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Properties of fine-grained concrete containing fly ash and bottom ash

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Abstract. In the present paper, large amounts of bottom ash (BA) and fly ash (FA) in a Vung Ang thermal power plant in Vietnam were used to substitute crushed sand (CS) to produce fine-grained concrete. The FA content was fixed at 20 %, the BA content increased from 20 % to 50 % corresponding to the CS content decreased from 60 % to 30 %. Four mixtures of fine-grained concrete were prepared to produce concrete. It was found that the compressive and splitting tensile strengths decreased when the amount of FA and BA increased from 40 % to 70 %. The compressive and the splitting tensile strengths were comparable to those in conventional concrete containing bottom ash. The larger content of bottom ash caused higher water absorption and resulted in lower chloride resistance, which is because of the porous structure of BA. Based on the results of chloride resistance, this fine-grained concrete is classified as moderately permeable concrete. The results of this study indicated that crushed sand (fine aggregate) of fine-grained concrete can be replaced by fly ash incorporated with bottom ash up to 60 % and this fine-grained concrete can be applied for construction works as conventional concrete.

1. Introduction

Industrial wastes discharged from the thermal power plant or cement factories such as fly and bottom ashes have increased rapidly and threatened the environment. A large amount of these industrial wastes are available in many countries, especially in developing countries as Vietnam. [1–6]. It was reported that the volume of these ashes released from the thermal power plant, annually, is approximately 25 million tons, and it is expected to be 40 million tons by 2030 [7]. Bottom ash content accounts for approximately 20-25 % of the total amount of these ashes [8], and the particle size of this bottom ash has a similar size compared to that of natural fine sand i.e. river sand [2, 6, 8–11]. If these bottom and fly ashes are not used, a large area of land is needed for dumping. This also causes environmental issues like heavy metal leaching [2, 6, 8]. Therefore, authors in the field have tried to capitalize fly and bottom ash instead of partially cement and fine aggregate to benefit both economic and environmental matters [5, 12–14].

Fly ash, a by-product is known as a pozzolanic material that consists of a high amount of silica like in silica fume or rice husk ash [15–19]. Thus, fly ash has been extensively employed in the concrete field in order to enhance concrete properties in the long term such as compressive strength and chloride resistance [20–23]. On the other hand, although previous studies found that bottom ash has a low pozzolanic reaction, it does not have a negative impact on the strength development of concrete when an

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appropriate amount for replacing for aggregate is used [11]. Many researchers have revealed that bottom ash could be utilized in pervious concrete or high-strength concrete, as fine aggregate [24–26].

In cement concrete, coarse aggregate takes a crucial role as a main component. However, the sources of the coarse aggregate are becoming scarce, thus, exploring a new ingredient to take the place of coarse aggregate is now essential. Natural or crushed sand has been using as a new material for replacing coarse aggregate in fine-grained concrete manufacturing (sand concrete) [3, 27, 28]. This fine-grain concrete is found to gain the same compressive strength as conventional concrete. The fine-sand concrete is considered to be fine aggregate concrete, whereas coarse aggregate is substituted by fine sand and filler material, respectively [4, 29–31]. The previous study indicated that fine-sand concrete can have comparable high compressive strength as well as durability as those of high strength concrete [4]. In addition, due to the scarcity of natural resources of river sand, researchers in the field have attempted to use fine sand, dune sand, and saline sand to replace river sand in fine-grained concrete [29, 32].

As previously discussed, bottom ash possesses a grain size, which is comparable to river sand, thus, it could be used as a new material for the replacement of fine aggregate (river sand and crushed sand). Besides, previous studies reported that bottom ash has a porous structure that could have advantages in reducing concrete shrinkage [33, 34], because of its high water absorption ability that could produce an internal curing effect [10, 35, 36]. Bottom ash has been popularly utilized in conventional concrete in many previous studies [2, 3, 6, 14, 26, 37, 38]. They found that using bottom ash could bring both positive and negative effects such as improving compressive and tensile strengths at later age, but reducing chloride resistance or increasing water absorption of concrete [2, 6, 8, 9, 26, 38]. However, to our best knowledge, the substitution of fine and coarse aggregates with a substantial amount of fly ash and bottom ash for producing fine-grained concrete has not been studied so far. Therefore, this study will firstly investigate mechanical characteristics and durability of fine-grained concrete using fly and bottom ash replaced for fine aggregate at a high level. Fly ash and bottom ash in Vung Ang thermal power plant, Vietnam is selected as a case study in this research. The mechanical characteristics are investigated through compressive and splitting tensile strengths and the durability is examined through chloride penetration and water absorption test.

2. Materials and Measurements

2.1. Materials, mixture proportion, and preparation

2.1.1. Materials

Portland cement (PC40), crushed sand (CS), fly ash (FA), bottom ash (BA) were used for producing fine-grained concrete in this study. CS was taken from Phu Ly province that meets ASTM C33 standards on particle size and other properties. FA and BA were sourced from Vung Ang thermal power plant. The chemical composition, as well as physical characteristics of cement, CS, FA, and BA, are presented in Table 1. A Superplasticizer Original Acrylic Polymers (Dynamon BT2) was used as well. The grain size distributions of fly ash, bottom ash, and crushed sand are shown in Fig. 1 and the pictures of these materials are displayed in Fig. 2.

Table 1. Chemical compositions of materials used.

Chemical composition (%)	PC40	FA	BA	Crushed sand
SiO_2	21.49	53.9	49.59	54.88
Al_2O_3	5.4	21.8	20.14	0.02
Fe_2O_3	3.49	6.7	3.50	0.04
CaO	63.56	4.27	4.13	0.17
MgO	1.40	1.45	1.15	0.45
Na_2O	0.12	0.67	0.15	0.02
K_2O	0.3	3.4	3.76	0.04
LOI	0.19	6.27	1.45	1.25
Density (g/cm^3)	3.1	2.2	2.34	2.72
Mean particle size (⌠m)	16.1	26.9	–	–
Blaine SSA (m^2/g)	3730	–	–	–

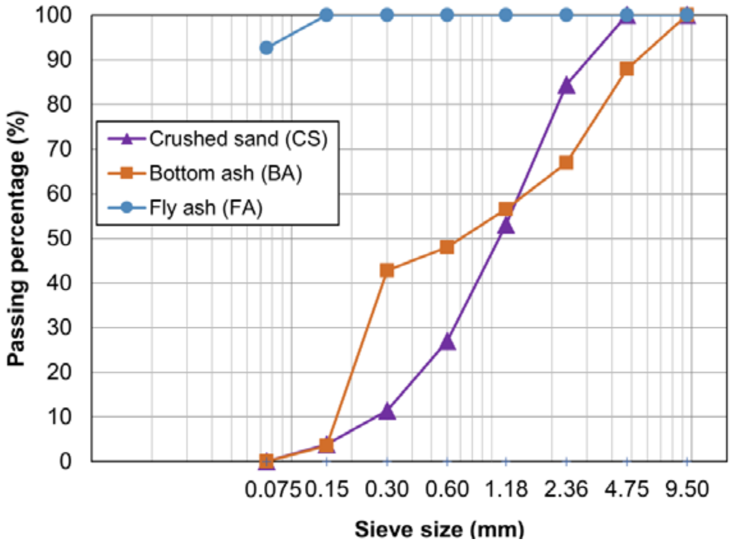

Figure 1. Distribution of particle size of crushed sand, fly ash, and bottom ash.

a. But Son Portland cement

b. Fly ash from Vung Ang

c. Bottom ash from Vung Ang

d. Crushed sand from Vung Ang

Figure 2. Materials for preparing fine-grained concrete.

2.1.2. Mixture proportions

Fine-grained concretes were prepared based on the absolute volume of the component materials [4]. The water/binder ratio was designed based on ACI 211.1 and ACI 363.2R. A consistent water/binder (w/b) ratio of 0.34 was used in all mixtures. The amount of cement was kept consistent for all mixtures (395 kg/m^3). FA and BA were adopted as a fine aggregate to partially replace the amount of crushed sand: the total amount of FA and BA ranging from 40 % to 70 % of the total weight of aggregate, whereas the amount of FA was fixed at 20 % in order to evaluate the effect of BA content to concrete properties. The amount of superplasticizer (water-reducing agent) was set constantly as 1.8 % by weight of cement. Table 2 shows the proportion of four mixtures and Fig. 3 presents the grain size distributions of all mixtures.

Table 2. Mixing proportion of fine-grained concrete.

Mixture	w/b	Water (kg/m^3)	Cement (kg/m^3)	Fly ash (kg/m^3)	Crushed sand (kg/m^3)	Bottom ash (kg/m^3)	Admixture (kg/m^3)
60CS-20BA-20FA	0.34	135	395	372	1116	372	7.11
50CS-30BA-20 FA	0.34	135	395	363	909	545	7.11
40CS-40BA-20 FA	0.34	135	395	355	710	710	7.11
30CS-50BA-20 FA	0.34	135	395	346	520	866	7.11

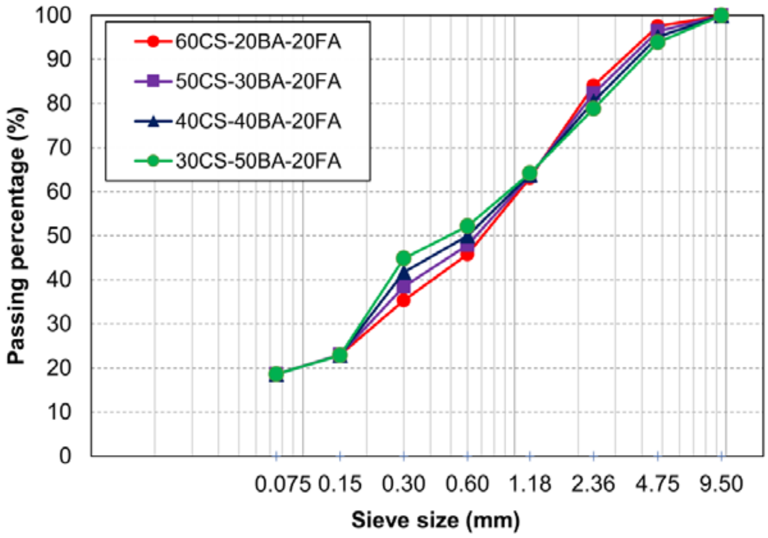

Figure 3. The particle size distribution of different mixtures.

2.1.3. Preparation and casting of specimens

A mixer is used to produce mixtures with 8 min of mixing for each mixture. Crushed sand, fly ash, bottom ash, and cement were mixed for 2 min in dry condition. After that, approximately 80 % water was added to the mixture and then they were mixed for 2 more min. Consequently, the remaining water combined with superplasticizer was supplied, and then mixed again for 4 min. The specimens used for determining compressive strength were cubed with a size of 70.7 × 70.7 × 70.7 mm, and the cylindrical specimens with a size of 150 × 300 mm were used to determine the splitting tensile strength. While the specimens used for chloride penetration and water absorption tests were also cylinders with a size of 100 × 200 mm. All specimens were cast with two layers using the vibration table, each layer was vibrated for 20 s. After compacting, the top of molds was sealed with polyethylene sheets and cured in a control room with a temperature of 20 °C. After one day, all specimens were demolded and cured in a water bath at 20 ± 2 °C up to designated ages. All tests in this study were conducted in triplicate and the mean value was used.

2.2. Testing of the specimens

2.2.1. Slump flow test

To assess the workability of fine-grained concrete, a slump flow test was conducted. The slump flow test was performed as per ASTM C143 [39]. Fig. 4 shows the measurement method of the test, in which the diameter of the circle reveals the slump value in three measurements.

Figure 4. Example of measuring the slump flow of fine-grained concrete.

2.2.2. Compressive strength and splitting tensile strength

To determine the compressive strength of fine-grained concrete, the compression test was conducted by referring to ASTM C39 [40, 41] for the specimens at the ages of 3, 7, and 28 days. The example of the compression test is described in Fig. 5.

Figure 5. Preparation of specimen and compression test*.*

The splitting tensile strength is one of the important factors, which affects properties of concrete such as controlling cracks, stiffness, bonding capacity to reinforcement, and durability. The splitting tensile strength was conducted based on ASTM C496 on specimens at 3, 7, and 28 days of curing [40, 41]. The pictures of examples of splitting tensile strength are shown in Fig. 6.

Figure 6. Example of the splitting tensile strength test.

2.2.3. Rapid chloride permeability and water absorption

The rapid chloride penetration was applied for the specimens at 28 days according to ASTM C1202-97 [42]. Fig. 7 shows the preparation and example of a chloride penetration test. The classification of chloride resistance can be referred to Table 3.

Table 3. Classification of chloride penetration value according to charge passed [42].

Charge passed (Coulomb)	Chloride ion penetration
> 4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very low
< 100	Negligible

Fig. 7. Preparation and example of a chloride penetration test

The water absorption test was conducted as per TCVN 3113-1993 [43]. The experiment was conducted using the specimen at 28 days and an example of the preparation procedure is shown in Fig. 8. The water absorption of each specimen can be calculated by equation 1.

$$H = \frac{(m_1 - m_0) \times 100\%}{m_0}, \quad (1)$$

where: H is the water absorption of each specimen by percentage (%);

m_1 denotes the specimen under saturated condition (g);

m_0 indicates the specimen weight under the dry condition (g).

Figure 8. Soaking and drying concrete samples.

3. Results and Discussion

3.1. Workability and density of the fresh mixture

The slump flow values of different fresh mixtures are shown in Fig. 9. It can be observed that the mixture with 20 % BA (60CS-20BA-20FA) achieved the highest value compared to other mixtures. The increase in the content of bottom ash caused a reduction in the slump flow value. We can see that when the amount of BA grew up from 20 % to 50 %, the slump flow value decreased from 27 to 23 cm. This result concurs with findings in the previous studies on the conventional concrete mixture using bottom ash and rice husk ash [4, 44–46]. As reported in previous studies, bottom ash is a porous material containing meso and macro-pores inside and on the surface of particles, which helps to generate a large surface area and consequently absorb more water [44–46]. Besides, BA has a rough surface with an irregular shape, which causes high friction between particles, resulting in decreasing the slump of the fresh mixture, as indicated in previous studies [6, 8, 24, 26].

Fig. 10 presents the density of different concrete mixtures. Similar to the slump flow, the density of mixtures also reduced with an increase of BA content. This could be explained by porous structure as mentioned above and the lower specific density of BA compared to that of crushed sand as displayed in Table 1. This result is in line with the results of previous studies using BA [1, 6, 8, 24, 26]. In addition, because BA can absorb more mixing water, more and larger pores appear which causes the porous structure of concrete [8]. As a result, when a higher amount of crushed sand is replaced by BA, the unit weight of fresh concrete decreases.

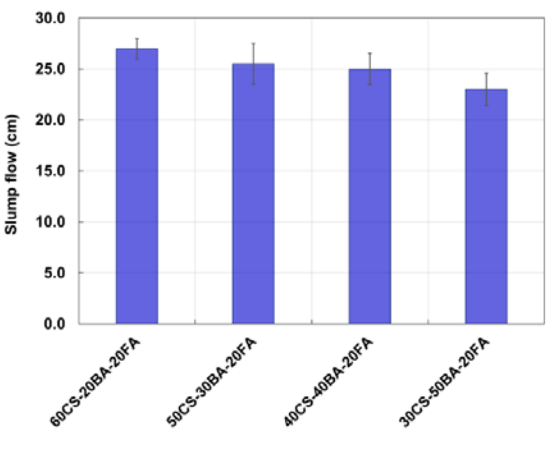

Figure 9. Slump flow of different fresh concrete mixtures.

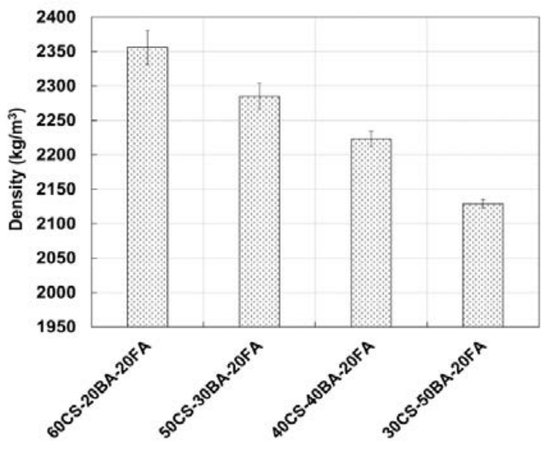

Figure 10. The unit weight of different fresh concrete mixtures.

3.2. Compressive strength and splitting tensile strength

3.2.1. Compressive strength

The compressive strength of different fine-grained concrete mixtures comprising FA and BA at 3, 7, and 28 days are presented in Fig. 11. The results imply that the compressive strength of different mixtures depends on the amount of BA in the mixture, as found in the previous study [45]. The compressive strength increased rapidly from 3 to 7 days, then slowlier from 7 to 28 days for all mixtures. Mixture with 20 % BA showed the highest values of compressive strength. These values were 27.0, 42.7, 52.7 MPa for the ages of 3, 7, and 28 days, respectively. The lowest values were observed for the mixture with 50 % BA. They were 14.4, 22.1, and 30.1 MPa for the age of 3, 7, and 28 days, respectively. The maximum differences of the compressive strength between the mixture containing 20 % BA and 50 % BA at 3, 7, and 28 days were 46.7 %, 48.2 %, and 42.9 %, respectively. Furthermore, when the amount of bottom ash increased, the compressive strength of concrete decreased for all curing ages, and this is consistent with results in the previous studies [24, 31, 39, 40, 43, 45, 47, 48]. The reason for lowering the compressive strength is similar to what was discussed in the previous section. Firstly, the BA particles are weaker and more porous compared to crushed sand particles [8]. Secondly, because of the larger surface area and porous structures, BA particles absorb higher amount of mixing water, which causes the increase in pore volume due to bleeding and thus lowering the density of fresh concrete. These pores reduce the bonding between aggregate and cement paste, and create a porous and weak interfacial transition zone (ITZ) between them; this resulted in the decreasing of compressive strength [8]. According to Fig. 11, we can see that at 28 days, the compressive strength achieved from is 30.1 to 52.7 MPa for all mixtures. These values of compressive strength are slightly higher than those (27.6–48.3 MPa) of conventional concrete containing bottom ash with similar cement content (ranging from 356 to 475 kg/m^3) and water/cement (0.32–0.67) [49]. From these results, it can be concluded that this fine-grained concrete is probably satisfied to use in construction works like conventional concrete.

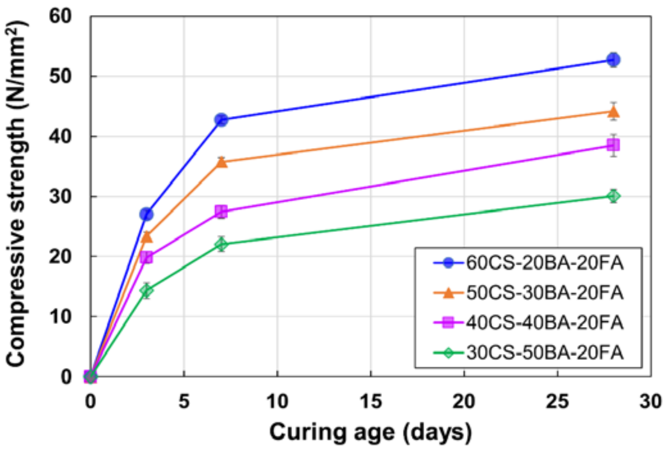

Figure 11. Compressive strength evolution of concrete until 28 days.

3.2.2. Splitting tensile strength

The splitting tensile strength of all mixtures has a similar behavior as obtained in the compressive strength as discussed previously. The splitting tensile strength increased linearly from 3 to 28 days. The highest tensile strength was observed in specimens with 20 % BA content and the lowest value was recorded in specimens with 50 % BA content. The highest values were 2.4, 3.2, and 4.3 MPa found in the mixture with 20 % BA at 3, 7, 28 days, respectively. The lowest values recorded in the mixture with 50 % BA were 1.6, 2.2, and 3.0 MPa for the ages of 3, 7, 28 days respectively. The maximum differences between the mixture containing 20 % BA and 50 % BA at 3, 7, and 28 days were 33.3 %, 31.3 %, and 30.2 %, respectively. These reduction values in the splitting tensile strength were smaller than those in the compressive strength reduction, it thus can be understood that bottom ash has less influence on the splitting tensile strength development than the compressive strength, this result is different from what has been found in the previous studies [8, 49]. This distinctive characteristic is probably attributed to the addition of water-reducing agents and material constituent (the previous study included coarse aggregate). It was indicated that the addition of this admixture could improve the splitting tensile strength [49]. Similar to the compressive, the splitting tensile strength decreased with increasing the amount of bottom ash, which agreed well with earlier studies (Fig. 12) [6, 47, 50, 51]. For example, at the age of 28 days, when the BA amount grew up from 20 % to 50 %, the splitting tensile strength decreased by approximately 30 %. This reduction was much stronger than that (ranging 2.02–15.74 %) in the previous study [6]. It was indicated that the tensile strength is mainly attributed to bonding between aggregate and cement paste [4, 52, 53].

The reduction in the tensile strength is possibly owing to the abundance of FA and BA that can cause porous micro-aggregate and increase porosity [4, 8]. These greatly weaken ITZ between aggregate and cement paste that causes the decrease of tensile strength. From Fig. 12, at 28 days, we can also observe that the splitting tensile strength ranged approximately from 3.0 to 4.3 MPa for all mixtures; this value is almost equal to those of 3.0-4.2 MPa and 3.8-4.3 MPa of self-compacting concrete and concrete comprising bottom ash with similar cement content, (ranging from 356 to 475 kg/m^3) respectively in previous studies [49, 52]. It implies that the value of splitting tensile strength of this fine-grained concrete could be satisfied with the requirement of conventional concrete.

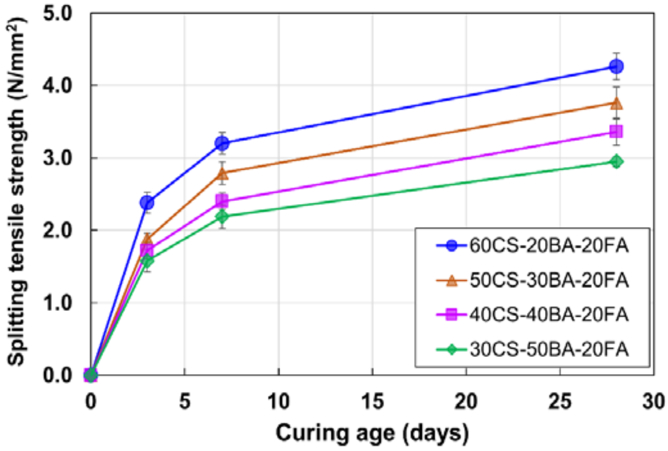

Figure 12. The tensile strength development of different mixtures.

The ratios between compressive/splitting tensile strength are shown in Fig. 13. Generally, the higher amount of FA and BA caused a lower ratio for all curing ages. At 28 days, the highest ratio was 12.4 for the mixture with 20 % BA, whereas the lowest one was 10.2 or the mixture with 50 % BA. Overall, it can be observed that the ratios were in the range of 9.1–13.4, similar to high-performance fine-grained concrete comprising rice husk ash [4] and lower than those (in range 10.5–15.2) of ordinary concrete [54]. It indicates that this fine-grained concrete containing a high amount of FA and BA can have a better splitting tensile strength in comparison with ordinary concrete with the same compressive strength. According to Le et. al [4] the high splitting tensile strength is because crushed sand used as a major aggregate can mitigate wall influence in cement paste and reduce the thickness of ITZ [44, 55].

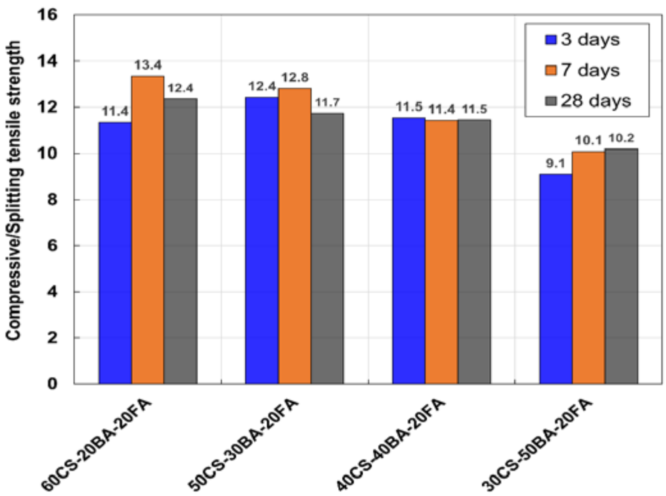

Figure 13. Ratios of compressive/splitting tensile strength.

3.3. Chloride Penetration Resistance and water absorption

3.3.1. Results of the chloride penetration test

In the marine environment, the lifecycle of reinforced concrete structures depends mainly on the degradation due to the corrosion of steel reinforcement resulted by chlorine penetration. It is generally accepted that the durability of mortar and concrete structures are governed by chloride penetration resistance. When the concentration of chloride is higher than a certain threshold, the reinforcement steel bar will be corroded [56, 57]. Thus, it is vital to discover the chloride penetration of this fine-grained concrete.

Fig. 14 shows the results of the rapid chloride test of different mixtures. The values of chloride permeability ranged from 2156 to 2430 coulombs. These values were slightly lower than those observed in the normal concrete containing similar cement content, water/cement, and amount of water-reducing admixture (416 and 475 kg/m^3 cement and water/cement ratio ranging from 0.322–0.526, and water-reducing admixture from 5.67–11.34 kg/m^3), and this concrete can be classified as a moderately permeable concrete [49]. In addition, these values were smaller than those of concrete comprising bottom ash in the previous study [10, 49]. It can be observed that chloride permeability values increase when the BA content in the mixture increases from 20 % to 50 %. These results agree well with previous studies [10, 49]. Ghafoori and Bucholc [49] stated that increasing the amount of bottom ash caused increasing chloride penetration of concrete containing bottom ash. The higher chloride permeability found in the mixture with a higher amount of BA can be explained by the porous microstructure of BA and lower fresh density when the amount of bottom ash increase [8].

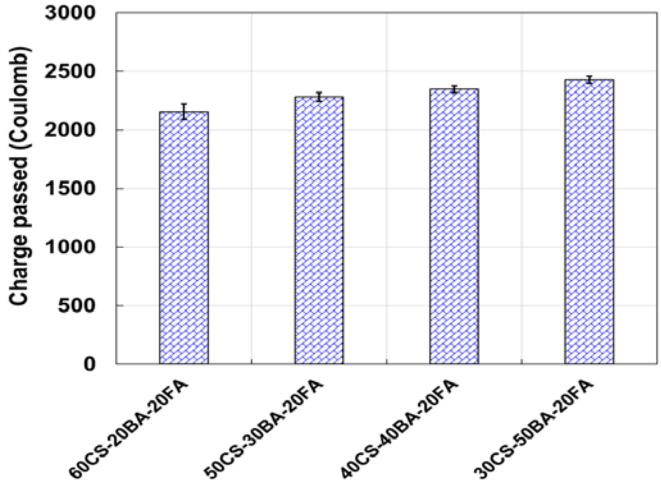

Figure 14. Chloride penetration of different mixtures at the age of 28 days.

3.3.2. Results of water permeability

The water absorption of different mixtures was conducted for the specimen at 28 days is shown in Fig. 15. From the figure, the water absorption ratio increases if the amount of BA is increased. Specifically, the absorption ratio increased from 2.0 to 3.0 % when the amount of BA increased from 20 to 50 %. In other words, the water absorption ratio increased approximately by 50% when the content of BA increased from 20 % to 50 %. This proves that the larger content of bottom ash produced the higher values of the water absorption and it is conformed with previous studies of concrete comprising bottom ash [2, 9, 47, 58]. This is the fact that owing to the porous structure of bottom ash and higher surface area, which caused a higher absorption capacity. As indicated in previous studies, concrete containing bottom ash is more porous compared to normal concrete [2, 9, 47, 58]. The structure of ITZ became porous when fine aggregate (sand) was substituted by bottom ash. Thus, the establishment of a porous structure resulted in a higher water absorption ability. Furthermore, as discussed previously, the increase in the amount of BA led to the decrease of concrete density, due to higher porosity, thus increasing water absorption ability. However, the water absorption values of this fine-grained concrete are smaller than those (4–5 %) of conventional concrete and concrete comprising bottom ash [2, 9, 47, 58]. In summary, these results of water absorption are in line with that of chloride permeability, splitting tensile and compressive strength. These findings also concur with previous studies.

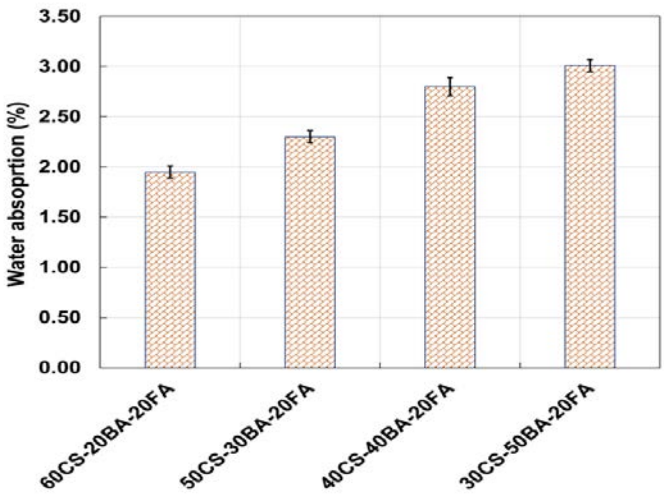

Figure 15. Water absorption of different mixtures.

4. Conclusions

In this research, we investigated mechanical characteristics and durability, namely compressive and splitting tensile strengths, chloride resistance, and water absorption of fine-grained concrete using waste material (fly and bottom ashes) to replace 30 to 60 % of fine aggregates. Some main conclusions could be derived from the experimental results:

- The compressive and splitting tensile strengths decreased with an increasing amount of bottom ash from 20 % to 50 % when the amount of fly ash fixed at 20 %. This is because of the porous structure and large surface area, which could have a high demand of water and create a large pore volume. The mixture with 20 % bottom ash had the highest compressive and splitting tensile strength, while the lowest values were observed in the mixture with 50 % bottom ash.
- The 28 day-compressive strength of this fine-grained concrete was in the range of 30.1 to 52.7 MPa and slightly larger than that of normal concrete; while the splitting tensile strength at 28 days was in the range of 3.0 to 4.3 MPa and almost similar to that of self-compacting concrete and concrete containing bottom ash with the same cement content.
- The values of chloride permeability ranged from 2156 to 2430 coulombs, and the absorption ratio ranged from 2.0 to 3.0 %. These values of chloride permeability and water absorption were almost the same or slightly higher than those of conventional concrete and concrete comprising bottom ash. Based on the results of chloride resistance, this fine-grained concrete is classified as moderately permeable concrete.
- The greater content of bottom ash addition caused the higher water absorption and resulted in the lower chloride resistance; these were caused owing to the coarse structure of bottom ash.
- The results of this study indicated that crushed sand (fine aggregate) of fine-grained concrete can be replaced by fly ash incorporated with bottom ash up to 60 %. This fine-grained concrete probably satisfies the requirement of conventional concrete in terms of mechanical properties and durability. Therefore, it is believed that this fine-grained concrete from a combination of fly and bottom ashes can be utilized for construction works in place of conventional concrete.

The findings of this study suggest that fine-grained concrete using fly ash and bottom ash replacing fine aggregate could be potentially applied for construction work instead of conventional concrete. However, this study has some limitations, for instance, only a fixed content of fly ash (20 %) and varied amounts of bottom ash ranging from 20 % to 50 % have experimented. In addition, this study mainly focused on the mechanical and durability investigation using compressive and tensile strength, chloride permeability, and water absorption. Thus, it is necessary to further investigate the amount of bottom ash replacement with 0 % and 10 % to have a consistent comparison and discussion; in which the amount of fly ash can be also a variable. The additional investigation on microstructural and physicochemical properties using thermal analysis, X-ray diffraction, scan electron microscopy, and porosity should be conducted to obtain clear evidence for explaining the influence of fly and bottom ash replacement for this fine-grained concrete.

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