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Quality Properties of Multi-Component Blended Binder High Fluidity Concrete for CO_2 Reduction

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ABSTRACT

In this study, CO_2 reduction type quaternary component high fluidity concrete was produced with more than 80% reduction in cement quantity to increase the use of industrial byproducts and enhance construction performance, thereby reducing CO_2 emissions. Furthermore, the quality properties, and CO_2 reduction performance of this concrete were evaluated. As a result of the quality evaluation of quaternary component blended high fluidity concrete with CO_2 reduction, the target performance could be achieved with a 80% or more reduction of cement quantity by mixing a large amount of industrial byproducts. The required performance level was obtained even though the flow, mechanics, and durability characteristics decreased a little compared to conventional mix.

1. Introduction

As environmental problems related to CO_2 emissions have recently become a social issue throughout industrial sectors, the matter of greenhouse gas emissions is recognized as a challenge to be addressed with collaborative efforts. Especially regarding the concrete industry where cement is used as a major raw material, various problems have been found in relation to global warming, destruction of ecosystems, resource depletion, and improper waste disposal since industrialization and urbanization were accelerated in line with economic development plans.

In addition, it is estimated that CO_2 emissions amount to about 52 million tons per year in the cement industry, and thus it is required to reduce greenhouse gases in this industry where cement is used as a major raw material. It is known that when 1 ton of cement is produced, it generates about 0.8 ton of CO_2, which corresponds to about 6.5% of the total emissions of CO_2 in Korea.

If the total amount of CO_2 emissions from concrete manufacturing to placing, the percentage is as high as 10%. CO_2 emissions from cement manufacturing are related

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to the decarboxylation process of limestone, electric power for fossil fuel combustion and pulverization, oil combustion for generator operation, etc. CO_2 emissions from limestone decarboxylation account for about 59% of the total CO_2 emissions from cement manufacturing, and those from fossil fuel combustion in the limestone pyro process account for about 31%, which indicates that the cement industry requires a tremendous amount of energy sources. Accordingly, efforts have been put forth into reducing greenhouse gases, developing new facilities, and increasing the content of admixtures in the cement industry, but such development of new technologies and installation of facilities involve the additional burden of more initial investments. In contrast, increasing the content of admixtures can reduce the volume of cement fundamentally and thus reduce greenhouse gas emissions as a direct result (Kim 2012).

In recent cases of research and technical development in the area of concrete materials, various types of concrete with admixtures used as a replacement of cement are examined and utilized. However, admixtures account for max. 50% of the concrete mixture except special cases. In general, the content is 20 to 30% in most of the cases.

Thus, this study aims to examine the quality and applicability of concrete mixtures where the cement content is under 20% in order to maximize carbon reduction performance. As for concrete mixing, the focus is on high fluidity concrete (Kim 2010) that can be compactly and thoroughly packed into a mold with no compaction but only with its self-weight. For admixtures, ground granulated blast-furnace slag and fly ash that are widely used in the area of existing high fluidity concrete are adopted. Multi-component blended binder high-fluidity concrete contains calcium carbonate as a non-reactive binder for high fluidity concrete strength adjustment. Its mixture and quality characteristics are examined in this study.

2. Experimental Program

2.1 Materials

2.1.1 Binder

Ordinary Portland cement (OPC), fly ash (FA), and ground granulated blast-furnace slag (GGBF) are used in this study as particulate materials. Calcium carbonate (C), which is a non-reactive mineral admixture, is used for strength adjustment. The chemical composition and physical properties of each particulate material are presented in Table 1, and their SEM imaging results are shown in Fig. 1.

Table 1. Chemical compositions and physical properties of powder used in the experiment

Type	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	Na_2O (%)	K_2O (%)	MgO (%)	SO_3 (%)	L.O.I (%)	Specific surface area (cm^2/g)	Density (g/cm^3)
OPC	21.60	6.00	3.10	61.40	-	-	3.40	2.50	0.03	3,540	3.15
GGBF	33.33	15.34	0.44	42.12	-	-	5.70	2.08	3.00	4,160	2.90

FA	58.20	26.28	7.43	6.51	0.80	-	1.10	0.30	3.20	3,550	2.18
CC	0.67	0.39	0.51	95.69	0.44	0.05	1.76	0.17	-	4,160	2.50

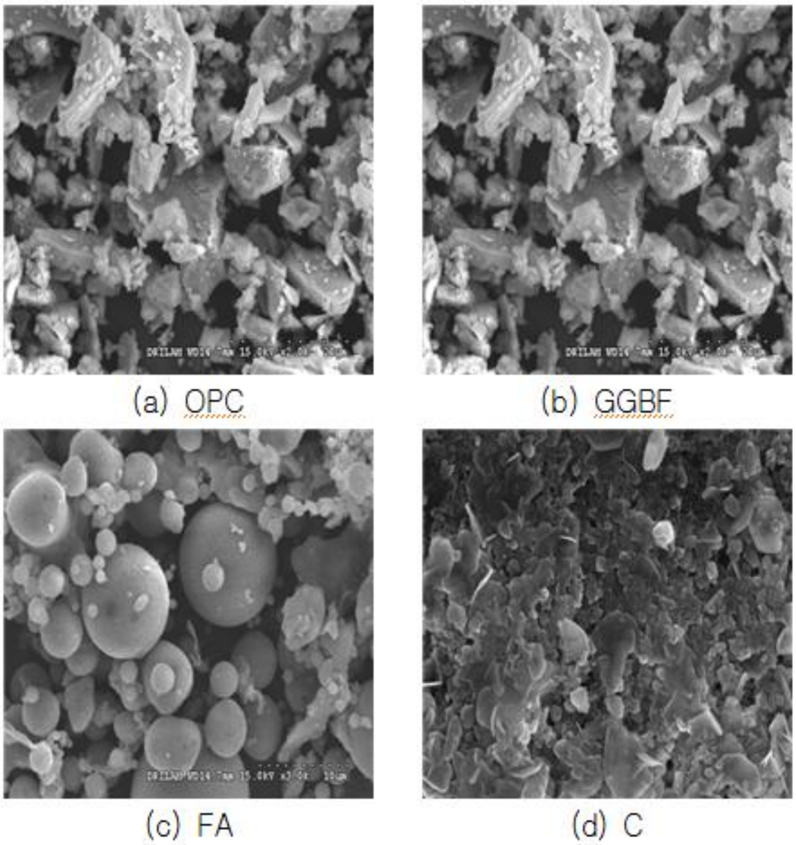

Fig. 1. SEM photograph of the powder

2.1.2 Aggregates

River sand whose density 2.59 g/cm^3 is used as fine aggregates in this study. Coarse aggregates are crushed ones whose G_{max} is 20 mm and density is 2.67 g/cm^3. Table 2 shows physical properties of the used aggregates.

Table 2. Physical properties of aggregatest

Type	S	G
Density (g/cm^3)	2.59	2.67
Absorption (%)	1.56	0.80
F.M.	2.70	7.10
Unit Weight (kg/m^3)	1.67	1.61
solid volume (%)	65.27	62.67
Gmax (mm)	-	20

2.1.3 Superplasticizer

The polycarboxylate superplasticizer of S company is used in this study to secure the fluidity of concrete. The content of superplasticizer accounted for 0.5 to 1.5% of the particulate material quantity, the extent that the required level of fluidity performance is met. Table 3 shows physical properties of the used chemical admixture.

Table 3. Physical properties of chemical admixture used in the experiment

Item	Type	Color	Density (g/㎤)	Total Solids (%)
SP	Liquid	Lemon Yellow	1.04 ± 0.01	34

2.2 Test Method

2.2.1 Mix design of concrete

For low-carbon multi-component fluidity concrete mixing in this study, fluidity concrete of particulate materials is utilized to secure viscosity. To assess the concrete quality characteristics, the plain mixture method is applied only with OPC used, and the ratio of OPC is decreased as much as 80%. Each particulate material is applied to manufacture the final multicomponent concrete. Table 4 and Table 5 show the experiment variables and concrete experiment equation.

As for the concrete slump flow, the slump flow is measured according to KS F 2594 "test method for unhardened concrete slump flow."The air volume was measured according to KS F 2421 "air content test method based on the pressure of unhardened concrete."

To assess the filling ability with the fresh concrete, a separator is installed in the middle of the U-box test. It is lifted up with one side of it filled with samples, and then the height of filling at the other side is measured while concrete passes between reinforcing rods (Choi 2006).

Table 4 Experimental parameters(mixing ratio of used powder)

Type	Mix (Mixing name)	Powder mass.%)			
		OPC	GGBF	FA	C
1	OPC (Plain)	100	0	0	0
2	GGBF60 FA10 CC 10 (G60F10C10)	20	60	10	10
3	GGBF50 FA10 CC 20 (G50F10C20)	20	50	10	20
4	GGBF40 FA10 CC 30 (G40F10C30)	20	40	10	30
5	GGBF50 FA20 CC 10 (G50F20C10)	20	50	20	10
6	GGBF40 FA20 CC 20 (G40F20C20)	20	40	20	20
7	GGBF30 FA20 CC 30 (G30F20C30)	20	30	20	30
8	GGBF40 FA30 CC 10 (G40F30C10)	20	40	30	10

9	GGBF30 FA30 CC 20 (G30F30C20)	20	30	30	20
10	GGBF20 FA30 CC 30 (G20F30C30)	20	20	30	30

Table 5 Mix design of concrete

No.	W/B (%)	Unit mass (kg/m³)						
		W	Binder				S	G
			OPC	GGBF	FA	C		
1	32	155	484	0	0	0	820	860
2		155	97	291	48	48	796	835
3		155	97	242	48	97	793	832
4		155	97	194	48	145	789	828
5		155	97	242	97	48	789	828
6		155	97	194	97	97	786	824
7		155	97	145	97	145	782	821
8		155	97	194	415	48	782	820
9		155	97	145	145	97	779	817
10		155	97	97	145	145	775	813

3. Experiment Result and Investigation

3.1 Slump Flow

Fig. 4 shows slump flow measurements in each concrete mixing ratio. As shown in the Fig., the experiment condition reached the target slump flow 600mm. To examine the effect of particulate materials used for concrete mixing on the mixing ratio, the slump flow of G60F10C10, G50F10C20, and G40F10C30 mixtures, where the FA mixing ratio was 10%, was measured with the GGBF and C mixing ratio changed over time. As a result, the slump flow decreased as C mixing ratio increased. This was the same when the FA was 20% and 30%. Since GGBF mixing ratio decreased and C mixing ratio increased, the slump flow tended to decrease, and GGBF was advantageous compared to C in terms of slump flow. In view of rheological aspects, C tended to increase the yield stress more than GGBF, and this is the same with the slump flow that is directly linked with yield stress.

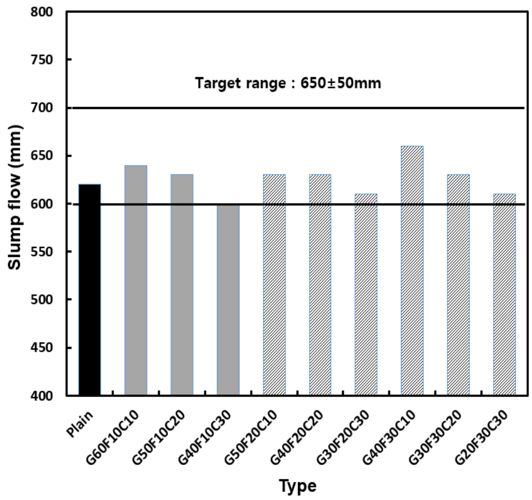

Fig. 4. Slump flow

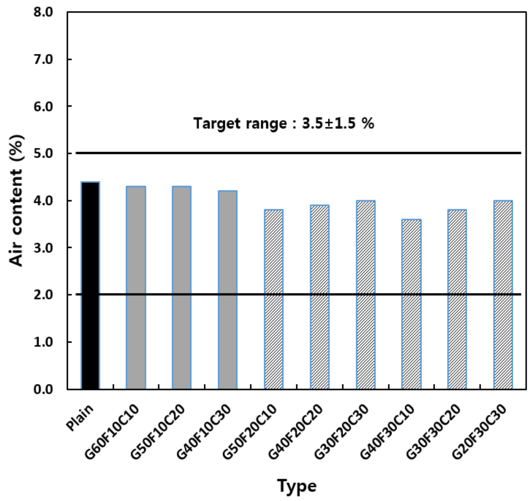

Fig. 5. Air content

3.2 Air Content

In general, the frost resistance decreases drastically when the air content within the concrete matrix is less than 3.0%. When the air volume is 5.0% or more, the effect of frost resistance is insignificant. When the air volume is excessive, it brings out adverse effects such as deterioration of mechanical properties or durability of concrete. Thus, the optimal range of air volume for a structure that requires a normal level of strength is 4.5±1.5%, which is appropriate to secure durability against freezing and thawing with little impact on mechanical properties. However, fluidity concrete with a large quantity of particulate materials can be of high strength over 40 MPa. Thus, the target air volume was 1.0% decreased down to 3.5±1.5%. A high-strength area is more resistible to water infiltration because of its more compact inner structure, which increases resistibility to freezing and thawing as well. Accordingly, the target air volume in this study is the general air content for a high-strength.

Fig. 5 shows the air content measurements of the concrete, which are within the target air volume range 3.5±1.5% although there was some difference depending on the mixed particulate materials. As the FA mixing ratio increased with the same air content used, the air content somewhat decreased accordingly probably because the FA elements included unburned carbon, which led to air absorption.

3.3 Segregation Resistance Ability

Segregation resistance ability is a property of resisting relative movement that results from difference in mass among fresh concrete elements. Separation of water from a solid, paste from aggregates, and mortar from coarse aggregates are examples. In this study, the segregation resistance ability of concrete was assessed based on the required to reach 500 mm of slump flow and time required to flow through V-funnel according to "Specifications of self-consolidating concrete" of JSCE.

Fig. 6 shows the required to reach 500 mm of slump flow. Fig. 7 shows the relation between the required to reach 500 mm of slump flow and time required to flow through

V-lot, which is the target range of segregation resistance ability.

As shown in Fig. 6, the required to reach 500 mm of slump flow was in the range of 5 to 20 seconds, and this time length tended to decrease as the FA mixing ratio increased. As C mixing ratio increased, the time length increased accordingly. This is because C increased the plastic viscosity twice more than GGBF in terms of rheological aspects. As for FA, the plastic viscosity increased as the amount of use increased, and this was the case with regard the required to reach 500 mm of slump flow, an assessment index of concrete viscosity.

Fig. 7 shows the assessment result of segregation resistance ability, the relation between the required to reach 500 mm of slump flow and time required to flow through V-lot, and the target range.

As Fig. 7 shows that the result was within the target range, the segregation resistance ability is sufficient.

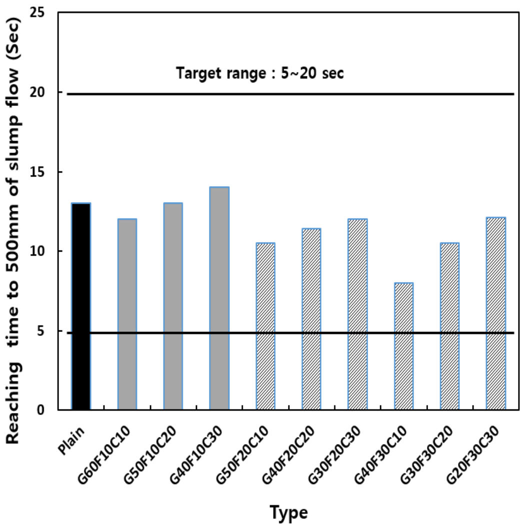

Fig. 6. Reaching time to 500 mm of slump flow

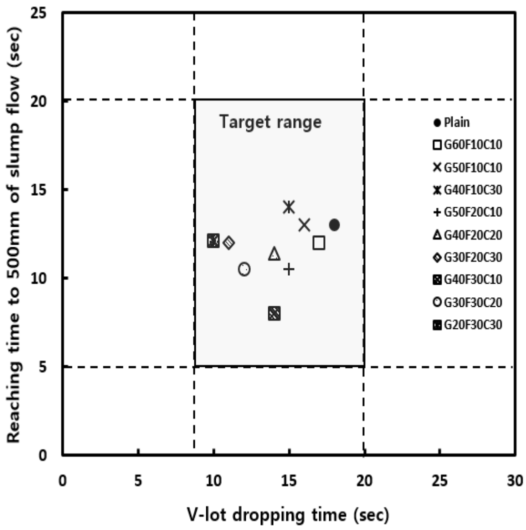

Fig. 7. Relationship between reaching time to 500 mm of slump flow and V-lot dropping time

3.4 Filling Ability

Since fluidity concrete needs to fill a mold compactly only with its self-weight, assessment of its filling ability is essential before use. In this study, filling ability was assessed by means of the U-Box test. Fig. 8 shows the standard for U-Box based filling ability assessment, and the standard was satisfied as the target range 300mm was reached. The filling ability was improved as much as 17% on average and up to max. 20% compared to that of the plain concrete. When a large quantity of the particulate material mixture is used with less OPC, the packing performance is expected to be improved.

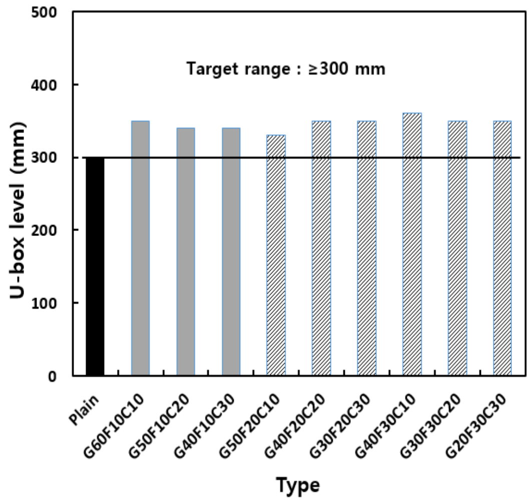

Fig. 8. U-Box test

4. Conclusion

To increase the use of industrial by-products and improve the construction performance, which will contribute to reduction of carbon use, low-carbon multicomponent fluidity concrete is manufactured with the use of cement reduced as much as 80% and the carbon-reducing performance is analyzed in this study. The conclusions are as follows:

(1) Cement was replaced as much as 80% with a large quantity of industrial by-products to produce low-carbon multicomponent fluidity concrete. As a result, the product reached the performance goal.

(2) As for filling ability and segregation resistance ability, the two major performance factors of fluidity concrete, the performance as high as that of 100% cement was secured.

(3) Since low-carbon multi-component fluidity concrete replaced cement as much as 80%, it is expected that its carbon-saving performance will be superior to that of 100% cement, which can contribute to both eco-friendliness and economical efficiency.

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