Applied Mechanics and Materials Vols. 752-753 (2015) pp 182-188
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doi:10.4028/www.scientific.net/AMM.752-753.182

Submitted: 10.10.2014
Revised: 05.12.2014
Accepted: 26.12.2014

Strength Development of Fine Grained Mortar Containing Fly Ash and Rice Husk Ash

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Keywords: Compressive strength, Flexural strength, Fine grained mortar, Fly ash, Rice husk ash

Abstract. Fine grained mortar (FGM) offers a new innovative technology binder system. The innovative technique is achieved by using a small maximum grain size of 600μm for the mortars. Most of the previous studies have focused on the FA to be replaced in the FGM. There is still lacking of research of using other pozzolanas in making FGM. This paper presents a study of the strength of FGM with partially replacement of ordinary Portland cement (OPC) with fine fly ash (FA) and ground rice husk ash (RHA). Flexural and compressive strength of FGM were tested. The results show that the use of FA and RHA produces FGM with improved strength with the replacement up to 20% than that of the control FGM. The use of FA and RHA is very effective in enhancing strength at the later age of FGM.

Introduction

The utilisation of fly ash and rice husk ash in mortar has increased rapidly because it contains high amount in siliceous and aluminous compounds. The use of pozzolana as cement replacement contributes to strength development as the results of both chemical and physical effects [1-6].

Fly ash is a by-product of the coal power generation industries is the most common pozzolana and widely used as a cementitious and pozzolanic ingredient in OPC. Meanwhile rice and palm oil plantation are part of major agriculture products in Malaysia. The manufacturing process will generate a waste product known as rice husk and palm oil fuel ash. Therefore, more works to be done to utilise this material for the benefits mankind and at the same time reducing the amount of waste ending up in landfill, creating problems to the environment as well as the surrounding community.

Rice husk with cellular microstructure and porous are produced with slow firing at a temperature 500 to 700°C [7-9]. When rice husk is burnt, about 20% by weight of the husk is recovered as ash in which more 75% by weight is silica. RHA contains high silica in the form of non-crystalline or amorphous silica with high specific surface area and high pozzolanic reactivity [10-13]. Therefore, it is pozzolanic material and can be used as supplementary cementitious materials. RHA particles have a complex shapes and will break down the porous structure.

Studies of the used of FA as a cement replacement in FGM have been reported by a number of researches [14-21]. However, research on use of RHA is still lacking. Thus, this study was adapted FA and RHA with 10 to 40% replacement by weight of cement to obtain the optimum formulation of FGM.

Fine Grained Mortar

The speciality of FGM as compared to commonly used mortar is a mortar containing fine sand with maximum grain size 600 mm. FGM mix shows highly flowable consistency which offer penetration of technical textiles. Due to the very small diameter of grain size, it is possible to get a new, very thin concrete element as application for the new material [22-23]. FGM also has high binder contents, by adding different pozzolanic additives and performance plasticizers [14], [23-26].

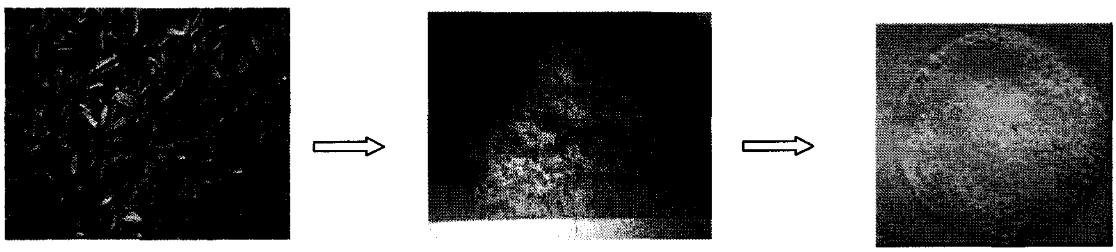
It is generally realised that the use of FA with low calcium content improves the properties of mortar [21] and also increasing the workability [15]. The cement content in mortar can be reduced by using FA as a replacement of cement. Furthermore, the combination of FA and superplasticizers will produce a very good flowing capability of the mortar [16]. Table 1 show the replacement of 28% to 36% of FA resulted in high performance mortar with compressive strength between 74-90 N/mm^2.

Table 1 Compressive and flexural FGM made of FA reported by previous researches

Fly Ash Replacement (%)	Water/ Cement	Sand/ Binder	Compressive Strength (N/mm^2)	Flexural Strength (N/mm^2)	References
36	0.57	1.73	74.2	7.6	[14]
32	0.35	2.0	75.0	11.5	[15]
-	-	-	78.3	4.4	[16]
28	0.34	0.94	76.0	7.1	[17]
-	-	-	70.0	5.0	[18]
-	-	-	89.0	5.7	[19]

Experimental Details

Materials. Fly ash was obtained from thermal power plants Kapar Energy Ventures in Kapar, Selangor. Rice husk was collected from Muar, Johor. FA was oven-dried at 105-110°C for 24 hours. Rice Husk is burnt at temperatures 600°C for six hours. Before burning, rice husks were washed 5 times to clean of all impurities then were oven-dried at 105-110°C for 24 hours. Then were ground by grinder with 1-3% retained on sieve number 325 (45μm) complying the requirement of ASTM C618. The process of rice husk ash as described in Fig. 1. Particle size distribution was measured by laser particle size analyzer (CILAS 528). Ordinary Portland Cement (OPC) and sand with maximum grain size of 600 mm were used.



(a) Rice husk (b) Burnt rice husk (c) Ground rice husk ash

Fig. 1 Process of rice husk ash

Mix Proportions. Nine (9) series of mix FGM were prepared. OPC is partially replaced with pozzolanas at the dosage of 0, 10, 20, 30 and 40% by weight cementitious materials. Sand to binder ratio of 2 by weight, water to binder (w/b) ratio of 0.45. Workability of FGM was adjusted by adding superplastisizer to maintain the mixes with similar penetration based on BS 4551 [27]. These result occurred with mix proportions of RHA because partial replacement of Portland by RHA required more water content. The FGM mix proportions are given in Table 2.

Flexural and Compressive Strength. Prism specimens of dimension 40 x 40 x 160 mm were used to test flexural and compressive strength. All specimens were prepared and tested according to BS EN 196-1 [28]. Flexural and compressive strengths of mortar specimens were determined at ages of 7, 28 and 90 days of curing. The prism specimens were covered with damped cloth and were demoulded at the age of 1 day. Next, the prism specimens were cured in water until the test ages. The reported results are the average of three samples for flexural strength. Flexural testing was done with used three point loading method. Compression test were carried out using the prism broken from flexural test. It is means that the compressive strength is mean of six made of three prism. If one result within six individual results varies by more than ± 10% from the mean, result was discarded and five remaining results were calculated.

Table 2 Mix proportion by weight of FGM used in compression and bending test

Mix No.	Symbol	Cement	FA	RHA	Superplasticizers	Fine Grained Sand	Water/ binder
M1	OPC	1	-	-	0.010	2	0.45
M2	FA10	0.90	0.10	-	0.010	2	0.45
M3	FA20	0.80	0.20	-	0.010	2	0.45
M4	FA30	0.70	0.30	-	0.010	2	0.45
M5	FA40	0.60	0.40	-	0.010	2	0.45
M6	RHA10	0.90	-	0.10	0.015	2	0.45
M7	RHA20	0.80	-	0.20	0.030	2	0.45
M8	RHA30	0.70	-	0.30	0.045	2	0.45
M9	RHA40	0.60	-	0.40	0.070	2	0.45

Results and Discussions

Characteristics of OPC, FA and RHA. The particle size distributions of Portland cement and pozzolanic materials are shown in Fig. 2. Particle fineness led by FA and followed by the OPC and RHA. The mean particle sizes of FA, OPC and RHA are 8.2, 94 and 12.1 μm, respectively. The chemical constituents are given in Table 3. Fly As is a Class F fly ash with 92.67% of SiO_2, Al_2O_3 and Fe_2O_3, 0.37% of SO_3 and 2.5% LOI meeting the requirement of ASTM C618 [29]. RHA on the other hand, consist mainly of SiO_2 and the other components are not significant. The SiO_2 content of 96% satisfies ASTM C618 [29] requirement as a natural pozzolan and 4% LOI indicates complete burning.

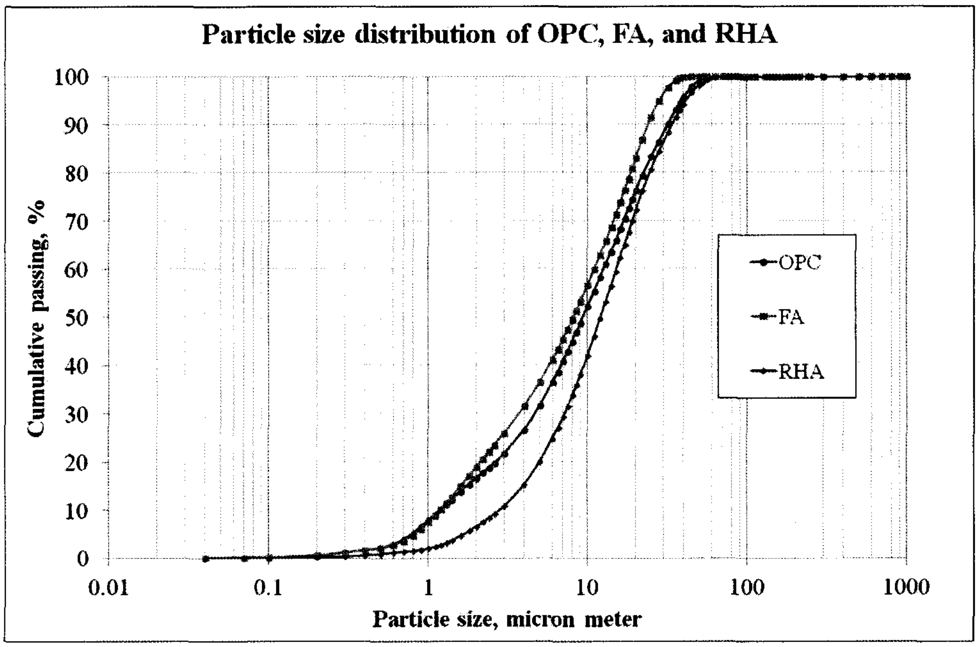


Fig. 2 Particle size distribution of OPC, FA, and RHA

Table 3 Chemical Composition of OPC, FA and RHA

Chemical composition (%)	OPC	FA	RHA
SiO_2 (Silicon dioxide)	16.40	62.90	96.0
Al_2O_3 (Aluminium oxide)	4.70	26.20	0.38
Fe_2O_3 (Ferric oxide)	3.70	3.57	-
CaO (Calcium oxide)	69.60	1.32	1.26
MgO (Magnesium oxide)	1.22	0.57	0.47
K_2O (Potassium oxide)	0.67	1.89	0.86
SO_3 (Sulfur trioxide)	2.65	0.37	0.27
LOI (Loss of Ignition)	2.2	2.5	4.0
$SiO_2 + Al_2O_3 + Fe_2O_3$		92.67	96.38

Flexural and Compressive Strength. Table 4 and 5 shows the results from the flexural and compressive strength of FGM containing FA and RHA. Fig. 3 shows the testing method for flexural and compression tests. As expected for all mixed mortar, an increase in curing ages of FGM in water leads to an increase in flexural strength of FGM. It is evident that replacement of FA and RHA to Portland cement about 10 - 20% increasing the flexural and compressive strengths. Additional, for all ages, FGM specimens with ground RHA replacement of 10-30% give higher strength than control FGM.

The incorporation of FA produces the filler and dispersing effects and increases the nucleation and precipitation sites [6, 11, 30]. The incorporation of RHA also produces the filler effect due to its fine particles size. The dispersing effect has not been reported for the RHA. However, its reactivity is high due to it high surface area.

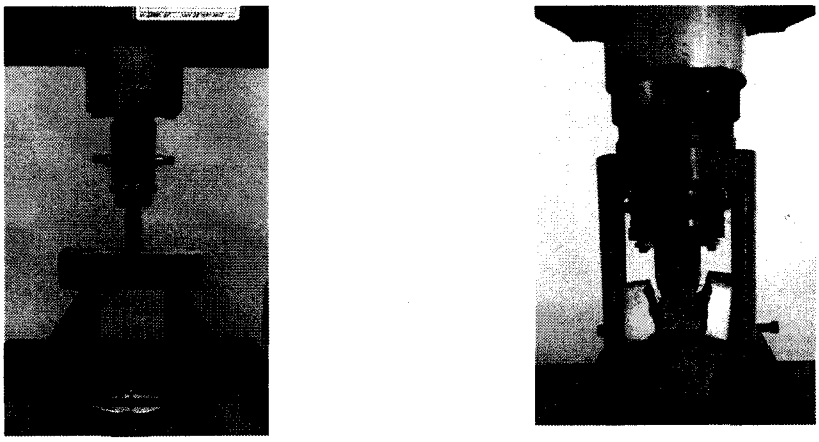
The increase in the amount of replacement to 30-40% reduces the early strength of both FA and RHA FGM. However, the strength at the ages 90 days of both FA and RHA are slightly higher than that of the OPC for compressive strength. This indicates that both FA and RHA are pozzolanic materials and pozzolanic reaction rate in the early stages is slow. The strength of mortar depends on the cohesion of the cement paste, on its adhesion to the aggregate particle and to a certain extent on the strength aggregate itself [1]. Depending on that, by a proper utilisation of FA it can be able to produce both high strength and high performance mortar.

Table 4 Flexural strength of FGM

Mix No.	Symbol	Flexural strength (MPa)					
		7 days		28 days		90 days	
M1	OPC	8.55	*-100*	10.82	*-100*	11.00	*-100*
M2	FA10	8.70	*-102*	10.99	*-102*	11.37	*-103*
M3	FA20	8.79	*-103*	11.25	*-104*	11.51	*-105*
M4	FA30	7.50	*-88*	9.61	*-89*	9.84	*-90*
M5	FA40	7.03	*-82*	9.38	*-87*	9.73	*-88*
M6	RHA10	8.60	*-101*	10.90	*-101*	11.25	*-102*
M7	RHA20	8.74	*-102*	11.13	*-103*	11.50	*-105*
M8	RHA30	6.91	*-81*	8.91	*-82*	9.38	*-85*
M9	RHA40	6.80	*-79*	8.79	*-81*	9.14	*-83*

Table 5 Compressive strength of FGM

Mix No.	Symbol	Compressive strength (MPa-*normalized*)		
		7 days	28 days	90 days
M1	OPC	38.25-*100*	67.34-*100*	66.49-*100*
M2	FA10	38.81-*101*	69.14-*103*	69.87-*105*
M3	FA20	39.52-*103*	70.45-*105*	70.65-*106*
M4	FA30	32.10-*84*	66.89-*99*	68.54-*103*
M5	FA40	30.26-*79*	65.78-*98*	66.56-*100*
M6	RHA10	38.54-*101*	68.34-*101*	67.91-*102*
M7	RHA20	39.12-*102*	70.05-*104*	70.58-*106*
M8	RHA30	30.14-*79*	66.45-*99*	68.10-*102*
M9	RHA40	29.32-*77*	65.13-*97*	66.45-*100*



(a) Flexural test (b) Compression test

Fig. 3 Flexural and compression tests

Conclusion

The use of FA and RHA as a partially OPC replacement significantly improves the FGM in terms of strength at the low replacement level and at the later age. FA is slightly more effective than RHA. However, the proper utilisation of RHA as a cement replacement will be a valuable and effective way for sustainable development of construction industry in Malaysia.

Acknowledgment

The first author thanks to the technical staff of the laboratory and members of the Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia (UTHM) and Universiti Teknologi MARA (UiTM) for their support. This work was supported in part by UTHM from the Ministry of Education Malaysia under Grant RAGS R035.

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