RESEARCH ARTICLE
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Properties of Self-Compacting Concrete in Corporating Bottom Ash as a Partial Replacement of Fine Aggregate

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ABSTRACT: This article presents the test results of fresh and hardened properties of self-compacting concrete (SCC) incorporating bottom ash as partial replacement of normal sand at 0 %, 10 %, 20 % and 30 % by weight. Mix proportion of the investigated powder-typed SCC was determined by fixing the water to powder ratio at 0.31 and the ratio of paste volume to void volume of compacted aggregate phase (γ) at 1.5. The effects of bottom ash on properties of SCC were investigated by comparing the test results of SCC mixed with bottom ash with those of the control SCC made of river sand. Test results revealed that slump flow and L-box passing ability of the SCC mixtures with bottom ash reduced, while 500-mm slump flow time (T_{500}) increased with the increase of bottom ash replacement level. The use of bottom ash resulted in the reduction of compressive strength and caused increase of porosity of hardened concrete. However, in long term these properties were improved by pore refinement due to pozzolanic reaction when bottom ash was used to replace 10 % of total fine aggregate and water curing was performed. In term of durability, chloride penetration, carbonation depth, drying shrinkage of most of the bottom ash SCC mixtures except for the mixture with 10 % bottom ash were larger than those of the control SCC, mainly due to higher porosity. On the other hand, the resistance against sodium sulfate was enhanced with the increase of bottom ash content. By considering overall performances of the tested SCC mixtures with bottom ash, the optimum replacement percentage of bottom ash was found to be about 10 % by weight of total fine aggregate.

KEYWORDS: Self-compacting concrete, Bottom ash, Fine aggregate, Filling ability, Strength, Durability.

INTRODUCTION

Popularity of using self-compacting concrete (SCC) in concrete construction has increased in many countries, since SCC is effectively applied for improving durability and increasing reliability of structures while reducing the need of skilled workers at the construction site. However, its use is still limited in Thailand due its high cost as the main reason. In general, the cost of SCC is 20-40 % higher than that of conventional concrete. Wastes and by-products have been introduced into Thai concrete industry to conserve natural resources and environment as well as to reduce the cost of concrete. As an example, fly ash, a by-product from thermal power plants, has been widely used in Thai concrete industries as a pozzolanic material for replacing a part of cement due to its main benefits on workability and durability. The idea of using by-products to replace natural aggregates is another alternative solution to achieve environmental conservation as well as to obtain a reasonable concrete cost.

Bottom ash is the companion to fly ash in process of coal-burning with an approximate amount of 20 % by volume of the total ash, depending on the type of boiler, dust collection system, burning temperature and the type of coal. Its particle is porous, irregular, and coarser than that of fly ash but its chemical composition is not much different[1]. Some studies on the usage of bottom ash in concrete had been focused on its potential to replace or partially replace fine aggregate due to its similar particle size to that of normal sand[2,3,4,5]. Various attempts to apply bottom ash as a pozzolanic material had also been reported[6,7]. The bottom ash produced annually in Thailand, with an estimated amount of 750,000 tons, has been mostly dumped in landfill sites. As an example, the bottom ash produced from Maemoh power plant, the largest coal-power plant in Thailand, has been completely dumped at the plant as class I waste (non-toxic waste). Though, fly ash had been proved to enhance various properties of SCC, there has been no studies on the effects of bottom ash on SCC's properties. Therefore, this study focused mainly on the essential properties of powder-typed SCC incorporating bottom ash as partial fine aggregate replacement. It is noted here that if river sand, mainly used as fine aggregate with the average cost of 250 Baht/m^3 of concrete, can be partially replaced by bottom ash at the minimum content of 10 % of total fine aggregate, the cost of SCC can be reduced by at least 25 Baht/m^3 of concrete (about 2% of the unit cost of concrete on average), which is still significant for cost saving in concrete industry. The properties of SCC in this investigation include deformability and filling ability (i.e. slump flow, 500-mm slump flow time, and L-box passing ability), physical and mechanical properties (i.e. porosity and pore size distribution, and compressive strength), and durability (i.e. chloride penetration, carbonation depth, shrinkage in drying environment, and expansion in sodium sulfate solution).

Materials and Methods

Materials

Ordinary Portland cement (OPC) and lignite fly ash were used as cementitious materials. Bottom ash collected from a power plant in Saraburi province of Thailand was used as partial replacement of fine aggregate. The control fine aggregate was river sand with a fineness modulus of 2.78. Figs. 1 and 2 show the particle characteristics and gradations of bottom ash and river sand, respectively. Crushed limestone with a maximum size of 20 mm was used as coarse aggregate. Chemical compositions and physical properties of the tested materials are shown in Table 1. Void content of the compacted mixtures of fine and coarse aggregates, used for determining mix proportions, was tested according to ASTM C29/C29M-91a. Sodium sulfate solution (Na_2SO_4) which contains 50g of Na_2SO_4 (SO_4^{2-} of 33,800 ppm) in 1.0 liter of solution was prepared for sulfate expansion test.

Mix Proportion

Mix proportion was determined by controlling the ratio of paste volume to void volume of compacted

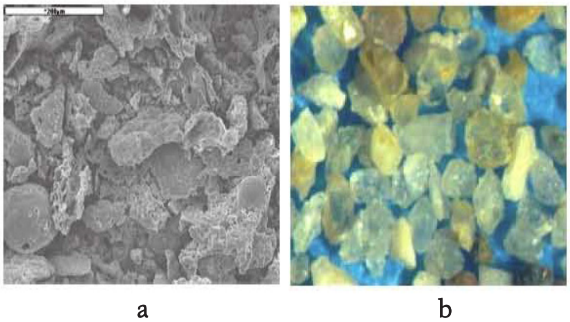

Fig 1. Bottom ash (Saraburi) (a) and river sand (b) which were used as fine aggregate in this study.

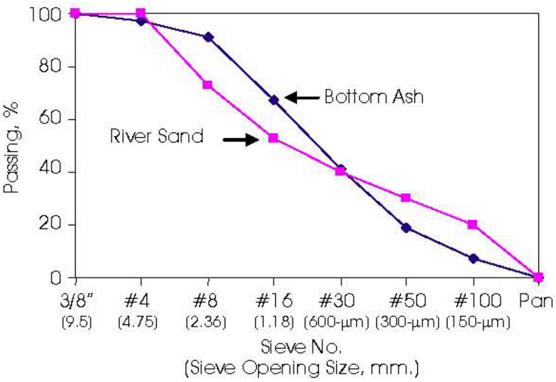

Fig 2. Gradations of river sand and bottom ash by sieve analysis test.

aggregate phase (γ) as a design parameter. The ratio γ is defined as,

$$\gamma = \frac{V_p}{V_{void}} \tag{1}$$

where V_p is the volume (m^3) of paste in a unit volume of fresh concrete and V_{void} is the volume (m^3) of void in the densely compacted total aggregate (fine and coarse aggregate) in a unit volume of the aggregate. The volume of paste can be derived from:

$$V_{paste} = V_c + V_f + V_w + V_{air} \tag{2}$$

where V_c, V_f, V_w, and V_{air} are the volume of cement, fly ash, water, and air, respectively.

In this study, the mix proportion of SCC was determined by fixing the γ value at 1.5 and the water to powder ratio at 0.31 in order to maintain the same paste content. The mixture using only river sand as fine aggregate was considered to be the control concrete and was prepared to have the minimum slump flow of 650 mm without visual segregation and the minimum L-box passing ability of 60 %. Bottom ash was used to replace fine aggregate at the ratios of 0 %, 10 %, 20 %, and 30 % by weight, and the notations of mixtures were specified as SCC-BA 0% (control), SCC-BA 10 %, SCC-BA 20 %, and SCC-BA 30 %, respectively. The dosage of superplasticizer was fixed at the same percentage of binder content. The tested mixture proportions are summarized in Table 2.

Previous studies have reported that concrete mixed with bottom ash is very stiff and non-workable due to a significant water demand from its porous properties[2,3,4]. In addition, water absorption of bottom ash cannot be obtained by using the standard test due to its specific characteristics i.e. rough surface, high porosity and light weight[8]. Therefore, water retainability of the porous solid particles in concrete has been introduced by some researchers for analysis and design of fresh concrete properties[9, 10, 11, 12]. Water retainability is defined as the water required to fill in pores and

Table 1. Chemical compositions and physical properties of materials used.

	Ordinary Portland cement	Fly Ash	Bottom Ash	River Sand
Chemical compositions				
SiO_2 (%)	20.10	38.07	38.64	-
Al_2O_3 (%)	4.93	22.89	21.15	-
Fe_2O_3 (%)	3.35	12.12	11.96	-
CaO (%)	66.04	18.40	13.80	-
MgO (%)	0.81	2.26	2.75	-
SO_3 (%)	2.57	1.77	0.61	-
Na_2O (%)	<0.01	1.09	0.90	-
K_2O (%)	0.56	2.29	2.06	-
Free lime (%)	0.73	0.72	0.03	-
Loss on ignition (%)	1.03	0.03	7.24	-
Physical properties				
Blaine fineness (cm^2/g)	3,230	2,640	8,365	-
Specific gravity (in ground form)	3.15	2.30	2.28	-
Water Required in percent of Control	-	95.0	123.5	-
Strength Activity Index at 7 days	-	83.7	48.6	-
Strength Activity Index at 28 days	-	89.0	56.1	-
% Passing of sieve analysis				
Opening size of sieve (sieve no.)				
9.50-mm (3/8")	-	-	100	100
4.75-mm (no. 4)	-	-	100	97
2.36-mm (no. 8)	-	-	73	91
1.18-mm (no. 16)	-	-	53	67
0.60-mm (no. 30)	-	-	40	41
0.30-mm (no. 50)	-	-	30	19
0.15-mm (no. 100)	-	-	20	7
Pan	-	-	0	0
Concrete Admixture	-	-	Water Reducer and Retarder	Superplasticizer
Brand	-	-	Daratard 500	Mighty MX
Based	-	-	Lignosulfonate	Naphthalene
Type According to ASTM C494	-	-	Type D	Type F
Specific Gravity	-	-	1.227	1.20
Solid Content (%)	-	-	48.08	40.0
pH	-	-	7.20	9.0

Table 2. Mix proportions of self-compacting concrete with the water to binder ratio of 0.31 and the ratio of paste volume to void volume of compacted aggregate phase of 1.5.

Mix	SCC-BA0%(Control)	SCC-BA10%	SCC-BA20%	SCC-BA30%
Cementitious Materials				
Cement-Type I kg./m.^{3}	385	385	385	385
Pulverised Fuel Ash (PFA) kg./m.^{3}	165	165	165	165
Water L./m.^{3}	**170**	**170**	**170**	**170**
Fine Aggregates				
River Sand kg./m.^{3}	850	765	680	595
Bottom Ash kg./m.^{3}	-	85	170	255
Coarse Aggregates				
Limestone (3/4"-#4) kg./m.^{3}	850	850	850	850
Admixtures				
Water reducer-Type D cc./m.^{3}	1,200	1,200	1,200	1,200
Superplasticizer-Naphthalene based cc./m.^{3}	5,800	5,800	5,800	5,800
Extra dosage of superplasticizer to obtain slump flow 700 mm. cc./m.^{3}	0	300	1,400	2,200
Water-Powder (w/p) ratio	0.31	0.31	0.31	0.31
Sand-to-Aggregate (s/a) ratio	0.5	0.5	0.5	0.5

dependently restricted on surface of solid particles. In other words, it comprises water absorption and water adsorption. It directly affects the amount of free water in fresh concrete[10, 11, 12]. When using porous aggregate, the water retainability had been recommended in stead of water absorption for the processes of design and quality control of fresh concrete[8]. As a result, in process of mix proportioning, the test method according to our previous publication[8] was adopted to determine the water retainability of bottom ash.

Tests

Tests for filling ability of SCC

Filling ability, the main property of fresh SCC, means the ability of the concrete to fill spaces in the formwork and encapsulate the steel bars only by gravity to achieve required performances of uniform-quality concrete structures. In general, filling ability can be characterized by three functional requirements of fresh concrete including deformability, segregation resistance and passing ability[13, 14]. Deformability was defined in this study to include deformation capacity and velocity of deformation indicated by slump flow value and 500-mm slump flow time (T_{500}), respectively. Both can be obtained from the slump flow test. The measurements were carried out conforming to RILEM Technical Committee-174. Segregation of SCC was observed by visual inspection during the slump flow test. The L-shape box apparatus was used to measure the passing ability of SCC through narrow openings. It is installed with four vertical bars to provide three 33-mm narrow openings as seen in Fig. 3. Its test result is expressed in percentage of passing ability calculated from the ratio of the drop height at the end of flow to the original height before the flow. In this study, the judgment of "not pass" for the L-box test was defined by the passing ability value of less than 60 %[15].

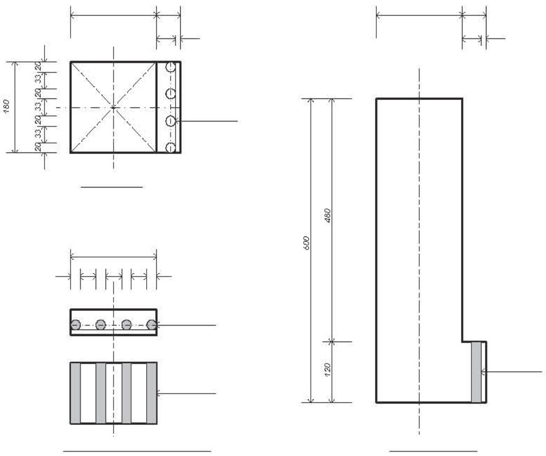

Fig 3. L-Shape test apparatus used to evaluate the passing ability through narrow openings.

Tests for physical property and strength of SCC

Total porosity and pore size distribution in hardened concrete were tested using mercury intrusion method at the concrete ages of 28 and 56 days. Compressive strength of SCC was tested according to BS 1881: Part 116.

Tests for durability of SCC

The test method of rapid chloride permeability was performed following ASTM C 1202 at the concrete ages of 7, 28, and 56 days. Each measured value was obtained from the averaged chloride charge pass of three specimens for each mixture. For measuring carbonation depth, the accelerated test method was conducted in accordance with the recommendation of RILEM Committee CPC-18, TC14-CPC. The concrete specimens were moist-cured for 28 and 56 days before carbonated in the accelerated carbonation chamber for periods of 2 and 4 weeks. The temperature and relative humidity in the carbonation chamber with carbon dioxide concentration of 4 % (40,000 ppm) were controlled at 40 °C and 55 %, respectively. Shrinkage in drying environment specimens was measured accordingly to ASTM C 387-99. The specimens were cured in water for 1 day and then put in the control room with the condition of 55 % relative humidity and 30 °C. The length change of specimens was measured at the drying ages of 1, 2, 3, 4, 7, 14, 28, 56, 91, 182 and 356 days by using the length comparator. Concrete deterioration subjected to sodium sulfate (Na_2SO_4, $N\underline{S}$) is usually exhibited in term of concrete expansion leading to cracking. Therefore, the test method for expansion of concrete specimens submerged in sodium sulfate solution was performed according to ASTM C1012. The initial length of the specimens was obtained by using the length comparator in accordance with the ASTM C 490 after 28 days of curing in saturated limewater. After that they were placed in the sodium sulfate solution and the length change was measured at 2, 3, 4, 8, 13, and 16 weeks of sodium sulfate exposure. After 16 weeks, the subsequent measurements were made every two months of exposure. Each expansion test result was obtained from the average of three specimens.

Results and Discussion

Effects of Bottom Ash on Filling Ability of SCC

Slump flow

Slump flow value is typically used as the measuring value for deformation capacity of self-compacting concrete (SCC). The effect of bottom ash on slump flow of SCC at different levels of river sand replacement is shown in Fig. 4(a). It can be seen that the slump flow of SCC mixed with 10 % bottom ash was slightly lower

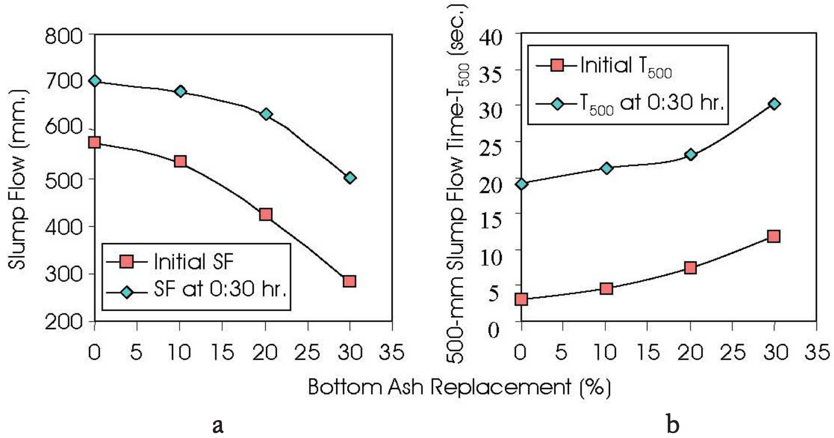

Fig 4. Slump flow (a) and 500-mm slump flow time (b) of the mixtures with bottom ash of 0%, 10 %, 20 % and 30 %.

than that of the control mixture. However, when the bottom ash content was more than 10 %, the slump flow of the bottom ash SCC decreased significantly with the increase of bottom ash content. It is considered to be due to the increase of aggregate-to-aggregate friction from the highly irregular shape and rough texture of bottom ash particles. However, the slump flow of SCC mixtures with bottom ash could be increased by adding an extra superplasticizer dosage with the increase of bottom ash content as shown in Table 2. This finding corresponds to the studies of effects of bottom ash on workability of conventional and asphaltic concrete[3, 4, 5]. It was also revealed that the mixtures with 20 % and 30 % bottom ash lost their slump flow significantly at 30 minutes after mixing when compared with either the control mixture or the mixture with 10 % bottom ash content. It indicated that the loss of slump flow must be paid attention for SCC incorporating bottom ash as partial replacement of river sand if the replacement percentage is over 10 %. Proper use of retarding admixture can be a solution to the slump flow loss problem.

Slump flow time (T_{500})

The measurement of 500-mm slump flow time (T_{500}) was conducted to evaluate the velocity of deformation of the tested SCC mixtures[14]. Fig. 4(b) also shows the effect of bottom ash on T_{500}. The figure shows that SCC-BA 30 % has the longest T_{500} followed by SCC-BA 20 %, respectively, while SCC-BA 10 % results in similar T_{500} as SCC-BA 0 %. The larger T_{500} of the bottom ash SCC is considered to be due to the increase of inter-particle frictions among aggregate particles produced from bottom ash particles. It is also seen that when increasing bottom ash content, the trend of slump flow time at 30 min after mixing was similar to that of the initial time just after mixing.

L-box passing ability

Fig. 5 shows the test results of passing ability through narrow openings evaluated by using the L-box apparatus. The values of passing ability of SCC-BA 0 %, SCC-BA 10 %, SCC-BA 20 % and SCC-BA 30 % are 83.0 %, 80.0 % 60.0 % and 5.0 %, respectively. It reveals that L-box passing ability of SCC-BA 10% was slightly lower than that of the control SCC but with the increase of the replacement levels of bottom ash, passing ability of SCC-BA 20% and SCC-BA 30% decreased significantly. Aggregate blocking was observed in mixture SCC-BA 30 % due to the higher of inter-particle friction caused by the bottom ash particles, promoting the aggregate bridging at the vicinity of clear spacing between steel bars. As the L-box passing ability of higher than 60 % was recommended as the passing condition for the test, the good L-box passing ability was recognized for the control mixture and the mixture containing 10 % and 20 % bottom ash. It should be noted here that the condition of the bar spacing in the L-box test is more critical than many of the real construction condition.

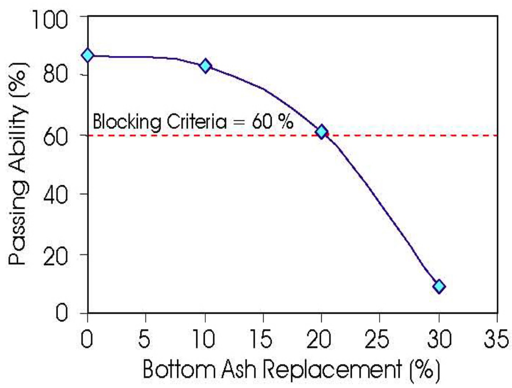

Fig 5. L-shape passing ability of the mixtures with bottom ash of 0%, 10%, 20% and 30%.

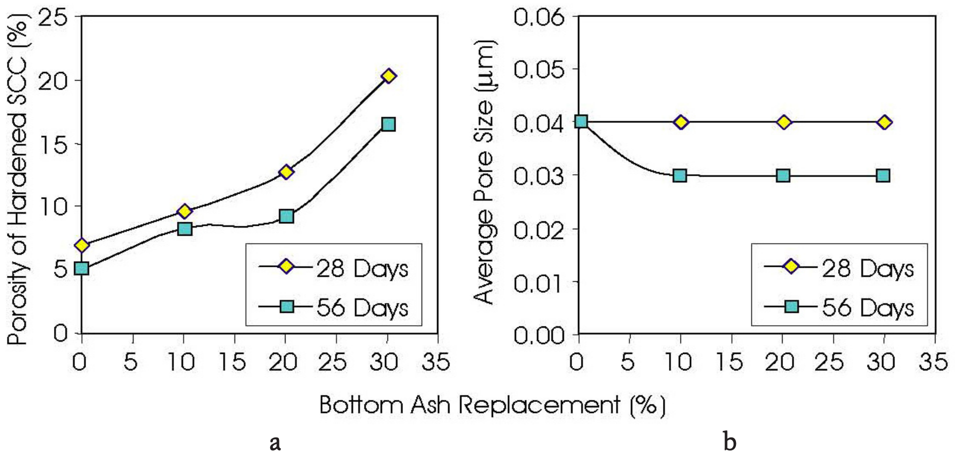

Fig 6. Porosity and average pore size of the mixtures with bottom ash of 0 %, 10 %, 20 % and 30 % at the ages of 28 and 56 days.

Segregation

By visual inspection during the slump flow test, segregation was not found in all tested SCC mixtures. The mixtures were stiffer when increasing bottom ash content.

Effects of Bottom Ash on Physical Property and Strength of SCC

Porosity of hardened SCC

From the test results presented in Fig. 6(a), it was observed that SCC-BA 30 % had the highest porosity at the concrete age of 28 days, followed by SCC-BA 20 %, SCC-BA 10 % and the control SCC, respectively. This is because the highly porous property of bottom ash particles increases total porosity of concrete. At the age of 56 days, the total porosity of all SCC mixtures reduced, however the total porosity of bottom ash SCC mixtures were still higher than that of the control concrete. Fig. 6(b) also shows that at the age of 28 days, all tested SCC mixtures had equivalent average pore size. The figure also reveals that comparing to the results at 28 days, the average pore size of all bottom ash SCC mixtures at 56 days of age became smaller while that of the control mixture was almost unchanged. It is considered to be due to the pore refinery effect by pozzolanic reaction especially from fine ash particles. Figs. 7 and 8 present the relationships between porosity of hardened SCC mixtures vs. compressive strength and durability (i.e. chloride permeability and carbonation depth). They indicate that there are relations between porosity and properties of hardened SCC incorporating bottom ash, which will be discussed in the sections of the related properties.

Compressive strength

Fig. 9 presents the effect of bottom ash on compressive strength of SCC when it was used to replace river sand at different percentages. It was found that almost all of the bottom ash mixtures except for SCC-BA 10 % had lower compressive strength than the control SCC at all concrete ages. At the replacement levels higher than 10 %, the compressive strength of bottom ash SCC decreased with increasing bottom ash content. It can be explained by considering Fig. 7 that

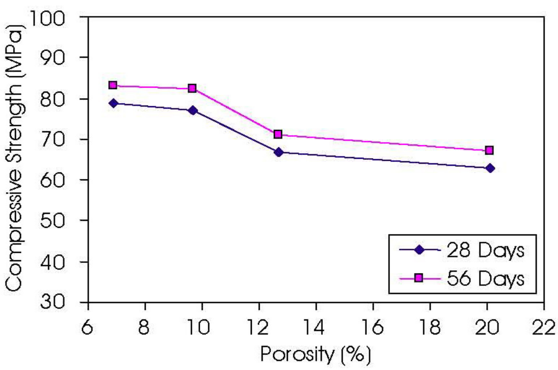

Fig 7. Relationship between porosity and compressive strength at the concrete ages of 28 and 56 days.

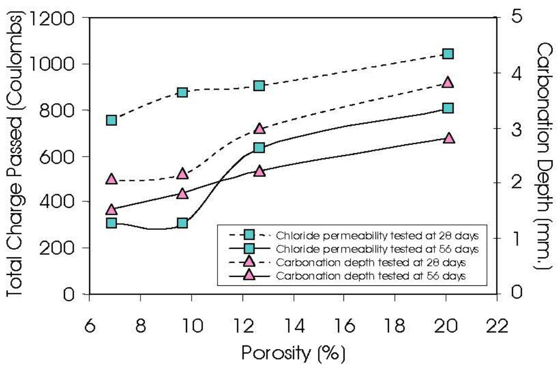

Fig 8. Relationship between porosity versus total chloride permeability and carbonation depth of the mixtures tested at the concrete ages of 28 and 56 days.

the increase of porosity in hardened concrete due to the use of bottom ash results in the reduction of compressive strength. At the age of 28 days, the compressive strength of the SCC mixed with 10 % bottom ash was equivalent to that of the control SCC and the strength of the SCC mixture became higher than that of the control SCC at the age of 56 days, while those of the mixtures containing 20 % and 30 % bottom ash were still lower. This may be due to the pore refinery effect, by pozzolanic reaction of bottom ash, which dominates over the effect of increase of porosity at the replacement level of 10 %. At the levels of 20 % and 30 % bottom ash content, the pore refinery effect by pozzolanic reaction is not dominant when compared to the increase of porosity (average pore size did not reduce when bottom ash replacement was increased from 10 % to 20 % and 30 % while the porosity increased). So, this indicates that the long term compressive strength of SCC can be enhanced by replacing 10 % of total fine aggregate by the bottom ash.

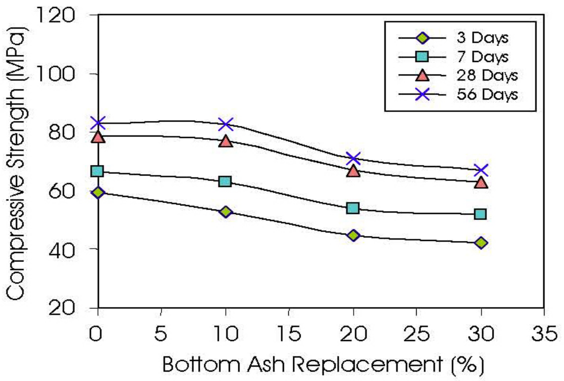

Fig 9. Compressive strength of the mixtures with bottom ash of 0 %, 10 %, 20 % and 30 %.

Effects of Bottom Ash on Durability of SCC

Chloride permeability

The chloride permeability of the tested SCC mixtures is shown in Fig. 10. It was found that the higher the bottom ash content the higher the chloride permeability at the concrete age of 7 days. It was also revealed that the chloride charge passed of all SCC-BA mixtures reduced with the age of concrete. At the age of 28 days, all tested SCC mixtures had not much different Cl^- permeability. The same tendency was also found for 56 days of age. It was mainly influenced by the tightness of the long-age mixtures due to low water to binder ratio. At the concrete age of 56 days, the Cl^- permeability of SCC-BA10 % was about the same as, in fact a little lower than, that of the control concrete, while those of SCC-BA 20 % and SCC-BA 30 % were higher. This reduction of chloride diffusion is considered to be due to the improved pore structure (reduced pore size) by pozzolanic reaction at the optimum bottom ash content (10 %) and long term water-curing.

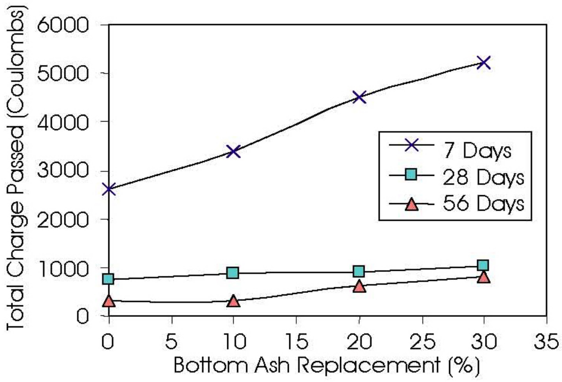

Fig 10. Rapid chloride permeability of the mixtures with bottom ash of 0 %, 10 %, 20 % and 30 %.

Carbonation depth

According to the test results of carbonation depth, shown in Fig. 11, tested for one month in acceleration chamber, the carbonation depth, tested at concrete ages of 28 and 56 days, increased with the increase of bottom ash content. The carbonation depths of SCC containing 10 % bottom ash were a little larger than those of the control concrete. On the other hand, carbonation depths of SCC-BA 20 % and SCC-BA 30 % were much larger than those of the control mixtures. Figs. 8 shows the strong relations between the tested carbonation depth and porosity implying that higher CO_2 diffusion was attributed to higher porosity of concrete due to the increase of bottom ash content. The carbonation depth of bottom ash SCC mixtures was smaller when tested at the longer concrete age due to the effect of pore densification by pozzolanic reaction of bottom ash.

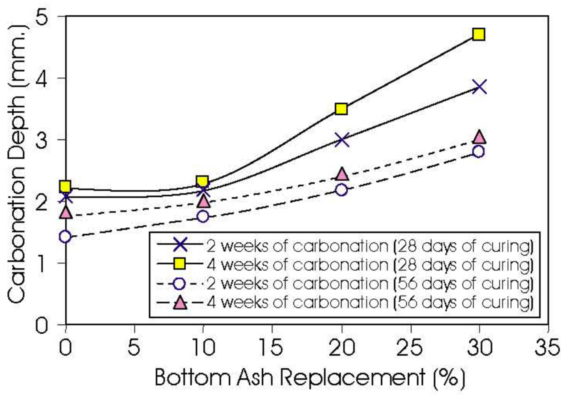

Fig 11. Carbonation depth of the mixtures with bottom ash of 0 %, 10 %, 20 % and 30 % tested after 28 and 56 days of curing.

Shrinkage in drying environment

Since the tested mixtures in this study had very low water to binder ratio, the shrinkage measured in drying environment includes both autogeneous and drying shrinkages. Fig.12 indicates that the trend of drying shrinkage of the test samples increased with drying period and gradually stabilized after about 91 days of drying. It was also found that the mixture with higher bottom ash content displayed larger shrinkage, whereas the control concrete exhibited the smallest shrinkage. Basically, the rate of water evaporation from concrete depends on the pore structures of concrete i.e. pores size and pore volume, and the condition of environment[16]. Test results of porosity indicate that the higher rate of concrete drying was attributed to the increase of porosity due to the increase of bottom ash content.

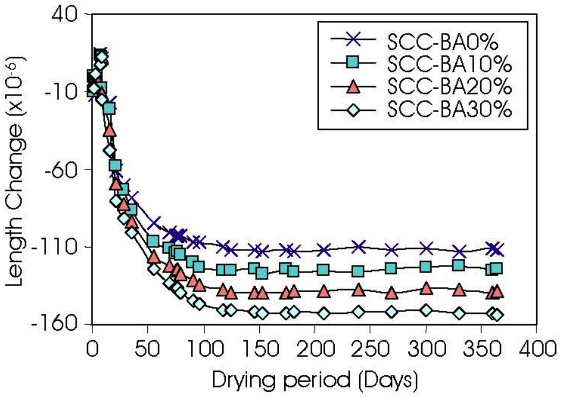

Fig 12. Shrinkage in drying environment of the mixtures with bottom ash of 0 %, 10 %, 20 %, and 30 %.

Expansion induced by sodium sulfate

The results of length change of specimens due to external sodium sulfate attack at various immersion times are shown in Fig. 13. The expansion of all concrete specimens increased linearly with the submerging period during the first 196 days. After that, the expansion of each mixture was nearly stabilized until the end of the test period (12 months). It revealed that the expansion of the control SCC was the largest, followed by SCC-BA 10 %, SCC-BA 20 % and SCC-BA 30 %, respectively. Specimen break-down was not found in this study possibly because of the dense matrix of SCC with a low water to binder ratio. The dense matrix significantly reduced permeability and then diffusion of SO_4^{2-} ions into the concrete. Test results indicate that the increase of bottom ash content results in better resistance to sodium sulfate. This is because gypsum produced by the reaction of sodium sulfate with calcium hydroxide from the hydration of cement, resulting in secondary ettringite to cause expansion in concrete[17], is reduced by the pozzolanic reaction of bottom ash. In spite of the higher porosity, the expansion of SCC mixtures with bottom ash decreases with the increase of bottom ash content. This indicates that the sodium sulfate resistance can be achieved by pozzolanic reaction of bottom ash, which dominates over the increase of porosity. The improvement on sulfate resistance is beneficial for SCC application in sulfate exposing structures such as underground structures, bored piles, and undersea structures etc.

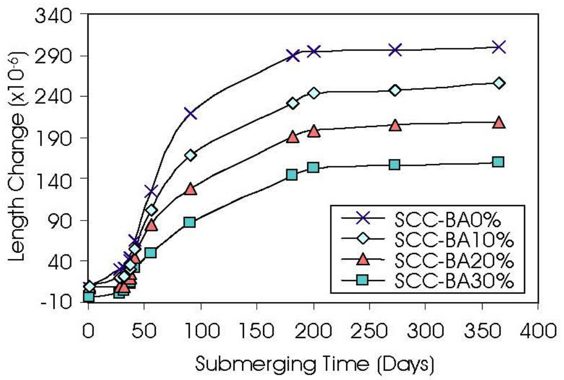

Fig 13. Expansion in sodium sulfate of the mixtures with bottom ash of 0 %, 10 %, 20 % and 30 %.

CONCLUSIONS

Experimental results revealed that slump flow and L-box passing ability of the SCC mixtures with bottom ash reduced, while the slump flow loss and 500-mm slump flow time (T_{500}) increased with the increase of bottom ash replacement level. However, the required slump flow could be maintained by adding an extra dosage of superplasticizer. The increase of bottom ash content resulted in the reduction of compressive strength and caused the increase of porosity of hardened concrete. However, at 10 % bottom ash replacement of fine aggregate, the compressive strength at 56 days of age was improved by pore refinement effect due to pozzolanic reaction which dominated over the increase of porosity. In terms of durability, chloride ion permeability, carbonation depth and shrinkage in drying environment of most of the tested bottom ash SCC mixtures except for the mixture with 10 % bottom ash were larger than those of the control SCC, mainly due to higher porosity. On the other hand, the resistance against sodium sulfate was enhanced with the increase of bottom ash content. The durability of SCC mixtures with bottom ash could be improved in long term by pore refinement due to pozzolanic reaction when water-curing was conducted. As a result, it is reasonable to conclude that the optimum replacement for the tested bottom ash was about 10 % by weight of total fine aggregate. However, the bottom ash replacement level higher than 10 % may be applied for particular works depending on total concrete cost and construction condition.

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