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Effect of different amount of LSP on Blast Furnace Slag Cement for Strength, Durability and Environmental Performance

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ABSTRACT

In the cement industry, reduction of CO_2 emissions is an important issue. One effective approach is to reduce the clinker ratio by using alternative materials. In Japan, the use of ground granulated blast furnace slag (GGBS) and limestone powder (LSP) is widely used because they are easy to obtain in Japan. On the other hand, it is also important to maintain the clinker ratio. This is because clinker uses a large amount of industrial waste as raw materials and fuel when it is produced. The objective of this study is to develop cement that both reduces CO_2 emissions and maintains waste usage. The strength and durability of cements composed by ordinary Portland cement (OPC), GGBS and LSP were examined. We conducted compressive strength tests, accelerated carbonation tests, and saltwater immersion tests. Also, CO_2 emissions and waste usage were calculated for each cement by using the inventory data in Japan. As a result, LSP addition enhanced initial strength. Also, correlation between strength and carbonation rate was confirmed. Further, the resistance to penetrating chloride ion was improved by the addition of GGBS. In the relationship between CO_2 emissions and waste usage, different results were observed depending on the OPC ratio.

INTRODUCTION

Recently, various actions are being taken in various fields to solve the problem of global warming. In the construction industry, the process of producing clinker emits a large amount of CO_2. Clinker is the main constituent of cement. Therefore, the cement industry is promoting the use of blended cement to reduce the clinker ratio. Raising the addition of the minor additional materials is also considered. In Japan, Blast-furnace cement containing ground granulated blast furnace slag (GGBS) is widely used for civil engineering structures. GGBS is a by-product of iron production. Japan manufactures the third largest amount of steel in the world. So, there is a large amount of GGBS in Japan and much of it used in blast furnace cement. At present, blast-furnace cement blended with about 45% GGBS is widely used. This type of blast-furnace cement is called BB. In recent years, research has been conducted on cements with increased GGBS additions of around 70%. This cement is also called BC. BB guarantee higher early-age strength and is easier to use than BC. However, BC can reduce the amount of cement to a greater extent, so it can reduce CO_2 emissions further. There are also plenty of limestone in Japan. Limestone powder (LSP) is commonly blended in Portland cement as a minor additional material. LSP is expected to be used further as an important material that can be self-sufficient in Japan. The current Japanese Industrial Standard (JIS) defines the addition rate of LSP to be up to 5% as a minor additional material. Recently, cements with increased LSP addition rate have been studied. Then, JIS is about to be revised to allow minor additional materials to be blended up to 10%. While much research has been done to reduce clinker ratio, maintaining clinker ratio is also an important approach. Because various industrial wastes are used as raw materials and fuel for clinker production. For example, scrap tires, which are mostly composed of combustible rubber, are used as thermal energy by being incinerated. In this way, the cement industry contributes to a recycling-oriented society. The goal of this research is to develop a three-component cement that considered environmental performance. In this study, strength and durability of cement made by adding GGBS and LSP to OPC were examined. Also, CO_2 emissions and waste usage were calculated for each cement mixing proportion by using the inventory data.

MATERIALS AND METHODS

Materials used and mix proportion of mortar.

In this study, ordinary Portland cement (OPC, Blaine 3620 cm^2/g), ground granulated blast furnace slag (GGBS, Blaine 4510 cm^2/g) and limestone powder (LSP, Blaine 6620 cm^2/g) were used as binder. Also, the fine aggregate without calcium carbonate ($CaCO_3$) were used.

The mix proportion of mortar is shown in Table 1. There were three categories of binders. The first one is only OPC. Other categories are BB with 45% GGBS blended and BC with 70% GGBS blended. These were used as the base mixture. And the addition rate of LSP was changed. In BB, the ratio of LSP was varied from 7, 10, and 20%. And LSP replaced with GGBS or OPC. In BC, LSP maintained at 10% and replaced with GGBS, OPC or BC. Replacement of BC means LSP was maintained at 10% and the ratio of OPC to GGBS was 3:7. OPC is composed of 93% clinker and 7% LSP. This 7% LSP is blended as the minor additional material. The amount of LSP added to the entire binder was added to take the 7% LSP into account. The ratio of water to binder (W/B) was set at 40, 50, and 60%. The ratio of fine aggregate to binder (S/B) was determined 2.6.

Table 1. Mix proportion of mortar

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		Sample name (GGBS_LSP)	Mix proportion of mortar (weight %)				
			Binder composition ratio			W/B	S/B
			Clinker	GGBS	LSP		
OPC		B0_L7	93	-	7	40 / 50 / 60	2.6
BB	BB(Base)	B45_L4	51.1	45	3.9		
	Replacement of GGBS	B42_L7	51.1	41.9	7		
		B39_L10		38.9	10		
		B29_L20		28.9	20		
	Replacement of OPC	B45_L7	48	45	7		
		B45_L10	45		10		
		B45_L20	35		20		
BC	BC(Base)	B70_L2	27.9	70	2.1		
	Replacement of GGBS	B62_L10	27.9	62.1	10		
	Replacement of BC	B64_L10	25.6	64.4	10		
	Replacement of OPC	B70_L10	20	70	10		

VERIFICATION OF STRENGTH AND DURABILITY

Specimens and experiment details.

Specimens were cast in the 40 x 40 x 160 mm square mold. The specimens were demoulded and sealed curing was applied the day after casting. Then, they're placed at a temperature of 20°C.

(i) Compressive strength tests

The tests were conducted at 7, 28, and 56 days of curing period in accordance with JIS R 5201.

(ii) Accelerated carbonation tests

The tests were implemented with reference to JIS A 1153. After 7 days of sealed curing, the specimens were installed in carbonation acceleration test equipment at 5% CO_2 concentration. Split the specimen on the measurement date and sprayed with phenolphthalein solution. Then, we measured the distance from the edge to the colored area.

(iii) Saltwater immersion tests

The tests were implemented with reference to JSCE-G572. After 7 days of sealed curing, the specimens were installed in immersed in salt water at 5% NaCl concentration. Split the

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specimen on the measurement date and sprayed with silver nitrate solution. Then, we measured the distance from the edge to the colored area.

Experimental results.

(1) Compressive strength

As a representative example, the compressive strength at W/B=50% is shown in Figure.1. In BB, early-age strength maintained or increased compared to BB(Base) for binders with LSP replaced by GGBS and B45_L7. In BC, regardless of the type of LSP replacement, compressive strength was almost the same as BC(Base). These are considered results of the addition of LSP.

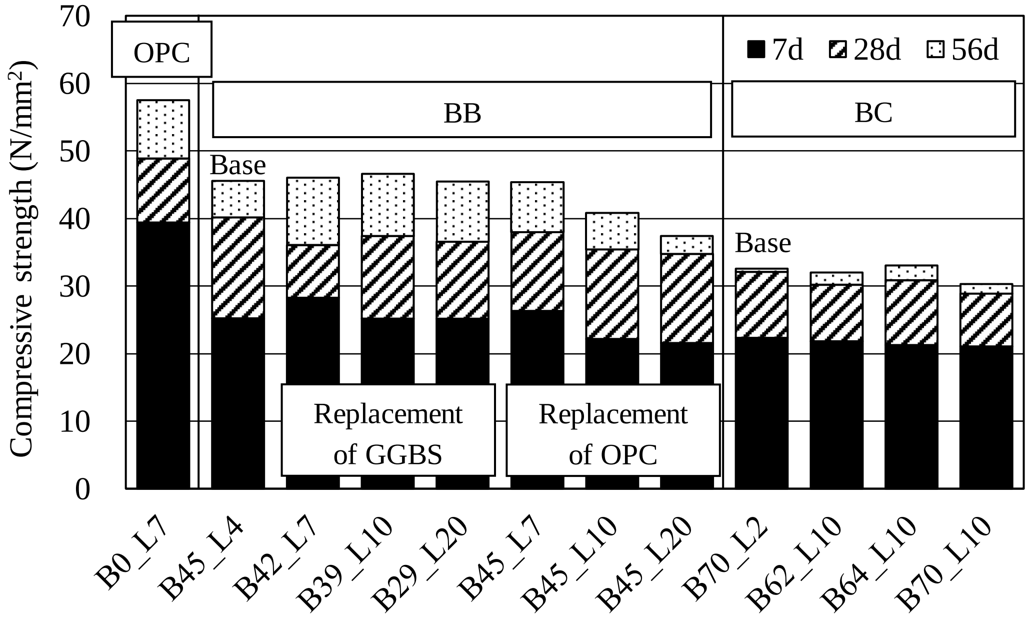

Figure 1. Compressive strength (W/B=50%)

(2) Carbonation rate

The carbonation rate at W/B=50% is shown in Figure.2. In BB, the addition of 20% LSP resulted in a greater carbonation rate than BB(Base). Also, carbonation rate of binders with LSP replaced by GGBS is about the same as BB(Base). As the LSP addition rate increased, the carbonation rate of binders with LSP replaced by OPC also increased. In BC, LSP addition

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of 10% resulted in a greater carbonation rate than BC(Base). These results indicate that it is necessary to maintain the OPC addition rate to ensure carbonation resistance.

(3) The relationship between compressive strength and carbonation rate

The relationship between compressive strength at 28 days of curing period and carbonation rate at W/B=40, 50, 60% is shown in Figure.3. High correlations between compressive strength and carbonation rate were confirmed. In general, it is known that strength and carbonation rate show such a tendency. From this result, the same trend was obtained when GGBS and LSP were added. Especially, carbonation resistance is lower than that of B0_L7 (OPC) in BB. However, these results suggest that the strength can also ensure the resistance to carbonation.

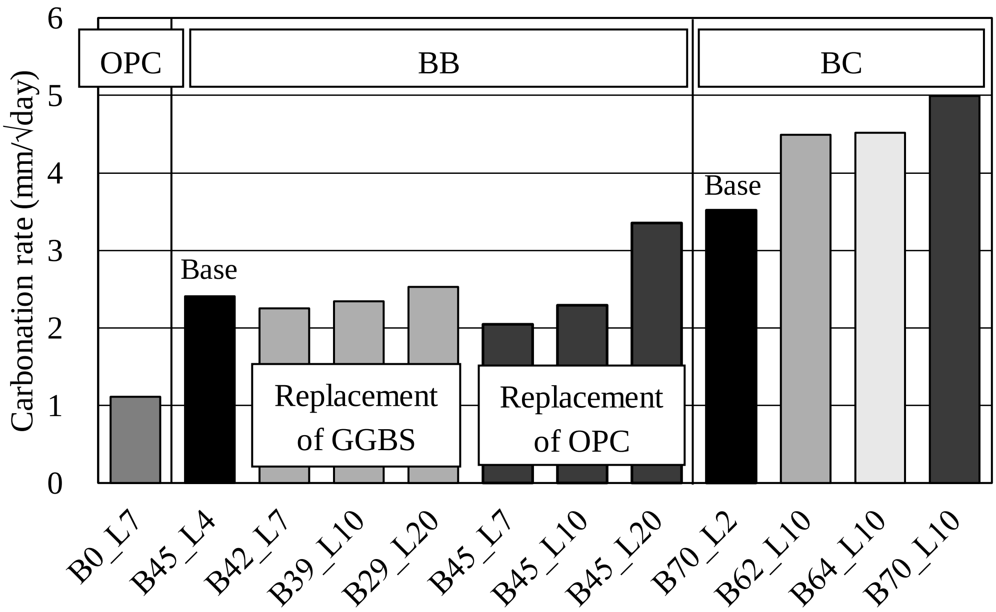

Figure 2. Carbonation rate (W/B=50%)

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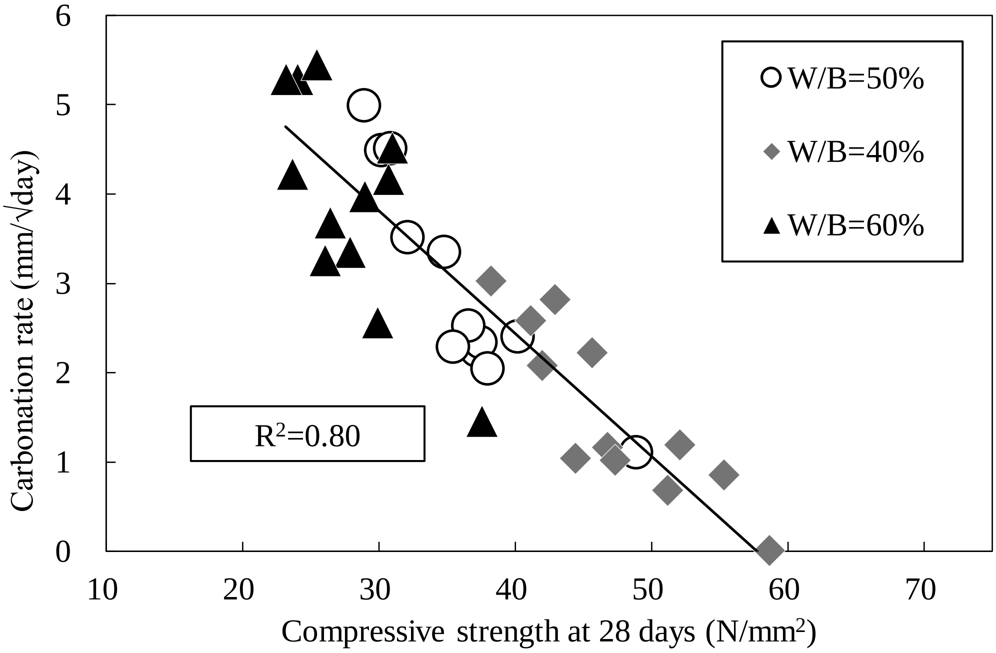

Figure 3. The relationship between compressive strength and carbonation rate

(4) Chloride ion penetration depth

Chloride ion penetration depth at W/B=50% is shown in Figure.4. Significantly different trends were obtained with and without the addition of GGBS. In B0_L7 (OPC), chloride ion penetration depth increases nearly linearly with immersion period. In the case of GGBS addition, chloride ion penetration depth stagnated at a certain depth. The depth of stagnation was 7-10mm in BB and 4-7mm in BC. These results show that the higher the amount of GGBS added, the more chloride ions stay on the mortar surface. In the previous studies, it has shown that some of the chloride ions that have penetrated the mortar or concrete are fixed in hydrates. And Friedel's salt and kuzel's salt is formed. Cement blended with GGBS has been reported to have high salt-fixation capacity. It's because GGBS promotes the formation of Friedel's salt and kuzel's salt. In this study, the results indicate that the salt-fixing capacity of GGBS is remarkable even when LSP is added. In order to evaluate the effect of LSP addition, it is necessary to measure the amount of Friedel's salt and kuzel's salt production.

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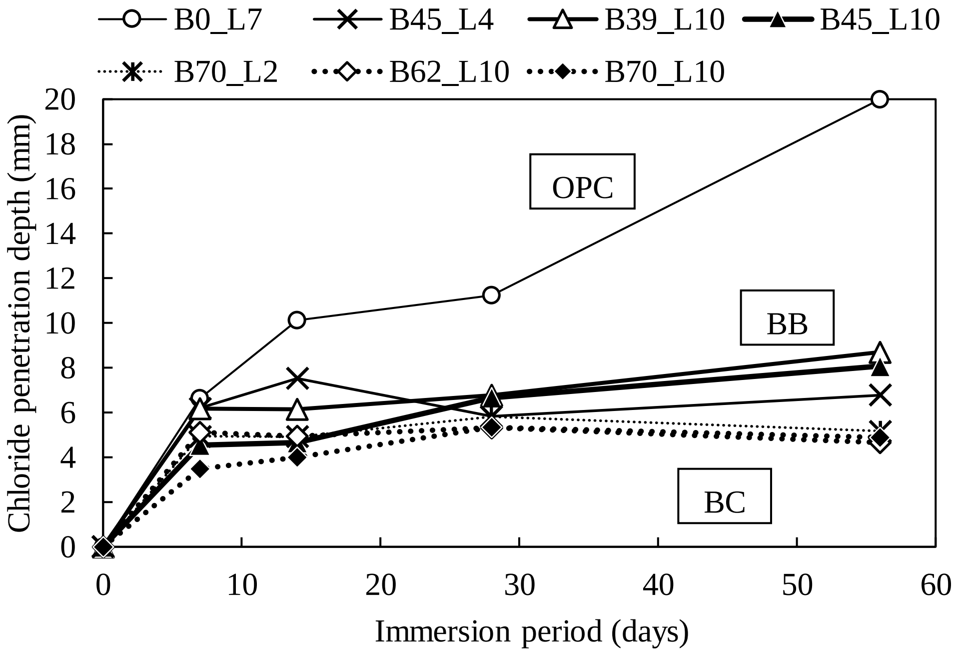

Figure 4. Chloride ion penetration depth (W/B=50%)

ENVIRONMENTAL PERFORMANCE

Calculation method.

CO_2 emissions and waste usage for making 1m^3 of mortar were calculated. The environmental performance was evaluated through different ratios of OPC, GGBS, and LSP. The values were calculated using "Environmental Impact Assessment Tool for Cement and Concrete by JCI". The inventory data of CO_2 emissions and waste usage per unit are shown in Table 2. The data of waste usage includes sludge, soot and dust, debris, mine dust and incinerated ash.

Table 2. Inventory data in Japan

	Unit	CO_2 emission	Waste usage
	(*)	(kg-CO_2/*)	(kg/*)
OPC	t	807	257
GGBS	t	40.2	-
LSP	t	17.2	-
Water	m^3	0.2	-
Fine aggregate	t	7.1	-

In this study, the environmental performance of mortars that ensure equivalent compressive strength was examined. This is intended for the use of cement in structures. First, W/B ensuring the equivalent strength (W/B*) was calculated. The relationship between W/B and compressive strength at 28 days of curing period is shown in Figure.5. To draw a line with a positive slope, the horizontal axis was set to B/W, the reciprocal of W/B. Considering the range of strength data, W/B* at 38 N/mm^2 was calculated. Next, the mortar composition was designed. Keeping the unit water volume constant, the ratio of binders and fine aggregate was calculated. Finally, the amount of each material was entered into the tool and CO_2 emissions and waste usage were calculated.

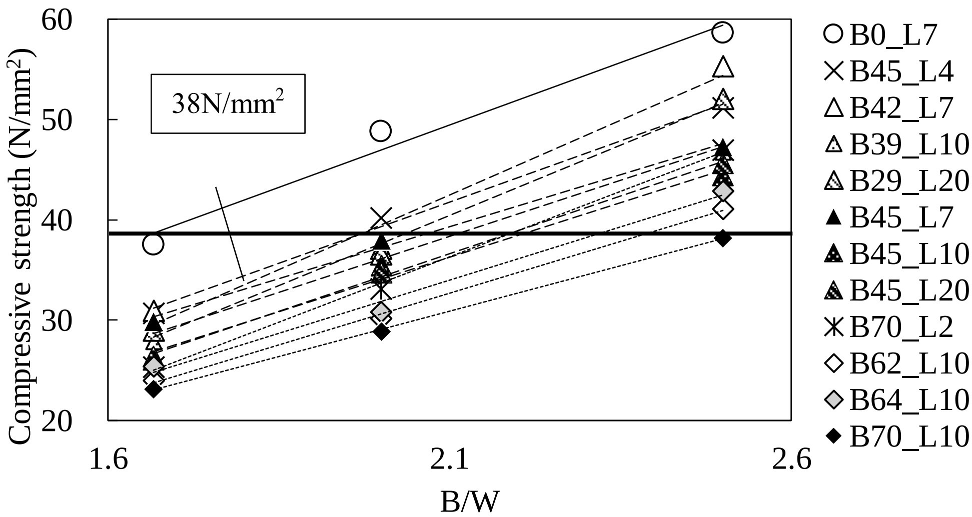

Figure 5. The relationship between W/B and compressive strength

CO_2 emissions and waste usage.

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(1) Considerations on strength

CO_2 emissions and waste usage and component ratio of paste in mortar are shown in Figure.6. In BB, similar results were obtained except for B45_L20. In BC, as the OPC ratio increased, CO_2 emissions and waste usage increased.

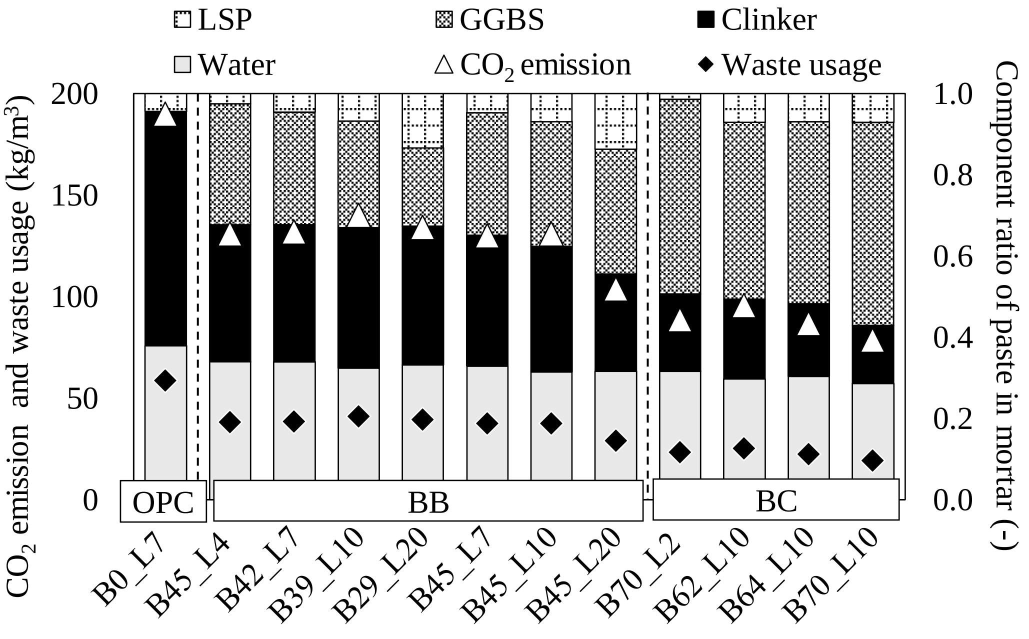

Figure 6. CO_2 emissions, waste usage and component ratio of paste in mortar

(2) Considerations on durability

From the results of durability tests conducted in this study, the relationship between durability and environmental performance was also considered. For carbonation resistance, as shown in Figure.3, there is a high correlation between compressive strength and the rate of carbonation. Therefore, the results would be similar to the relationship between strength and environmental performance. For instance, as GGBS blending rate increases, carbonation resistance decreases. However, CO_2 emissions and waste usage decrease. As for the resistance to penetrating chloride ion, it is estimated that blending GGBS can balance both environmental performance and high resistance to penetrating chloride ion.

CONCLUSIONS

The following are the results of this study.

(1) Early-age strength was maintained or enhanced by the addition of LSP.
(2) Carbonation resistance was decreased by the addition of GGBS and LSP.

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(3) A high correlation was obtained between compressive strength and carbonation rate.
(4) Chloride ion penetration resistance is improved by the addition of GGBS even when LSP is added.
(5) It suggests that environmental impact and strength durability are balanced in cement blended with GGBS, with strength assured.

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