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Compressive Strength of Concrete Based on Slag Binder Using Pig Iron Preliminary Treatment Slag as Activator†

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As a way of recycling industrial waste and reducing carbon dioxide emissions, this study has tried to improve the compressive strength of concrete that contains a large amount of fine blast furnace slag powder. To investigate the low compressive strength resulting from using a large amount of the fine blast furnace slag powder in ordinary portland cement concrete, we analyzed the concrete by measuring setting time, compressive strength, pH, SEM, EDS and XRD. A pig iron preliminary treatment slag, which is a by-product of the slag generated during the steel production process, was added based on the principle of destroying the impermeable film of the blast furnace slag powder due to the cement hydration product. As a result, it was possible to manufacture concrete with a compressive strength of 20 MPa by using 100 % industrial by-product. This was judged to affect the compressive strength by generating hydrates, such as ettringite, $Ca(OH)_2$ and C-S-H gel, through failure of the fine blast furnace slag powder film due to the pig iron preliminary treatment slag. Also, pH and Si/Al ratio were determined to be the main factor in the development of the compressive strength.

Keywords: Cement, Blast Furnace Slag, Compressive Strength, pH, SEM and EDS, XRD.

INTRODUCTION

Recently, minimization of environmental load through, for example, the reduction of carbon dioxide emissions generated from the use of energy resources, has become a prime focus internationally. Approximately 8 % of these carbon dioxide emissions have been determined to be emitted from the cement manufacturing sector. The manufacturing of ordinary portland cement (OPC) emits about 0.7 to 1.0 ton of CO_2 gas per ton of cement because it consumes a large amount of energy, as it is manufactured through a high temperature melting process (about 1450 °C)[1]. However, the demand for cement is expected to increase globally by 2.5-5.8 % per year until the early 21st century and thus, the development of cements with low carbon dioxide emissions is urgently required[2]. In order to solve these problems, industrial by-products, such as blast furnace slags (BFS), are being used as a substitute material for cement. Blast furnace slags is vitrified by water quenching molten blast furnace slags, produced as a by-product of smelting pig iron. As blast furnace slags has a high reactivity, it is used as admixture materials for cement and concrete[3]. Especially, blast furnace slags powders have a latent hydraulic property of becoming hardened by the stimulation of alkali among the cement hydrates, although the property of becoming hardened by itself is weak.

Therefore, in the case of using them as a concrete admixture, they can benefit from various effects, such as the hydration heat velocity reduction of the concrete, suppression of the temperature rise, improvement of the long-age strength of concrete, improved durability due to increased water tightness and reduced corrosion of the rebar due to suppression of chloride ion permeation[4]. In addition, about 40 % less limestone, a base material for ordinary portland cement, could be used through using fine blast furnace slags powders. Furthermore, since limestone use and energy consumption is lowered, carbon dioxide emission reductions are possible due to less limestone pyrolysis and fuel combustion and the reuse of the industrial by-products.

This study has performed a comparative analysis on the properties of the compressive strength of concrete by applying the pig iron preliminary treatment slag, a by-product generated in the process of steel production based on the principle of destroying the impermeable film of the blast furnace slags powder due to the cement hydration product.

EXPERIMENTAL

Property evaluation and indoor mixing: Table-1 shows the concrete formulation. The W/B and the unit weight have been fixed to 53 % and 179 kg/m^3, respectively and the binder

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TABLE-1
CONCRETE FORMULATION

ID	W/B (%)	Slump (mm)	Air (%)	S/a (%)	Unit weight (kg/m^3)							Measurements
					W	C	BFS	A	S	G	SP	
Plain					179	337	-	-	841	921	1.35	-Compressive Strength (MPa)
BFS40	53	180 ± 30	4 ± 2	48.8	179	202	118	10	837	945	1.68	-pH
BFS70					179	101	209	15	833	912	2.03	-SEM&EDS
BFS100					179	-	287	33	829	908	2.36	-XRD

content has been set to 337 kg/m^3. In order to evaluate the effect of the fine blast furnace slags powder replacement ratio on the concrete compressive strength, the replacement ratio has been set to 0, 40, 70 and 100 %. A superplasticizer was used to achieve the goal slump. A 2-axis mixer was used to mix the concrete and specimens of size 100 mm × 200 mm were manufactured based on "KS F 2403 concrete compressive strength specimen production method" and has passed through a standard treatment for 28 days with a constant temperature and humidity of 20 ± 3 °C and 50 ± 5 %, respectively. The aged hardened paste was crushed to UTM and specimens were collected for analysis by SEM and EDS and XRD. The hydration product was observed by SEM and EDS and the amount of the hydration products was analyzed by XRD.

Three kinds of blast furnace slags that satisfy the regulations of KS F 2563 "Furnace slag powder for concrete" were used. The pig iron preliminary treatment slag used were made by pulverizing the by-products produced in the preliminary treatment during the process of steel production.

RESULTS AND DISCUSSION

Fig. 1 shows the compressive strength of the concretes as a function of age. As the fine blast furnace slags powder replacement ratio increases, it shows a trend of decreasing compressive strength, but the long-age strength has confirmed exceeds the ordinary portland cement strength value after 28 days in the case of blast furnace slags 40 % replacement. In addition, blast furnace slags 100 % has showed a 28-day-old strength of approximately half that of ordinary portland cement, but the measurement value is 20 MPa, which means that it is possible to apply it as regular strength concrete if a compressive strength of greater than or equal to 24 MPa can be achieved through future work.

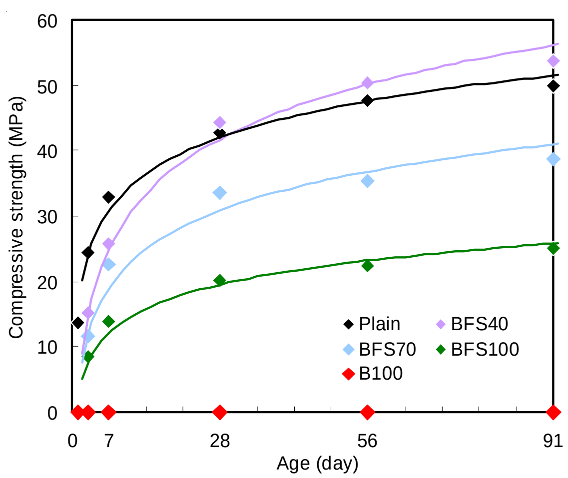

Fig. 1. Compressive strength

Fig. 2 shows the results of concrete pH measurements as a function of age. After mixing, the relationship between the pH and the concrete compressive strength shows a noteworthy correlation. Mortar, the slag binding material that uses a large amount of the fine blast furnace slags powders, is considered to improve its compressive strength, within the range of the same binding materials, due to the increase in the pH immediately following mixing.

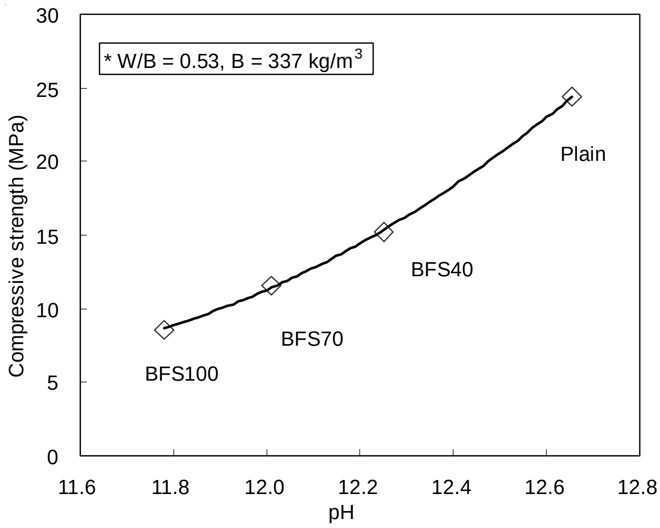

Fig. 2. Relationship between pH and compressive strength at 3rd day

Fig. 3 shows SEM images of the fracture surface microstructure of the hardened paste as a function of the fine blast furnace slags powder replacement ratio. In case the of ordinary portland cement, the tissues have been elaborately formed and thus, the C-S-H gel has been abundantly formed. However, as the fine blast furnace slags powder replacement ratio increases, the tissues of the reaction product become less delicate and the amount of the hydration product become smaller. It is judged that the C-S-H gel densifies the tissues of the specimen, as the amount of the hydration products continuously increases as seen by the gel surrounding the ettringite. The compressive strength increases with age by charging the internal gaps.

Fig. 4 shows EDS spectra obtained from the fracture surface of the hardened paste as a function of the fine blast furnace slags powder replacement ratio. It has been verified that the amount of Ca, Si and Al in the reaction products decreases as the fine blast furnace slags powder replacement ratio increases. Because of this, the amount of the hydration products decreased, which affected the compressive strength.

Fig. 5 describes an analysis through the SEM for the microstructure of the fracture surface of the hardened paste according to the replacement ratio of the fine blast furnace

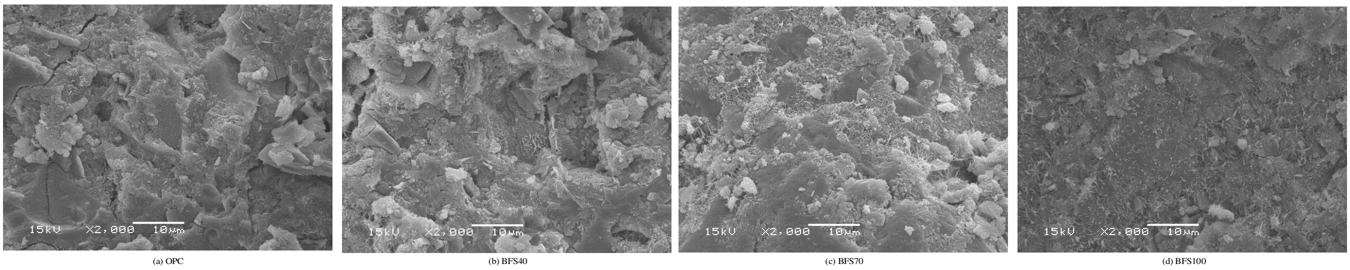

Fig. 3. SEM of the fine blast furnace slag powder replacement ratio

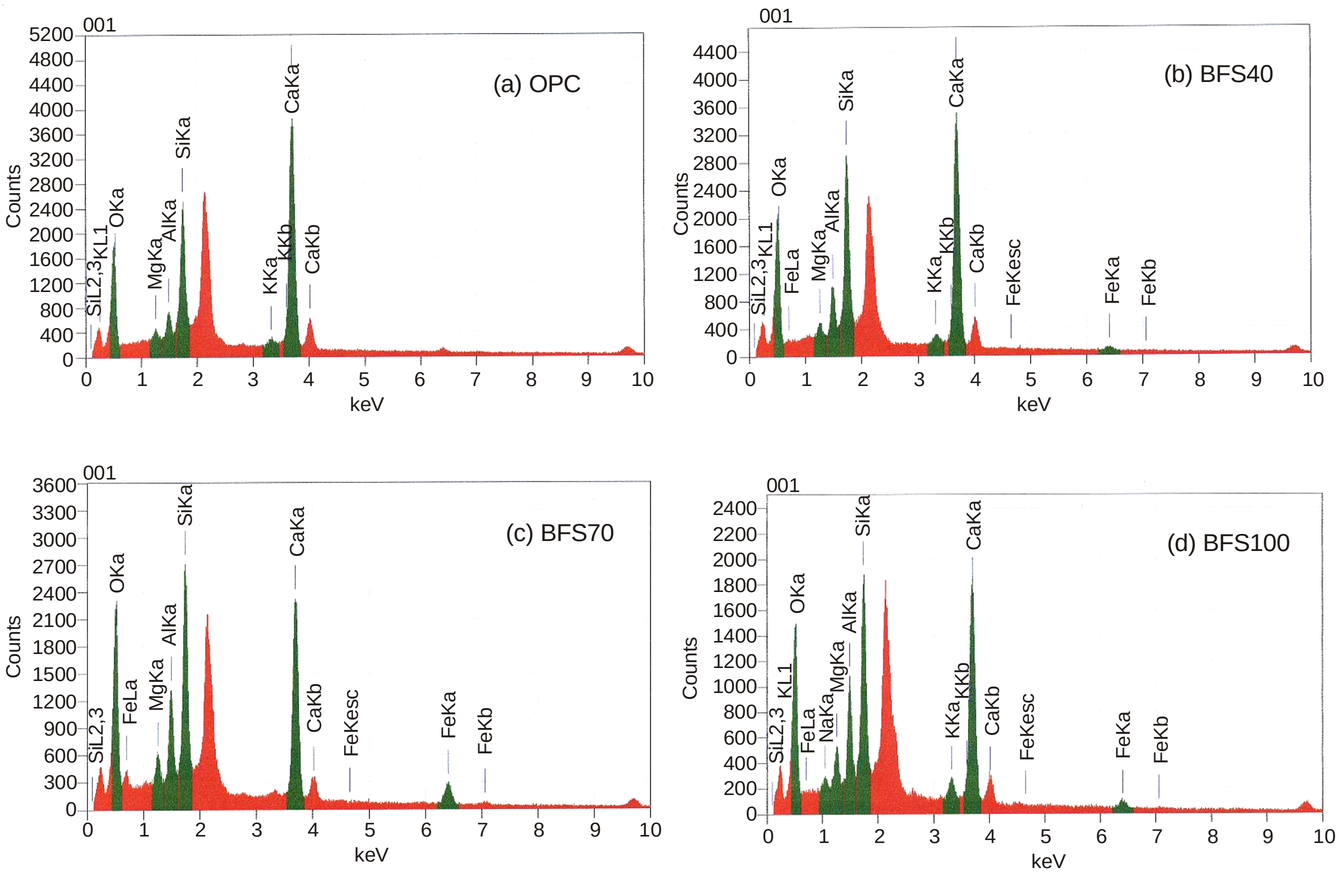

Fig. 4. Energy dispersive X-ray spectroscopy of the fine blast furnace slag powder replacement ratio

slags powder and an analysis through the XRD. In case of the ordinary portland cement specimen, the ettringite peak was almost not observed and $Ca(OH)_2$ and C-S-H gels are mainly produced. In addition, as the fine blast furnace slags powder replacement ratio increases, ettringite was almost not produced and $Ca(OH)_2$ and C-S-H gel have considerably reduced. It is judged that the compressive strength has increased as the C-S-H gel forms the elaborate tissue structure that compact the internal gaps. In case of the replacing with the fine blast furnace slags powder, the acid resistance and the seawater resistance will increase as the amount of $Ca(OH)_2$ will decrease compared to that of ordinary portland cement and it will be advantageous to use it as an admixture in mountains and seawater.

Conclusions

• As a result of the evaluation of the dynamic properties of the concrete according to the pig iron preliminary treatment slag and the fine blast furnace slag powder replacement ratio, it was possible to achieve a compressive strength in the regular strength range with 100 % fine blast furnace slag powder, when mixed with pig iron preliminary treatment slag, even if the amount of the fine blast furnace slag powder increased.

• In case of the Portland cement that has a high content of CaO in the composition mineral, it has been possible to continuously develop the strength by inducing a second hydration reaction in the blast furnace slag through the CSH hydrate with a high pH. The Si/Al ratio has showed an intimate relation between the mechanical strength and the microstructure in the range between 1.5 and 2.15.

• The relationship between the pH and the compressive strength of the concrete shows a noteworthy correlation right after the mixing, because the strong alkalinity, with a pH of greater than or equal to 12, at an early stage, destroys the passive film surrounding the fine blast furnace slag powders and boosts the interior hydration reaction, which then promotes the hydration products, such as C-S-H and ettringite.

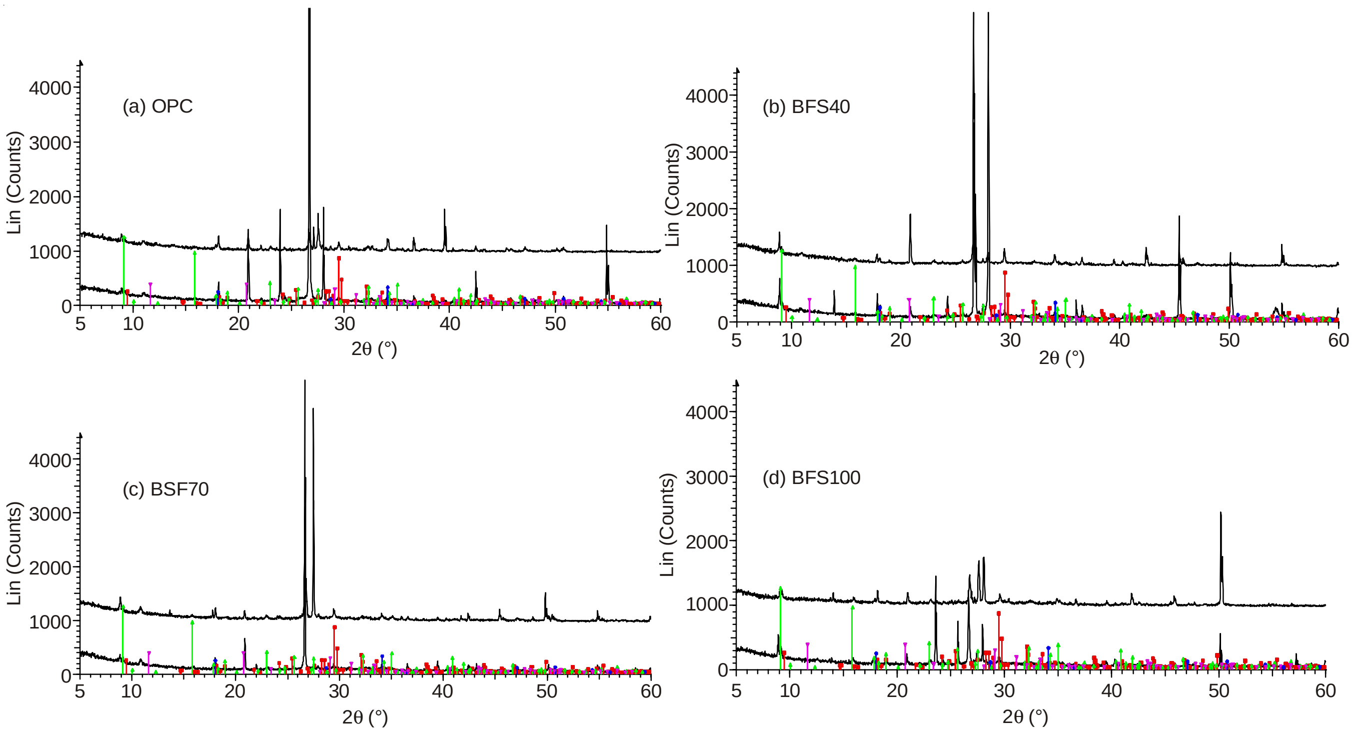

Fig. 5. X-ray powder diffraction of the fine blast furnace slag powder replacement ratio

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