Strength of ternary blended cement mortar containing Portland cement, rice husk ash and fly ash

Sumrerng Rukzon[1] and Prinya Chindaprasirt[2]
[1]Department of Civil Engineering, Faculty of Engineering, Khon Kaen, University, Khon Kaen
[2]Sustainable Infrastructure Research and Development Center, Khon Kaen University
E-mail: rerng197@yahoo.com and prinya@kku.ac.th

Abstract

This paper presents a study of strength development of mortars made with ternary blends of Portland cement, rice husk ash and fly ash. The mortar mixtures made with 0%, 20% (10% of rice husk ash, 10% of fly ash) and 40 % (20% of rice husk ash, 20% of fly ash) replacement of Portland cement Type I with different finenesses of rice husk ash and fly ash was prepared. Three rice husk ash finenesses viz., original rice husk ash (RAO), ground rice husk ash with percentages retained on sieve No. 325 of 15-20% (RA1) and 0-5% (RA2) were used. Three fly ashes finenesses viz., original fly ash (FAO), classified fly ash with percentages retained on sieve No. 325 of 15-20% (FA1) and 0-5% (FA2) were also used. The compressive strength at 3, 7, 28, 60, 90 and 180 days were tested. Test results showed that mortar with 20% cement replacement has a high strength development. The mortars with fine rice husk ash and fly ash showed better compressive strength than those with the coarser ones owing to the reduced water requirement, the filling effect and the increased pozzolanic reaction of the fine fly ash and rice husk ash.

1. Introduction

Owing to the environmental concern and the need to conserve energy, numerous researches have been directed towards the utilization waste materials and by-products. Rice husk is one of the major agricultural by-products. When rice husk is burnt at temperature lower than 700 °C, the ash with a cellular microstructure rich in non-crystalline or amorphous silica is produced [1]. This rice husk ash ground to a suitable fineness can be used as pozzolan.

Fly ash is also a pozzolanic material and is being used worldwide in concrete work. It is generally agreed that the use of fine fly ash improves the properties of mortar and concrete [2,3]. The average pore size of the paste is reduced and this results in a less permeable paste [4,5]. The interfacial zone of the interface between aggregate and the matrix is also improved as a result of the use of fly ash [6,7].

It has been shown that the use of the finer fly ash resulted in a better mechanical properties of mortar and concrete as compared to the coarser ones. The fine fly ash with spherical particle and smooth surface reduces the water requirement of the mortar, and increases the strength and the resistance to sulphate solution as well as to chloride penetration [8]. The use of the finer fly ash reduces the average pore size of the paste as compared to the coarser one and also increases the pozzolanic reaction of the paste.

The knowledge of the effect of rice husk ash and fly ash on the strength development of mortar and concrete would therefore be beneficial to the understanding of the mechanism as well as for future applications of these materials. The use of cement made with Portland cement and two supplementary materials, we called ternary cements. This paper, therefore, presents an experimental study on the effects of the ternary blending of Portland cement, rice husk ash and fly ash with different finenesses on compressive strength of mortar.

2. Materials

Ordinary Portland cement type I (OPC) used in this work was a type I cement (as per ASTM C150). Lignite fly ash from Mae Moh power plant in the northern part of Thailand

RECEIVED 10 October, 2005
ACCEPTED 6 January, 2006

was classified into three lots, and rice husk ash was ground into three lots a well.

1. FAO: original coarse fly ash with 36% retained on sieve No. 325 slightly coarser than the limit specify in ASTM C618.
2. FA1: medium fly ash obtained from air classification of FAO until the particle retained on sieve No. 325 was 15-20%.
3. FA2: fine fly ash obtained from air classification of FAO until particle retained on sieve No. 325 was 0-5%.
4. RAO: original coarse rice husk ash with 69% retained on sieve No. 325.
5. RA1: medium rice husk ash obtained from grinding of RAO by ball mill until 15-20% retained on sieve No. 325.
6. RA2: fine rice husk ash obtained from grinding of RAO by ball mill until 0-5% on sieve No. 325.

The refinement and separation process of fly ash is shown in Fig. 1.

River sand with the S.G. of 2.63 and fineness modulus of 2.82 was used.

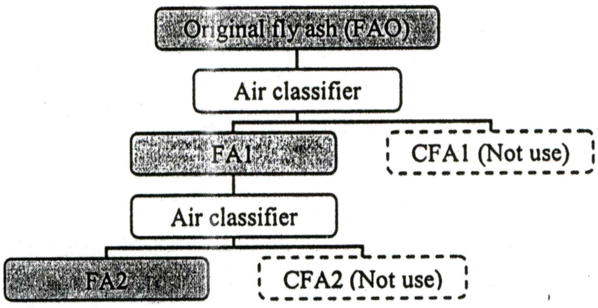

Fig. 1 Schematic process of FA1 and FA2

3. Experimental procedures

The sand-to-binder ratio of 2.75 by weight was used and the water content was adjusted to obtain a constant flow of 110±5%. The cast specimens were covered with polyurethane sheet and damped cloth in the 23±2°C chamber. They were demoulded at the age of 1 day and were moist cured at 23±2°C until the test age. The 50x50x50 mm cube was used for the compressive strength test of mortar. They were tested at the age of 3, 7, 28, 60, 90 and 180 days. The test was done in accordance with the ASTM 109. The reported result is the average of three samples.

Seven mix proportions of mortar were used in the current study. The first mix was control mortar (OPC) containing only Portland cement type I as cementitious materials. The second to seventh mixes contained Portland cement type I partially replaced with 20 and 40% of three different blends of fly ash and rice husk ash. The three blends were made with equal portion of FAO and RAO; FA1and RA1; and FA2 and RA2. The mortar mix proportions are given in Table 1.

Table 1 Mortar mix proportions

Symbol	Mix Proportions						
	Cement	Pozzolanic materials			Sand	W/B	Flow (%)
		FAO RAO	FA1 RA1	FA2 RA2			
OPC	1.00	-	-	-	2.75	0.50	110.0
20FAO-RAO	0.80	0.10 0.10	-	-	2.75	0.65	110.9
20FA1-RA1	0.80	-	0.10 0.10	-	2.75	0.54	110.8
20FA2-RA2	0.80	-	-	0.10 0.10	2.75	0.51	110.5
40FAO-RAO	0.60	0.20 0.20	-	-	2.75	0.66	109.9
40FA1-RA1	0.60	-	0.20 0.20	-	2.75	0.56	110.2
40FA2-RA2	0.60	-	-	0.20 0.20	2.75	0.52	107.5

4. Results

4.1 Characteristics of fly ash and rice husk ash

The physical properties of Portland cement, fly ash and rice husk ash are summarized in Table 2. The Blaine's fineness of the FAO was 2800 cm^2/gm which is a little coarser than that of the Portland cement. The Blaine's fineness of the FA1 and FA2 was 3800 and 4600 cm^2/gm while the specific gravity of the FAO, FA1 and FA2 was 2.20, 2.38 and 2.45, respectively.

The Blaine's finenesses of the Portland cement, rice husk ash RA1 and RA2 were 3600, 6800 and 11200 cm^2/gm while the specific gravity of the OPC, RAO, RA1 and RA2 were 3.14, 1.98, 2.21 and 2.23, respectively. The increase in the S.G. of fine fly ash is due to the reduction in the amount of the hollow particle (see Fig. 2-3). The increase in the S.G. of fine rice husk ash is due to the reduction in the pore of the cellular structure of the original rice husk ash particle (see Fig. 2-3) [9,10]. As the finenesses of the rice husk ash and fly ash increased, the specific gravity increased as shown in Fig. 4.

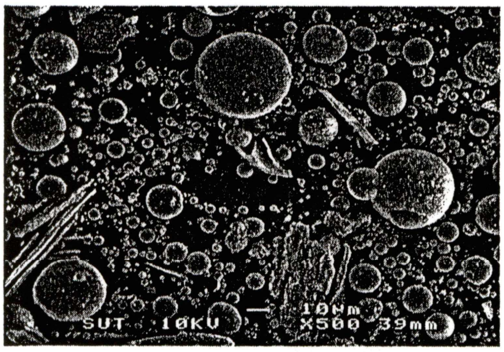

Fig. 2 SEM photograph of FAO-RAO

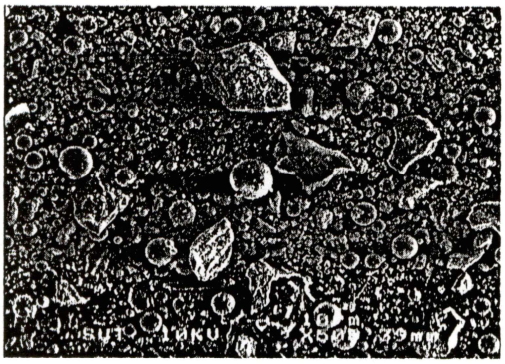

Fig. 3 SEM photograph of FA2-RA2

Table 2 Physical properties of fly ash, rice husk ash and Portland cement

Materials	Symbol	Specific Gravity	Blaine Fineness (cm^2/g)	Retained on sieve No. 325 % by weight
Portland cement type I	OPC	3.14	3,600	-
Original fly ash	FAO	2.20	2800	36
Fly ash-medium	FA1	2.38	3,800	15-20
Fly ash-fine	FA2	2.45	4,600	0-5
Original rice husk ash	RAO	1.98	-	69
Rice husk ash-medium	RA1	2.21	6,800	15-20
Rice husk ash-fine	RA2	2.23	11,200	0-5

4.2 Chemical compositions of materials

The chemical constituents of OPC, fly ashes and rice husk ash are given in Table 3. The chemical composition indicated that FAO, FA1 and FA2 are the fly ash of Class F as prescribed by ASTM C618 since the sum of components SiO_3, Al_2O_3, and Fe_2O_3 are higher than 70%, and LOI and SO_3 are not higher than 6% and 5%, respectively.

On the other hand, RAO, RA1 and RA2 are Class N pozzolanic materials with the sum of SiO_3 and Al_2O_3 higher than 70%, and LOI and SO_3 are not higher than 5% and 6%, respectively.

The FA2 was light brown in colour and the coarse FAO was a lot darker indicating the containment of some carbon. The fine fly ash was more spherical and its surface was smoother in comparison with the coarser original fly ash. With regard to the chemical constituents, there was no significant difference in chemical compositions of fly ash and rice husk ash of different finenesses.

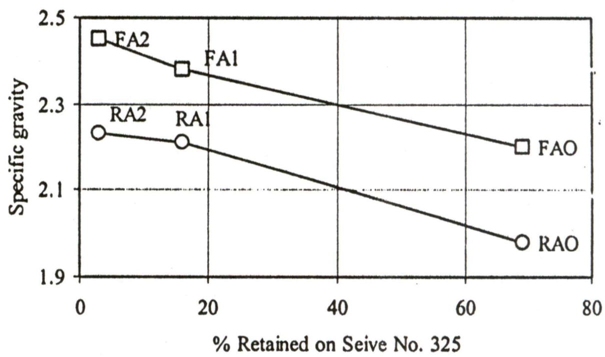

Fig. 4 Relationship between specific gravity and fineness

Table 3 Chemical analysis of Portland cement, fly ashes and rice husk ash

Oxides	OPC	FMO	FM2	FM2	RAO	RA1	RA2
SiO_2	20.9	42.7	42.2	41.1	92.0	90.1	93.2
Al_2O_3	4.8	21.8	21.9	21.6	0.29	0.25	0.4
Fe_2O_3	3.4	11.7	11.4	11.3	0	0	0.1
CaO	65.4	12.9	13.1	14.4	1.28	1.45	1.1
MgO	1.25	3.35	3.5	3.25	0.37	0	0.01
Na_2O	0.24	1.27	1.2	1.10	0.05	0.08	0.03
K_2O	0.35	2.71	2.90	2.58	2.19	2.42	1.27
SO_3	2.71	1.80	1.80	2.15	0.94	0.92	0.96
LOI	0.96	1.50	1.90	2.38	3.43	3.56	3.72

4.3 Water requirement and strength

Fig. 5 presents the water requirement of mortar. The water requirement of all mixes containing fly ash and rice husk ash rice husk ash were increased in comparison with OPC mortar owing primarily to the porous structure of the rice husk ash despite the tendency to reduce the water requirement of the fly ash. The increase in the water requirement was increased with an increase in the replacement level and decreased with an increase in the grinding and fineness of rice husk ash.

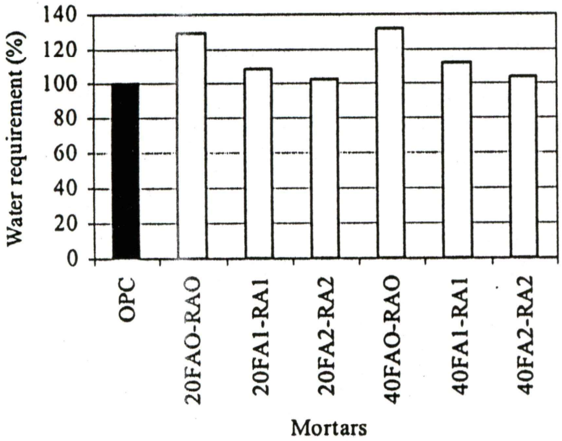

Fig. 5 Water requirement of mortars

The compressive strength of mortar 20FAO-RAO and 40FAO-RAO was lower than that of the control mortar (OPC) at all age as shown in Table 4. In addition, the compressive strength of mortar was reduced with an increase in the replacement level as shown in Table 4. At all age, the compressive strengths of 20FA1-RA1 and 20FA2-RA2 mortar were higher than those of 40FA1-RA1 and 40FA2-RA2 mortars.

The use of fly ash medium fineness FA1 and rice husk ash RA1 resulted in an increase in the strength as compare with that of the original coarse fly ash FAO and rice husk ash RAO at all age as shown in Table 4. The increase in compressive strength could be attributed to the reduced water content, the filler effect and the higher pozzolanic reaction.

The use of fine fly ash FA2 and rice husk ash RA2 resulted in a better development of compressive strength due to the high fineness of materials and a decrease in the water requirement as shown in Fig. 6-7.

Table 4 Compressive strength of Portland cement and ternary blended cements

Symbol	W/B	Compressive strength (MPa)					
		3d	7d	28d	60d	90d	180d
OPC	0.50	23.2	28.4	39.4	47.7	49.5	51.5
20FAO-RAO	0.65	15.8	19.8	29.8	36.2	39.8	43.4
20FA1-RA1	0.54	20.2	24.3	40.6	55.1	56.6	61.4
20FA2-RA2	0.51	20.5	24.9	41.0	56.6	58.8	63.2
40FAO-RAO	0.66	14.7	18.2	29.3	35.8	38.7	42.5
40FA1-RA1	0.56	17.7	21.9	31.7	38.6	42.3	46.5
40FA2-RA2	0.52	18.4	22.8	35.5	45.0	46.3	49.8

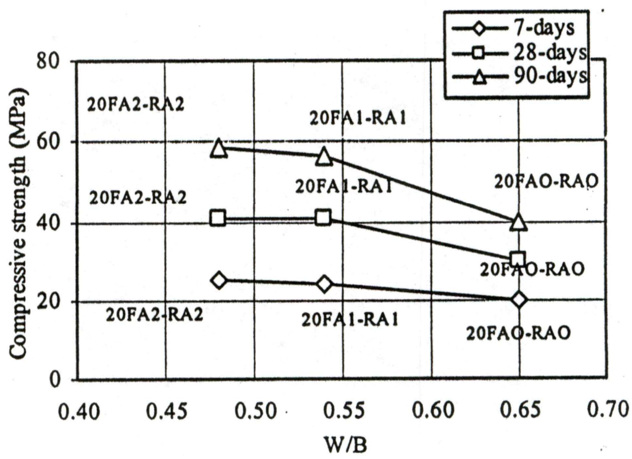

Fig. 6 Relationship between compressive strength and W/B at replacement of 20%

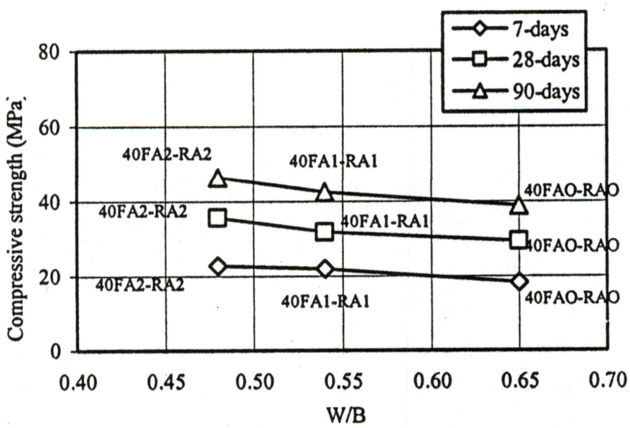

Fig. 7 Relationship between compressive strength and W/B at replacement of 40%

Fig. 8 shows the strength ratio of mortar made from FAO and RAO in comparison to those of OPC mortar. The strength ratio at early age was low about 64 and 74% at the ages of 7 and 28 days and did not conform to ASTM C 618 owing primarily to the large particle sizes. At later age of 60-180 days, the strength ratio of 20FAO-RAO and 40FAO-RAO fared better and varied between 75-84% of the control mortar indicating a pozzolanic reaction.

The strength ratios of mortar with medium and high fineness of fly ash and rice husk ash as shown in Fig. 9 and 10 indicated that the strength ratio increased with an increase in fineness, The strengths of FA1 and RA1 mortars were 76-118% of control mortar and those of FA2 and RA2 mortars were 79-123% of control mortar.

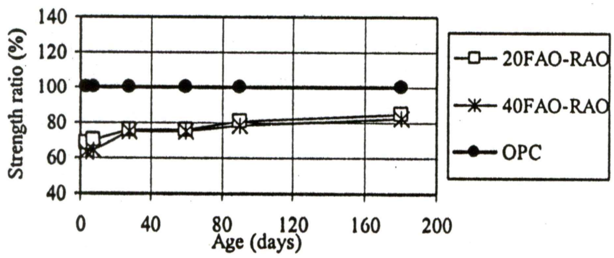

Fig. 8 Relationship between strength ratio of FAO-RAO and age

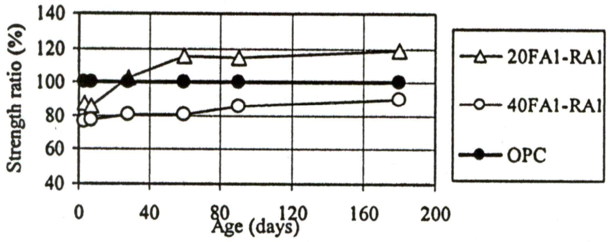

Fig. 9 Relationship between strength ratio of FA1-RA1 and age

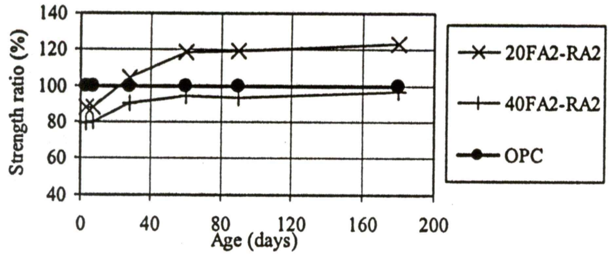

Fig. 10 Relationship between strength ratio of FA2-RA2 and age

Therefore, the classified fly ash with high fineness and the grinding of rice husk ash to obtain a high fineness can improve the pozzolanic activity and can be used as a cement replacement with ternary blended cement. Similar improvement in strength of the ternary blended cement have been reported [10,11]. This synergic effect of the blending of two materials can be used to advantages.

5. Conclusions

From the tests, the following conclusions can be made.

1. Fly ash and rice husk ash in equal portions could be used to partially replace Portland cement. The use however increased the water requirement of all mix in comparison with the control mortar owning mainly to the porous structure of the rice husk ash.
2. The coarse original fly ash and rice husk ash significantly increased the water requirement of the mixes. Increase in fly ash and rice husk ash fineness help reduce the water requirement. The FA2, RA2 with higher surface area reduces the water requirement more than the FA1 and RA1 owing to the smoother surface of the fine fly ash and the less porous structure of fine rice husk ash.
3. The compressive strength of original fly ash and rice husk ash mortars were relatively low. The strengths of 20FAO-RAO and 40FAO-RAO mortars were lower than those of the control mortar (OPC) at all age. The gain in strength at the later age suggested the pozzolanic reaction of the ternary blended cement.
4. The strength development of the fine fly ash and rice husk ash mortar was good especially for the 20% replacement level. The strength of the 20FA2-RA2 was greater than those of the control mortar except at the early age of 3 and 7 days. The increase in strength was due to the more reactive fine fly ash and rice husk ash.

6. Acknowledgements

The researchers would like to acknowledge the financial supports of the Sustainable Infrastructure Research and Development Center Khon Kaen University

(SIRDC), Rajamongala University of Technology (RMUT), Department of Civil Engineering Faculty of Engineering Khon Kaen University (KKU) for proving working places and laboratory for this work.

References

[1] PK. Metha, "The chemistry and technology of cement made from rice husk ash", In UNIDO/ESCAP/RCTT Proceeding of work shop on rice husk ash cement, Peshawar, Parkistan, Regional Center for technology transfer, Bangalor, India, 1979, p. 113-122.

[2] K. Erdogdu and P. Turker, "Effects of fly ash particle size on strength of Portland cement fly ash mortars", Cement and Concrete Research, Vol. 28, 1998, pp. 1217-1222.

[3] S.H. Lee, E. Sakai, M. Diamond and W. K. Bang, "Characterization of fly ash directly from electrostatic precipitator", Cement and Concrete Research, Vol. 29, 1999, pp. 1791-1797.

[4] CS. Poon, YL. Wong and L. Lam, "The influence of different curing conditions on the pore structure and related properties of fly ash cement pastes and mortars", Construction and Building Materials, Vol. 11, 1997, pp. 383-393.

[5] P. Chindaprasirt, C. Jaturapitakkul and T. Sinsiri, "Effect of fly ash fineness on compressive strength and pore size of blended cement paste", Cement and Concrete Composites, Vol. 27, 2005, No. 4, pp. 425-28.

[6] YL. Wong, L. Lam, CS. Poon and FP Zhou, "Properties of fly ash-modified cement mortar-aggregate interfaces, "Cement and Concrete Research", Vol. 29, 1999, pp. 1905-1913.

[7] M. Kuroda, T. Watanabe and N. Terashi, "Increase of bond strength at interfacial transition zone by the use of fly ash", Cement and Concrete Research, vol. 30, 2000, No. 2, pp. 253-258.

[8] P. Chindaprasirt, S. Homwuttiwong, and V. Sirivivatnanon, "Influence of fly ash fineness on strength drying shrinkage and sulfate resistance of blended cement Mortar", Cement and Concrete Research, Vol. 34, 2004, pp. 1087-1092.

[9] S. Rukzon and P. Chindaprasirt, "Strength and carbonation of Portland cement rice husk ash", Conference on concrete and geopolymer. Khon Kaen Uni., Khon Kaen, Thailand, October 31, 2005, pp. 98-105.

[10] P. Chindaprasirt, T. Chaiyasena and V. Sirivivatnanon, "High strength concrete containing fly ash and black boiler rice husk ash", Proceedings of the Fourth Symposium on Infrastructure Development in Civil Engineering (RSID), Kasetsart Uni., Tokyo Institute of Technology and Uni. of the Philippines-Diliman, Bangkok, Thailand, April 3-5, 2003, pp. 363-368.

[11] GC. Isaia, ALG. Gastaldini and R. Moraes, "Physical and pozzolanic action of mineral additions on the mechanical strength of high-performance concrete", Cement and Concrete Composites, Vol. 25, 2003, pp. 69-76.