Journal of Ceramic Processing Research. Vol. 11, No. 3, pp. 311~315 (2010)

J O U R N A L O F
Ceramic Processing Research

Effect of rice husk ash and silica fume in ternary system on the properties of blended cement paste and concrete

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The effects of rice husk ash (RHA) and fume silica (SF) in both binary and ternary systems on the properties of cement pastes and the compressive strength of concretes were studied. The amount of cement replacement in both systems was 15%. The free calcium hydroxide ($Ca(OH)_2$) content was analyzed using XRD and TG/DTA for the hardened cement pastes. The results showed that the amount of $Ca(OH)_2$ decreased significantly the curing ages for all blended cement pastes. At 28 days, the amount of $Ca(OH)_2$ in OPC is 17.31%, 8.18% in RHA and 6.43% in SF replacements, respectively. The ternary system similarly indicates a significant reduction of $Ca(OH)_2$ content. The compressive strength of concretes was improved significantly by blending the aforementioned materials in both systems. In the ternary system, the concretes containing 7.5% SF and 7.5% RHA gave remarkable improvement in the compressive strength. For example after 90 days curing, the strength is 57.8 MPa whilst only 47.5 MPa for OPC. Therefore, the application of proper ratios of RHA and SF in a ternary system is able to increase the properties of the concrete.

Key words: Ternary system, $Ca(OH)_2$, Blended cement, Silica fume, Rice husk ash.

Introduction

Portland cement is the essential binding agent in concrete. Concrete properties are associated with the binder behavior. During hydration of ordinary Portland cement (OPC), compounds present in the cement, such as C3S and C2S react with water and form calcium silicate hydrates (C-S-H) and calcium hydroxide ($Ca(OH)_2$) [1]. The hydrated cement paste consists of approximately 70% C-S-H, 20% $Ca(OH)_2$, 7% sulfoaluminate, and 3% secondary phases. $Ca(OH)_2$ which is formed as a result of a chemical reaction, is soluble in water and has a low strength. These properties affect the quality of concrete negatively [2-3]. When rice husk ash (RHA) and silica fume (SF), which are pozzolanic materials, are added to cement, they react with $Ca(OH)_2$ to form additional C-S-H in the hydrated cement matrix. These additional hydrates increase the density of the matrix and refine the pore structure. This is the reason for the improvement of properties of cement and concrete [4].

Research on the use of RHA in concrete is not new. In 1973, Mehta investigated the effect of pyro-processing on pozzolonic reactivity of RHA as reported by Nehdi *et al*. [5]. Zhang *et al*. [6] found that it is possible to produce high strength concrete using fine enough RHA at an optimum replacement level. RHA and SF can be called pozzolonic or silica-rich materials which consist of a high silica content and a similar chemical composition but are physically different. Various studies have investigated the individual effect (binary) and the combination of RHA with other materials (ternary) such as fly ash on the engineering properties of concrete. But the ternary of blended RHA and SF is rarely seen in the literature review. Fortunately, Aminul and Talukdar [7] had experimentally investigated the effect of a ternary system of RHA and SF on the rheological properties of concrete. The investigation found that the combination of RHA and SF yield the most suitable rheological performance in moderating the plastic viscosity and low yield stress. Unfortunately, no investigation has been done on the effect of using ternary system of RHA and SF on the properties of hardened cement paste and concrete. Therefore, it is necessary to investigate the ternary system of RHA and SF on the hardened cement paste and concrete properties. An understanding of the effect of RHA in both binary and ternary systems on the properties of cement paste and concrete could lead to an increase in the use of RHA in concrete construction.

X-ray diffraction (XRD) and thermogravimetric analysis (TG/DTA) have been widely used to determine the hydration of hardened cement paste. The objective of this paper is to determine the $Ca(OH)_2$ content analysed by XRD and TG/DTA of SF and RHA in both binary and ternary systems of hardened cement pastes and the compressive strength of concretes.

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Experimental

OPC (Blue Lion Cement) supplied by Cement Industries of Malaysia Berhad and a commercial SF (BM-SF, Degussa) supplied by Global Composite Technologies Berhad, Malaysia were used in this study. The RHA had been produced by burning rice husk at 700 °C in a gas furnace for 6 hours. The burning conditions had been chosen according to Della *et al*. [8]. The ash was then ground using a porcelain ball mill for 80 minutes in order to produce RHA. The physical and chemical properties of the raw materials are given in Table 1.

Six concrete mixtures were prepared with a compressive strength of 40 MPa at 28 days in accordance to "Design of Normal Concrete Mixes" [9]. The amount of cement content was fixed, superplasticizer (Glenium C380) and water/binder ratio are given in Table 2. A replacement level of 15% was used for the binary system of RHA and SF and denoted as CSF15 and CRHA15, respectively. For the ternary system, 15% was fixed by varying the combination of SF and RHA contents. The amounts of RHA used were 5, 7.5 and 10% and denoted as CRS5, CRS7.5 CRS10, respectively.

The cement pastes were prepared with a w/c ratio of 0.4. The pastes were cast in 50 mm cube molds and compacted using a tamping rod and were sealed in plastic sheets to prevent water evaporation. The samples were cured in water at 20 ± 1 °C for a duration of 1, 3, 7, 28 and 90 days. At the specified testing age, the samples were crushed and then immersed in acetone for 24 hours to stop the hydration process. The samples were ground and sieved through a 75 μm sieve. A small amount of the sample was used to determine the $Ca(OH)_2$ content analyzed by TG/DTA technique (Linseis Thermowaage L81).

The compressive strength test of all the concrete mixes was performed on 100 mm cube molds. The specimens were compressed using a compression machine (Wyremham Farrance) with its maximum load of 2000 kN and 1.5 kN/sec of loading speed was used. Results presented are the average of three tested specimens.

The vacuum saturation method was used to determine the porosity of concrete in this study. Cylindrical concrete specimens 50 mm diameter and 40 mm high were prepared. Three specimens were tested and an average of the three is presented.

Table 1. Physical and chemical properties of raw materials

Properties	OPC	SF	RHA
Physical properties			
mean particle size (μm)	16.78	---	6.64
surface area (m^2/kg)	359	26250	16900
specific gravity (g/cm^3)	3.12	2.31	2.02
Chemical properties	wt%	wt%	wt%
CaO	64	---	0.4
SiO_2	19	95	91
Al_2O_3	5	0.3	0.1
Fe_2O_3	3	---	0.1
MgO	1	0.2	0.9
SO_3	3.8	0.7	0.5
K_2O	1.1	0.5	3.3
L.O.I.*	3	3.5	2

Table 2. Concrete mix proportions

Symbols	Materials, kg/m^3							
	OPC	RHA	SF	FA	CA	W	w/b	S
OPC	380	--	--	770	1025	205	0.54	0.4
CRHA15	323	57	--					
CSF15	323	--	57					
CRS5	323	19	38					
CRS7.5	323	28.5	28.5					
CRS10	323	38	19					

FA : Fine aggregates
CA : Coarse aggregates
W : Water
w/b : Water/binder ratio
S : Superplasticizer (%)

Results and discussion

Figs. 1 and 2 are examples of XRD patterns for both

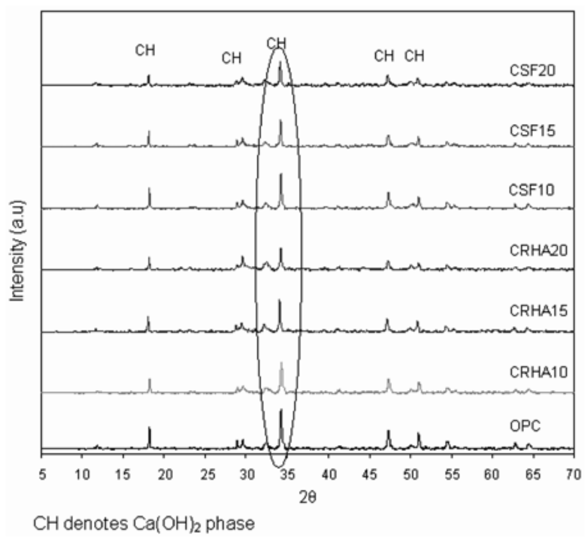

Fig. 1. XRD patterns of OPC and binary system CRHA and CSF pastes at 90 days.

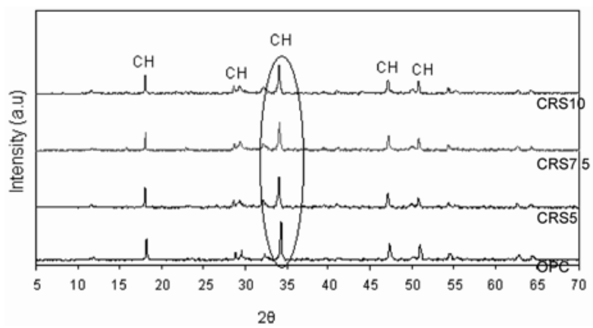

Fig. 2. XRD patterns of OPC and ternary system CRS pastes at 90 days.

the binary and ternary cement pastes at 90 days curing time, respectively. The TG/DTA curves shown in Figs. 3 to 6 represent the TG/DTA results of OPC paste at 3 days, CSF15 at 28 days, CRHA15 at 90 days and CRS7.5 at 90 days, respectively. A similar observation was made by Vedalakshmi *et al*. [1]. The $Ca(OH)_2$ content results as determined by TG/DTA technique of the hardened cement pastes are given in Table 3. It shows that the $Ca(OH)_2$ content in OPC paste increases with curing time whereas in the RHA and SF blended pastes $Ca(OH)_2$ content decreases with time. It can also be seen in Table 3 that the $Ca(OH)_2$ contents of CRHA15 and CSF15 at 3 days curing are 10.27% and 8.25% respectively, compared to the OPC paste which is 13.48%. The reaction rate of $Ca(OH)_2$ in RHA and SF pastes increased rapidly during the first 28 days. The SF blended with OPC shows a higher $Ca(OH)_2$ reaction compared to RHA of all ages.

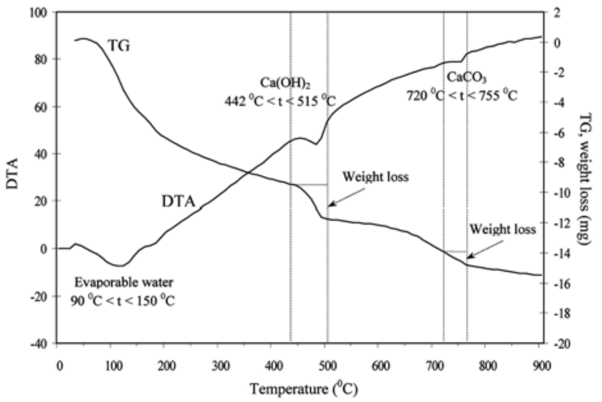

Fig. 3. TG/DTA results of OPC paste at 3 days.

Table 3. $Ca(OH)_2$ content of the cement pastes at 3, 28, and 90 days

Cement pastes	$Ca(OH)_2$ content (wt%)		
	3 days	28 days	90 days
OPC	13.48	17.31	20.44
CRHA15	10.27	8.18	7.80
CSF15	8.25	6.43	5.71
CRS5	8.56	7.51	6.80
CRS7.5	9.53	6.97	5.75
CRS10	10.00	8.17	7.16

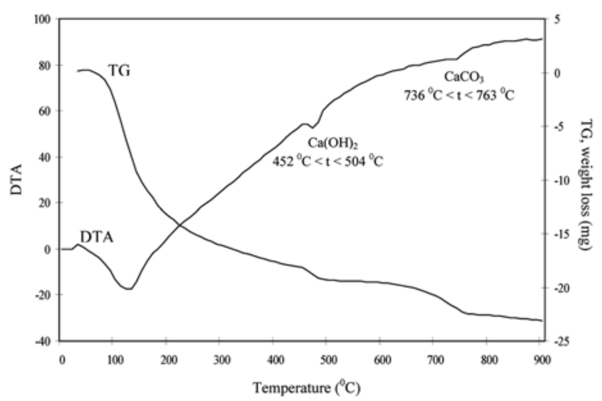

Fig. 4. TG/DTA results of CSF15 paste at 28 days.

It shows that all the ternary pastes appear with a high $Ca(OH)_2$ reaction compared to OPC. The highest reduction of $Ca(OH)_2$ has been found in the CRS7.5 mix (the mix containing 7.5% RHA and 7.5% SF).

The reduction of $Ca(OH)_2$ in the blended cement paste indicates its consumption in pozzolanic activity. This shows that the $Ca(OH)_2$ is consumed during hydration for all blended cement pastes, whereas for plain OPC, $Ca(OH)_2$ is produced.

The compressive strength results are given in Fig. 7. This shows that the compressive strength was not significant for all blended concrete mixes at 3 days except for the CSF15. A significant improvement of the blended

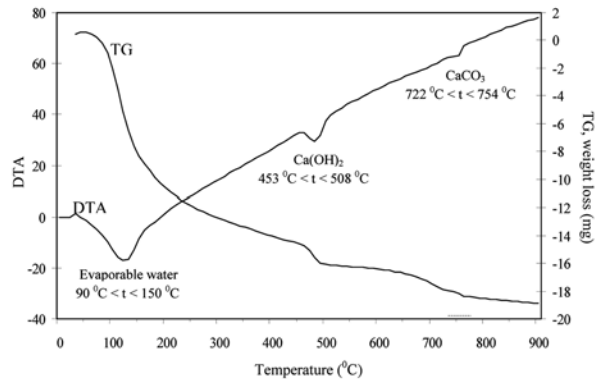

Fig. 5. TG/DTA results of CRHA15 paste at 90 days.

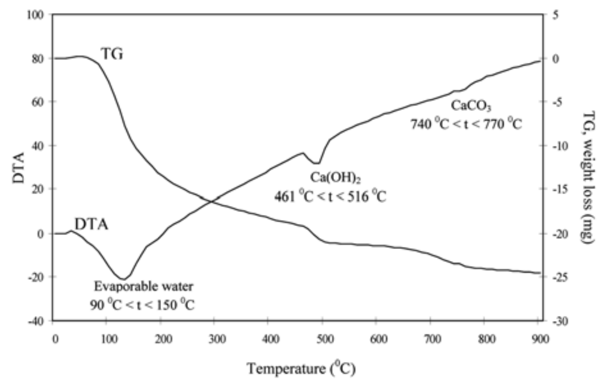

Fig. 6. TG/DTA results of CRS7.5 paste at 90 days.

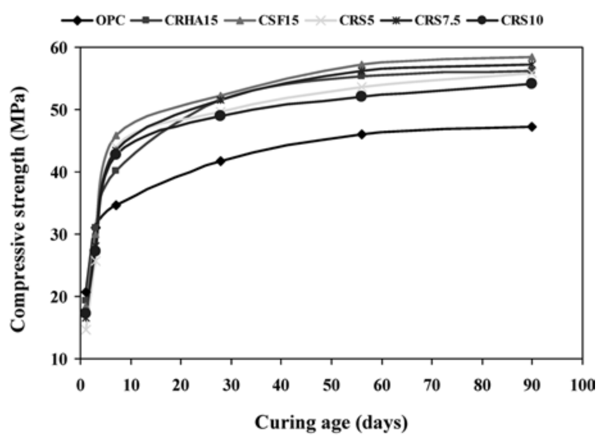

Fig. 7. Compressive strength of the concrete mixes.

concretes was been found at 7 days onwards. Similar observations were reported by other researchers [10-13]. The compressive strength of the concrete at 28 days is 41.8, 49.0, 52.2 and 51.6 MPa, for OPC, CRHA15, CSF15 and CRS7.5, respectively. The incorporation of 7.5% RHA and 7.5% SF (CRS7.5) showed a remarkable improvement in ternary concretes. This was confirmed strongly by the TG/DTA results (Table 3) of the con sump-tion of $Ca(OH)_2$. Moreover, the significant improvement of concrete properties incorporating with SF and RHA is because of the filler effect and pozzolanic effect of pozzolanic materials.

The strength development of the concrete mixes, generally, provides different effects due to the use of different types and replacement levels of pozzolanic materials. Therefore, the effects of pozzolanic materials on strength development relative to the control mix can be quantified by relative strength plots. Fig. 8 shows the development of the strength of the concrete mixes relative to the curing time. It can be seen that the incorporation of SF and RHA in either binary or ternary systems improve the strength of concrete significantly even if the w/b ratio is 0.54 at 7 days curing and onwards. However, a decrease of the strength development in the early age (at 3 days curing) has been found. The strength reduction is because of the low reactivity of the pozzolanic reaction of RHA with $Ca(OH)_2$ in OPC at an early age. It can be seen that the maximum contribution of the pozzolanic materials in improving the strength of concrete took place between 7 and 28 days. At 90 days, the relative strength of CRHA15, CSF15 and CRS7.5 is 118.82, 123.68 and 121.14%, respectively.

The results of porosity of the concretes are presented in Fig. 9. It can be observed that the incorporation of RHA and SF in both binary and ternary systems can reduce the porosity of concrete significantly compared to the control mix for all curing times. For the ternary system, the higher the incorporated amount of SF, the lower the porosity obtained. At 90 days, the reduction of porosity of the concretes is about 22.57, 22.11 and 19.68%, respectively for the concretes CRS5, CRS7.5 and CRS10 compared to the control mix. It can be seen in Fig. 9 that the ternary concrete CRS7.5 provides a lower porosity compared to binary concrete CRHA15, but gives a slightly higher porosity compared to binary concrete CSF15. The lower porosity of blended concretes can be attributed to the higher ability of the pozzolanic materials to refine the microstructure of the binder phase of the concrete [14].

Conclusions

The $Ca(OH)_2$ content of OPC paste increases with an increase of the curing time, whereas both binary and ternary pastes decrease with the hydration time and decreased gradually with an increase of the replacement level. The concrete containing SF (CSF15) provided the most significant improvement on strength compared to the other mixes. For the ternary concretes, the highest strength has been found in the CRS7.5 mix.

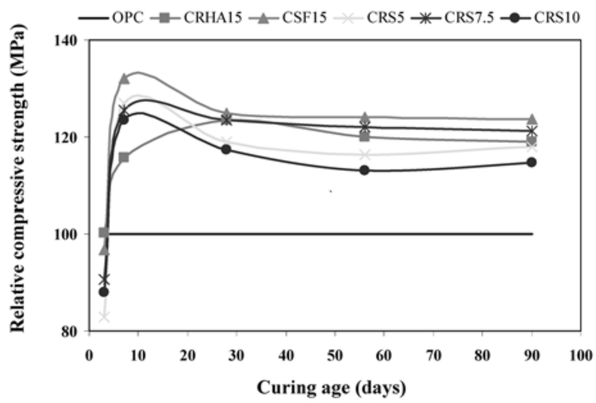

Fig. 8. Relative compressive strength of the concrete mixes.

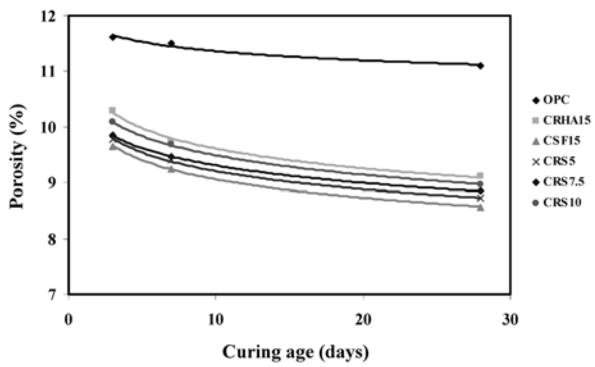

Fig. 9. Porosity of the concrete mixes.

Acknowledgement

We would like to acknowledge Universiti Sains Malaysia and AUN/SEED-Net Program for providing a research grant.

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