

PRODUCTION OF PRECAST UHPFRC PAVEMENT COVER PLATES IN HIGH-SPEED RAILWAY CONSTRUCTION

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Abstract

Pavement cover plates are railway ancillary facilities, which are designed to cover the cable trenches. In recent years, Ultra High Performance Fiber Reinforced Concrete (UHPFRC) has been encouraged to be applied for pavement cover plates production by the Railways Ministry of the People's Republic of China.

In this study, a cost-effective UHPFRC material, named as Eco-UHPFRC, was designed firstly in the laboratory. The workability, mechanical properties and durability of this material were tested and all of them achieved the required value. Then, the manufacture procedure of the plates was determined in the factory after several production trials. Before application, the appearance, size and load-carrying capacity of the produced plates have to be examined according to the requirements of quality control. By virtue of its excellent performance, Eco-UHPFRC designed in this study has been successfully employed to produce pavement cover plates which are widely used in the high-speed railway projects in China.

Résumé

Les plaques de couverture de chaussées sont des installations auxiliaires ferroviaires destinées à recouvrir les tranchées de câbles. Ces dernières années, l'usage de béton fibrés à ultra-hautes performances (BFUP) pour la production de ces plaques a été encouragé par le ministère des transports de la république populaire de Chine.

Dans cette étude, un BFUP économiquement attractif appelé Eco-UHPFRC a été formulé en laboratoire. L'ouvrabilité, les propriétés mécaniques et la durabilité du matériau ont été mesurées et ont atteint les niveaux nécessaires. Ensuite, le processus de fabrication a été mis au point en usine après plusieurs essais. Avant utilisation, l'aspect, la taille et la capacité portante des plaques produites sont mesurés selon une procédure de contrôle qualité. Grâce à ses excellentes performances, Eco-UHPFRC a été retenu pour la production des plaques de couverture de chaussées largement utilisées dans les projets de trains à grande vitesse en Chine.

1. INTRODUCTION

Pavement cover plates are used to cover the cable trenches along the railway, enduring loads from the pedestrian and small track maintenance devices. In the past, normal concrete (NC) was used to produce these cover plates in China. But due to the poor performance of the normal concrete, the plates frequently crack, flake off or even totally break down, which is unsafe for the pedestrian and for the maintenance devices. In addition, the dead weight of the normal concrete cover plates is also a big problem for the overhead railways.

The high-speed railway network in China has been rapidly expanding these years. The national standards for the high-speed railways construction were also renewed, requiring higher quality and longer service life. In order to meet these higher requirements, one of the strategies recommended by the Railways Ministry of China was to use Reactive Powder Concrete (RPC), a typical type of Ultra High Performance Fiber Reinforced Concrete (UHPFRC), to produce the cover plates. By virtue of RPC's lower dead weight and superior mechanical properties, the weight of the plates can be reduced by almost 60% [1]. Moreover, easy installation, low maintenances and few replacements can be achieved as well. RPC pavement cover plates were firstly used in Qingzang high-speed railway in 2005, and then their application was extended to the second Xiangyu high-speed railway (2007) and Zhengxi passenger dedicated line (2008). Figure 1 shows the applications of RPC pavement cover plates along the high-speed railways.



Figure 1: Applications of RPC pavement cover plates

RPC exhibits many advantages compared to normal concrete, with the exception of its high cost [2]. So in this study, in order to lower its cost, fly ash and river sand were used to substitute for expensive quartz powder and quartz sand to design a new type of UHPFRC, which can meet all the requirements for cover plates. The designed UHPFRC was named Ecological UHPFRC (Eco-UHPFRC) for its low cost and energy consumption, which follows the requirements of sustainable development.

2. PROPORTION DESIGN FOR ECO-UHPFRC

The mix proportion was firstly determined in the laboratory, and thereafter adjusted in the precasting factory. The objective of the laboratory experiments was to develop a basic mix proportion achieving the required properties with low cost and energy consumption.

2.1 Property requirements

According to the technical regulations [3] drafted by Railways Ministry of China, the mechanical properties and the durability of the material used for cover plate production must meet the requirements listed in Table 1.

Table 1: Property requirements for UHPFRC used for cover plates production

Compressive strength	Flexural strength	Young's modulus	Resistance to chloride penetration	Resistance to Freeze-thaw attack
$\geq 130\text{MPa}$	$\geq 18\text{MPa}$	$\geq 48\text{ GPa}$	$< 40\text{ C}$	$F > 500$

The compressive strength, flexural strength and Young's modulus were measured according to the Chinese standard GB/T 50081-2002 (*Standard for test method of mechanical properties on ordinary concrete*). The sizes of the specimens were 10 cm × 10 cm × 10 cm, 10 cm × 10 cm × 40 cm and 10 cm × 10 cm × 30 cm respectively. The resistance to chloride penetration was tested according to ASTM C 1202-97. '< 40 Coulombs' denotes that the chloride permeability of UHPFRC should be negligible. And 'F > 500' indicates that UHPFRC should be able to endure at least 500 freeze-thaw cycles according to GB/T 50082-2009 (*Standard for test method of long-term performance and durability of ordinary concrete*), i.e. after enduring 500 freeze-thaw cycles, the mass loss of Eco-UHPFRC should be less than 5 % and the relative dynamic modulus of elasticity should be higher than 60 %.

2.2 Laboratory experiments

Materials

Three cementitious materials were used in this study, i.e. ordinary Portland cement with 28d compressive strength of 49.7 MPa, class F fly ash and silica fume. Natural river sands were used as fine aggregate. The sands had a maximum size of 10 mm and the fineness modulus is 2.7. Steel fibers were copper coated and supplied by Bekaert. The length, aspect ratio and tensile strength of the fibers were 13 mm, 65 and 1800 MPa, respectively. The superplasticizer was a type of liquid agent from Sika, with 28 % solid content.

According to the technical regulations [3], after casted for 24 hours, the specimens were demoulded and steam cured at 85°C for 2 days.

Mix Design

In order to reduce the cost of the material, the quartz powders and quartz sands were replaced by fly ash and river sands in this study. So the content of fly ash and river sands in the mixture is the main concern during the mixture design. The water to binder (cement + fly ash + silica fume) ratio (W/B), silica fume to binder ratio (SF/B), volume fraction of steel

fibres (V_f), superplasticizer to binder ratio (SP/B) were kept constant, while the fly ash to binder ratio (FA/B) and sand to binder ratio (Sand/B) were varied to investigate their influences on the workability and mechanical properties of UHPFRC.

It is well acknowledged that fly ash could modify the workability of the fresh concrete [4]. For UHPFRC, fly ash is also very effective to reduce the viscosity and improve the workability [5]. However, if too much fly ash is used, the mechanical properties of UHPFRC will be impaired due to the low pozzolanic reactivity of fly ash. So based on a series of experimental results as shown in Figure 2, the optimum content of fly ash was determined to be 15% of the binder by mass, at which the excellent workability was achieved and the compressive strength was relatively high.

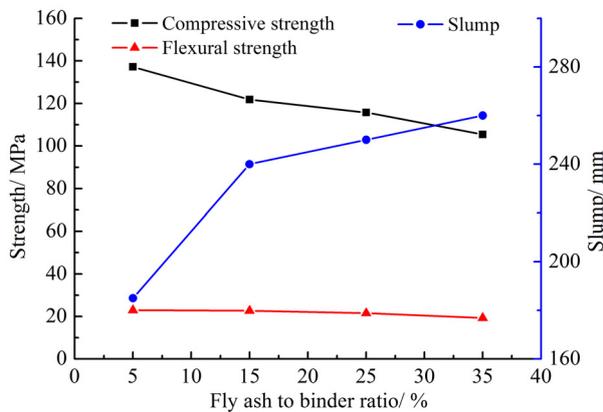


Figure 2: Effect of fly ash to binder ratio on the mechanical properties and workability of UHPFRC

(W/B=0.17; SF/B=15%; Sand/B=120%;
 $V_f=1.3\%$; SP%=3.5%)

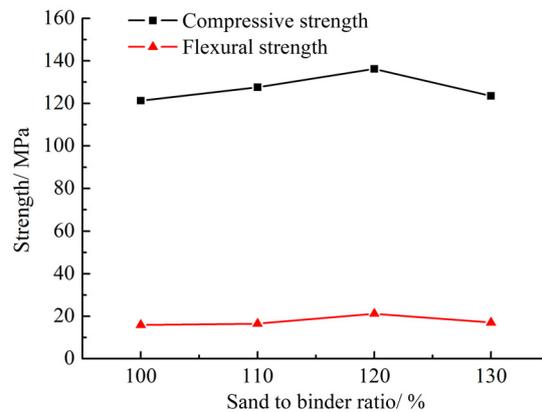


Figure 3: Effect of Sand to binder ratio on the mechanical properties of UHPFRC

(W/B=0.17; FA/B=15%; SF/B=15%;
 $V_f=1\%$; SP%=3.5%)

In view of the homogeneity of UHPFRC, river sands with a maximum size of 2.36 mm were used in the first place to investigate the optimal sand to binder ratio. The effect of sand to binder ratio on the mechanical properties of UHPFRC can be found in Figure 3. It shows that, in this case, UHPFRC exhibits the maximum mechanical properties when the sand to binder ratio is 1.2.

With regard to the river sands, there was another issue that they have to be sieved before mixing, which consumed time and energy and also wasted lots of materials (the coarser sand particles). So in order to eliminate this procedure, the sieved river sands with a maximum size of 10mm were employed in the mixture. The results turned out to be quite encouraging. As a result of the presence of the coarser sand particles, the water to binder ratio of the mixture was reduced to 0.15, thus the mechanical properties of UHPFRC were increased. And it is further proved that the large sands in the material did not cause any negative influence on the properties of the cover plates.

With the optimum content of fly ash and river sand, the final mix proportion for Eco-UHPFRC is summarized in Table 2.

Table 2: Mix proportion of Eco-UHPFRC

	Content(kg / m ³)		Content(kg / m ³)
Cement	686	Steel fibers	80
Fly ash	147	Superplasticizer	34.3
Silica fume	147	Water	122.3
River sands	1176	Water to binder ratio = 0.15	

Properties

After steam curing at 85°C for 2 days, both the mechanical properties tests and durability tests were performed on the Eco-UHPFRC specimens, and the results are shown in Table 3. All the properties achieved the required values listed in Table 1. So this proportion was employed to produce the cover plates in the precasting factory.

Table 3: Properties of Eco-UHPFRC

Mechanical properties	Compressive strength	150.3 MPa
	Flexural strength	19.6 MPa
	Young's modulus	50.6 GPa
Resistance to chloride penetration	Charge Passed	33.2 C
Resistance to Freeze-thaw attack	Mass loss of Eco-UHPFRC after 500 freeze-thaw cycle	1.8%
	Relative dynamic modulus of elasticity of Eco-UHPFRC after 500 freeze-thaw cycles	72.3%

3. PRODUCTION OF THE COVER PLATES

The workability of the material plays an important role in the manufacture process of the cover plates. Nevertheless, it is sensitive to the quality of the raw material, the temperature and the humidity, which varies all the time. So the superplasticizer content, sometimes together with the water content, has to be adjusted to meet the workability requirements.

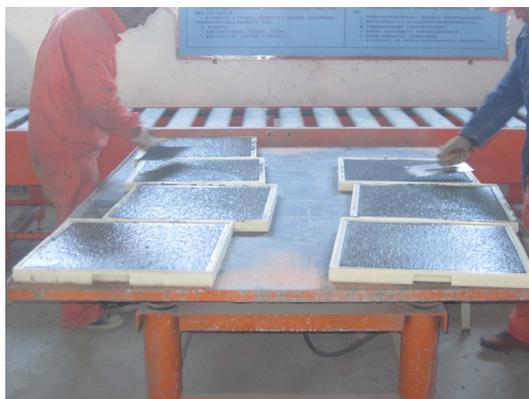
The production procedures, as shown in Figure 4, were determined in the precasting factory after several times of trial production. After mixing for 8~10 minutes, the fresh mixture could flow into the moulds through the hopper of the mixer (Figure 2(a)). And then the mixture in every mould was weighed (Figure 2(b)), ensuring that the amount of the mixture in the moulds was exactly the same and accurate. After vibration for one minute (Figure 2(c)), the moulds were removed from the vibration table and then covered with plywood (Figure 2(d)) to inhibit water evaporation from the material surface which may cause dry shrinkage. The cover plates were demoulded after one day, and then steam cured at 85°C for 2 days (Figure 2(e)). After curing, the plates can be removed out of the curing room, and placed in the stock area (Figure 2(f)).



(a) the mixture flows into the moulds



(b) Weigh the mixture



(c) Vibration



(d) Cover the moulds with plywood



(e) Curing room



(f) Stock area

Figure 4: Manufacture process of the cover plates

4. QUALITY CONTROL

In order to ensure the quality of the cover plates, several quality control measurements were taken in the precasting factory.

All the raw materials, including cement, fly ash, silica fume, steel fibers, river sands and superplasticizer, must undergo a strict entrance test within the scope of the quality control.

As to the properties of the mixture, samples were taken from every 50 m³ mixture to perform the mechanical tests. And the durability samples were taken from every 1000 m³ mixtures. All the properties have to achieve the values listed in Table 1. Otherwise, all the plates made with the same mixture will be considered to be unqualified and can't be used on the high-speed railways.

The appearance of the plates also has to be examined before leaving the factory. The upper surface of the plates should be very smooth, without any obvious defects and cracks.

The size examination of the plates is another part of quality control. In the precasting factory, two types of cover plates with different sizes were produced. The size deviations should be within an allowable range. The sizes of the plates and the allowable deviations of the size are listed in Table 4 and Table 5.

Table 4: Sizes of two types of cover plates

Type	Length/mm	Width/mm	Thickness/mm
C1	744	494	25
D1	494	494	25

Table 5: Allowable deviation of the size of the plates

	Allowable deviation (mm)
Length	+3, -2
Width	+3, -2
Thickness	+2, -0.5
Warping	Length/1000

The load-carrying capacity is the most important property of the plates, so it has to be strictly inspected as well. Bending tests with line load and concentrated load were performed on the plates. The plates for the both two types of bending tests must exhibit a load-carrying capacity higher than 5 kN/m, which is specified in “*General references for railway construction: ancillary facilities for passenger dedicated line*”. The test methods and some results were presented in paper [1].

5. A COMPARISON OF ECO-UHPFRC, PRC AND NORMAL CONCRETE COVER PLATES

A brief comparison of Eco-UHPFRC, RPC and NC cover plates is show in Table 6, from which the economic and environmental benefits of the Eco-UHPFRC cover plates can be illustrated. Cover plate Type D1 was taken as an example in Table 6. Compared to normal concrete, using Eco-UHPFRC could reduce the size, dead weight and cement consumption of the cover plate. Although the cost of the Eco-UHPFRC is higher than that of NC, the maintenance cost will be much lower for its superior mechanical properties and durability. And the labour cost and energy consumption also could be reduced for its lower dead weight and fewer replacements. Compared with RPC, the cost of Eco-UHPFRC is greatly reduced by substituting the expensive quartz powder and quartz sand with FA and river sand. The total

cost could be reduced by more than 20 %. So, compared to RPC and NC, Eco-UHPFRC has obvious advantages for the cover plates production.

The Eco-UHPFRC cover plates were employed in the construction of the Beijing-Shanghai high-speed railway in 2010 for their low cost and energy consumption, excellent performance and easy manufacture process. And good feedbacks on the performance of Eco-UHPFRC cover plates were received.

Table 6: A comparison of Eco-UHPFRC, RPC and NC cover plates

	Size /mm×mm×mm	Cost /Chinese Yuan per plate	Cement Consumption / kg per plate	Dead weight / kg per plate	Installation and maintenance
Eco-UHPFRC	494×494×25	15~20	4.2	14	Easy and low cost
RPC	494×494×25	25~30	4.2	14	Easy and low cost
RC(C40)	494×494×60	5~8	6.1	36	Difficult and high cost

6. CONCLUSIONS

A cost-effective UHPFRC material, namely Eco-UHPFRC, was developed for the pavement cover plates production. The properties of this material meet all the requirements defined by the Railways Ministry of China.

The production process of the Eco-UHPFRC cover plates was determined and it is simple and practicable, which also reduces the labour cost and energy consumption.

Compared with NC, using Eco-UHPFRC could reduce the size, dead weight, cement consumption and maintenance cost of the cover plate, and it follows the requirements of sustainability. And compared to RPC, the cost of the plates produced with Eco-UHPFRC is reduced by at least 20%, which means millions of RMB can be saved.

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