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Basic Property and the Method of Effective Use on Portland Blast-Furnace Slag Cement and Ground Granulated Blast Furnace Slag

Kenji NOBATA*1 Yasutomo UEKI*1

Abstract

The CO_2 emission to produce Portland blast-furnace slag cement decreased in comparison to ordinary Portland cement. Furthermore, concrete to use slag cement improved the durability to salt damage and chemical attack, and alkali-aggregate reaction. This report introduces the basic properties and the method of effective use on Portland blast-furnace slag cement and ground granulated blast furnace slag.

1. Introduction

Portland blast-furnace slag cement is the kind in which ground granulated blast furnace slag is mixed with ordinary cement. Blast furnace slag cement, with an annual production of over 23 million tons as a by-product of steel manufacturing, is used as the raw material for Portland blast-furnace slag cement, accounting for about 60% of the total production.

Portland blast-furnace slag cement has long been used chiefly for civil engineering works and construction groundwork by taking advantage of its properties for controlling alkali-aggregate reaction and reducing the heat generated by hydration. In recent years, it is highly valued for small-volume CO_2 emission during production. In addition, it is expanding its applications because of its excellent long-term strength and resistance to salt damage amid the movement toward life-cycle cost rationalization, namely the reduction in repair charges relating to public works.

This paper summarizes the potential for future use of Portland blast-furnace slag cement and ground granulated slag cement with an emphasis placed on their properties.

2. Standards of Portland blast-furnace slag cement and ground granulated blast furnace slag cement

As **Table 1** shows, the three grades of A, B and C, of Portland blast-furnace slag cement are standardized as JIS R 5211 Portland Blast-furnace Slag Cement. However, most of the Portland blast-furnace slag cement now on the market belong to grade B, in which slag is mixed by 40 to 45%. Little difference in quality is found among the products of cement manufacturers. Triggered by alkali-aggregate reaction control, resource conservation, energy conservation, and cost reduction, the sales amount of Portland blast-furnace slag cement has been on the increase since the 1980's, accounting for 25% of the total domestic cement sales amount (See **Fig. 1**).

As **Table 2** shows, blast furnace slag has also been standardized in JIS as concrete admixture. It can be used in any pulverized degree and in any mixing proportion depending on its application.

3. Production of blast furnace slag and ground granulated slag

Blast furnace slag is in a molten state at high temperatures when produced in a blast furnace, but turns into sandy granulated slag (quenched slag) when quenched with pressurized water. Granulated slag has a latent hydraulic property, and can be rendered similar in property to ordinary cement, which cures when hydrated, by pulverizing into ground granulated blast furnace slag. Granulated slag is mostly used as an admixture of Portland blast-furnace slag cement and for ground granulated blast furnace slag by taking advantage of

Table 1 Standard of Portland blast-furnace slag cement (JIS R 5211)

Kind	Weight % of blast furnace slag
Grade A	Above 5 and below 30
Grade B	Above 30 and below 60
Grade C	Above 60 and below 70

*1 Slag & Cement Div.

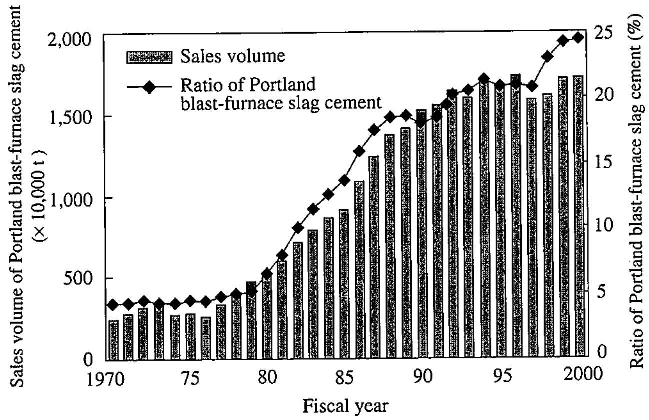

Fig. 1 Transition of sales volumes of Portland blast-furnace slag cement

Table 2 Standard of ground granulated blast furnace slag (JIS A 6206)

Kind	Specific surface area (cm^2/g)
Ground granulated blast furnace slag 4,000	Above 3,000 and below 5,000
Ground granulated blast furnace slag 6,000	Above 5,000 and below 7,000
Ground granulated blast furnace slag 8,000	Above 7,000 and below 10,000

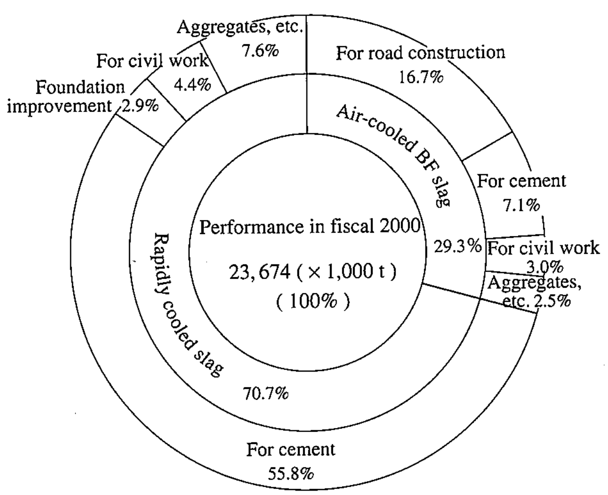

Fig. 2 Consumption by uses of the Blast Furnace Slag

those characteristics (See **Fig. 2**).

4. Properties of ground granulated blast furnace slag

4.1 Enhancement of long-term strength

Ground granulated blast furnace slag undergoes hydration for a prolonged period. This enhances its long-term strength. As **Fig. 3** shows, ordinary cement, when replaced with ground granulated blast furnace slag in greater proportion, lowers its initial strength, but improves its long-term strength after 28 days. When strength-controlled material age is lengthened by utilizing this property, unit cement

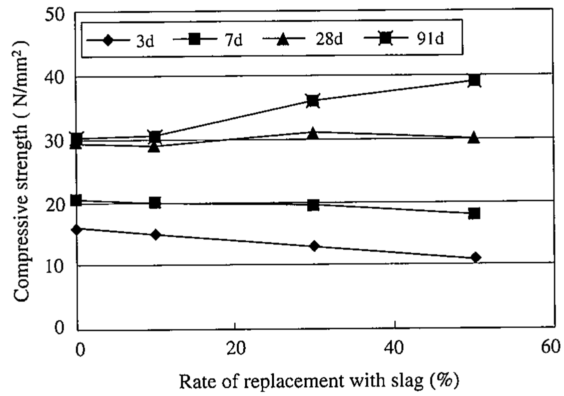

Fig. 3 Rate of replacement of ordinary cement with ground granulated blast furnace slag and compressive strength of concrete

quantity can be reduced, thus leading to the reduction in the heat of hydration and cost.

4.2 Control of salt damage

Concrete in which ground granulated blast furnace slag is used has a higher chlorine ion blocking property than ordinary cement, and therefore is effective for controlling salt damage. As **Fig. 4**[1)] shows, ordinary cement, when mixed with ground granulated blast furnace slag, acts in such a manner that chlorine remains on the surface layer without permeating deeper unlike ordinary cement.

The mechanism of controlling salt damage can be considered as follows. Ordinary cement, when hydrated, yields Ca $(OH)_2$, which occupies about 25% of the cured cement volume. Because $Ca(OH)_2$ dissolves outside in the chlorine environment to render concrete porous, chlorine permeates deep inside. On the other hand, blast furnace slag, when combined with Ca $(OH)_2$, produces a water-insoluble hydrate of lime silicate, and makes the cured cement structure more dense. At the same time, its hydrate can control the permeation of chlorine because it chemically fixes chlorine ions.

4.3 Control of alkali-aggregate reaction

The alkali-aggregate reaction means that, when silica-rich aggregate is used, alkali silica gel is formed by the reaction between silica in the aggregate and alkali hydroxides, such as the Na^+ ion and the K^+ ion. This silica gel, because of its hygroscopic swelling, destroys concrete from inside by swelling.

As **Fig. 5** shows, an increased ratio of replacement of ordinary cement withg ground granulated blast furnace slag decreases swell-

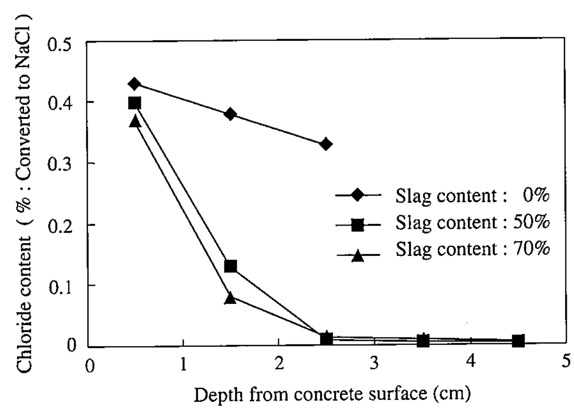

Fig. 4 Permeability of salt into a sample substrate exposed for 5 years in a coastal splashing zone

ing due to alkali-aggregate reaction. This is because alkali hydroxides are decreased in amount by the replacement with slag, and fixed to slag hydrates. It is also stipulated in JIS that a ratio of replacement with slag should be over 40% when an aggregate likely to cause alkali-aggregate reaction is used.

4.4 Reduction in hydration heat

Recently, the members of concrete structures are becoming large, and as such, measures against temperature-induced cracking are urgent. As the rate of replacement of cement with ground granulated blast furnace slag increases and the fineness size of ground granulated blast furnace slag becomes smaller, the rate of initial hydration reaction becomes lower resulting in the control of hydration heat during curing. It is desirable that in practical application the rate of replacement with ground granulated blast furnace slag and a proper blending of the slag depending on its fineness size should be determined after careful consideration of a member size and a construction period.

4.5 Increase in fluidity

Because of its low rate of initial hydration reaction, ground granulated blast furnace slag increases in its fluidity in fresh concrete (still unhardening). As **Fig. 6** shows, fluidity (mortar flow value) increases in proportion to an increase in the rate of replacement with slag. This is also effective for increasing packing density. The usable time of mortar also becomes longer in proportion to an increase in the rate of replacement with slag, and various service conditions can therefore be met.

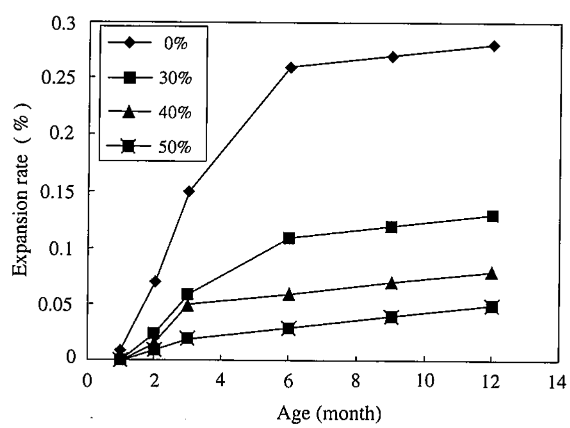

Fig. 5 Relationship between the rate of replacement of ordinary cement with ground granulated blast furnace slag and the volume of expansion of a mortar bar

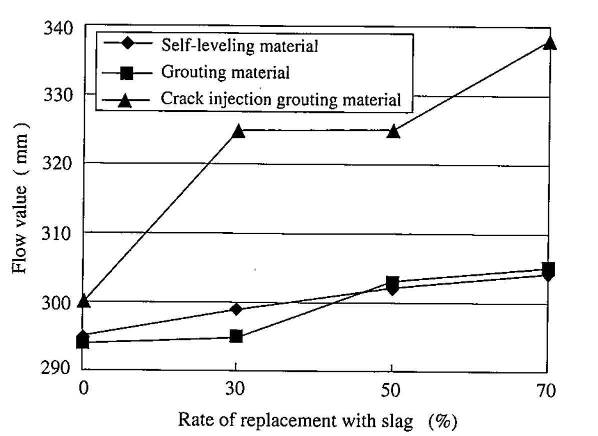

Fig. 6 Relationship between the rates of replacement of various kinds of mortar with slag and flow values

5. Products in which the features of ground granulated blast furnace slag are utilized

By taking advantage of the features of ground granulated blast furnace slag as above-described, Nippon Steel's group is now selling various products besides Portland blast-furnace slag cement. Three typical products among those are summarized here.

5.1 Esment Super 60

Although blast furnace slag mixed contributes to improving durability and fluidity, it was difficult to apply it to a structure member whose initial strength is particularly required. Esment Super 60, produced to solve the problem of initial strength, was enhanced in hydration reactivity by increasing the specific surface area of ground granulated blast furnace slag from normal 4,000 (cm^2/g) to 6,000 (cm^2/g).

This product can be used, for example, as the measures against salt damage to the upper part of a bridge pier for which initial strength is required. Many instances have been reported recently that the upper parts of coastal concrete structures are deteriorated by salt damage[2]. Deterioration due to salt damage is feared in a cold district because of the abundant use of anti-freezing admixtures in response to the ban on the use of a spike tire. However, Esment Super 60 enables a lengthened service life by improving a salt screening property while securing the initial strength at the time of construction. The number of its positive achievements in Japan amounts to 22 cases since it was first used in Okinawa Prefecture in May, 1998.

5.2 Eslevel

For finishing a concrete floor has been used a method of smoothing its surface with a metal trowel. This method, however, requires high skill and much labor. Eslevel is a floor finishing agent developed to alleviate this work by taking advantage of the fluidity of ground granulated blast furnace slag. According to the flow test as given in **Fig. 7**, Eslevel can be used for 6 hours after the start of water pouring at outside temperatures between 5 and 40°C. This makes it possible to supply it almost all year-round over a wide area far away from the ready-mixed concrete plant. Because of its fluidity, it can be used for covering a wide area at one time.

5.3 High-strength and high-durability mortar (NEM-RS)

Concrete deteriorates in the sewage system in many cases by the influence of acid hydrogen sulfide produced by bacteria. NEM-RS has been developed as a kind of mortar for repairing deterioration and corrosion-proofing by taking advantage of the acid resistance of

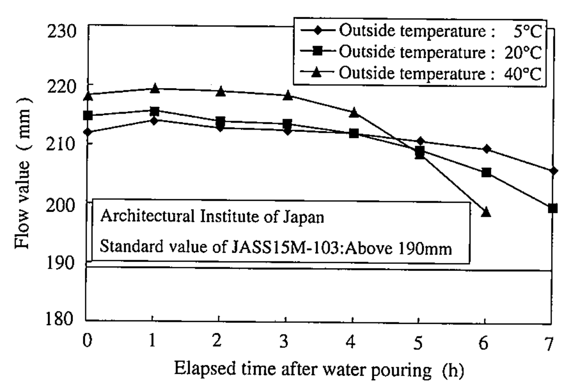

Fig. 7 Changes over time in Eslevel's flow value

Table 3 Physical properties of NEM-RS (Sulfuric-acid-proof type)

Items of required performances		Material age (d)	Tokyo Metropolis standard value	NEM-RS
Strength properties	Compressive strength (N/mm²)	3	Above 25	34
		28	Above 45	52
	Flexural strength (N/mm²)	3	Above 3.0	4.0
		28	Above 7.0	7.5
Permeation resistance	Depth of permeation by sulfuric acid (mm)	28	Below 3.0	2.5
Crack resistance	Changes in length (%)	28	Above − 0.1	− 0.08
Integrity	Bond strength (N/mm²)	28	Above 1.5	2.0
Sulfuric acid resistance	Changes in mass (%)	28	Within ±10	− 1.3

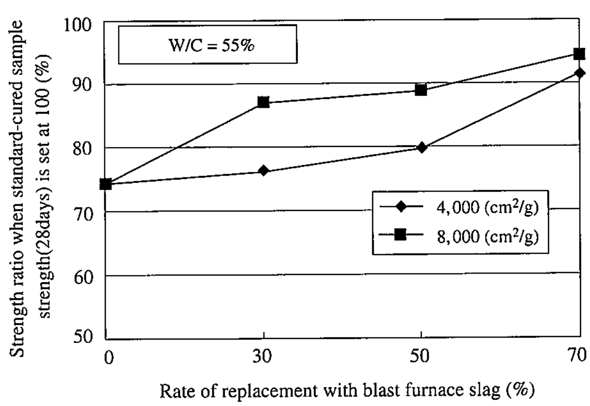

Fig. 8 Influence of the rate of replacement of ordinary cement with ground granulated blast furnace slag on acid resistance (dipped in 2% HCl solution for one year)

ground granulated blast furnace slag. **Table 3** shows its basic properties. As the test results show as given by **Fig. 8**[3], acid-induced deterioration lowers strength when ordinary cement is used alone. However, cement improves its strength when replaced partly with blast furnace slag, and improves further with the slag pulverized to a higher degree. This accounts for the control of acid attack by the structure made more dense due to the hydration of the ground granulated slag.

6. Reduction in environmental load

A process is required for the manufacture of ordinary Portland cement to calcine and crush limestone. However, granulated slag cures with water when simply mixed with ordinary Portland cement. This reduces energy consumption or carbon dioxide emission volume in the process of manufacture. As **Table 4** shows, the volume of carbon dioxide emission is about 800 kg for the manufacture of 1 ton of ordinary Portland cement, but can be reduced almost to half in case of Portland blast-furnace slag cement, grade B, composed of ordinary cement and ground granulated blast furnace slag, with each mixed nearly by half. Because of this effect, ground granulated blast furnace slag and Portland blast-furnace slag cement are registered as a pattern of Eco-marked article (Pattern No.30).

Table 4 Volume generated of CO_2 per ton of cement

		Ordinary cement A	Portland blast-furnace slag cement, gradeB B	Reduced volume (%) (A−B)/A
Quantity of limestone used (kg)		1,092.0	600.6	45
Consumed energy	Coal (kg)	103.6	57.8	44
	Electric power(kWh)	99.2	72.6	27
Volume generated of CO_2 (kg)		775.6	437.0	44

7. How the government is working around Portland blast-furnace slag cement

The following two laws have beenenforced since April, 2001:

a) Portland blast-furnace slag cement specified for public works based on the Green Purchase Law

In the national basic policy based on the Green Purchase Law, a law concerning the procurement of environment-related goods by the government, aiming at structuring a sustainable society with little load on the environment, Portland blast-furnace slag cement, in which blast furnace slag exceeds 30% in weight, has been specified as an item as an environment-related article with priority given to procurement in public works.

b) Common Specifications of Construction Works, published by the Public Construction Association and supervised by the Government Buildings Department, Minister's Secretariat, Ministry of Land, Infrastructure & Transport in fiscal 2001.

Portland blast-furnace slag cement, grade B, has been listed in the Common Specifications for piles driven at a building site. Its use for a building proper has also been made possible.

8. Conclusions

With interest in the durability of concrete structures growing in recent years, the requirement of concrete has been shifted from specifications to performance, thus resulting in the request for various types of performance to respond to the differences not only in the applications to structures but also in environmental conditions during their service life. Under the circumstances, the application of ground granulated blast furnace slag is expected to expand to a greater range in the future in addition to Portland blast-furnace slag cement hitherto used. In other words, an optimal kind of cement can be realized that can respond to a variety of environmental conditions if ground granulated blast furnace slag can be controlled in quality based on the understanding of its characteristics, since it can be controlled in strength development, durability, and heat generation by changing the degree of its pulverization and a ratio of mixing in ordinary cement.

In the future as well, Nippon Steel's group intends to develop articles that will answer the social needs in line with the research of the properties and functions of Portland blast-furnace slag cement.

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