Third International Conference on Sustainable Construction Materials and Technologies http://www.claisse.info/Proceedings.htm

Field Performance and Durability of Eco-friendly Prestressed Concrete Sleeper

Taehoon Koh[1], Seonkeun Hwang[1*]

[1]*Korea Railroad Research Institute, KOREA*
[*]*360-1 Woram-Dong, Uiwang-City, Gyeonggi-Do, KOREA, 437-757,*
thkoh@krri.re.kr; skhwang@krri.re.kr

ABSTRACT

In Korea, eco-friendly PSC (Prestressed Concrete) sleeper using steel slag was developed in order to dramatically reduce the usage of cement and natural fine aggregate as main ingredients of the concrete. It was already found that eco-friendly PSC sleeper satisfied its static/dynamic performances required by the Korean standard (KRS) and European standard (EN). In this study, the field performance of eco-friendly PSC sleeper was evaluated in the operating line of conventional railway, and its durability against extreme environmental conditions was tested as well. Based on the field monitoring and laboratory/field tests, the eco-friendly PSC sleeper can be an environmental as well as mechanical alternative to traditional PSC sleeper in railway.

Keywords. PSC sleeper, CO_2 emission, Ground granulated blast furnace slag, Electric arc furnace oxidation slag

INTRODUCTION

PSC (Prestressed Concrete) sleeper is one of the main components of the railway track, so that PSC sleeper needs the high performance to directly support the heavy wheel load of the train beneath the rail. However, cement as the main ingredient of the PSC sleeper has been recently one of the main social, environmental issues because of the carbon dioxide (CO_2) emission from the cement production.

In Korea, eco-friendly PSC sleeper using steel slag was developed in order to dramatically reduce the usage of cement and natural fine aggregate as main ingredients of the concrete. Mixing design was done for manufacturing the eco-friendly PSC sleeper, in which high-early-strength Portland cement (Type III) was partially replaced by ground granulated blast furnace slag to reduce carbon dioxide emissions in railway concrete structure, and electric arc furnace oxidation slag was used as an alternative to fine aggregate for the preservation of the natural resources.

In this study, eco-friendly PSC sleeper which satisfied its required static/dynamic performances was installed in the operating line of conventional railway in order to evaluate its field performance through the long-term field monitoring and field test.

Additionally, the durability of eco-friendly PSC sleeper was tested against extreme environmental condition.

DEVELOPED OF ECO-FRIENDLY PSC SLEEPER

Materials. Eco-friendly PSC sleeper developed in Korea is for railway ballasted track, which was manufactured by pretension method. Requirements for its concrete mixing design are in accordance with Korean railway standard as shown in Table 1.

Table 1. Requirements for Mixing Design of PSC Sleeper

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

GGBF (Ground Granulated Blast Furnace) slag was used as an another binder for eco-friendly PSC sleeper in addition to high-early-strength Portland cement in order to improve long-term strength and freeze-thaw resistance etc.

EAF (Electric Arc Furnace) oxidizing slag, a byproduct of steel making recovered after the oxidizing process, is an acceptable fine aggregate specified in KS F 4571 standard, so that it was used as an alternative to the natural fine aggregate for eco-friendly PSC sleeper.

Table 2 and 3 show chemical compositions and physical properties of ingredients used for eco-friendly PSC sleeper.

Table 2. Chemical Compositions of Ingredients for Eco-friendly PSC Sleeper

Ingredients		CaO (%)	SiO_2 (%)	Al_2O_3 (%)	MgO (%)	Fe_2O_3 (%)
Binder	High-early-strength Portland cement	62.1	19.7	5.9	3.53	3.0
	GGBF Slag	41.9	34.1	14.8	3.7	0.98
Fine Aggregate	EAF Oxidizing Slag	27.7	15.3	7.39	6.61	31.8

Table 3. Physical Properties of Aggregates for Eco-friendly PSC Sleeper

Ingredients	Density (g/cm^3)	Absorption (%)	F.M.
EAF Oxidizing Slag for Fine Aggregate	3.4	1.81	3.21
Natural Coarse Aggregate	2.67	0.8	6.59

Mixing Design. Trial and field mix approaches for eco-friendly PSC sleeper were carried out in order to determine appropriate mix proportions, which satisfied requirements of mixing design of PSC sleeper as shown in Table 1. Eco-friendly PSC sleeper shows higher compressive strength than ordinary PSC sleeper as shown in Table 4.

Table 4. Compressive Strength of Eco-friendly PSC Sleeper

	Eco-friendly	Ordinary	Acceptance Criteria
Initial Compressive Strength (MPa)	51.2	36.7	35
28-day Compressive Strength (MPa)	72.8	58.5	50

Based on the mixing design in which the cement usage for each eco-friendly PSC sleeper was reduced by about 10.4kg when compared to the ordinary PSC sleeper, its carbon footprint was reduced by around 10kg since the carbon emission factor (CEF) is 0.944kgCO_2/kg for Portland cement.

Prototype Manufacture. With the same production facilities and manners with ordinary PSC sleeper, eco-friendly PSC sleepers were manufactured for field application as shown in Figure 1. Based on the previous research results (Koh, 2011; Koh, 2012), eco-friendly PSC sleeper satisfies its static/dynamic performances required by the Korean standard (KRS) and European standard (EN), and shows superior performances to the ordinary one. Figure 2 shows the development procedures for eco-friendly PSC sleeper.

Figure 1. Prototype of Eco-friendly PSC Sleeper

Figure 2. Development Procedures

FIELD APPLICATION OF ECO-FRIENDLY PSC SLEEPER

Field Applicability. Eco-friendly PSC sleeper with the same productivity as ordinary one could be applied to the site in the same way with the ordinary one. In other words, there was no additional equipment and manners necessary for the installation of eco-friendly PSC sleeper as shown in Figure 3. Eco-friendly PSC sleepers were installed at the 40m-curved section with radius 400m and 10m-straight section of existing track in the operating line of conventional railway about 3 years ago.

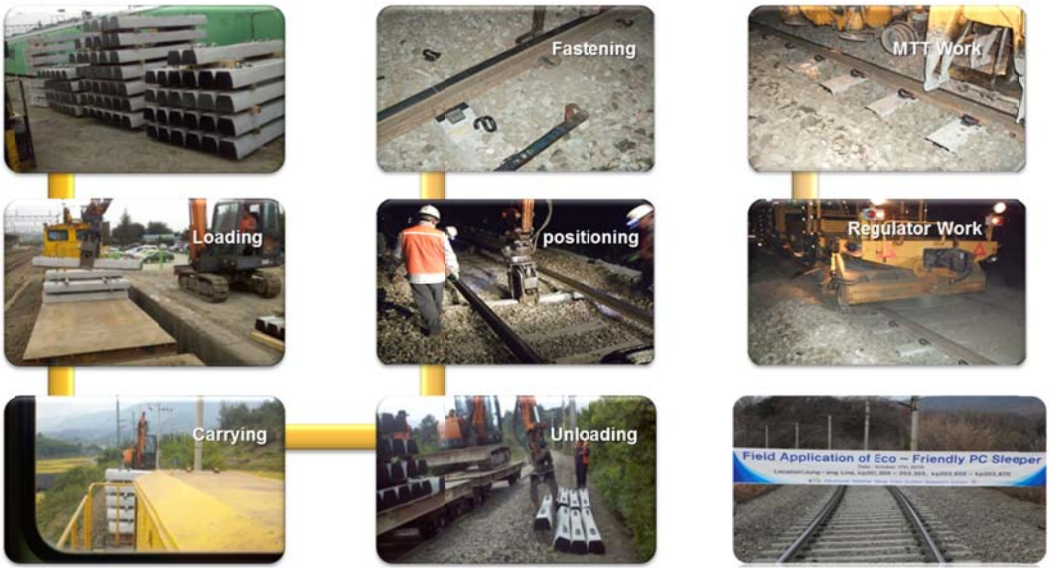


Figure 3. Field Applicability of Eco-friendly PSC Sleeper

In this study, periodical visual inspection, field monitoring, and field test were done in order to evaluate the field performance of eco-friendly PSC sleeper

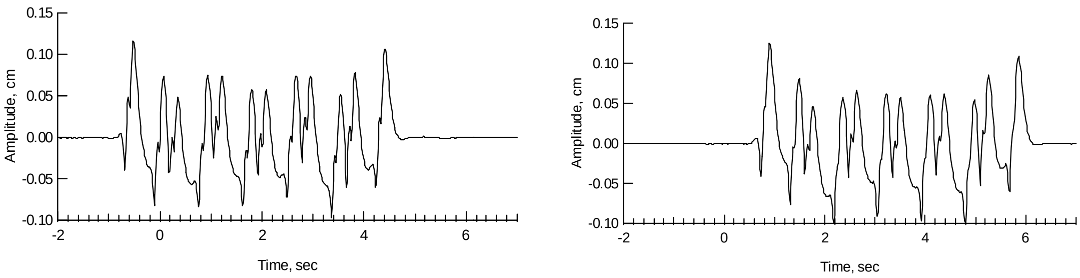
Visual Inspection. As shown in Figure 4, no crack was detected on the surface of eco-friendly PSC sleeper so far.

Figure 4. Visual Inspection

Field Monitoring. The performance of eco-friendly PSC sleeper was seasonally monitored focusing on its vertical displacement and lateral acceleration. As shown in Figure 5, geophone, seismic sensor that converts ground vibrations into voltage, was installed on the surface of the eco-friendly PSC sleeper in order to monitor its vertical displacement, and its lateral acceleration was observed using the accelerometer attached on its surface.

Figure 5. Geophone and Accelerometer

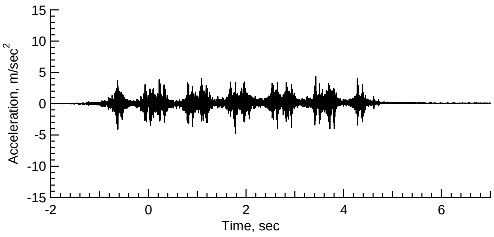
Each sleeper satisfied the acceptance criteria (maximum 2mm) for vertical displacement of railway sleeper, and eco-friendly PSC sleeper showed almost the same response with ordinary one as shown in Figure 6.



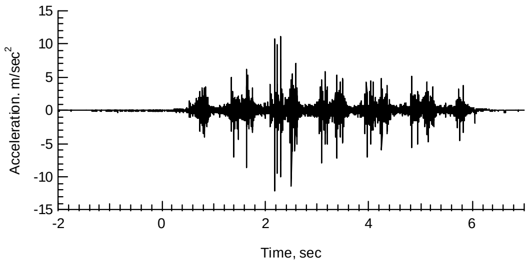
(a) Eco-friendly PSC sleeper (b) Ordinary PSC sleeper

Figure 6. Vertical Displacement from Geophone

In this study, an alternative to natural fine aggregate used for eco-friendly PSC sleeper, EAF oxidizing slag leads to the weight gain of about 10% comparing with ordinary PSC sleeper because of its heavier density than natural fine aggregate, which can contribute the track safety (Profillidis, 2000). Therefore it was shown that eco-friendly PSC sleeper reduced lateral acceleration by about 50% compared to the ordinary one in Figure 7.



(a) Eco-friendly PSC sleeper



(b) Ordinary PSC sleeper

Figure 7. Lateral Acceleration from Accelerometer

Field Test. Lateral resistance of PSC sleeper affects significantly the track safety and stability. Especially, speed-up of conventional line needs to improve the lateral resistance of PSC sleeper on the curved section.

Based on the test result, lateral resistance of eco-friendly PSC sleeper was increased by more than 15% comparing with ordinary one due to its weight gain of about 10%.

Figure 8. Lateral Resistance Test

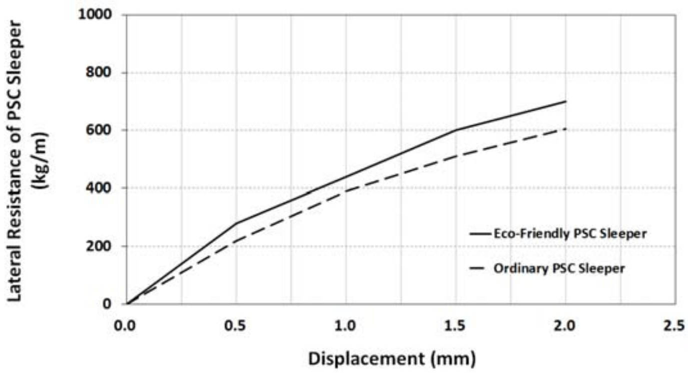


Figure 9. Lateral Resistance Test Results

DURABILITY OF ECO-FRIENDLY PSC SLEEPER

In this study, durability against extreme environmental condition was estimated as well as the mechanical tests. Based on the freeze-thawing, salt, scaling, carbon, chemical corrosion resistance tests, it is found that eco-friendly PSC sleeper shows the excellent long-term durability. Especially, eco-friendly PSC sleeper offers superior performance to ordinary one with higher resistance for freeze-thawing, salt-attack and chemical-attacks.

Table 5. Durability Test Results

Test Results		Eco-friendly	Ordinary	Acceptance Criteria
	Freeze-thawing (%)	93	91	> 80
	Salt Resistance (Diffusion Coefficient, $\times 10^{-12} m^2/s$)	6.2	6.5	< 8~12
	Scaling Resistance (Weight Decrement, kg/m^2)	0.8	0.7	< 1
	Carbonation Resistance (Thickness, mm)	2	1	< 6~12
	Chemical(Na_2SO_4) Corrosion Resistance (Strength Rate of Change, %)	-8.5	-9.4	-
	Chemical(H_2SO_4) Corrosion Resistance (Strength Rate of Change, %)	-31	-54	

CONCUSIONS

The following conclusions can be drawn from this research:

1. Steel slag is suitable alternative concrete ingredients to cement and natural resources for railway infrastructure applications.
2. Eco-friendly PSC sleeper can contribute to reduce carbon dioxide (CO_2) emissions in railway concrete infrastructure.
3. Eco-friendly PSC sleeper has mechanically, environmentally, and economically improved performances comparing to the ordinary PSC sleeper.

4. Since this technology is the fundamental material know-how, it is applicable to the railway PSC sleeper of the ballasted track, precast concrete of the slab track, and other precast concrete structures.

REFERENCES

European Committee for Standardization. (2009). *EN 13230-2 Railway Applications-Track-Concrete Sleepers and Bearers Part 2: Prestressed Monoblock Sleepers.*

European Committee for Standardization. (2002). *EN 13146-5 Railway Applications-Track-Test Methods for Fastening Systems-Part 5: Determination of Electrical Resistance.*

European Committee for Standardization. (2002). *EN 13481-2 Railway applications-Track-Performance Requirements for Fastening Systems Part 2: Fastening Systems for Concrete Sleepers. Annex A.*

Korean Committee for Railway Technology. (2009). *KRS TR 0008-09(R) Prestressed Concrete Sleeper.*

Korean Agency for Technology and Standards. (2007). *KS F 4571 Electric Arc Furnace Oxidizing Slag Fine Aggregate for Concrete.*

Koh, T. H., Han, S. H., and Sagong, M. (2011). "Development of Eco-friendly PC Sleeper using Slag." 9th World Congress on Railway Research, France.

Koh, T. H., Bae, Y. H., Hwang, S.K., and Sagong, M. (2012). "Dynamic Performance of Eco-friendly Prestressed Concrete Sleeper." Recent Advances in Concrete Technology and Sustainability Issues, SP-289, American Concrete Institute 35-42.

Profillidis, V. A. (2000). "Railway Engineering 2ndedition." Ashgate, 125-127.