Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 7 (21): 3256-3261, 2007
ISSN 1812-5654
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Synergic Effect of Wheat Straw Ash and Rice-Husk Ash on Strength Properties of Mortar

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Abstract: Pozzolan materials obtained from various sources; when used as partial replacement for Portland cement in cement based applications play an important role not only towards sustainable development but in reducing the construction costs as well. Present study was conducted to investigate the synergic effect of Rice-Husk Ash (RHA) and Wheat Straw Ash (WSA) on the strength properties of ash substituted mortar. Ash materials were obtained after burning the wastes at 600°C for 5 h at a control rate of 2°C min. Two binary blends of mortar substituting 15% cement with WSA and RHA and three combinations of ternary blend with (10+5)%, (5+10)% and (7.5+7.5)% mix ratios of WSA and RHA, together with a control specimen were subjected to destructive (compressive and flexural strength) as well as non-destructive (ultrasonic pulse velocity) tests till 180 days of curing. Ternary blend with (7.5 + 7.5)% combination of WSA and RHA showed better strength results than control and other blends and proved to be the optimum combination for achieving maximum synergic effect.

Key words: Wheat straw ash, rice-husk ash, blended mortar, synergy effect and mechanical strength

INTRODUCTION

Sustainable development is an emerging political and social issue of global significance. The increasing need for the concrete industry to comply with the fundamental goals of sustainable development and to reduce its impact on the environment, has led the scientists and researchers to improve upon the properties of concrete products and at the same time to develop materials and technologies that can recycle the various wastes for their effective and economical use in cement based products and thus ultimately making these materials as commodity products. Over the years, many waste materials like fly ash, ashes produced from various agricultural wastes such as palm oil waste, rice-husk ash, wheat straw ash, have been tried as pozzolan or alternate cementitious materials (Deepa *et al*., 2006; Malhotra and Carino, 1991; Tay, 1990; Visvesvaraya, 1986) in cement based products.

Pozzolans are defined as siliceous and aluminous materials which, in themselves possess little or no cementitious value but will, in finely divided form and in presence of moisture, chemically react with $Ca(OH)_2$ at ordinary temperature to form compounds possessing cementitious properties. These materials play an important role when added to Portland cement because they usually increase the mechanical strength and durability of concrete structures. According to Mehta and Aïtcin (1990), the small particles of pozzolans themselves are less reactive than Portland cement but when dispersed in paste they generate a large number of nucleation sites for the precipitation of hydration products. Therefore, the mechanism makes the paste more homogeneous and dense, because of the pozzolanic reactions between the amorphous silica of the mineral added and the calcium hydroxide produced by the cement hydration reactions.

In general, the effect of pozzolan not only depends upon the pozzolanic reaction but also on the physical or filler effect of the smaller particles in the mixture. The physical effect of the finer grains allows denser packing within the cement and reduces the wall effect in the transition zone between the paste and the aggregates (Isaia *et al*., 2003). Roy (1992) explaining the filler effect; have reported that replacement of 15% of cement mass by silica fumes will add approximately 2,000,000 particles to each cement grain replaced thus filling the voids and densifying the matrix. Some researchers performed tests with non-pozzolanic fillers (Carles *et al*., 1989) to quantify their action on the increase of concrete strength. Goldman and Bentaur (1993a, 1993b) studied the effect of the addition of carbon black as micro-filler in comparison to the effect of silica fume and concluded that largest strength increase in the silica fume concrete was due to the micro-filler effect and testified that micro-filler effect is equally important or even more significant than the

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pozzolanic effect. Mehta (1987) also showed that the chemical action of pozzolanic reaction enhances the physical effects because of the higher segmentation of pores and the refinement of CH grains as the curing time progresses. Berry *et al.* (1994) also detected that fly ash particles that are not completely reacted may fill the voids and increase paste density.

In this study, abundantly available Wheat Straw Ash (WSA); a less reactive and scarcely used pozzolan was employed in ternary blends together with Rice-Husk Ash (RHA); which relatively is a more reactive pozzolan. According to Isaia (1997) and Isaia *et al.* (1999); when a less reactive pozzolan is employed in ternary blended system together with a more reactive pozzolan such as silica fume or rice-husk ash, the synergy between these pozzolans resulting in achieving better strength than those verified in the respective binary mixtures; is called synergic effect.

MATERIALS AND METHODS

The experimental study was carried out on mortar specimens using Portland cement and standard sand (conforming Japan Industrial Standards, JIS 5201 R) and ash samples prepared after burning wheat straw and rice-husk.

Rice-husk and wheat straw: The annual production of rice amounts to ~ 400 million tons, of which more than 10% is husk (Yelcin and Sevinc, 2001). Rice (136.5 tons)-wheat (72 million tons) is a major cropping system in north-west India (FAO, 2006) and rice-husk - wheat straw are waste materials produced in large amounts. For every 4 tons of wheat grain-6 tons of wheat straw and for every ton of rice ~ 0.23 tons of rice-husk is formed (Chandrasekhar *et al.*, 2003). In year 2000, out of 347 million tones of agricultural waste, 200 million tones was of rice-husk and wheat straw (Thakur, 2002).

Ash production from rice-husk and wheat straw: Apart from the source and type of material; properties and amorphous nature of ash depends upon various pre-treatments and calcinations conditions such as burning duration, rate of burning and cooling rate as well (Biricik *et al.*, 1999). Under controlled burning conditions, about 10% ash material is obtained with very high amount of silica; > 90% in rice-husk ash and > 70% in wheat straw ash (Chandrasekhar *et al.*, 2006). The ashes obtained from rice-husk are reported to be highly reactive while ashes obtained from wheat straw materials are not so reactive because of lesser amount of silica present in it.

For present study, RHA and WSA, both with high amount of amorphous silica, having large surface area and low loss on ignition; were obtained by burning raw materials in 2 stages-pre-burning (to reduce smoke formation and the volume of dry matter), followed by controlled burning at 600°C for 5 h at of the rate 2°C/min (Mehta, 1979; Chopra *et al.*, 1981; Biricik *et al.*, 1999; Nehdi *et al.*, 2003). Ashes obtained were ball grinded for two hours to increase the surface area (James and Rao, 1986) (Table 1).

EXPERIMENTAL PROGRAM

Preparation of test specimens: As shown in Table 2; binary and ternary blended mortar specimens were prepared replacing OPC with different combinations of Rice-husk Ash (RHA) and Wheat Straw Ash (WSA) and their strength development was evaluated by conducting destructive (compressive strength and flexural strength) and non-destructive (ultrasonic pulse velocity-UPV) tests. Control (CTR) specimens without any ash substitution were also prepared, to compare the respective test results (Table 2). All specimens were prepared as per Japan Industrial Standards (JIS 5201-1997) and the following mix proportion was used in preparing one set, comprising of three rectangular prisms (40×40×160 mm): (cement + ash): 450 g standard sand: 1350 g and water:225 g (cementitious material: sand = 1:3 and w/c = 0.5). Just before placing the mortar in the moulds, flow test was also conducted to check the effect of different combinations of ash substitution on the workability of the blended mortars. Hardened specimens were kept fully immersed in water (20±1°C) for curing until the day of testing. For each replacement ratio, 7 sets (7×3 = 21 specimens) were prepared for destructive and non-destructive testing conducted after 3, 7, 14, 28, 56, 91 and 180 days of curing. Effect of different combinations of ash substitution on the setting time was also evaluated by measuring the initial and final setting time of ash blended pastes.

Table 1: Physical and chemical properties of WSA and RHA in comparison with OPC

	Chemical composition								Physical properties		
Specimens	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	LOI	Density (g cm^{-3})	Surface area (cm^2 g^{-1})	Av. particle size (µm)
OPC	18.41	5.60	3.00	66.81	1.38	2.81	0.49	2.00	3.15	3250	18.61
WSA	74.23	1.34	4.46	6.68	-	2.16	6.69	5.04	1.98	5540	9.13
RHA	90.11	-	2.95	1.15	-	0.56	3.95	3.94	2.09	5980	8.86

Table 2: Blended ratios and abbreviation used for different combinations of ash replacement

Blending ratio (by weight)	Mix (Symbol)
100% OPC+0% WSA+0% RHA	CTR
85% OPC+15% WSA+0% RHA	W15
85% OPC+10% WSA+5% RHA	W10
85% OPC+5% WSA+10% RHA	W5
85% OPC+7.5% WSA+7.5% RHA	W7
85% OPC+0% WSA+15% RHA	R15

RESULTS AND DISCUSSION

Particle size, high specific surface area and combined percentage of $SiO_2 + Al_2O_3 + Fe_2O_3$ (93.06% in RHA) and (80.03% in WSA) present in both ash samples suggested the pozzolanic character of the ashes as per ASTM C-618. Presence of a significant hump in XRD patterns (Fig. 1) of both ash samples indicated the amorphousness of ashes as only very small peaks were there in the XRD patterns, which could be identified as crystalline silica (Chandrasekhar *et al*., 2003; Nehdi *et al*., 2003; Martirena *et al*., 2006). The SEM pictures (Fig. 2, 3) clearly show the size and shape of particles with wide ranging sizes. As reported earlier, a little amount of crystallization of minerals noticed in both ash samples may have been due to the presence of carbon (Wu *et al*., 2004; Liou, 2004) and presence of potassium (Krishana *et al*., 2001).

The flow table values of the freshly prepared mortar mix (Table 3) decreased with the substitution of Portland cement with WSA and RHA and also with different combinations of ash substitution when compared with CTR. But within various combinations of ash substitution this effect was little and insignificant from all practical considerations. As per Nabil and Bilal (2002) higher specific surface area of WSA and RHA in the blended mortars required more amount of water that was necessary to wet the surface of the ash particles and thus was the cause of reduction in the flow values of blended mortars. Retardation in Initial Setting Time (IST) and Final Setting Time (FST) was observed in ash substituted paste samples (Table 3). For W15, W10, W5, W7 and R15; IST was 52.0, 52.0, 44.0, 44.0 and 60.0%, respectively, more than CTR and the respective increase in FST was 47.8, 50.0, 39.1, 37.0 and 54.4%. For all replacement combinations, increase in IST and FST, was possibly because of the slower initial hydration reaction of ash particles with OPC; a typical characteristic of a pozzolan material.

Mechanical strength development: Synergic effect of WSA and RHA combination was studied by evaluating the strength development of ternary blended mortar specimens, W10, W7 and W5. Compressive strength, flexural strength and Ultrasonic Pulse Velocity (UPV) tests were conducted at 3, 7, 14, 28, 91 and 180 days after curing and the respective results were compared with CTR and two binary blended (W15 and R15) mortar specimens prepared and cured under similar conditions.

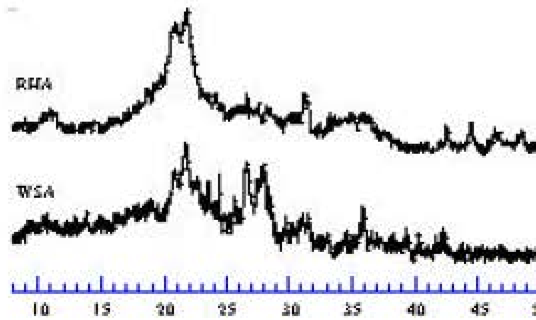

Fig. 1: X-ray diffractograms of RHA and WSA

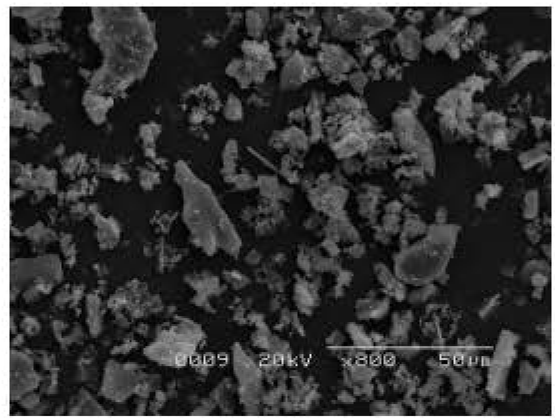

Fig. 2: SEM picture of wheat straw ash

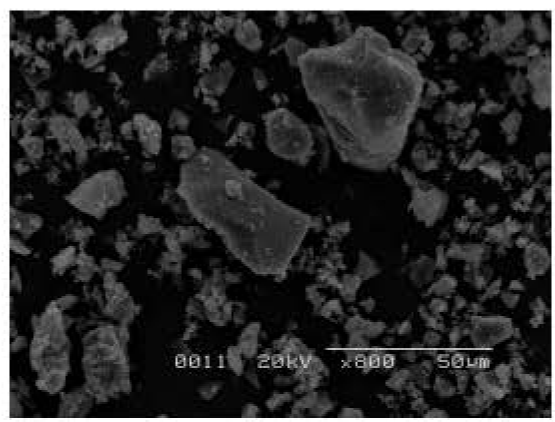

Fig. 3: SEM picture of rice-husk ash

Table 3: Water consistency, setting time and flow values

Mix	WC (%)	IST (min)	FST (min)	Flow* (mm)
CTR	0.330	125	230	178
W15	0.334	190	340	159
W10	0.332	190	345	155
W5	0.330	180	320	158
W7	0.331	180	315	162
R15	0.330	200	355	158

WC: Water Consistency, *: For fresh mortar; IST: Initial Setting Time, FST: Final Setting Time

Compressive Strength (CS) and Flexural Strength (FS): All blended mortar specimens exhibited higher strength at early ages. Compressive strength (CS) of 3 day cured ternary blends was 12.3% (W10), 15.9 % (W7) and 11.0% (W5) more than CTR; whereas in case of binary blends, W15 and R15 it was 14.3 and 10.6% more than CTR. This can be explained by the physical or filler effect of the smaller size of the ash particles present in the blended mixture (Isaia *et al*., 2003). With the progression of hydration, strength of all blended specimens decreased below CTR specimen (Fig. 4a, b); possibly because of the slow pozzolanic reaction and also due to the fact that the early days predominance of the filler effect was overtaken by the hydration reaction in CTR specimen. But at later stages (after 56 days or so), the pozzolanic reaction in the blended specimens steadily caught up with hydration reaction happening in CTR specimen. Compressive strength at 180 days (Fig. 5) for all mortar specimens was in the following order: W7 > W5 > R15 > CTR > W10 > W15. Results clearly illustrated the effect of synergy existing among RHA and WSA; as CS of ternary blended mortar specimens, W7 and W5 was more than CTR and two binary blended mortar mix, W15 and R15. But 180 day CS of W10 was less than CTR and R15. It indicated that Synergic Effect (SE) in ternary blends of RHA and WSA was optimum with 7.5% WSA in combination with RHA substituting OPC by 15% in total. Nabil and Bilal (2002) had also reported that paste specimens containing up to 7.3% WSA replacement reveal more hydration products than CTR specimens.

Flexural strength test results exhibited almost same trends as CS test results. FS of 180 day cured mortar specimens was as follows: - W7 > W5 > R15 > CTR > W10 > W15 (Fig.5). Evaluation of FS and CS results suggested that the higher ultimate strength achieved by W7 and W5 was due to the synergic effect, which was achieved by the combination of hydration reaction, pozzolanic reaction and /or by the physical action caused by the smaller water/binder ratio or pore and grain refinement through a blocking or filling effect of finer particles (Isaia *et al*., 2003).

To verify the relative quality and strength development of mortar, Ultrasonic Pulse Velocity (UPV) test was also carried out as per ASTM C597-03. The UPV

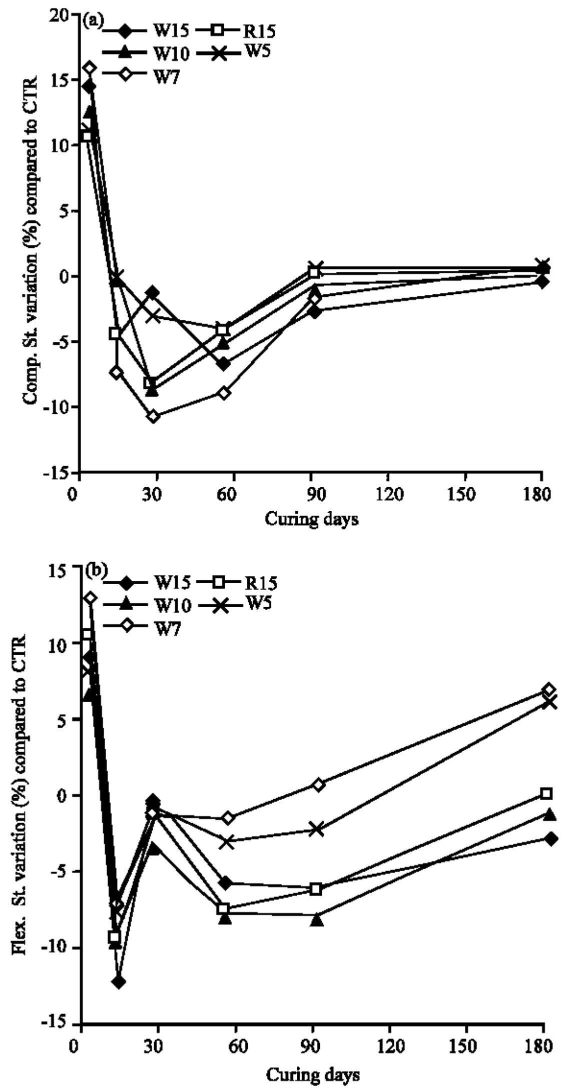

Fig. 4: Variation in compressive strength (A) and flexural strength (B) of blended mortar specimens in comparison to CTR specimen after 3, 7, 14, 28, 56, 91 and 180 days of curing

development rate per initial 7 day strength, as an indicator of strength development (Malhotra and Carino, 1991) (Fig. 6). All blended mortar specimens showed higher UPV development rate than CTR, possibly because more amount of resistant particles per unit volume and the physical action caused by grain refinement that resulted in densely packed structures through blocking or filling of finer particles. UPV values recorded were in the following order: W7 > W5 > R15 > W10 > W15 > CTR which were almost in agreement with CS and FS results and again highlighting the optimum percentage of WSA substitution in achieving better synergy effect, in combination with RHA.

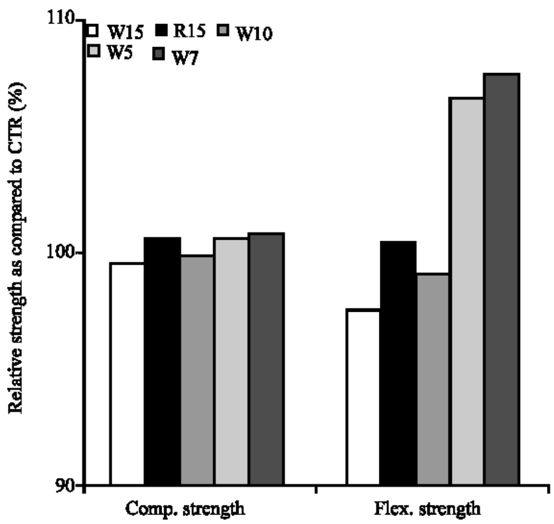

Fig. 5: Compressive and flexural strength (%) of 180 day cured blended mortar specimens relative to control specimen

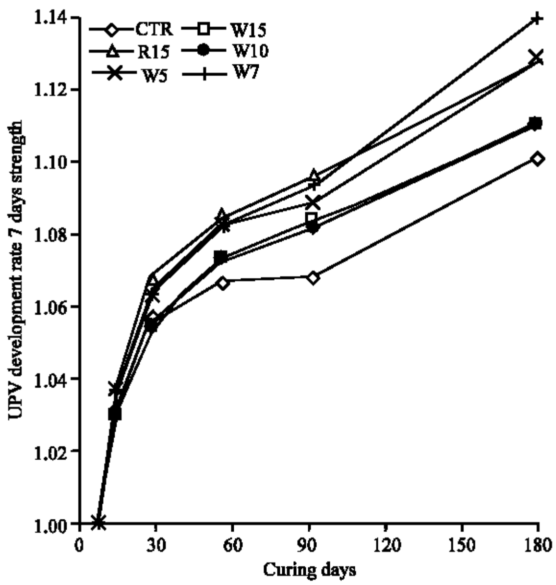

Fig. 6: Ultrasonic Pulse Velocity (UPV) development rate (per 7 days values) of blended and CTR mortar specimens after 7, 14, 28, 56, 91 and 180 days of curing

CONCLUSIONS

When part of Portland was replaced by RHA and WSA, each of these mineral additions reacted in a complementary way, depending upon the particle size and chemical or physical activity, concerning its interactions with in the cementitious gel. From the results of the present study following conclusions can be made:

Ternary blended mortar specimen; W7 with 7.5% WSA and 7.5% RHA combination, substituting OPC by 15% in total, exhibited higher compressive and flexural strengths than CTR, suggesting that significant improvement in strength properties of mortars can be achieved by using abundantly available WSA.

Results indicated that synergy existing between RHA and WSA was due to the optimization of pozzolanic reaction and filler effect and was effective in improving the ultimate strength of mortars, even higher than the specimens substituted only with relatively more reactive RHA.

ACKNOWLEDGMENTS

The authors would like to acknowledge the technical guidance and help of Prof. Katada N (Deptt of Material Science), Ms. Eiko Kawahara, (Faculty of Agriculture), Mr. Hayashi Akitomi, (Civil Engg. Deptt.), Tottori University, Japan and Prof. Nonaka T (Shimane University, Japan).

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