Third International Conference on Sustainable Construction Materials and Technologies   http://www.claisse.info/Proceedings.htm

Development of grout containing classified fly ash and its application in repair and rehabilitation methods

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ABSTRACT

For various construction repair and rehabilitation work, grouts need to have good fluidity, stable hardening characteristics and high durability to fill and reinforce gaps. There are some reports that mixing fly ash with cement-based mortar improved the mortar’s flowability. In Japan, effective uses of fly ash have been promoted due to the limited disposal sites. The development of grouts containing high volumes of fly ash makes an important contribution to the environment in reducing landfill waste, and subsequently to the realization of sustainable societies. This study has shown that circularity of fly ash particles and grout particle size distribution do have an influence on fluidity. Compared to original fly ash, classified fly ash increased compressive strength and freeze–thaw resistivity of grout. Finally, construction examples utilizing this developed fly-ash-enriched grout for repair work and rehabilitation are presented.

Keywords. Classified fly ash, Grout, Fluidity, Durability, Rehabilitation and Fly-ash-enriched grout

INTRODUCTION

Among the man-made pozzolans, fly ash is probably the most successful material constituent in cement-based grout. Fly ash combines with calcium hydroxide in the presence of water to form cementitious compounds such as calcium silicate hydrate (CSH). There are some reports that mixing fly ash with the cement-based grout improved grout’s flowability due to the ball-bearing effect of spherical fly ash, however, a decrease in compressive strength is observed as the fly ash-to cement ratio in the mixture increases (Bouzouba, 2001). In designing a structure involving cementitious construction, the most important property which has to be considered, besides the ability of the structure to resist all loads, is its durability. The durability of cement-based grout strongly depends on its material transport properties such as permeability. It is well known that incorporation of pozzolanic materials as partial replacement for cement improves the durability of grouts (Martys, 2004).

In Japan, effective uses of fly ash have been promoted because of the limited disposal sites. The development of cement-based grouts containing high volumes of fly ash makes an important contribution to the environment in cutting down on landfill waste and pollution, and subsequently to the realization of sustainable societies. This work set out first of all, to describe the effects of circularity of fly ash particles and of grout particle size distribution on fluidity, second, to measure compressive strength and freeze–thaw resistance of the developed grout containing classified fly ash, and third, to present construction examples utilizing this grout for repair work using pre-packed methods and for sewage drain rehabilitations using trenchless renewal methods.

EXPERIMENTAL

Materials. The grouts consist of high early-strength Portland cement, inorganic fine powder, silicious sand with a maximum grain size of 1.0 mm, polycarboxy ether (PCE) super plasticizer and other undisclosed admixtures. The proportions of materials used in the mixing of the grouts are shown in table 1. Classified fly ash (FA1 and FA2), original fly ash (OFA), calcium carbonate powder ($CaCO_3$) and blast furnace slag were used as an inorganic fine powder to substitute up to 50 % cement (maximum). Characteristics of the inorganic fine powders are shown in table 2. Average circularity and average particle size were measured using the particle shape image analyzer PITA-1 (Seishin Co.). Circularity was defined as a circumference of the spherically projected particle divided by perimeter of the particle (Tanaka, 1991). Figure 1 shows the particle size distribution of grout powders A and B with different grades of aggregate S1–S4 and FA1 substitution rate of 40%. A handheld electric mixer was used to mix the grout powder with water for 2 min at 1100 rpm.

Table 1 Constituents of grouts containing grout powders A and B (grouts A and B) and their proportions (unit; g)

Grouts	Cement and inorganic fine powder	Sand	PCE	Others	Water
A	4000	6000	7.00	> 300	1600
B	4500	5500	7.90	> 300	1800

Table 2 Characteristics of the inorganic fine powders

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Ignition loss	Blaine specific surface area	Average circularity	Average particle size
	%						cm^2/g	—	μm
FA1	61.8	24.8	4.7	1.6	1.0	1.5	5800	0.921	4.7
FA2	57.3	27.7	6.3	2.6	1.0	1.9	3510	0.904	13.2
OFA	62.9	20.8	6.7	3.0	1.2	2.6	2320	0.876	22.7
$CaCO_3$	0.1	0.0	0.0	55.5	0.3	43.9	5820	0.905	7.6
Slag	31.4	14.3	0.2	42.1	6.5	1.0	4630	0.895	10.8

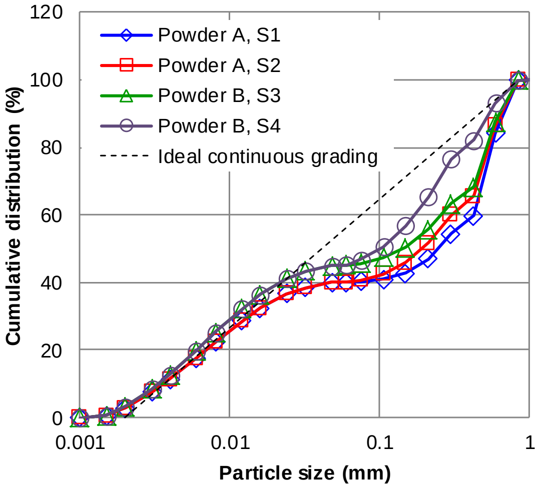

Figure 1 Particle size distribution of the grout powders with different grades of aggregate S1–S4

Methods. Fluidity, compressive strength and freeze–thaw resistance of grouts were measured in a 20 °C constant temperature room. Every test was repeated more than three times under the same conditions.

Fluidity was evaluated by flow value and J_{14}-funnel efflux time. The flow value was measured using a 50 mm*100 mm mini-slump cone, based on JIS R 5201. The spread of the grout on a flow plate was determined and the J_{14}-funnel efflux time was measured based on JHS 312. The grout was set into a funnel immediately after mixing. The time elapsed until the entire grout flowed through it was measured as the J_{14}-funnel efflux time. Compressive strength was measured based on JIS A 1142. Samples were cured in water and tested at time intervals of 3, 28, 56 and 91 days. Relative dynamic elastic modulus and weight loss of hardened grouts in the rapid freezing and thawing process were investigated based on JIS A 1148. The samples were cured for 28 days before the rapid freezing and thawing process and were tested at intervals of a maximum 300 cycles.

RESULTS AND DISCUSSION

Fluidity. Figures 2 and 3 show the flow value and the efflux time of grout A with the aggregate grade S2 as a function of the substitution rate of inorganic fine powders. As higher levels of inorganic fine powders were substituted for cement, flow value increased and efflux time decreased due to the ball-bearing effect of spherical and fine particles. As circularity of the fine powders was close to 1 and average particle size of the inorganic fine powders became smaller, the ball-bearing effect became more pronounced. However, grout samples with excessive replacement of the inorganic fine powders exhibited a decrease in the flow value and increase in the efflux time. Table 3 shows the flow value and efflux time of grouts A and B with different particle size distributions as shown in Fig. 1 and FA1 substitution rate of 40 %. Well-distributed aggregate defined as a continuous grading has a soaring and smoothening grading curve and enhances the flowability of grout (Kasai, 1998). As the particle size distribution of grouts approached the line of ideal continuous grading (S1, S2, S3 and S4, in that order), flow value increased and efflux time decreased.

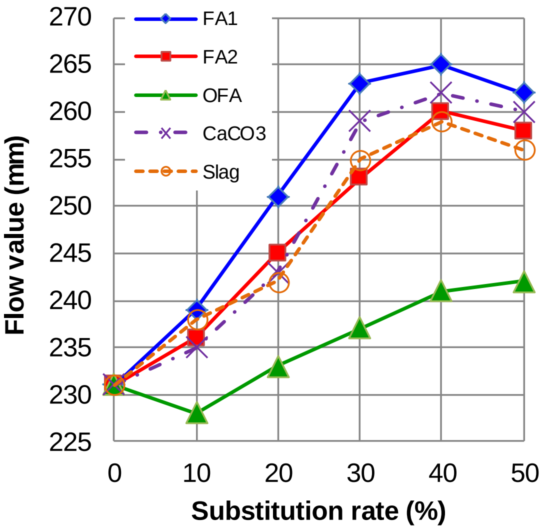

Figure 2 Flow value of grout A as a function of substitution rate

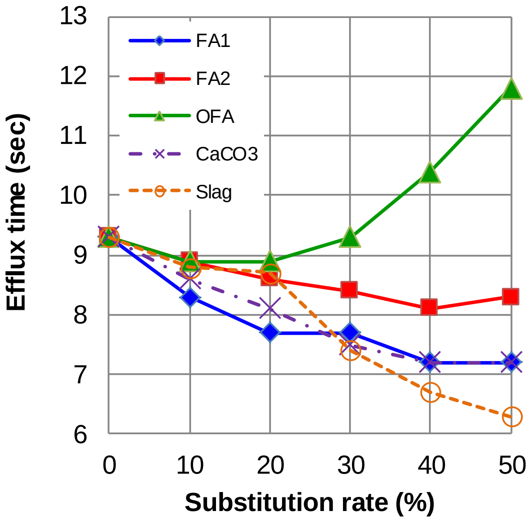

Figure 3 Efflux time of grout A as a function of substitution rate

Table 3 Fluidity of grouts A and B with different particle size distribution

Grouts	FA1 substitution rate (%)	Aggregate grades	Flow value (mm)	Efflux time (sec)
A	40	S1	265	7.8
		S2	270	7.2
B		S3	276	6.8
		S4	288	6.2

Compressive strength. Figure 4 shows compressive strength of grouts B with aggregate grade S4 containing different kinds and amounts of fly ash as a function of curing time. Compressive strength increased with substitution of FA1, FA2 and OFA in that order, however, decreased with an increase in the substitution rate of FA1. Over periods from 56 to 91 days, increases in strength became more pronounced with a mixture of FA1. After 91 days, the strength of the grout with a FA1 or slag substitution rate of 30% was almost identical with that of the grout excluding any inorganic fine powders (blank). Replacement of OFA decreased in initial strength as well as in long-term strength. These results indicate that the packing effect of the fine fly ash, especially FA1, could improve the long-term compressive strength. The small and spherical fly ash particles fill the voids or air spaces and increase the density of hardened grout. Higher Blaine specific surface area could also increase the pozzolanic reaction rate.

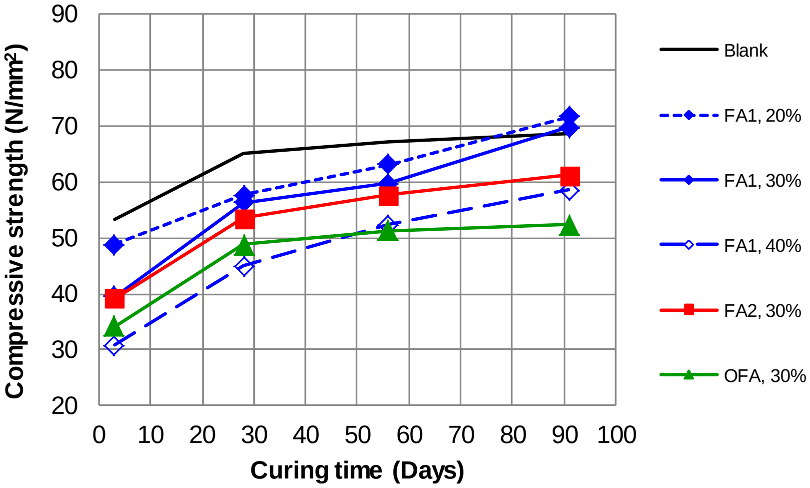

Figure 4 Compressive strength of grouts B containing different fly ash

Freeze–thaw resistance. Figures 5 and 6 show weight loss curves and relative dynamic elastic modulus curves of grouts B with aggregate grade S4 containing different kinds and amounts of fly ash. The weight loss increased with a substitution of FA1, FA2 and OFA in the order. As the substitution level of FA1 became smaller, the weight loss curves of the grouts replaced by fly ash approached the curve of the blank. There was little difference of relative dynamic modulus of elasticity in each grout samples. Pore diameters of 0.1–1 μm have influenced the freeze–thaw resistance. Chindaprasirt et al. (2005) investigated the capillary porosity (10 nm–10 μm) of Portland cement pastes replaced by different classes of fly ash. According to their report, capillary porosity of the cement pastes replaced by fine and well-classified fly ash was equal to that of blank paste, although original fly ash increased the capillary porosity excessively. Compared to FA2 and OFA, the fine and well-classified FA1 powders could have superior freeze–thaw resistivity as the microstructure of grout becomes denser and excessive increases in capillary porosity are inhibited.

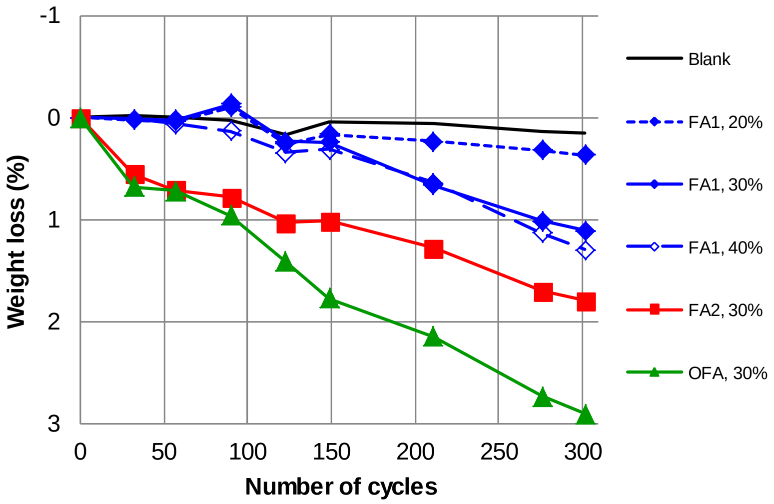

Figure 5 Weight loss curves of grouts B containing different fly ash

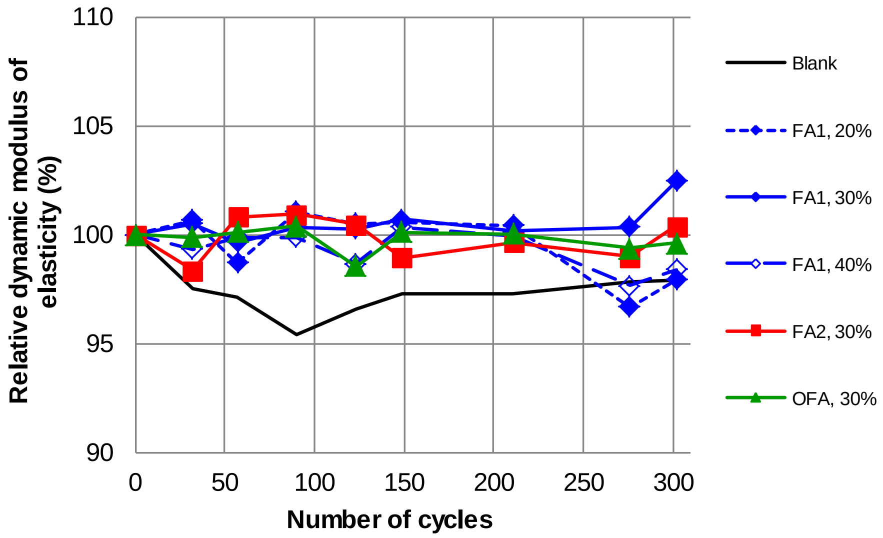

Figure 6 Relative dynamic elastic modulus of grouts B containing different fly ash

APPLICATION OF THE DEVELOPED GROUT

The developed grout containing aggregate grade S4 and FA1 has been applied to many practical structures. The following presents construction examples utilizing this grout for repair work using pre-packed methods and for sewage drain rehabilitations using trenchless renewal methods.

Repair work. The grout was applied to repair the damaged parts of a bridge in Ube, Japan using pre-packed methods. Prior to setting up a formwork, the damaged parts were coated by lithium nitrite corrosion inhibitor and ethylene-vinyl acetate primer in order to passivate reinforcing steels and increase the adhesive strength. The grout was filled in the formwork with 15cm thickness and a rectangular cross of 4 m by 3 m where crushed stones of 15–20 mm in diameter were put with a solid volume percentage of 55 %. Figure 7 represents before and after the repair work.

Figure 7 Before (left) and after (right) the repair work of a bridge using pre-packed grout

Rehabilitation. The grout has been employed in trenchless renewal methods to fill and reinforce the gap between new and existing (ageing) sewage pipe. Figure 8 shows a sketch of formed-in-place-pipe (FIPP) method, which is one type of the trenchless renewal methods (Koerner, 1996). The FIPP technique consists of a uniform concentric ring of two or more thin sheets of high density polyethylene, in which the outer sheet is smooth and the second or inner is studded. The studs provide an annular space into which is injected the grout that subsequently hardens and locks around the studs. The annulus-injected grout measures up to about 5 cm in width.

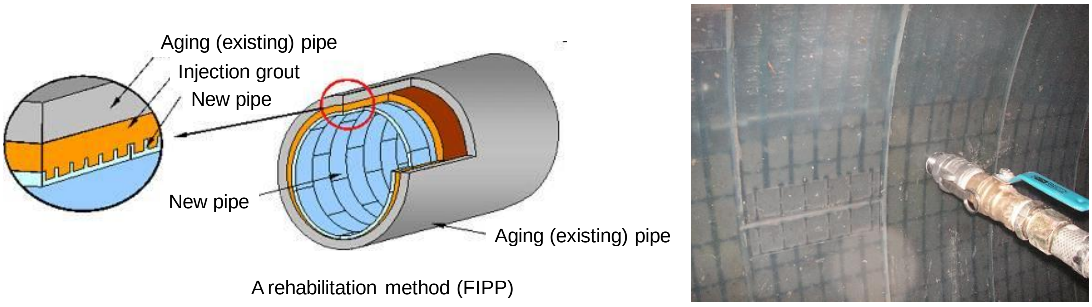

Figure 8 Sketch of FIPP method (left) and injection point (right)

CONCLUSION

Based on the results of our study, the following conclusions can be drawn:

1. As the circularity of the inorganic fine powders was close to 1 and particle size distribution became smoothened, flowability of grouts was improved.

2. Compared to original fly ash, classified fly ash — especially FA1 — inhibited a pronounced decrease in compressive strength of grouts and increased the long-term strength.

3. Grouts containing classified fly ash had more superior freeze–thaw resistivity than the grout with original fly ash because their microstructure became denser and an excessive increase in capillary porosity was inhibited.

4. The developed grout containing classified fly ash has been applied in repair work and rehabilitation of many existing practical structures.

Through the industrial use of this developed cement-based grout containing high volumes of fly ash, substantial amounts of waste material and pollution can be reduced, and therefore, a critical step can be made to protect the environment and develop sustainable societies.

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