Development of Eco-friendly PC Sleeper using Slag

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Abstract

Cement is one of the main construction ingredients. On the other hand, it causes the environmental impacts. In other words, carbon dioxide (CO_2) emissions from the cement production have been recently one of the main social issues. In Korea, five types of Portland cement are defined and standardized by the KS (Korean Standards), especially high-early-strength Portland cement (Type III) is used for railway prestressed concrete (PC) sleeper in order to provide high strength and rapid hardening satisfactorily at early period.
In this study, eco-friendly PC sleeper using slag was developed in order to reduce the usage of cement and natural resources (fine aggregate) as components of the concrete. Mixing design was done for manufacturing the eco-friendly PC sleeper, in which high-early-strength Portland cement was partially replaced by ground granulated blast furnace slag (GGBFS) and electric arc furnace (EAF) oxidizing slag was used as an alternative to fine aggregate. Finally, the prototype of eco-friendly PC sleeper was released which satisfied the required performance by the Korean railway standards (KRS) and European standards (EN). Besides, and it is hoped that the eco-friendly PC sleeper can contribute the reduction of carbon dioxide (CO_2) emissions in railway concrete infrastructure.

Keywords: Ground granulated blast furnace slag, Electric arc furnace oxidizing slag, PC sleeper, CO_2 emissions

1. Introduction

The important social impacts of reducing carbon dioxide (CO_2) emissions are widely recognized. At this point, railway is recognized as one of the typical eco-friendly transportations, and various sponsored activities for the development of green vehicles have been recently doing throughout the several years. However, sponsored development activities and research on the eco-friendly infrastructure are still limited.

In this study, eco-friendly PC sleeper was developed in which the usage of the cement and natural resources was reduced, and typical industrial byproducts (steel slag) was recycled as ingredients of the concrete. A series of mix approaches was done to determine to satisfy the mix design criteria for PC sleeper for the eco-friendly PC sleeper, in which high-early-strength Portland cement was partially replaced by ground granulated blast furnace slag (GGBFS), and electric arc furnace (EAF) oxidizing slag was used as an alternative to fine aggregate. Finally, its prototype was released to evaluate the required performance by the Korean Railway Standards (KRS) [5] and European standards (EN) [1, 2, 3].

2. Experimental Program

This study focused on the railway PC sleeper for ballast track, which is manufactured by pretensioning method in Korea. Korean railway standards [5] requirements for its concrete mixing design were shown in Table 1.

Table 1. Requirements for Mixing Design of PC Sleeper

	Unit	Requirements	Remarks
G_{max}	mm	19	-
28-day Compressive Strength	MPa	50	-
Initial Compressive Strength	MPa	35	-
Air	%	3.5±1.5	-
Slump	mm	80±25	-
Amount of Cement	kg/m^3	Less than 440	Type III
W/C	%	Less than 35	-
Curing Condition	-	-	Steam Curing

2.1 Constituent Materials

2.1.1 Binders

In addition to high-early-strength Portland cement, GGBFS was used as a binder for eco-friendly PC sleeper. It has been informed that concrete made with GGBFS and Portland cement as binders shows the improvement of long-term strength and freeze-thaw resistance etc [6]. Table 2 showed chemical compositions and physical properties of binders (high-early-strength Portland cement and GGBFS) used for PC sleepers in this study.

Table 2. Chemical Compositions and Physical Properties of Binders

	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	Ig. loss (%)	Density (g/m^3)	Specific Surface Area (cm^2/g)
High-early–strength Portland Cement	19.7	5.9	3.0	62.1	3.53	3.25	1.0	3.14	4,180
GGBFS	34.1	14.8	0.98	41.9	3.7	1.8	0.7	2.88	4,365

2.1.2 Aggregates

It is fact that EAF oxidizing slag, a byproduct of steel making recovered after the oxidizing process, is an acceptable fine aggregate specified in KS F 4571 standard [4]. However, its application in the construction industry has been very limited in Korea. Table 3 showed chemical compositions of EAF oxidizing slag as a fine aggregate for eco-friendly PC sleeper, and Table 4 presents physical properties of aggregates used for PC sleepers in this study.

Table 3. Chemical Compositions of EAF oxidizing slag as Fine Aggregate

	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)
EAF oxidizing Slag	15.3	7.39	31.8	27.7	6.61

Table 4. Physical Properties of Aggregates

	Density (g/m^3)	Absorption (%)	F.M.
Natural Fine Aggregate	2.60	1.4	2.78
EAF oxidizing Slag Fine Aggregate	3.4	1.81	3.21
Coarse Aggregate	2.67	0.8	6.59

2.1.3 Admixture

The polycarbonic acid-based water reducer was used as an admixture for PC sleeper in this study. Table 5 showed properties of water reducer.

Table 5. Properties of AE Water Reducer

Main Composition	Specific Gravity	Type	Color
Polycarbonic Acid	1.052	Liquid	Dark Brown

2.2 Mix Design and Prototype Manufacture

A series of laboratory trial mix and field mix approaches was done to select appropriate mix proportions for eco-friendly PC sleeper, which satisfied the mix design criteria for PC sleeper referred as Table 1. As shown in Table 6, a specimen for eco-friendly PC sleeper has higher compressive strength than its required strength of 35MPa and 50MPa at initial and 28-day compressive strength, respectively. Its resistance to freeze-thaw also was more than the allowed limit (80%).

Based on the mix design results, it is found that each eco-friendly PC sleeper can lead to the reduction of carbon dioxide (CO_2) emissions of about 10kg when compared to the ordinary PC sleeper.

Table 6. Results of Mix Design

		Eco-friendly PC Sleeper	Ordinary PC Sleeper	Remarks
	Initial compressive strength (MPa)	44 – 51	36 -42	More than 35
	28-day compressive strength (MPa)	64 – 73	59 – 63	More than 50
Freeze-thaw Resistance (%)		92 - 94	90 – 91	More than 80

Prototypes of eco-friendly PC sleeper and ordinary one were manufactured in order to evaluate the required performance of PC sleeper by Korean Railway Standards (KRS) and European Standards (EN). Figure 1 shows the prototype of eco-friendly PC sleeper which is the same profile with the ordinary sleeper.

In case of eco-friendly PC sleeper, weight gain of about 10% was observed since it used EAF oxidizing slag as an alternative to natural fine aggregate, which implies that eco-friendly PC sleeper can contribute the track safety due to its additional weight by unit length [7].

Figure 1. Prototype of Eco-friendly PC Sleeper

3. Standards Tests

The required performance tests are in accordance with Korean Railway Standards (KRS) [5] and European Standards (EN) [1, 2, 3]. Test arrangements are shown in Figure 2.

3.1 Static Test at Rail Seat and Center Sections

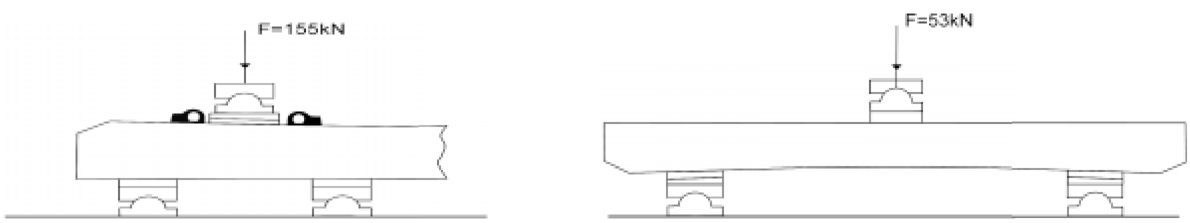
The static test at rail seat and center sections of the PC sleeper is in accordance with KRS TR 0008-09 (R) [5] and EN 13230-2 [2]. Loads at crack initiation were checked while the positive test loads (155 and 53kN, respectively) were applied to the rail seat and center sections.

3.2 Vertical Load Test for Cast-in Fastening Components

The vertical load test for cast-in fastening components of the PC sleeper is in accordance with EN 13481-2 [3]. Load at crack initiation was checked while the required test load (60kN) was applied normal to the rail seat of the sleeper.

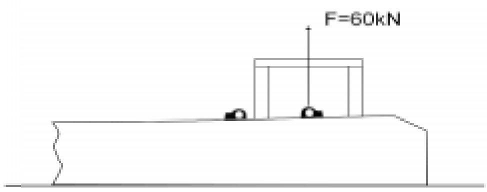
3.3 Electrical Resistance Test

The test for determining the electrical resistance in wet conditions is in accordance with EN13146-5 [1]. The required test conditions are 1) room air temperature of 15 to 30 , 2) water conductivity of 20 to 80 S/m, 3) water temperature of 10 to 20 and 4) alternating current supply of 30V and 50Hz.

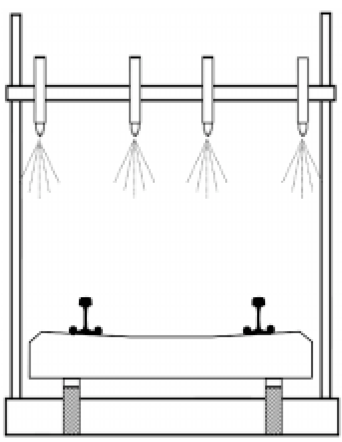


(1) Positive Load Test at Rail Seat Section (2) Negative Load Test at Center Section

(a) Static Tests at Rail Seat and Center Section



(b) Vertical Load Test for Cast-in Fastening Components



(c) Test for Electrical Resistance

Figure 2. Test Arrangements required by KRS and EN Standards

4. Test Results

As shown in Table 7, the required performance of the developed eco-friendly PC sleeper and the ordinary PC sleeper satisfied KRS and EN standards. Under test loading conditions, no crack was detected around the rail seat section, center section and fastening insert of the PC sleeper. And PC sleepers tested in this study have higher electrical resistance than its minimum limit (5k). Moreover, applied loads at crack initiation of the eco-friendly PC sleeper were higher than that of the ordinary PC sleeper.

Table 7. Test Results

	Eco-friendly PC Sleeper	Ordinary PC Sleeper
Static Test at Rail Seat and Center Section	No crack at test loads	No crack at test loads
Load at Crack Initiation (kN)	285 – 345 (at rail seat section) 105 – 120 (at center section)	240 – 320 (at rail seat section) 90 – 95 (at center section)
Vertical Load Test for Cast-in Fastening Components	No crack at test load	No crack at test load
Load at Crack Initiation (kN)	80 – 90	65 – 90
Electrical Resistance (k)	13 – 18 (More than 5k)	16 – 20 (More than 5k)

5. Conclusions

In this paper, a developed eco-friendly PC sleeper has been introduced. In mixing design, high-early-strength Portland cement was partially replaced by ground granulated blast furnace slag (GGBFS), and electric arc furnace (EAF) oxidizing slag was used as an alternative to fine aggregate. Mix proportions for the eco-friendly PC sleeper was determined to satisfy the mix design criteria for PC sleeper, its prototype was released to evaluate the required performance by the Korean Railway Standards (KRS) and European standards (EN). Consequently, the eco-friendly PC sleeper showed superior performance to the ordinary PC sleeper.

Based on the research findings, BBGFS and EAS oxidizing slag were found to be suitable alternative concrete constituent materials to cement and natural resources for railway infrastructure applications. Besides, it is hoped that the eco-friendly PC sleeper can contribute the reduction of carbon dioxide (CO_2) emissions in railway concrete infrastructure.

Acknowledgements

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