Article

Physical and Mechanical Properties of Rural-Road Pavement Concrete in South Korea Containing Air-Cooled Blast-Furnace Slag Aggregates

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Abstract: The purpose of this study was to assess the physical and mechanical properties of pavement concrete for rural roads of South Korea made with air-cooled slag aggregate, which is an industrial byproduct. This study assessed the physical and chemical properties according to the following performance requirements based on the design criteria of the Korea Ministry of Agriculture's Agricultural Production Infrastructure Maintenance Business Plan and the Korea Expressway Corporation's Highway Construction Specialized Specifications: slump of 80 mm or greater, air content of $4.5 \pm 1.5\%$, compressive strength of at least 21 MPa, splitting tensile strength of at least 4.2 MPa, and a chloride penetration resistance of less than 4000 C. The slump, air content, compressive strength, splitting tensile strength, flexural strength, and chloride ion permeability of the aggregate-containing concretes were measured. The air-cooled slag aggregates provided the necessary physical and chemical properties and presented no environmental issues. Furthermore, the slump and air content of concrete made with the aggregates met the target values. The slump decreased and the air content increased with increasing amounts of air-cooled slag aggregate. Mechanical testing of the concretes containing air-cooled slag aggregate established that they met the performance requirements for rural road pavement.

Keywords: air-cooled slag aggregate; concrete aggregates; mechanical properties; physical properties; rural-road concrete pavement; steel manufacturing byproduct

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1. Introduction

High-quality natural aggregate for concrete widely used in the construction industry is in short supply, and the use of natural aggregate has been restricted to preserve the environment. Therefore, alternative sources of concrete aggregate that can be supplied sustainably are needed [1,2]. Alternative aggregates include waste-concrete aggregate obtained by crushing waste concrete, and blast-furnace slag aggregate derived from blast-furnace slag generated in the steelmaking process [1–4]. The latter forms as the high-temperature discharge cools, and it is considered environmentally harmless [3–5]. Notably, blast-furnace slags are valuable as alternative concrete aggregates because they have specific gravities that are similar to those of natural aggregates [1,3]. The use of blast-furnace slags aggregates in concrete has been studied since the 1980s [6–10]. Recent studies have focused on using waste slags (granulated water-quenched blast-furnace slags) as admixtures for cement and concrete [11–14]. Research on use of air-cooled slag aggregates in concrete is not extensive, and most commercial applications have used recycled aggregates [1,15–20]). These new high-value-added aggregates for concrete offer the potential of lower loadings, and supplement the commonly used low-value-added slag aggregates. [5–7]. Replacing natural aggregates with air-cooled slag aggregates would consume large quantities of industrial byproducts and help the environment [1,15–20].

However, to use air-cooled slag aggregates in concrete, certain physical and environmental properties must be present to satisfy the quality and performance requirements of the concrete [1]. Environmental factors, such as soil and groundwater contamination, must also be considered because these industrial byproducts come into contact with groundwater through exposure to rain. Therefore, we report herein the quality and environmental properties of air-cooled slag aggregates in a rural-road paving application [1]. The physical and mechanical properties were analyzed with a view toward improving the manufacturing process, and by extension, the end-use performance.

2. Materials, Mix Proportions, and Test Methods

2.1. Materials

In this study, we used American Society for Testing and Materials (ASTM) Type 1 cement from Ssangyong Cement Industrial Co., Ltd. (Seoul, Korea). The physical properties and chemical composition of the cement are listed in Table 1. The fly ash used in this study was collected and refined by an electrostatic precipitator from the bituminous coal-fired Dangjin Thermal Power Plant (Dangjin, Korea). Its physical and chemical properties are listed in Table 2. The physical properties and chemical composition of the blast-furnace slag powder used in this study are listed in Table 3. Sea sand (Dangjin, Korea) with a density of 2.62 g/mm³ was used as the fine aggregate. A cone crusher (Kyoungsung Development Co., Ltd. Dangjin, Korea) was used to produce the air-cooled slag aggregates (Figure 1). The properties of the crushed fine (“GS”) and coarse (“GG”) aggregates are listed in Tables 4 and 5, respectively. The fine aggregate passed through the 8 mm sieve and was classified as the aggregate remaining in the 0.08 mm sieve, and that of the coarse aggregate was classified as aggregate that passed over 90% of the 25 mm sieve and remained in the 8 mm sieve. A polycarboxylic acid-based high-performance water-reducing agent (Dongnam Co., Ltd., Pyeongtaek, Korea) was used; its characteristics are listed in Table 6.

Table 1. Properties of the cement.

Type of Cement	Fineness (cm ² /g)	Specific Gravity	Stability (%)	Setting Time		Compressive Strength (MPa)		
				Initial (min)	Final (min)	3 Days	7 Days	28 Days
Type 1 Portland	3200	3.15	0.02	220	400	20.3	30.2	38.7

Table 2. Physical and chemical properties of the fly ash.

Density (g/mm ³)		Fineness (cm ² /g)		Absorption		L.O.I. * (%)	
2.14		3400		0.13		3.28	
Chemical compositions (%)							
SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	TiO ₂
58.12	23.56	7.69	2.59	1.12	0.31	1.42	1.05

* L.O.I.: Loss on ignition.

Table 3. Physical and chemical properties of the blast-furnace slag powder.

Density (g/mm ³)			Fineness (cm ² /g)			L.O.I. (%)	
2.8			4000~6000			3.0	
Chemical composition (%)							
SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	MnO	TiO	S
33.1	13.9	0.29	42.4	6.1	0.4	0.96	0.66

Figure 1. Manufacturing process of air-cooled aggregate for rural-road concrete pavements.

Table 4. Quality test result of the crushed fine aggregate.

Quality Items	Results
Fineness modulus	2.72
Density (g/mm^3)	2.58
Water-absorption ratio (%)	1.58
0.08 mm pass efficiency	6.9

Table 5. Physical properties of the coarse aggregate.

Type of Aggregate	Density (g/mm^3)			Absorption (%)	F.M.
	Bulk	Bulk (SSD)	Apparent		
Crushed coarse aggregate	2.80	2.65	2.83	0.35	6.92

Table 6. Properties of the polycarboxylic acid-based, high-performance water-reducing agent.

Type	Color	Solids (%)	Density (g/mm^3)	pH
Liquid	Light brown	≥ 40	1.10~1.20	4.0~7.5

2.2. Mix Proportions

The mixing ratio in this study was defined by the ratio of the air-cooled slag coarse and fine aggregates. The target design of concrete using air-cooled slag was based on the design criteria of the Korea Ministry of Agriculture's Agricultural Production Infrastructure Maintenance Business Plan [21] and the Korea Expressway Corporation's Highway Construction Specialized Specifications [22] (Table 7). The results of experiments carried out with different substitution ratios were compared with those for concrete made using only natural aggregate. Tables 8 and 9 list the mixing variables and mixing ratios used, respectively, and the coding used to identify the various samples. The concrete was mixed as follows: aggregates and cement were injected into a fan-type forced mixer and dry-mixed for 1.5 min, after which water and the polycarboxylic acid water-reducing agent were added to the mixer; mixing was continued for 2 min.

Table 7. Target performance of the rural-road pavement using air-cooled slag aggregate [1,21,22].

Properties	Unit	Target Performance
Slump	Mm	≥80 mm
Air contents	%	4.5 ± 1.5
Compressive strength	MPa	≥21
Splitting tensile strength	MPa	≥4.2
Flexural strength	MPa	≥4.5
Repeated freezing and thawing cycles (relative mechanical modulus)	%	≥80%
Chloride ion penetration	Coulombs	<4000

Table 8. Rural-road pavement concrete mixing test plan.

Item	Replacement Ratio of Air-Cooled Slag Aggregate	
	Coarse Aggregate	Fine Aggregate
Plain	0%	0%
GS 50%	0%	50%
GG 50%	50%	0%
GG 100%	100%	0%
GS 50%/GG 100%	100%	50%

Table 9. Mix proportion of the rural-road pavement concrete.

Type of Mix	W/B (%)	S/a (%)	Unit Weight (kg/m ³)									
			W	C	BFS	FA	CS	SS	GS	G	GG	AD
Plain	55.5	49.6	161	173	73	44	458	452	-	926	-	2.03
GS 50%			161	173	73	44	229	226	455	926	-	2.03
GG 50%			161	173	73	44	458	452	-	463	463	2.03
GG 100%			161	173	73	44	458	452	-	-	926	2.03
GS 50%/GG 100%			161	173	73	44	229	226	455	-	926	2.03

2.3. Test Methods

2.3.1. Physical Properties of the Air-Cooled Slag Aggregates

The physical and chemical properties of the air-cooled slag aggregates were assessed for chemical composition, density, absorption rate, unit volume weight, and particle size according to the KS F 2527 standard [23].

2.3.2. Environmental-Hazard Testing of the Air-Cooled Slag Aggregates

The environmental hazards were assessed according to the Waste Management Act of the Ministry of Environment of the Republic of Korea [24] and the Japanese standard JIS K 0058 [25].

2.3.3. Slump Value and Air Content

The slump test was conducted according to the ASTM C143 “Standard Test Method for Slump of Hydraulic-Cement Concrete” [26]. The air content was determined according to the ASTM C231/C231M “Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method” [27].

2.3.4. Compressive Strength

Compressive strength was measured according to the ASTM C39/C39M “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens” [28]. A test specimen with a diameter of 100 mm and height of 200 mm was made and cured at

23 ± 2 °C and 58% relative humidity for 24 h. The form was removed 1 day later, and the specimen was then water-cured at 23 ± 2 °C for 28 days.

2.3.5. Flexural Strength

The flexural strength was measured according to the ASTM C78/C78M “Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)” [29]. A 100 × 100 × 400 mm³ test specimen of the square-post type was made and cured at 23 ± 2 °C and 58% relative humidity for 24 h. The form was then removed, and the specimen was water-cured at 23 ± 2 °C.

2.3.6. Splitting Tensile Strength

The splitting tensile strength was measured according to the ASTM C496/C496M “Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens” [30]. A test specimen with a diameter of 100 mm and height of 200 mm was made and cured at 23 ± 2 °C and 58% relative humidity for 24 h. The form was then removed, and the specimen was water-cured for 28 days at 23 ± 2 °C.

2.3.7. Chloride Ion Penetration

The chlorine ion penetration resistance test was performed as follows. A test specimen with a diameter of 100 mm and height of 200 mm was made and cured at 23 ± 2 °C and 58% relative humidity for 24 h; then, the form was removed, and the specimen was water-cured at 23 ± 2 °C for 28 days. After curing, the specimens were cut to a height of 50 mm. The cut specimens were placed in a vacuum desiccator and maintained under vacuum for 3 h. The desiccator was then opened, the specimens were immersed in distilled water, and the vacuum was reapplied for another hour. The specimens were then removed from the desiccator. Each specimen was mounted onto the test cell filled with 3.0% NaCl solution on one side and 0.3% NaOH solution on the other side. Testing was done according to the ASTM C1202 “Standard Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration” [31].

3. Results

3.1. Physical Properties of the Air-Cooled Slag Aggregates

The physical and chemical test results of the air-cooled slag aggregates established that they satisfied the quality metrics of blast-furnace slag aggregate required by the KS standards. The chemical composition was 40.81% CaO, 0.78% S, 0.39% SO₃, and 1.19% FeO, which all met the requirements of the KS standards of less than 45%, 2.0%, 0.5%, and 3.0%, respectively. Furthermore, the air-cooled slag fine aggregates had a density of 2.77 g/cm³, an absorption rate of 1.57%, and a unit volume mass of 1.70 kg/L, which all satisfied the requirements of over 2.5 g/cm³, less than 3.5%, and over 1.45 kg/L, respectively. Tables 10 and 11 list the physical properties of the fine and coarse air-cooled slag aggregates.

Table 10. Properties of the air-cooled slag fine aggregate.

Item	Component (%)				Fine Aggregate		
	CaO	S	SO ₃	FeO	Absolute Dry Density	Water Absorption Ratio	Unit Volume Weight
Value	40.81	0.00	0.39	1.19	2.77	1.57	1.70

Table 11. Properties of the air-cooled slag coarse aggregate.

Item	Component (%)				Coarse Aggregate		
	CaO	S	SO ₃	FeO	Absolute Dry Density	Water Absorption Ratio	Unit Volume Weight
Value	40.81	0.00	0.39	1.19	2.49	4.28	1.41

3.2. Environmental-Hazard Testing of the Air-Cooled Slag Aggregates

The air-cooled slag aggregates and concrete made with them satisfied all of the criteria of the Korean waste elution test (Table 12). The concentrations of seven elements in the eluate, including Pb and Cu, were below the maximum allowable levels. The air-cooled slag aggregates yielded undetectable amounts of Pb, As, Hg, Cd, and Cr⁺⁶. Copper and CN concentrations were 0.0012 and 0.0025 mg/L, respectively, which easily satisfied the maximum allowable limits of 3 and 1 mg/L, respectively. Concrete containing the air-cooled slags yielded undetectable levels of As, Hg, Cd, and Cr⁺⁶, and only 0.020, 0.004, and 0.003 mg/L of Pb, Cu, and CN, respectively, which satisfied the maximum allowable limits of 3, 3, and 1 mg/L. The measurable level of Pb extracted from the concrete containing the air-cooled slags was attributed to Pb contained in the other materials used in preparing the cement; i.e., the water and admixture. Conventional concrete made with natural aggregates yielded undetectable levels of all species except Cu and CN, which were detected at 0.0014 and 0.003 mg/L, respectively. Nevertheless, these levels easily satisfied the maximum allowable amounts. The elution volumes were slightly greater for concrete made with the air-cooled slag aggregates, but were well within the regulatory limits for all of the analyzed species. This testing established that both the air-cooled slag aggregates and concrete made with them met the environmental hazards requirements. Hence, air-cooled slag aggregates are suitable for use as concrete aggregate from the perspective of resource recycling. The results of testing according to the Japanese JIS K 0058 standard [25] are given in Table 13. The air-cooled slag aggregates gave the following results for Cd, As, Se, F, and B: 0.0923, 0.3, 3.633, 107.17, and 68.61 mg/kg, respectively, and which satisfied the respective maximum allowable limits value of all the test items. Pb, Cr⁺⁶ and Hg were not detected. The air-cooled slag aggregates yielded elution volumes of 1.287, 1.330, not detected, 0.333, 0.133, 1.203, 143.937, and 35.69 mg/kg for Cd, Pb, Cr⁺⁶, As, Hg, Se, F, and B, respectively. Although Pb and Hg were detected, their elution volumes were within the normal range, and their detectable amounts were attributed to the cement admixture. The elution volumes of heavy metals from conventional concrete made with natural aggregates were 1.65, 10.033, not detected, 1.227, 0.013, 3.967, 189.647, and 36.53 mg/kg for Cd, Pb, Cr⁺⁶, As, Hg, Se, F, and B, respectively. The elution volume of the concrete made with air-cooled slag aggregates was less than that of the concrete made with the natural aggregate.

Table 12. Hazardous-substance content analysis results according to JIS K 0058 (unit: mg/kg).

Item	Cd	Pb	Cr ⁺⁶	As	Hg	Se	F	B
Elution standard	150	150	250	150	15	150	4000	4000
Value	0.9233	ND	ND	0.3	ND	3.633	107.17	68.61

Table 13. Results of heavy-metal leaching test according to the waste-management law (unit: mg/L).

Item	Pb	Cu	As	Hg	Cd	Cr ⁺⁶	CN
Elution standard	3	3	1.5	0.005	0.3	1.5	1
Value	ND	0.0012	ND	ND	ND	ND	0.0025

3.3. Slump Values and Air Contents

The slump test results for the rural-road pavement concrete made with the air-cooled slag aggregates are shown in Figure 2. The slump value decreased with increasing air-cooled slag aggregate content, from 97.25 for the Plain to 94.25, 90.25, 87.00, and 85.25 mm for the GS 50%, GG 50%, GG 100%, and GS 50%/GG 100% mixes, respectively. The reduction in slump value was due to greater water absorption by the air-cooled slag aggregates because of their greater surface porosity. Not surprisingly, mixes containing the coarse air-cooled slag aggregate returned higher slump values than the corresponding mixes made with the fine aggregate. The air-content ratio was used to evaluate the effect of substitution ratio of the air-cooled slag aggregates on slump. The Plain, GS 50%, GG 50%,

GG 100%, and GS 50%/GG 100% mixes had slump values of 1.00, 0.97, 0.93, 0.89, and 0.88, respectively. It was evident that the slump value decreased with an increasing substitution ratio of the air-cooled slag aggregates. The GS 50%/GG 100% mix gave the greatest reduction (12%) compared with the Plain mix. The slump value affects workability, and an appropriate amount of slump is necessary in the field. Our target minimum slump value of 80 mm was satisfied by all of the mixes, and so we do not expect any workability issues with use of these mixes in field applications of rural-road pavement concrete containing air-cooled slag aggregates. Figure 3 shows the air-content test results for the rural-road pavement concrete. The air content increased with increasing air-cooled slag aggregate fraction, as follows: from 4.66 for the Plain to 4.86, 5.03, 5.27, and 5.39% for the GS 50%, GG 50%, GG 100%, and GS 50%/GG 100% mixes, respectively (Figure 3a). This trend was attributed to the greater surface porosity of the air-cooled slag aggregates. Additionally, the values for mixes containing the coarse air-cooled slag aggregate were much higher than those of the corresponding mixes made with the fine aggregate. This result was attributed to the coarse aggregate having a greater surface porosity than the fine aggregate. The air content for all of the test mixes satisfied this requirement. The air-content ratio was defined as the ratio of the air content of the mix containing an air-cooled slag aggregate to that of the Plain mix containing conventional aggregate. The Plain, GS 50%, GG 50%, GG 100%, and GS 50%/GG 100% samples had air content ratios of 1.00, 1.04, 1.08, 1.13, and 1.16, respectively (Figure 3b). The presence of air-cooled slag aggregates increased the air content relative to the Plain mix.

3.4. Compressive Strength

Figure 4 shows the results of the compressive-strength test for the rural-road pavement concrete containing the air-cooled slag aggregates. The compressive strengths were 27.16, 26.48, 26.36, 25.60, and 25.43 MPa for the Plain, GS 50%, GG 50%, GG 100%, and GS 50%/GG 100% mixes, respectively, showing a decreasing value with an increasing substitution ratio of the coarse or fine air-cooled slag aggregates. This behavior was attributed to the higher surface porosity of the air-cooled slag aggregates compared with the conventional aggregate. All of the mixes met the design criterion of 21 MPa. The compressive strength ratios of the Plain, GS 50%, GG 50%, GG 100%, and GS 50%/GG 100% samples were 1.00, 0.97, 0.97, 0.94, and 0.94, respectively. It was evident that incorporating the air-cooled slag aggregates decreased the compressive strength relative to the Plain mix. As noted above, the GS 50%/GG 100% combination had an air content that was 6% lower than that of the Plain mix. It was established that a 1% increase in air content led to a 4–6% lower compressive strength [32]. Therefore, the trend in compressive strength was not surprising. However, the absolute reduction in compressive strength was not as large as expected; i.e., 10% or less, which was attributed to the presence of fly ash and blast-furnace slag powder that filled some pores [33]. The compressive strengths of all of the mixes exceeded the design value, so we do not expect any issues regarding this property in the field.

(a) Slump values.

(b) Slump value ratios.

Figure 2. Slump test results.

(a) Air-content values.

(b) Air-content ratios.

Figure 3. Air-content test results.

(a) Compressive strengths.

(b) Compressive-strength ratios.

Figure 4. Test results for compressive strength.

3.5. Flexural Strength

Figure 5 shows the results of flexural-strength testing for the rural-road pavement concrete mixes containing the air-cooled slag aggregates. This property decreased with increasing amounts of air-cooled slag aggregate, following the same trend as that for the compressive strength. The measured compressive strengths for the Plain, GS 50%, GG 50%, GG 100%, and GS 50%/GG 100% mixes were 5.69, 5.28, 4.98, 4.88, and 4.80 MPa, respectively.

(a) Flexural strengths.

(b) Flexural-strength ratios.

Figure 5. Test results for flexural strength.

The flexural strength ratios of the Plain, GS 50%, GG 50%, GG 100%, and GS 50%/GG 100% mixes were 1.00, 0.93, 0.88, 0.86, and 0.84, respectively. The value for the GS 50%/GG 100% combination was 16% lower than that of the Plain mix, which was attributed to the higher porosity of the experimental mixes. We adopted a flexural-strength design target of 4.5 MPa, which is the quality standard of the Korea Expressway Corporation's Highway Specialized Specifications [22]. All of our mixes met the design target. The fly ash and blast-furnace slag powder present in the mixes effectively filled the pores generated by the addition of the air-cooled slag aggregates [34]. The flexural strengths of all of the mixes exceeded the design value, so we do not expect any issues regarding this property in the field.

3.6. Splitting Tensile Strength

Figure 6 shows the results of the splitting tensile strength test for the various mixes. This property decreased with increasing air-cooled slag aggregate content. The values for the Plain, GS 50%, GG 50%, GG 100%, and GS 50%/GG 100% samples were 4.53, 4.48, 4.37,

4.32, and 4.27 MPa, respectively. The splitting tensile strength ratios of the Plain, GS 50%, GG 50%, GG 100%, and GS 50%/GG 100% samples were 1.00, 0.99, 0.96, 0.95, and 0.94, respectively. Incorporating air-cooled slag aggregates clearly decreased the splitting tensile strength relative to the Plain mix. As noted above, the GS 50%/GG 100% combination had an air content that was 6% lower than that of the Plain mix. Although the large pores introduced by the air-cooled slag aggregates decreased the tensile strength, the reduction was less than 10%. This was because the fly ash and blast-furnace slag powder present in the mix filled the pores of the concrete generated by the introduction of the air-cooled slag aggregates [33,34]. We adopted a design target value of 4.2 MPa for the splitting tensile strength, which is the Korea Expressway Corporation's quality standard for highway pavement concrete. The splitting tensile strength of all of our mixes satisfied this standard. Therefore, we do not anticipate any issues in the field from the perspective of splitting tensile strength.

(a) Splitting tensile strengths.

(b) Splitting tensile strength ratios.

Figure 6. Test results for splitting tensile strength.

3.7. Chloride Ion Penetration

Figure 7 shows the results of chloride ion permeability testing. The targeted permeability of 4000 C or less was satisfied by all of the mixes. The values for the Plain, GS 50%, GG 50%, GG 100%, and GS 50%/GG 100% mixes were 3483, 3458, 3351, 3421, and 3232 C, respectively. The permeability increased with an increasing amount of air-cooled slag aggregate.

(a) Chloride ion penetration values.

(b) Chloride ion penetration ratios.

Figure 7. Test results for chloride ion penetration.

The chlorine ion permeability ratios for the Plain, GS 50%, GG 50%, GG 100%, and GS 50%/GG 100% samples were 1.00, 0.99, 0.96, 0.98, and 0.92, respectively. Relative to the Plain mix, mixes that contained air-cooled slag aggregates had lower chloride ion permeabilities. The fly ash and blast-furnace slag powder in all of the mixes filled the

micropores present in the air-cooled slag aggregates and concrete. The GS 50%/GG 100% composition had an air content that was 8% lower than that of the Plain mix, which was consistent with such pore filling. The chlorine ion permeabilities of the experimental samples all met the 4000 C maximum design criterion. Therefore, we do not anticipate any issues in the field concerning chloride ion permeability.

4. Conclusions

This study was conducted to establish the utility of air-cooled slag aggregate, which is an underutilized byproduct of the steel industry, as an aggregate for concrete. The air-cooled slag manufacturing process was analyzed and adjusted to produce aggregates with appropriate physical properties. Rural-road pavement concrete containing these aggregates was then prepared and tested according to the design criteria of the Korea Ministry of Agriculture's Agricultural Production Infrastructure Maintenance Business Plan and the Korea Expressway Corporation's Highway Construction Specialized Specifications.

1. As a result of evaluating the physical properties of the air-cooled slag aggregate produced as a concrete aggregate, the quality standards (KS F 2527) of the blast-furnace slag aggregate for concrete were satisfied.
2. As a result of conducting a dissolution test in accordance with the Waste Management Act of the Ministry of Environment of the Republic of Korea and the Japanese standard JIS K 0058 to evaluate the environmental properties of the air-cooled slag aggregate, it was found that there was no effect on the dissolution of hazardous substances, as all the standards were satisfied.
3. The slump and air-content values of the experimental mixtures met the targeted performance criteria. However, the slump decreased, and the air content increased, with increasing amount of air-cooled slag aggregate. This result was because the air-cooled slag aggregate had pores on the surface compared to the natural aggregate, which increased the absorption of mixed water and the contents of air.
4. The compressive, flexural, and splitting tensile strengths of the experimental mixtures met the targeted performance criteria based on the design criteria of the Korea Ministry of Agriculture's Agricultural Production Infrastructure Maintenance Business Plan and the Korea Expressway Corporation's Highway Construction Specialized Specifications. However, as the content of the air-cooled slag aggregate increased, the strength decreased, and the coarse air-cooled slag aggregate had a greater effect on the strength reduction than the fine air-cooled slag aggregate.
5. The chloride ion penetration of the experimental mixtures met the targeted performance criterion of the design criteria of the Korea Ministry of Agriculture's Agricultural Production Infrastructure Maintenance Business Plan and the Korea Expressway Corporation's Highway Construction Specialized Specifications. In addition, the amount of chlorine ion penetration increased as the content of the air-cooled slag aggregate increased.

This study did not take into account the effects of different subsurfaces and subgrade conditions in rural areas. We assumed that the different subsurface and subgrade conditions do not affect the concrete pavement, and the performance was evaluated when air-cooled slag aggregate was used as the concrete pavement material.

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