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A Study on High Performance Fine-Grained Concrete Containing Rice Husk Ash

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Abstract: Rice husk ash (RHA) is classified as a highly reactive pozzolan. It has a very high silica content similar to that of silica fume (SF). Using less-expensive and locally available RHA as a mineral admixture in concrete brings ample benefits to the costs, the technical properties of concrete as well as to the environment. An experimental study of the effect of RHA blending on workability, strength and durability of high performance fine-grained concrete (HPFGC) is presented. The results show that the addition of RHA to HPFGC improved significantly compressive strength, splitting tensile strength and chloride penetration resistance. Interestingly, the ratio of compressive strength to splitting tensile strength of HPFGC was lower than that of ordinary concrete, especially for the concrete made with 20 % RHA. Compressive strength and splitting tensile strength of HPFGC containing RHA was similar and slightly higher, respectively, than for HPFGC containing SF. Chloride penetration resistance of HPFGC containing 10–15 % RHA was comparable with that of HPFGC containing 10 % SF.

Keywords: high performance fine-grained concrete, rice husk ash, workability, compressive strength, splitting tensile strength, chloride penetration resistance.

1. Introduction

The use of locally available materials as well as the use of industrial and agricultural waste in building industry has become a potential solution to the economic and environmental problems of particularly developing countries. Coarse aggregate is considered as the main ingredient to produce Portland cement concrete. However, the resources of this material are depleting in many countries or in specific regions, therefore finding a potential substitute for coarse aggregate is crucial. The use of sand (natural or crushed) as a substitute for coarse aggregate to produce sand concrete was investigated. This kind of concrete has strength comparable with conventional Portland cement concrete. By definition, sand concrete is therefore defined as a fine aggregate concrete, in which coarse aggregate is replaced by sand and fine aggregate is by filler material (Bederina et al. 2012; Bederina et al. 2007; Khay et al. 2010). High performance fine-grained concrete (HPFGC) is considered as a new generation of sand concrete, and can be comparable with high performance concrete in strength and durability.

RHA is the residue of completely incinerated rice husk under proper conditions. Rice husk, the outer covering part of rice kernel, is an agricultural waste from the milling process of paddy. Rice husk is abundant in many parts of the world, especially in rice cultivating countries, like Vietnam. Each ton of paddy rice can produce approximately 200 kg of rice husk, which on combustion produces about 40 kg of ash (Bui 2001). According to the”Rice market monitor” report [FAO (2012)], the global rice paddy production in 2011 was about 723 million tons (in which the Vietnam paddy production was about 42 million tons) that results in approximately 145 million tons of rice husks. Rice husk from paddy rice mills is disposed directly into the environment or sometimes is dumped or burnt in open piles on the fields. This results in serious environmental pollution, especially after it is disintegrated under wet conditions.

RHA is classified as a highly reactive pozzolan. It possesses a very high silica content similar to that of SF (Mehta 1994). Using less-expensive and locally available RHA as a mineral admixture in concrete brings benefits to the economy, the technical properties of concrete and the environment as well. RHA is a porous material. Pore structure is the most important characteristic of this material. The change of this characteristic results in a different specific surface area (SSA) and therefore a different pozzolanic reactivity and different water absorption of RHA (Bui 2001; Nguyen 2011; Le et al. 2012; Van et al. 2013). RHA has been studied to

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replace SF as a partial Portland cement replacement, and the results show that RHA can fully substitute SF in terms of calcium hydroxide consumption, autogeneous shrinkage, compressive strength and durability of high performance concrete (Bui 2001; Van et al. 2013; Feng et al. 2004; Le et al. 2012; Salas et al. 2009) and ultra high performance concrete (Nguyen 2011; Nguyen et al. 2011). However, the effect of RHA on properties of HPFGC needs additional research.

The objective of this study is to investigate effects imposed by RHA blending on properties of HPFGC. Blending percentages were varied. Slump, compressive and splitting tensile strength, abrasion resistance and chloride penetration resistance of concrete containing RHA were evaluated. These properties were assessed for the reference and SF containing samples as well. The knowledge obtained in this study can be instrumental for optimizing strength and durability of mortar and concrete in future applications.

2. Experimental Program

2.1 Materials

Portland cement (PC40 conforming to Vietnamese standard TCVN 2682:1999 and is similar to CEM I 42.5 R conforming to DIN EN 197-1), RHA, SF, limestone powder (LSP) and two kinds of natural sand, i.e. fine sand and coarse sand were used in this study. RHA was produced by burning rice husk under proper temperature conditions in a simple incinerator prototype in Vietnam. It was designed based on the principle of the atmospheric bubbling fluidized bed (Armesto et al. 2002). The obtained ash was ground in a ball mill. The physical properties and the chemical composition of the cement, RHA, SF and LSP are summarized in Table 1. The physical properties of fine and coarse sand are presented in Table 2. In addition, a polycarboxylate-based superplasticizer (Viscocrete-V3000) was used.

2.2 Mixture Proportions

HPFGC mixtures were designed based on the absolute volume of the constituent materials (Béton de sable 1994; Béton 1995) in which the paste volume was computed from the void content in the sand mixture with mass ratio of coarse to fine sand of 2.33. This ratio corresponded to the mixture with highest granular packing density assessed experimentally. Water binder (w/b) ratio was determined according to ACI 211.1 and ACI 363.2R. The designed compressive strength of HPFGC was fixed at 60 MPa. In this study, six mixtures were designed with a constant w/b ratio of 0.33, resulting from the binder (cement, RHA) content of 530 kg/m^3 and a filler content (RHA+LSP) of 150 kg/m^3. Herein, RHA acts as a part of the binder and of the filler. RHA was incorporated with replacement levels of 5, 10, 15, and 20 % by weight. One control mixture and one mixture incorporating 10 % SF were prepared for comparison purpose. The mixture proportions of HPFGC are shown in Table 3.

2.3 Preparation of Test Specimens

All mixtures were prepared in a compulsory mixer with total mixing time of 8 min. Coarse and fine sand and powder materials (cement, LSP, RHA) were mixed in dry conditions for a period of 2 min. Next, about 80 % of the water was added, whereupon the concrete mixture was mixed for 2 min. Finally, about 20 % of the water and superplasticizer were added and the concrete mixture was mixed for 4 min. Slump test were conducted to evaluate workability of mixtures according to ASTM C143. Cylinders of 150 × 300 mm^2 were cast for determination of compressive and splitting tensile strength. Cylinders of 100 × 200 mm^2 were cast for determination of chloride penetration resistance. Cube specimens of 70.7 × 70.7 × 70.7 mm^3 were cast for determination of abrasion resistance. All specimens were compacted in two layers on a vibrating table. Each layer was vibrated for 20 s. The moulds were covered with polyethylene sheets and

Table 1 Chemical composition and physical properties of cement and mineral admixtures.

Chemical analyses (%)	PC40	RHA	SF	LSP
SiO_2	21.29	86.81	96.20	0.17
Al_2O_3	5.72	0.50	0.70	0.02
Fe_2O_3	3.30	0.87	0.30	0.04
CaO	63.18	1.04	0.00	54.88
MgO	1.10	0.85	0.10	0.45
Na_2O	0.12	0.69	0.06	0.02
K_2O	0.30	3.16	0.37	0.04
LOI	0.193	4.6	1.60	43.46
Density (g/cm^3)	3.10	2.24	2.26	2.72
Mean particle size (μm)	16.12	8.42	0.29	18.19
Blaine SSA[BET-SSA] (m^2/g)	0.369	[23.32]	[26.43]	0.321

LOI loss on ignition.

Table 2 Sieve analysis and physical properties of the fine and coarse sand.

	Passing percentage (%)	
	Fine sand	Coarse sand
Sieve size (mm)		
4.75	100	100
2.36	100	94.9
1.18	99.7	72.2
0.6	89.1	38.2
0.3	42.9	14.1
0.15	1.1	0.6
Fineness modulus	1.9	2.8
Density (g/cm^3)	2.6	2.6
Absorption (%)	2.0	1.9

Table 3 Mixture proportions of HPFGC investigated.

Mixture	Cement (kg/m^3)	RHA (kg/m^3)	SF (kg/m^3)	LSP (kg/m^3)	Water (kg/m^3)	Coarse sand (kg/m^3)	Fine sand (kg/m^3)	SP (%)
REF	530	0	0	150	175	1,045	448	0.12
5 % RHA	505	25	0	125	175	1,055	452	0.12
10 % RHA	482	48	0	102	175	1,064	456	0.11
15 % RHA	461	69	0	81	175	1,073	460	0.11
20 % RHA	442	88	0	62	175	1,081	463	0.11
10 % SF	482	0	48	102	175	1,064	456	0.11

SP superplasticizer.

moistened for 24 h. After 1 day, the specimens were demoulded, and stored in water at 20 ± 2 °C until testing at 3, 7, and 28 days. Compressive and splitting tensile strength of concrete were determined in agreement with ASTM C39 and ASTM C496, respectively. Chloride penetration resistance was determined at 28 days in agreement with ASTM C1202. The tests were carried out in triplicate and the average values were reported. Abrasion resistance of HPFGC was determined at 28 days following Böhme method (CEN 2003). A dried specimen is held in contact with a cast iron disc with a pressure of 0.6 daN/cm^2. The disc rotates at 30 ± 1 rpm. For each specimen, the disc runs 140 revolutions. During the process, the specimen is progressively rotated through 90^o, and sand with maximum particle size of 2 mm is spread on the disc. The abrasion index (g/mm^2) is calculated by dividing the mass loss of each specimen by its abraded area.

3. Results and Discussion

3.1 Workability

Slump data of the fresh concrete are presented in Fig. 1. It can be seen that the control mixture had highest slump compared to mixtures containing RHA and SF. Increasing RHA content resulted in a lower slump of fresh concrete. As reported in (Le et al. 2012; Van et al. 2013), RHA is a porous material with macro and meso-pores inside and on surface of the particles resulting in a very large SSA. SF also has a very large SSA, significantly larger than that of cement, due to its very fine particles (Table 1). RHA will absorb a certain amount of mixing water. Using RHA or SF as replacements for cement leads to an increase in SSA of the binder (cement + RHA/SF) thus to a decrease in free water compared to the mixture made without RHA or SF. Consequently, mixtures incorporating RHA or SF had lower slump. This effect was more pronounced, when a higher content of RHA was used.

3.2 Compressive Strength and Splitting Tensile Strength

3.2.1 Compressive Strength

In Fig. 2, compressive strength of HPFGC containing RHA/SF and control HPFGC at 3, 7 and 28 days is shown. Incorporating RHA increased compressive strength of HPFGC compared to control concrete regardless of ages, except for mixture containing 20 % RHA at 3 days. A highest value of 62.3 MPa was obtained for compressive strength at 10 % RHA blending, and the lowest value of 54.0 MPa for the control sample. As seen in Fig. 2, the optimum content of RHA tended to be higher at later age,

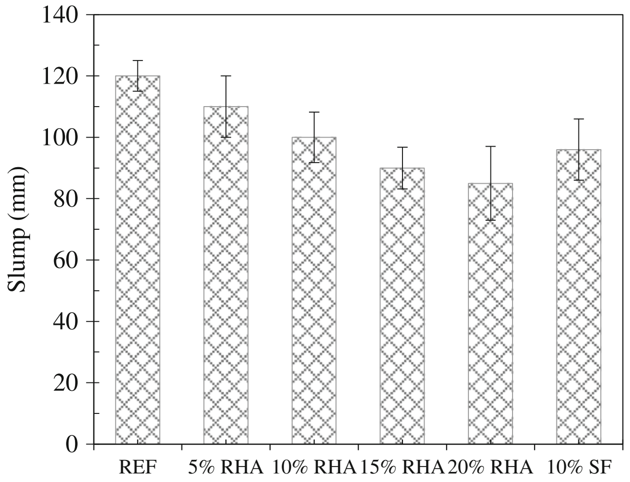

Fig. 1 Slump of fresh HPFGC.

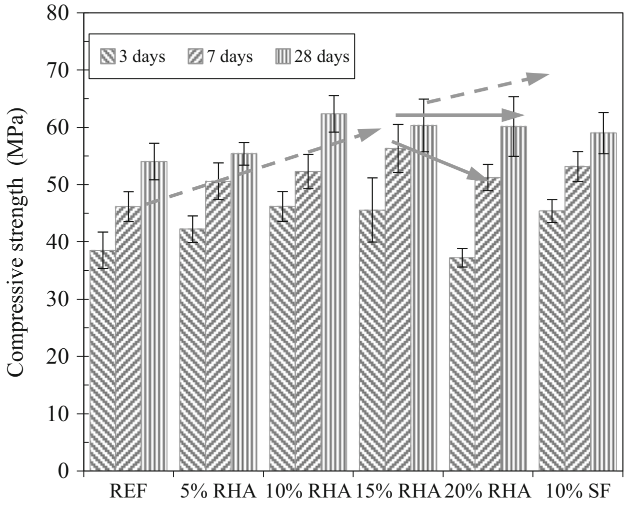

Fig. 2 Compressive strength of HPFGC.

i.e. 10 % RHA at 3 days, 15 % RHA at 7 days and 10–20 % RHA at 28 days, and may be 15–20 % RHA at later ages, e.g. 56 and 90 days as found in (Le et al. 2012).

The positive effect of RHA on compressive strength will be due to the high pozzolanity of RHA resulting from the large SSA and the high silica content. RHA reacts intensively with the water and the calcium hydroxide generated from the hydration of cement to produce additional C–S–H (Bui 2001; Nguyen et al. 2011; Safiuddin et al. 2011). The additional C–S–H itself is the main strength-contributing compound, and also fills in the capillary pores to improve the microstructure of the paste matrix and transition zone in concrete resulting in enhancement of compressive strength. Another reason is that the finer RHA particles can fill the empty spaces between the cement particles leading to higher density of the paste matrix (Safiuddin et al. 2011). Moreover, the increase in compressive strength of concrete made with RHA at more matured conditions is also due to the internal curing of RHA in the cement paste. RHA with porous structure may absorb free water during mixing leading to lower w/b ratios of RHA mixtures. This amount of water is released from the pores, when the relative humidity in paste diminishes at further maturation because of cement hydration, and causes a prolonged hydration (Nguyen et al. 2011). The internal curing by RHA could be an important reason for the improvement of compressive strength at later age of HPFGC containing high RHA content, e.g. the HPFGC made with 15 and 20 % RHA at 28 days and later ages. However, the addition of very high content of RHA is supposed to induce adverse effects on compressive strength, especially at early ages, e.g. 3-day compressive strength of HPFGC containing 20 % RHA. This is consistent with with the 7-days compressive strength results of UHPC (Nguyen et al. 2011). At high blending percentages of RHA, the concrete will contain a significantly reduced cement content. This diluting effect may account for the lower strength at 3 days (Kjellsen et al. 1999; Siddique and Khan 2011). Besides, RHA absorbs a certain amount of water during mixing resulting in the lack of available water in the system for cement hydration. Moreover, RHA particles are themselves weakest points in the hardened matrix due to their pore structure, as mentioned in (Le et al. 2012).

As seen in Fig. 2, the compressive strength of 10 and 15 % RHA HPFGC was similar to that of the 10 % SF sample at 3, 7, and 28 days. Indeed, RHA is not only comparable with SF with respects to the enhancement of the packing density of granular mixtures, but also on the pozzolanic reaction (Le et al. 2012; Nguyen et al. 2011). RHA is however assumed to improve compressive strength due to the internal water curing and the lower effective w/b ratio of concrete, as mentioned previously.

3.2.2 Splitting Tensile Strength

It is found that the trend in splitting tensile strength was almost similar with that of compressive strength (Fig. 3). Generally up to a replacement level of 15 %, splitting tensile strength of RHA containing HPFGC was higher than that of the control sample. The highest value of 6.49 MPa was obtained for splitting tensile strength at 10 % RHA replacement, and the lowest value of 5.12 MPa was obtained for the control sample. HPFGC proportioned with 20 % RHA had lower splitting tensile strength with respect to the control sample. It is well documented that splitting tensile strength is mainly governed by aggregate-paste bond (Nazari and Riahi 2011; Parra et al. 2011). RHA incorporation refined the transition zone between cement matrix and aggregate, and reduced the amount of large calcium hydroxide crystals and ettringite due to additional C–S–H phases generated from pozzolanic reaction, as mentioned in the previous section.

Generally speaking, shrinkage will be stimulated at higher cement contents (De Schutter et al. 2008). This may lead to crack formation along the aggregate-paste interface and, as a consequence, to a lower tensile splitting strength (Nguyen et al. 2011). As discussed previously, RHA particles absorb a certain amount of mixing water into their pores. It has been proposed that at later age, the absorbed water released from inside of the pores to the surrounding cement matrix will cause the relative humidity in the interior not to drop, resulting in significantly less autogeneous shrinkage due to self-desiccation (Nguyen 2011).

The decrease in splitting tensile strength of 20 % RHA HPFGC compared to the control sample may be due to abundance of RHA particles that can be emphasized as porous micro-aggregate. Those weaken the matrix and hence reduce the split strength of concrete.

Figure 3 also shows that splitting tensile strength of samples containing 10 and 15 % RHA was comparable with that of sample containing 10 % SF, irrespective of ages. The higher splitting tensile strength of the SF sample compared to the control sample can also be explained by refinement of the transition zone due to the pozzolanic and filler effect. This is consistent with another study (Bhanja and Sengupta 2005).

3.2.3 Ratio of Compressive Strength to Splitting Tensile Strength

In Table 4, the ratio of compressive to splitting tensile strength is presented. The ratio of RHA HPFGC was higher than that of the SF sample regardless of the RHA content. Only the ratio of HPFGC containing 20 % RHA was higher than that of control sample. The highest ratio amounted 11.10 at a RHA content of 20 %.

In this study, the ratio of compressive to splitting tensile strength of HPFGC was in the range of 9.6–11.0. Whereas the ratio of ordinary concrete is in the range of 10.5–15.2 (Shetty 2003). This indicates HPFGC to have higher splitting tensile strength than ordinary concrete at equal compressive strength. In this study, sand was used as the main aggregate, possibly resulting in the reduction in wall effect in the cement paste in the vicinity of the aggregate surfaces and the reduction in thickness of the interface transition zone (Nguyen 2011; Ollivier et al. 1995). Consequently, the splitting tensile strength of the HPFGC was improved.

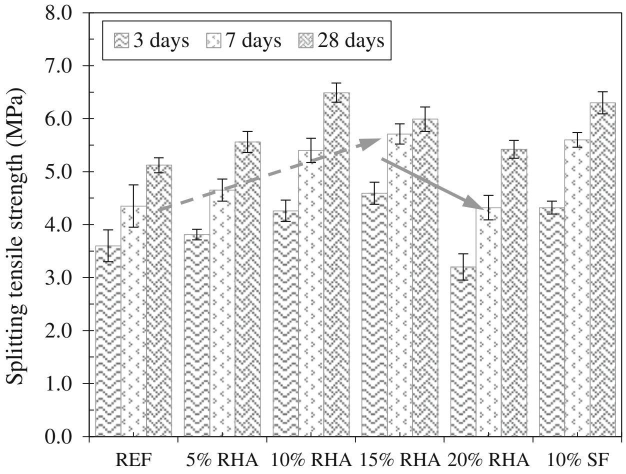

Fig. 3 Splitting tensile strength of HPFGC.

3.3 Mechanical Abrasion Resistance

Abrasion index of HSPC determined at 28 days is shown in Fig. 4. The higher abrasion index, the lower mechanical abrasion resistance is. The result shows that mechanical abrasion resistance of HPFGC was very high. RHA containing HPFGC had a lower abrasion index, indicating better abrasion resistance than that of the control sample. The lowest value for the abrasion index of 0.0006 g/mm^2 was found for the 10 % RHA blend. It is generally known that compressive strength is one of the most important factors influencing the abrasion resistance of concrete (Horszczaruk 2005). This is supported by the outcomes of this study (see Figs. 2 and 4). The abrasion index of 10 % SF concrete was similar to those of 10 and of 15 % RHA samples. It is closely related to the results of compressive strength above.

3.4 Chloride Penetration Resistance

Charge passed of HPFGC at 28 days is displayed in Fig. 5. It can be seen that RHA or SF incorporation substantially decreased the charge passed of concrete, indicating an increase in resistance to chloride penetration. Increasing RHA replacement percentage decreases charge passed. The lowest value of charge passed was obtained for 20 % RHA sample as 261 coulombs, and the highest value was found for the control sample as 2,782 coulombs. For concrete mixed with 10 % SF, the value of charge passed was also significantly lower than that of the control concrete, and similar to those of the concretes mixed with 15 and 20 % RHA.

The chloride penetration resistance of mortar and concrete is one of the most essential aspects concerning the durability of concrete structures. The reinforcement steel bar in concrete starts to corrode due to depassivation, when the chloride concentration of mortar or concrete exceeds a certain threshold (Alonso et al. 2000; Thomas 1996). The incorporation of a pozzolan is generally accepted to improve the resistance to chloride penetration and reduce the chloride-

Table 4 Compressive and splitting tensile strength at 28 days.

Mixtures	Compressive strength (MPa)	Splitting tensile strength (MPa)	Compressive/Splitting tensile strength
REF	54.0	5.1	10.6
5 % RHA	55.4	5.6	10.0
10 % RHA	62.3	6.5	9.6
15 % RHA	60.3	6.0	10.1
20 % RHA	60.2	5.4	11.1
10 % SF	59.0	6.3	9.4

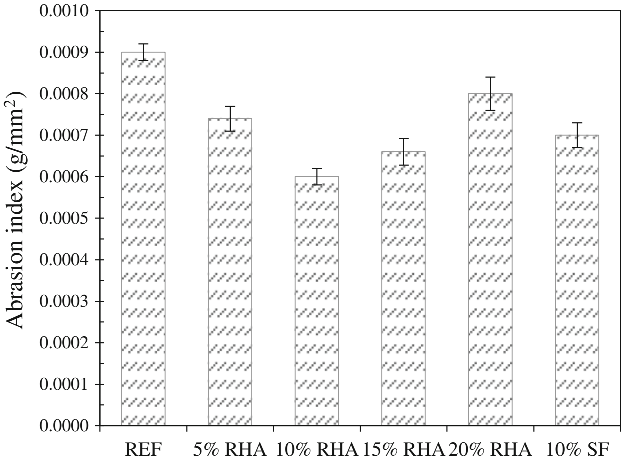

Fig. 4 Abrasion of HPFGC at 28 days.

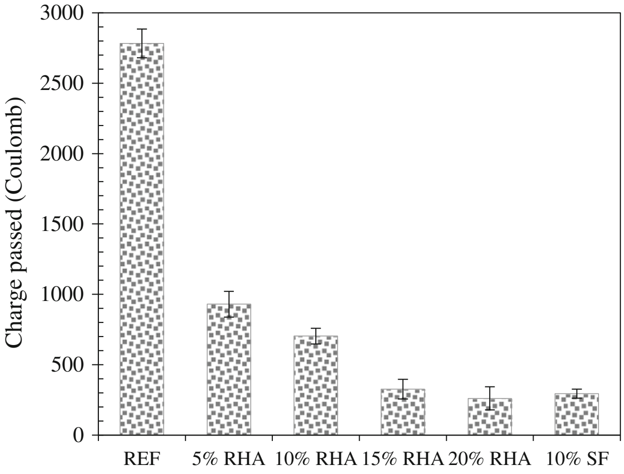

Fig. 5 Chloride penetration of HPFGC.

induced corrosion initiation period of steel reinforcement. The improvement is mainly due to the reduction of permeability/diffusivity, particularly to chloride ion transportation of the concrete containing mineral admixtures (Bijen 1996; Thomas and Bamforth 1999). As mentioned previously, RHA incorporation refines the cement matrix and reduces the amount of large calcium hydroxide due to additional C–S–H phases generated from the pozzolanic reaction. Furthermore, RHA with pore structure might be considered as internal curing agent to significantly prolong hydration of the blended cement. Therefore, the permeability of concrete is reduced. The pore-refining capacity of RHA in concrete has been assumed to improve resistance to chloride penetration (Salas et al. 2009; Chindaprasirt et al. 2008; Ganesan et al. 2008; Rodríguez de Sensale 2010).

4. Conclusions

This study analyses aspects of compressive strength, splitting tensile strength, abrasion resistance and durability in terms of chloride penetration resistance of HPFGC containing RHA with various replacement levels. For comparison, control and SF containing samples were evaluated for these properties. Based on the experimental results in the present study, the following conclusions can be drawn.

(1) Workability of HPFGC containing RHA decreases at the higher replacement levels compared to that of the control mixture due to the pore structure of RHA.

(2) Incorporating RHA increased compressive strength of HPFGC compared to that of the control concrete regardless of ages, except for concrete containing 20 % RHA at 3 days. Compressive strength of 10 and 15 % RHA blended HPFGC is similar to that of 10 % SF sample at 3, 7, and 28 days.

(3) In replacement range of 5–20 % RHA, there exists an optimum RHA content resulting in the highest compressive strength of concrete at each age. The optimum content is higher at later age, i.e. 10 % RHA at 3 days, 15 % RHA at 7 days and 10–20 % RHA at 28 days.

(4) Up to 15 % RHA replacement, splitting tensile strength of RHA containing HPFGC is higher than that of the control sample. Splitting tensile strength of samples containing 10 and 15 % RHA is comparable with that of the sample containing 10 % SF, irrespective of ages.

(5) Addition of RHA provides a dramatic improvement in chloride penetration resistance of HPFGC. The increase in RHA replacement level increases the chloride penetration resistance. The resistance to chloride penetration of concretes mixed with 15 and 20 % RHA is similar to that of concrete mixed with 10 % SF.

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