after removing the slab. Even fine adjustment of the level for track slab had been taken measured to keep the slab cavity thickness at the level of 40–60 mm. Different samples from the same CA mortar filling layer were selected to study the influence of thickness on electric flux at 90 days of the age, and the result was shown in Figure 1.

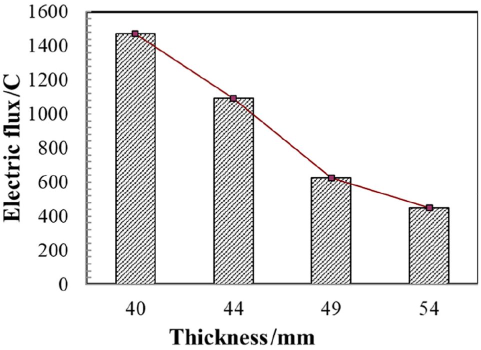

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Figure 1.
Effect of thickness on electric flux

Figure 1 showed that electric flux of 90 days' CA mortar decreased gradually with the increment of thickness. The electric flux of the samples with thickness of 44 mm was slightly higher than 1,000 C, while the electric flux of the CA mortar with the thickness of 54 mm was lower than 500 C. It indicated that both the durability and anti-permeability performance of CA mortar filling layer under track slab were good according to the standard. This phenomenon could be attributed to the thickness of mortar samples, which increased the resistance of mortar to chloride penetration and lead to the decrease of electric flux at the same time. In addition, when the thickness of specimen was not higher than 49 mm, the electric flux of the mortar was almost negative linear correlation with thickness of filling layer. The linear trend gradually weakened when the thickness of specimen was greater than 49 mm. Therefore, appropriate increment of the thickness of CA mortar filling layer was helpful to improve the durability of mortar. Therefore, the thickness of the CA mortar filling layer should be over 49 mm.

CA mortar was grouted into the nonwoven fabrics bag under the track slab during practical construction. The pressure of mortar near the inlet was higher than the pressure of mortar near the outlet, due to the liquid-level height pressure of fresh mortar in funnel. The effects of curing age on the electric flux of the mortar, which was near the inlet and the outlet at the same mortar filling layers were showed in Figure 2.

Figure 2 showed that the electric flux of CA mortar near the inlet was below that near the outlet at eight months of the age. That could be caused by the combination of two reasons: firstly, during the grouting process, the pressure at the inlet of the CA mortar filling layer was higher than the pressure at the outlet. Secondly, the nonwoven fabric bag for the CA mortar owned good permeability. Under higher pressure, more water was discharged from the CA mortar filling layer. Seepage water brought out more particles of cement and asphalt from fresh CA mortar at the same time. These particles accumulated on the inner wall of nonwoven fabric bags and further formed hardening layer structure. The higher pressure near the inlet of the filling layer, the more exudation, the thicker the hardening layer structure and the more compact the mortar. As a result, electric flux of the CA mortar near the inlet was less than that near the outlet.

The composition of raw materials was one of the key factors on the electric flux of cement-based material in practical engineering. There were many manufacturers for special dry-mixed powders, and the test results of electric flux data of CA mortar prepared with different dry-mixed powders were showed in Figure 3.

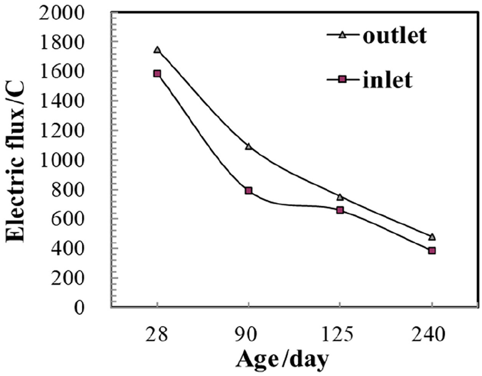

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Figure 2.
Effect of curing age on electric flux

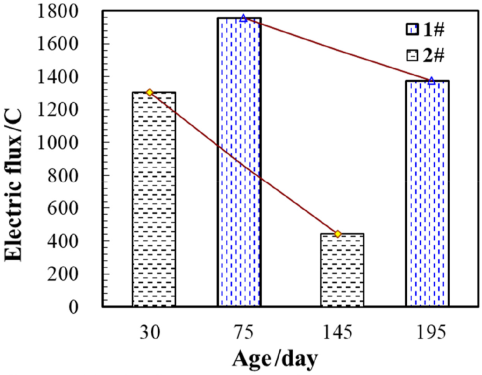

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Figure 3. Effect of dry-mixed powders on electric flux

As shown in Figure 3, the electric flux of mortar was closely related to dry-mixed powders. It clearly showed that the electric flux of Sample 2# was less than that of Sample 1#, and the rate of decrease in electrical flux of Sample 2# was significantly greater than that of Sample 1#. It was possible because that the 2# dry-mixed powders match better with emulsified asphalt, then they formed more ideal microstructures, and the strength of mortar developed faster.

3.2 Performance of mortar under track slab

When the CA mortar has been grouted into the cavity under the track slab for 28 days, the track slab which was on the CA mortar filling layer could be removed and then the samples could be obtained by drilling from the CA filling layer. Besides, the molded samples in the lab were prepared by using the same batch of mortar and they were maintained for 28 days. These two kinds of CA mortar samples were subjected to the water immersion experiment and then weighed separately. The water absorption rate of these two mortar samples which varied with time were showed in Figure 4.

Figure 4 showed that the water absorption rate of the CA mortar sample, which were obtained from the filling layer reached about 0.5% after immersion in water for one day and the water absorption rate trended to be stabilized. While the water absorption rate of the samples which were mold-formed in the lab, increased gradually as the prolongating of

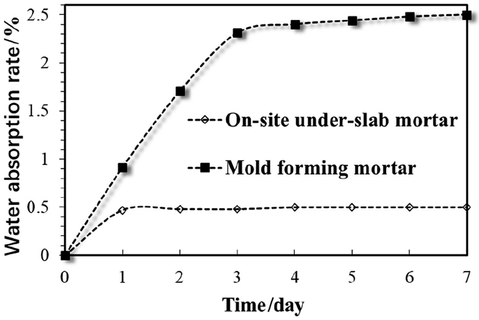

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Figure 4. Water absorption rate of under the core of track slab/mold forming sample

immersion time. The water absorption rate increased rapidly within three days and then it increased slowly and finally, it reached about 2.5% at seven days, which was about five times more than that of the on-site samples. There were more internal pores and larger water absorption rate for the mortar prepared in the lab. Compared with mold-formed samples, during the hardening process, more water seeped out of the CA mortar prepared on-site and it could lead to the decrease in the internal porosity of the mortar under slab. Therefore, the water seepage of mortar under the track slab would improve the density of mortar and ultimately increased the durability of the filling layer mortar.

3.3 Compressive strength

Apart from samples in the lab, the actual thickness of CA mortar filling layer in practical engineering was not uniform. The samples were drilled core with different proportions of height and diameter in the same mortar filling layer. The results were shown in Figure 5, with the diameter/thickness ratio as the X-coordinate and the compressive strength as the Y-coordinate.

As indicated in Figure 5, the compressive strength of CA mortar increased gradually with the growth of diameter/thickness ratio (D/T). Comparing with the sample which the proportion of D/T was 1, the compressive strength of the sample which the proportion of D/T was 1.5 increased 0.5 MPa and the range of increase was 12.8 %. Before filling CA mortar into the slab cavity, the height of track slab was controlled with fine adjustment, the D/T of the samples drilled core from the filling layer mostly was 1.3 and thus, the samples with D/T 1.3 were used to evaluate the compressive strength of CA mortar in the following text.

By selecting the linear railway and the curve section with the same raw material and the same construction time, four corners and middle part samples were obtained both from the linear and curve section, respectively, and the compressive strength was tested. The compressive strength of samples at 28 days' age were shown in Figure 6, and the slab corner near the inlet was taken as zero center, the long edge as the X-coordinate and the short side as the Y-coordinate.

As shown in Figure 6, the results of compressive strength exhibited a slightly difference within 0.5 MPa in different parts of CA mortar filling layer under the slab, and the compressive strength of the samples at the middle parts was the lowest. The compressive strength of the samples in the linear railway was slightly higher than the samples in the curve section at both the four corners and center. This trend could be caused by the differences in the setting and hardening processes of CA mortar. Under the same resistance pressure for the float of track slab, the CA mortar filling layer under the slab would expand vertically by 1%~3%, because that the aluminum powders reacted with the fresh CA mortar. The

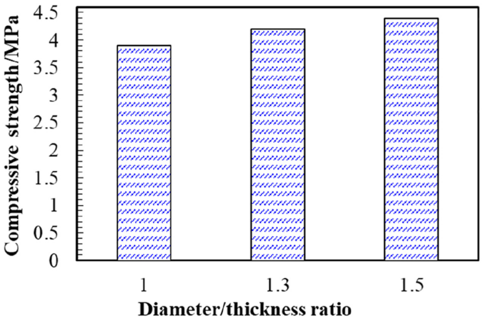

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Figure 5.
Effect of specimen size on compressive strength

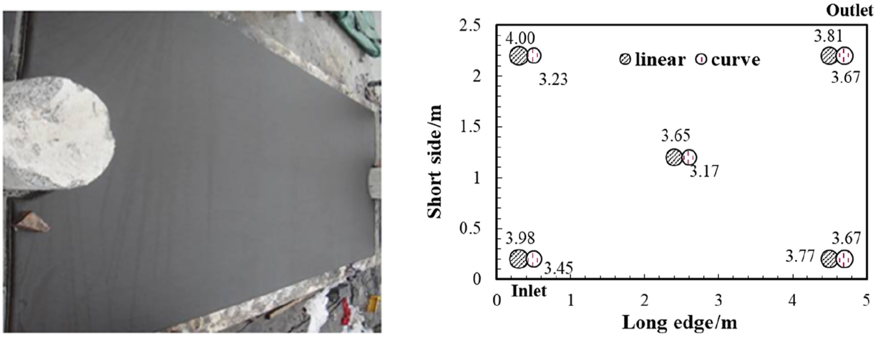

Photo of CA mortar after removing slab

(a)

Distribution map of compressive strength

(b)

Source(s): Authors own work

Figure 6. Distribution of compressive strength of CA mortar under slab (unit: MPa)

phenomenon slightly disturbed the mortar hardening process. At the curve section, partial expansion force would be released along inclined plane, so the influence of CA mortar on the curve segment was bigger than that at the linear railway and it would cause the differences of compressive strength for the CA mortar in working condition.

Curing age was one of the main factors for the compressive strength of CA mortar under slab. Time-dependent mortar compressive strength of the three drilling core samples from different pieces of filling layer mortar were continuously tested during the one year and the results were shown in Figure 7.

As indicated in Figure 7, the compressive strength of CA mortar increased gradually and stabilized in the later stage after 90 days. In contrast with the 28 days' compressive strength, the increase ranges of the 365 days' compressive strength were quite different among the three pieces of CA mortar (about 42 %–85.3 %).

Dry-mixed powder was one of the main raw materials of CA mortar; the CA mortar filling layers were prepared with two kinds of dry-mixed powders from different manufacturers, respectively. The compressive strength of CA mortar at the corner under track slab was tested at 28 days' age and the corresponding results were shown in Figure 8.

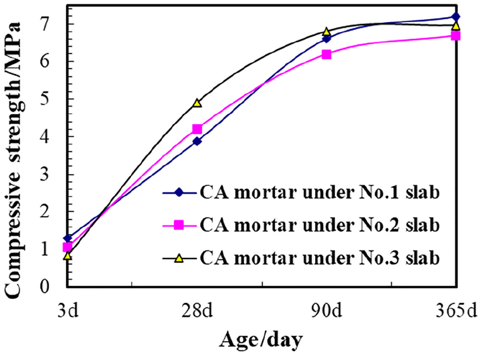

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Figure 7. Compressive strength curve of CA mortar during 365 days

As indicated in Figure 8, the compressive strength of CA mortar under slab was closely related to the kinds of dry-mixed powders. The compressive strength of two kinds of CA mortar which were prepared by using different dry-mixed powders was compared. It could be found that the difference value of the compressive strength was over 1.0 MPa, which was near to 70 % of CA mortar compressive strength value prepared by the 1# dry-mixed powders.

3.4 Density

The density was one of the indexes for the material property; it could be used to characterize the compactness degree of CA mortar. Density distributions of CA mortar at 56 days' age under slab were shown in Figure 9. With the slab corner near the inlet as zero centers, the long edge and the short side were taken as the X-coordinate and Y-coordinate, respectively.

As shown in Figure 9, the density of CA mortar was slightly different in different parts of the filling layer, the maximum different value was 0.049 × 10^3 kg/m^3 and the density of CA mortar at the middle parts was largest relatively. Under different working conditions, the density of CA mortar which was at the linear railway and at the curve section was almost equal and the maximum different value was 0.018 × 10^3 kg/m^3. According to the changing trend of the compressive strength in Figure 5, the compressive strength of CA mortar near the

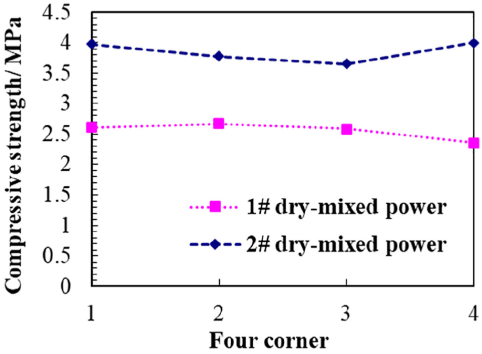

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Figure 8.
Effect of dry-mixed powders on compressive strength

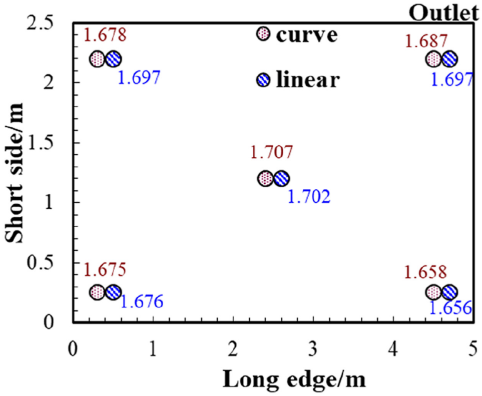

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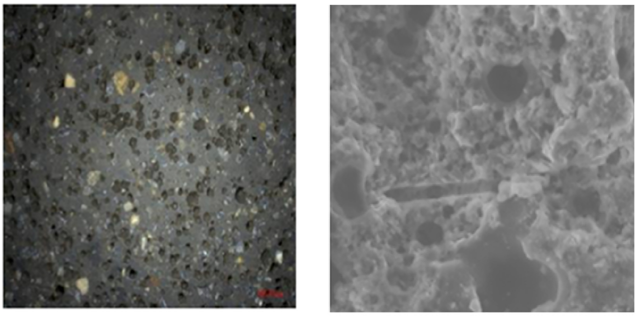
Figure 9.
Distribution of density of CA mortar under slab (unit: × 10^3 kg/m^3)

center was lower relatively and the density was higher. It was because that a very small amount of water seeped out of fresh CA mortar during hardening process and the amount of interconnected pores was fewer in hardened mortar, it was difficult to evaporate for moisture. But the amount of seepage water was larger at the edge of CA mortar filling layer, then water/binder ratio reduced, the amount of interconnected pores increased and it became more easily for water to evaporate in late stage. Finally, the phenomena that the compressive strength was lower relatively occurred and the density was higher relatively of the CA mortar near the center of filling layer under track slab.

Inner pore structure of CA mortar was observed in different objective magnification by optical microscope and scanning electron microscope. The results were shown in Figure 10.

As indicated in Figure 10, nonconductive and independent pores were the mainly inner structure of CA mortar and there was a layer of dense organic matter adhering on pore inner-walls, which proved that it was difficult for water to transfer between pores inner and external environment in microscope.

The density of CA mortar under track slab was closely related to curing age. The samples were drilled core sample from the center, inlet and outlet parts of the mortar filling layer, respectively. Time-dependent mortar densities were tested continuously during the 90 days and the corresponding results were shown in Figure 11.



Optical microscope image

(a)

Scanning electron microscope image

(b)

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Figure 10.
Images of independent pores and inner wall

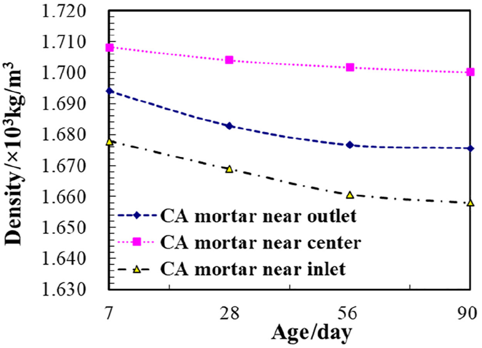

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Figure 11.
Density curves at different locations of CA mortar under slab in 90 days

As shown in Figure 11, the density of CA mortar was reduced gradually over time, and it was eased up in 56 days and stabilized in the late stage. In contrast with the seven days' density, the decrease range of the density in 90 days was no more than 1 %. It took a significantly decrease range of density for CA mortar near the outlet and inlet than near the center, and it indicated that the amount of interconnected pores were fewer. It was difficult for moisture to evaporate near the center of hardened mortar.

The pore characteristics of CA mortar were investigated with MIP (mercury intrusion porosimetry), the total porosity of surface mortar was 14.1% and the center part was 18.7%. It showed that the surface of CA mortar under slab was more compact than the inner.

3.5 On-site uncovering inspection

On-site uncovering inspection was one of the important means to evaluate the quality of mortar filling under track slab. Referring to the inspection requirements for uncovering slab in the process test before the formal construction of CA mortar, the mortar was continuously pumped into the cavity under the slab of P4962 type. The thickness of the cavity under the slab was 50 mm, and the uncovering slab was used to check the filling effect of the space under the slab when CA mortar had been grouted for 24 hours. The surface and section of the filling mortar after the uncovering were shown in Figures 12 and 13.

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Figure 12.
The surface of the pumped CA mortar

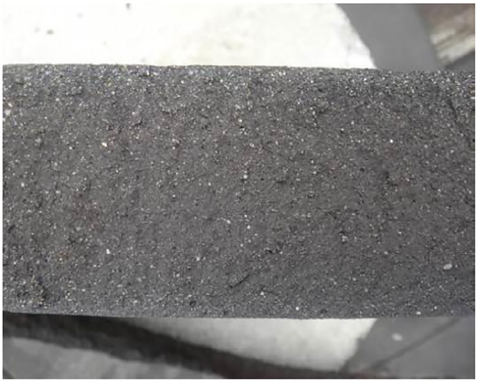

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Figure 13.
The cross section of the pumped CA mortar

Figure 12 showed that the surface of the CA mortar filling layer under the track slab was flat, without peeling; the color was light black-brown and evenly distributed. Furthermore, Figure 13 showed that the cross section of the pumped CA mortar was uniform and no segregation of the materials, which corresponded with the inspection requirements of the mortar uncovering slab.

4. Conclusions

1. The electric flux of CA mortar decreased gradually with the increment of the specimen thickness in 90 days' age, the electric flux of samples with the thickness of 54 mm was lower than 500 C. The permeability resistance and durability could be improved by properly increasing the thickness of CA mortar filling layer.
2. The electric flux, density and compressive strength of CA mortar with different parts were slight different and it was related to the seepage water and inner expansion of fresh CA mortar under slab. With the prolongation of time, the compressive strength gradually increased, while the electric flux and density gradually decreased. After some water seeped out of the CA mortar on-site, the water absorption rate of the mortar under the slab was much lower than that in the lab, which improved the compactness and durability of mortar.
3. The electric flux and the compressive strength of CA mortar filling layer were closely related to the kinds of dry-mixed powders, it was helpful to the durability of CA mortar by using the suitable dry-mixed powders, which could improve the compressive strength and reduce the electric flux of CA mortar. The surface of the mortar filling layer was smooth, without peeling and the color was light black-brown and evenly distributed. The cross section of the pumped mortar was uniform and no sand sank, which matched with the inspection requirements of the CA mortar filling layer.

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