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Use of Hybrid Rice Husk Ash/Fly Ash as Sustainable Materials for Concrete in a Marine Environment

D. V. Reddy, Diana Arboleda, Khaled Sobhan, and Abhi Tipnis

Center for Marine Structures and Geotechnique; Florida Atlantic University, Bldg 36, Room 216, 777 Glades Road, Boca Raton, FL 33431,USA. E-mail: <reddy@civil.fau.edu>, <darboled@fau.edu>, <sobhan@civil.fau.edu>.
Contracting Specialists Inc.; 1600 N. Powerline Road, Pompano Beach, FL 33069,USA.
E-mail: < mailto:atipnis@contractingspecialists.com>.

ABSTRACT

This paper presents the comparison of shrinkage and corrosion characteristics of optimized Hybrid Rice Husk Ash (RHA)/Fly Ash (FA)-modified Concrete, with those of normal concrete in the marine environment. Uses of both FA and RHA have numerous environmental benefits. The restrained shrinkage experiments are being performed following the ASTM C1581-04 “Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage”. This test consists in placing concrete around a 305 mm diameter steel ring, and measuring the strain of the ring, until the concrete cracks. The time to cracking of the concrete is compared for the different mix combinations to determine shrinkage performance characteristics. The corrosion testing of reinforced columns is being performed in a simulated tidal cycle Marine Environment. The corrosion performance of the specimens is monitored using Potentiostat equipment, in order to provide a comparison of corrosion behavior.

INTRODUCTION

A desirable advance in construction materials technology is the use of environmentally friendly materials, which also improve the properties of the final product. This is accomplished with partial replacement of cement with pozzolanic material such as Fly Ash (FA) or Rice Husk Ash (RHA). Rice Husk Ash (RHA) is a sustainable material, as it is a renewable resource. Additionally, both Fly Ash (FA) and Rice Husk Ash are green materials, since they do not contribute to the production of CO_2 or greenhouse gas emissions like cement does; and they are recycled waste materials, so their use decreases landfill disposal.

Rice husk is the outer cover of rice that accounts for 20% of its weight, and it is a waste material that contributes not only to landfill volume, but when rice husk is fermented by microorganisms, methane is emitted contributing to global warming problem [Thipwimon et al. 2004]. Rice husk can be used as solid fuel (biofuel) for power generation. About 25 % of the husk weight is converted into ash during the firing process. Unlike the waste materials of other crops, Rice Husk contains the highest amount of silica. Specifically, the RHA used for this experiment, which was acquired from Agrilectric Power Plant in Lake Charles, Luisiana, USA, contains 87.9% Silicone Dioxide (SIO_2), and 5.32% Carbon content.

Fly Ash is the byproduct of coal combustion for power generation, and also a waste material that contributes to landfill volume. There are two main types of Fly ash, Type C and Type F, differentiated mainly by their chemical composition. Type F Fly ash contains generally less than 8% calcium oxide (CaO), and averages about 45% SIO_2 and 20% AL_2O_3 so it is considered a pozzolanic material. Type C Fly ash contains generally more that 15% CaO, which gives it some hydraulic properties in addition to pozzolanic properties.

The study presented in this paper is a continuation of research at Florida Atlantic University, into the characteristics of concrete made with RHA as a partial substitute for cement. The reason that cement cannot be replaced 100% is that while cement is a hydraulic material, that reacts with water to form the binder in concrete (calcium silicate hydrates C-S-H), RHA and other materials such as FA, silica fume, metakaolin, are pozzolanic materials, which react with the product of the hydraulic process, hydrocarbons (CH), to form more binder. The reason that a hybrid mix of RHA and FA was selected for this study is that in a cooperative investigation conducted by Chulalongkorn University in Thailand, concretes were made with varying levels of RHA, FA, and Hybrid FA/RHA as partial substitutes for cement, to determine optimum admixture combinations based on their chloride ion permeability compared to normal concrete. The hybrid mixes showed the best chloride ion permeability-resistant characteristics over mixes with either RHA or FA alone. This is an important performance measurement for concrete used in marine environments, such as piers, offshore structures, tidal barriers, jetties, tanks etc.

In this study, concretes were made with the optimized hybrid FA/RHA mixes as partial substitutes for cement, to levels of 25%/10%, 25%/5%, and 15%/10%, to determine their shrinkage and corrosion characteristics, compared to normal concrete. The FA is class F Fly ash and the RHA particle size is 45 µm. Compressive, split tensile, and flexural strength tests were also conducted to verify no degradation of these characteristics. Shrinkage is being determined by conducting restrained shrinkage experiments following ASTM C1581-04 "Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage". This test consists in placing concrete around a 305 mm inside diameter and 13 mm thick steel ring. As the concrete shrinks during its curing process, it produces a strain in the steel, which is measured as a function of time. Once the concrete cracks, the strain in the steel shows a significant reduction, thus establishing the time to crack of the concrete. These parameters will be compared for the different mix combinations, to determine the influence of FA/RHA mix ratio on crack performance.

Durability characteristics are of considerable concern for concrete in marine environments with seawater exposure, as corrosion of the reinforcing steel will lead to spalling of the concrete. This corrosion occurs most severely in the tidal zone of the structure as it is exposed to repeating wet and dry cycles. To simulate this condition, the corrosion tests are being performed in a tidal cycle environment, where the middle third of the specimens is subjected to repeated wet and dry cycles.

EXPERIMENTAL INVESTIGATION

Specimen Details

A number of specimens were cast, specifically, for each of the three proposed mixes, plus a control cement only mix. Three specimens were needed for each of the tests: compressive strength, splitting tensile strength, flexural strength, restrained shrinkage, and corrosion monitoring. A total of 60 specimens were made as summarized in Table 1. A water/cementitious (w/cm) ratio of 0.40 was selected for all the mixes.

Table 1. Specimen Descriptions

Type of Test	Specimen Shape	Specimen Size	Quantity
Restrained Shrinkage	Ring	318mm inside dia x 420mm outside dia x 152mm height	12
Accelerated corrosion	Reinforced concrete column with four #4 rebar at each corner with 25.4mm cover.	152mm x 152mm x 813 mm length	12
Compressive strength and modulus of elasticity	Cylinder	152mm diameter x 303mm height	12
Splitting tensile strength	Cylinder	152mm diameter x 305mm height	12
Flexural strength (modulus of rupture)	Square column	152mm x 152mm x 533mm length	12
		Total	60

Materials and Mix proportions

The materials used for the mix design were ASTM Type I Portland cement, tap water, sand as the fine aggregate, pea rock as the coarse aggregate, and Fly Ash Class F/ Rice Husk Ash combinations. The mix proportions are the same as in the preceding study conducted as a cooperative investigation at Chulalongkorn University in Thailand [Teeranop, Stitmannaithum, 2006]. A Summary of the mix proportions for each of the experiments is presented in Table 2.

Table 2. Proportions of Materials Used for Concrete Mixes

	Control Batch w/c = .4		Hybrid 1 .25 FA/.1 RHA		Hybrid 2 .25 FA/.05 RHA		Hybrid 3 .15 FA/.1 RHA	
Material	**Mix (kg/m^3)**	**kg/batch**	**Mix (kg/m^3)**	**kg/batch**	**Mix (kg/m^3)**	**kg/batch**	**Mix (kg/m^3)**	**kg/batch**
Cement Type I	499.78	73.6	324.85	47.84	349.84	52.53	374.83	55.2
RHA	0.00	0.00	49.98	7.36	24.99	3.68	49.98	7.36
fly ash	0.00	0.00	124.94	18.4	124.94	18.4	74.97	11.04
3/8" aggregate	991.54	146.04	991.54	146.04	991.54	146.04	991.54	146.04
Sand	752.87	110.89	752.87	110.89	752.87	110.89	752.87	110.89
Water	200.23	29.49	200.23	29.49	200.23	29.49	200.23	29.49

Restrained Shrinkage Experiments

The shrinkage ring experiment follows the standard ASTM C 1581-04 "Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage". The steel rings have measurements of 30.5cm inside diameter x 1.3 cm thickness x 15.2 cm height. The base is a 50.8 x 50.8 cm form board material, and the outer ring is a 40.6 cm inside diameter x 15.2 cm height Sure-tube concrete column form. Fig. 1 below shows the specimen details.

Fig. 1. Restrained shrinkage specimens

Strain gages were attached to the steel rings in a quarter bridge configuration connected through a signal conditioning circuit, designed in-house, to a data acquisition system. The specimen's outer circumference is exposed to allow for radial drying. Shrinkage of the concrete will induce a gradual strain in the steel ring, which is relieved after the concrete cracks due to tensile stress. Strain data is collected in order to measure the time to cracking of the different sample mixes. The data collection system is controlled with software. Data is collected at 5 minute intervals and averaged for every 30 minutes for each data point.

Corrosion Testing Experiments

Corrosion testing in a simulated Marine (tidal cycle) Environment is conducted by placing the reinforced column specimens in two tanks, partially submerged in seawater. Through the use of pumps and timers, the water is cycled back and forth through the two tanks to simulate accelerated tidal cycles. It has been shown that this cyclical change in environment exposure will favor the corrosion rate in concrete columns due to increased chloride content at the concrete surface [Bertolini et al, 2004]. When wetting and drying occurs, the evaporation of water leads to the enrichment of chloride ions [Bertolini et al, 2004]. A Potentiostat is used to measure the corrosion performance of the specimens for the duration of the experiment. The electrode connections were made as shown below, in Figure 2. The reinforced specimens are shown in Fig. 3 in the tidal cycle tanks.

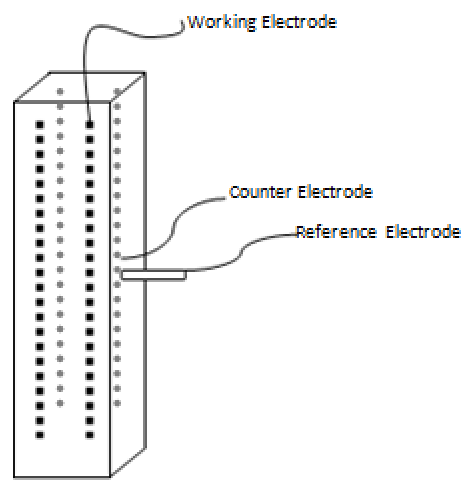

Fig. 2. Electrode connection diagram for corrosion tests (dashed line is rebar)

Fig. 3. Specimens in accelerated corrosion tidal cycle tanks

RESULTS AND DISCUSSIONS

Compression, Split Tensile, and Flexural Strengths

The figures below summarize 28-day compressive, tensile, and flexural strengths obtained for this experiment. Three specimen average values were obtained for each of the four mixes. Column 1 is for control specimens with a regular Portland cement mix. columns 2, 3, and 4, are for mixes with 25%FA/10%RHA, 25%FA/5%RHA, and 15%FA/10%RHA cement replacement respectively.

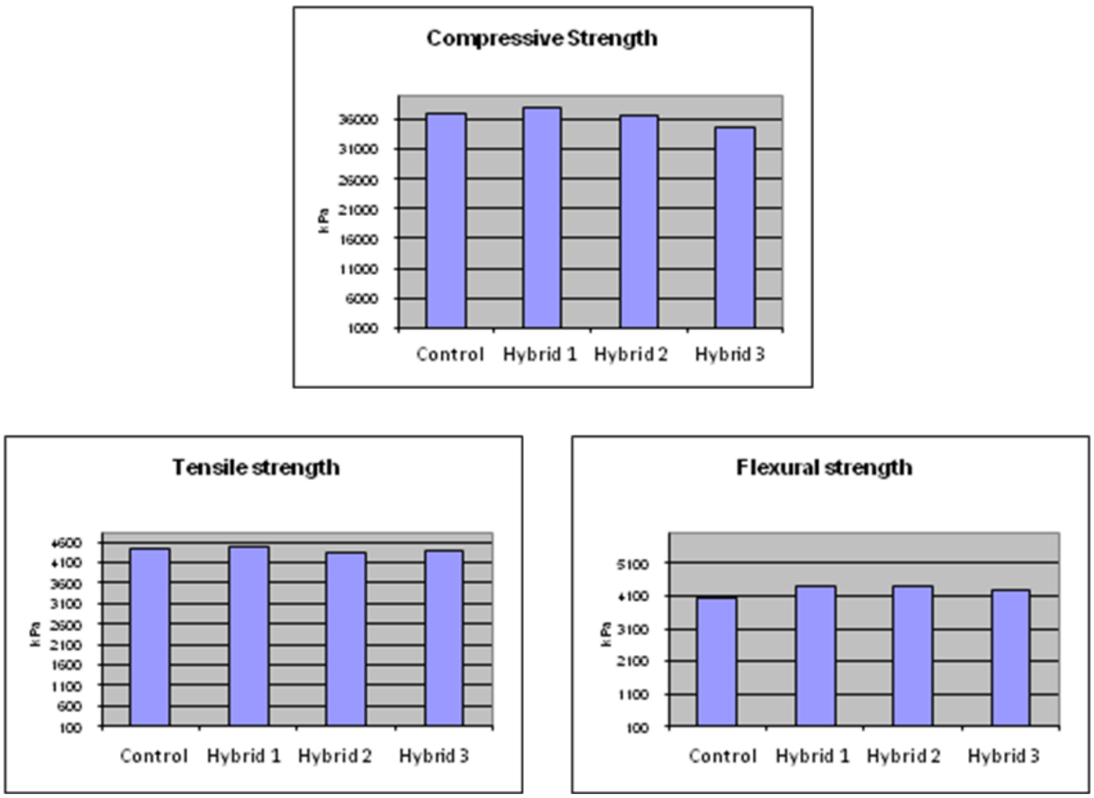

Fig. 4. Strength test results

It can be seen from the graphs, that the strength of the concrete was not compromised with the different mix replacements. Although, an increase in these properties is expected by partial cement substitution, this increase occurs at a higher curing time.

Restrained Shrinkage

A graph of average strain developed in each of the steel rings is plotted each day. The trend for this test shows a slight performance improvement with the hybrid mixes as shown in Fig. 5, Fig. 6, Fig. 7, and Fig. 8. Specifically, the better performing mix was the one with the highest replacement of cement by 25%FA/10%RHA, followed by 15%FA/10%RHA.

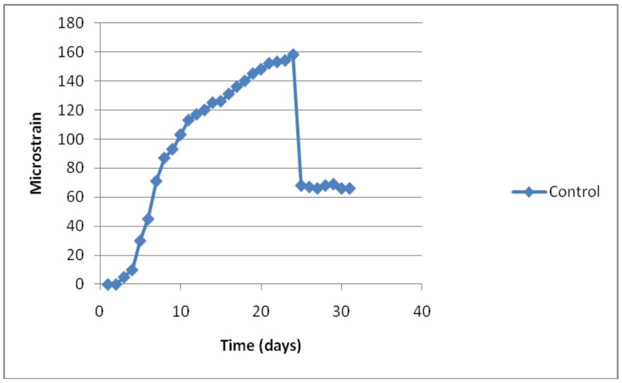

Fig. 5. Time to initial cracking for the control mix.

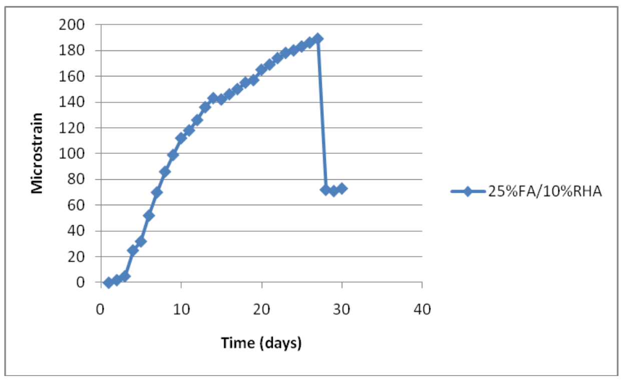

Fig. 6. Time to initial cracking for the 25%FA/10%RHA mix.

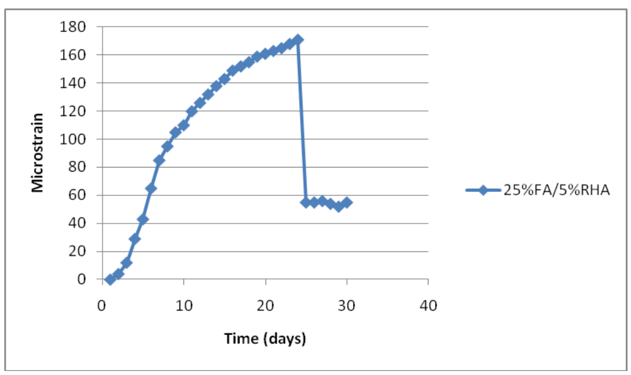

Fig. 7. Time to initial cracking for the 25%FA/5%RHA mix.

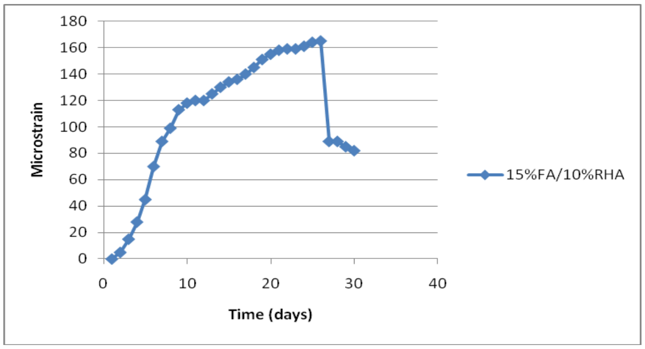

Fig. 8. Time to initial cracking for the 15%FA/10%RHA mix.

These results are supported by previous research indicating improved shrinkage performance of RHA substitution [Alvarez, 2006], and FA substitution [ACI, 1996].

Corrosion in a simulated Marine Environment

The voltage differential between the rebar and the reference electrode was measured, as well as resistivity, in order to determine the corrosion potential, which is shown in Fig. 9. The values are indicated for three specimens of each mix type. Again, the mix with the highest replacement of cement shows the most improvement.

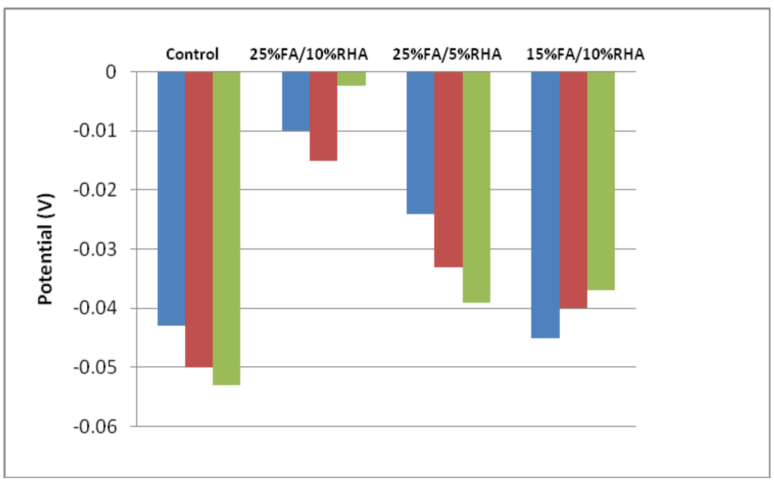

Fig. 9. Corrosion potential

The data trend supports previous chloride ion penetration results [Teeranop, Stitmannaithum, 2006] that suggest improved performance of hybrid mixes. In that study, the chloride ion penetrability of the hybrid mixes decreased close to a third of that from the control mix.

CONCLUSIONS

- The economics for use of innovative materials for sustainability depends on local availability of those materials. Specifically, FA has already found worldwide availability, while RHA is cheaply available in areas where rice husk is used for energy production, such as China and India, according to the Food and Agriculture Organization of the

United Nations. The same site lists the top producing countries of rice, where the United States is in 11th position after mostly Asian Countries.

- The results presented in this paper reinforce the trend of improved performance characteristics derived from the partial replacement of cement with pozzolans, such as RHA and FA.

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