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Rice Husk Ash as a Sustainable Concrete Material for the Marine Environment

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ABSTRACT

This paper presents the results of a research project comparing the strength and durability characteristics of Rice Husk Ash-modified Concrete with those of normal concrete in the marine environment. The use of green supplementary cementitious materials as partial replacements of the cement in concrete will play a significant role in the environmental control of greenhouse effects, and the turning down of the global thermostat. Additionally, many of these materials are cost-effective, with the unbelievable effect of cheaper being better! Currently, the most widely used supplementary cementitious material, all over the world, is Fly Ash, a waste product of the coal power plants. Other cementitious materials include Silica Fume, Blast Furnace Slag, and Natural Pozzolans (such as volcanic ash). Quite recently, Rice Husk Ash (RHA), obtained as a by-product of the Rice Husk fuel-based power plants, has been identified as a suitable alternate to fly ash, with a renewable source, i.e., rice, as opposed to fossil fuel, like coal. The use of rice husk ash as a supplementary cementitious material not only enhances the compressive strength and durability properties of concrete, but also reduces carbon dioxide and other greenhouse gas emissions associated with cement production. Global production of rice is approximately 580 million tonnes a year, and this is rising as the world population and the consequent consumption of rice increases. The milling of rice produces rice husk, which is a waste material. This makes the research on the potential uses of rice husk and rice husk ash of primary importance. The manufacturing of cement produces carbon dioxide (CO2), which is a prime contributor to global warming. Typically, cement production results in CO2 emissions of about 0.8 – 1.2 tonnes/tonne of cement product. Using RHA in concrete will help to reduce the amount of cement due to the partial substitution of cement by RHA and also make the concrete last longer.

In this investigation, concretes made with RHA as a partial substitute for cement, to levels of 10% and 20% by weight of cement, were investigated to determine their performance characteristics compared to normal concrete. Two different water cementitious (w/cm) ratios, 0.40 and 0.55, were investigated for a total of six different mixes. The main objective was to investigate and compare the performance characteristics in the marine environment of specimens prepared with rice husk ash-modified concrete, to those of specimens prepared with normal concrete. After 150 and 300 cycles of marine exposure, the mixes containing RHA showed better performance characteristics such as strength, shrinkage, chloride ion permeability, resistance to corrosion, and load capacity after corrosion, than the normal concrete mixes. The mixes with lower w/cm ratios performed better than those with higher ratios.

Further research is ongoing to determine the optimum RHA-other admixture combinations to be used as partial replacements for the cement. Additional experiments, involving tidal cycle simulation of the marine environment for corrosion testing, as well as restrained shrinkage testing, comprise the new tasks.

Keywords: Concrete Properties, Rice Husk Ash, Cement Replacement.

1. INTRODUCTION

The annual worldwide concrete production is 12 billion tonnes, of which cement constitutes 1.6 billion tonnes. Production of 1 tonne of cement generates approximately 1 tonne of CO2 with a requirement of 7,000 MJ of electrical power. Therefore, the concrete industry significantly impacts the ecology of the earth. Use of supplementary cementitious materials, as partial replacements of the cement in concrete, will play a significant role in the environmental control of greenhouse effects, and the turning down of the global thermostat. Additionally, many of these materials are cost-effective, with the unbelievable effect of cheaper being better! Currently, the most widely used supplementary cementitious material, all over the world, is Fly Ash, a waste product of the coal power plants. Other cementitious materials, also known as admixtures, include Silica Fume, Blast Furnace Slag, and Natural Pozzolans (such as volcanic ash). Quite recently, Rice Husk Ash (RHA), obtained as a by-product of the Rice Husk fuel-based power plants, has been identified as a suitable alternate to fly ash, with a renewable source, i.e., rice, in contradistinction to fossil fuel, like coal. Economic development, urbanization, higher living standards, tighter environmental regulations, and consolidation in the rice milling industry are reducing some of the traditional uses of husks, and creating new opportunities for husk utilization (Velupillai, 1997).

Global production of rice is approximately 580 million tonnes a year, and this is rising as the world population and the consequent consumption of rice increases. The milling of rice produces rice husk, which is a waste material. Rice husk is generated at a 20% rate by weight of the rice that is processed. Most of the husk is burned or dumped as waste. The burning of the husks produces ash at an average of 18% by weight of the husks. In 1973, Mehta published the first of several papers describing the effect of pyroprocessing parameters on the pozzolanic reactivity of RHA (Bouzoubaa, 2001). Rice husks are also a good source of fuel to produce power. Each MW hour of electricity produced requires 1.5 – 2.0 tonnes of rice husk giving a cost of 2-3 cents per kWhr. The annual production of rice around the world generates about 116 million tones of rice husks. The estimated energy content of husks is 13.5GJ/tonne giving a global energy potential of 1.57 billion GJ/year. At a cost of US$5/GJ this will have an annual value of US$7.8 billion, which is equivalent to over 1 billion barrels of oil per year.

Silica precipitation technology, developed at the Indian Institute of Science, Bangalore, is a very innovative method for extraction of pure silica from RHA, which would be a very cost-effective alternative to silica fume, Mukunda (2002).

ENVIRONMENTAL IMPACT

The use of rice husk ash as a supplementary cementitious material not only enhances the compressive strength and durability properties of the concrete, but also reduces carbon dioxide and other greenhouse gas emissions associated with cement production. The majority of rice husk goes into landfills because the burning in open piles is not acceptable due to environmental constraints. This makes the research on the potential uses of rice husk and rice husk ash of primary importance in the world. The manufacturing of cement produces carbon dioxide (CO2), which is a prime contributor to the global warming. Typically, cement production results in CO2 emissions of about 0.8 – 1.2 tonnes/tonne of cement product, depending on the production process and the fuel used. Using RHA in concrete will help to reduce the amount of cement due to the partial substitution of cement by RHA and by making the concrete last longer.

PROPERTIES OF RICE HUSK ASH MODIFIED CONCRETE

The use of RHA in the production of high-performance and high-durable concrete has been presented in several papers. The significant findings were as follows: i) Substantial reduction in mass loss on exposure to hydrochloric solutions (Mehta and Folliard, 2002, Sugita et al, 1997, and Wada et al, 2000). ii) Considerable reduction in alkali-silica and sulfate expansions, (Mehta et al, 2002, and Wada et al. 2000). iii) Higher frost resistance of non-air entrained RHA concrete compared to similar mixtures of silica fume concrete (Mehta and Folliard , 2002). iv) Higher compressive strength (Wada et al, 2000). , v) Higher resistance to chloride ion penetration of a) RHA concrete with 10% cement replacement compared to normal concrete (Gjorv et al , 1998, Sugita et al. , 1997), and b) ternary blends containing both fly ash and RHA, compared to binary blends containing only fly ash (Bhanumathidas and Mehta, 2001), vi) reduction in the heat of hydration, vii) Higher resistance to carbonation (Sugita et al., 1997). viii) Higher abrasion compared to control mortar specimens (Wada et al., 2000

TERNARY RICE HUSK AND FLY ASH MODIFIED CONCRETE

Study of mixes using RHA in high-volume fly ash (HVFA) concrete were carried out by Bhanumathidas and Mehta (2001) with the following significant findings : 1) For the same w/cm (water/cementitious ratio), the slump of mixes containing RHA and HVFA compared to mixes with cement only was significantly higher. 2) The incorporation of RHA in concrete reduced the bleeding and segregation, which would result in more durable concretes. 3) For the same w/cm, the compressive strengths at 28 days of mixes containing RHA and HVFA were higher than those for mixes with HVFA only. 4) For the same w/cm, the resistance to chloride ion penetration of mixes with RHA and HVFA was far superior compared to mixes containing HVFA or cement only.

2. SCOPE OF RESEARCH

The main objective was to investigate and compare the performance characteristics in the marine environment of specimens prepared with rice husk ash-modified concrete, to those of specimens prepared with normal concrete. Six different concrete mixes were tested to determine characteristics, such as strength, shrinkage, chloride ion permeability, resistance to corrosion, and load capacity after corrosion.

SPECIMEN DESIGN AND PREPARATION

The materials used for the mix design were ASTM Type I Portland cement, tap water, Palmdale Silica Sand with a fineness modulus of 2.2 and moisture content of 2.03% for the fine aggregate, pearock of size 3/8 in. (9.5 mrn) with moisture content of 3.53% and dry-rodded weight of 98 lb/ft3 (1,570 kg/m3) for the coarse aggregate. The admixtures used were rice husk ash, a water reducer, and a superplasticizer.

For this investigation, six mixes with w/cm ratios of 0.40 and 0.55 were designed. The mixes were designed by the weight method as recommended by ACI (American Concrete Institute) Code. Mixes with RHA contents of 0%, 10% and 20% were investigated for a total of six mixes.

The experimental program was accomplished by casting and testing two- hundred and seventy (270) specimens. Three (3) specimens for each RHA % and each w/cm ratio were cast. Table 1 shows the specimen descriptions, including shape, size, and quantity of specimens, that were cast for each of the tests. Note that for the specimens subjected to marine exposure and accelerated corrosion, the numbers of the specimens were double, because test and control specimens had to be investigated.

Table 1: Specimen Descriptions

Type of Test	Specimen Shape	Specimen Size	Quantity
Compressive strength and modulus of elasticity at 28 days	Cylinders	4 in. diameter x 8 in. height	18
Compressive strength and modulus of elasticity after 150 cycles of marine exposure	Cylinders	4 in. diameter x 8 in. height	36
Compressive strength and modulus of elasticity after 300 cycles of marine exposure	Cylinders	4 in. diameter x 8 in. height	36
Splitting tensile strength at 28 days	Cylinders	4 in. diameter x 8 in. height	18
Splitting tensile strength after 150 cycles of marine exposure	Cylinders	4 in. diameter x 8 in. height	36
Splitting tensile strength after 300 cycles of marine exposure	Cylinders	4 in. diameter x 8 in. height	36
Flexural strength (modulus of rupture) at 28 days	Cylinders	6 in. height x 6 in. width x 21 in. length	18
Resistance to chloride ion penetrability	Cylinders	4 in. diameter x 8 in. height	18
Shrinkage	Prisms	3 in. height x 3 in. width x 11.25 in. length	18
Accelerated corrosion and load capacity after corrosion	Reinforced concrete columns	6 in. height x 6 in. width x 32 in. length	36
		Total	**270**

3. METHODOLOGY

The cylinders for compressive strength, static modulus of elasticity, and splitting tensile strength testing, after 150 cycles and 300 cycles of marine exposure were moist cured for 90 days. When the curing period was completed, these specimens were placed in durability tanks, and exposed to alternate wet and dry cycles for a total of 4 cycles each day, with 4 hours of wetting and 2 hours of drying. The cylinders for resistance to chloride ion penetration testing were moist cured for 90 days. When the curing period was completed, one core from the top side of each specimen was cut to obtain cores of 2 in. thickness by 4 in. diameter. These cores were coated around the sides with epoxy, vacuum saturated with water, and soaked for 18 hours.

4. RESULTS

The comparison of the results for average compressive strength and modulus of elasticity of the six mixes is shown in Figure 1. The compressive strength of the specimens ranged from 5,558 psi (38.35 MPa) to 8,396 psi (57.93 MPa). For similar w/cm, the compressive strength of RHA modified concrete was higher than normal concrete prepared with Portland cement only. For similar w/cm ratios, the average compressive strength of specimens prepared with 10% and 20% RHA was similar

The static modulus of elasticity of the specimens ranged from 3.68 x $l0^6$ psi (25.38 GPa) to 4.68 x $l0^6$ psi (32.27 GPa). For both w/cm ratios, the static modulus of elasticity of RHA modified concrete was somewhat lower than for normal concrete prepared with Portland cement only. Also, the average static modulus of elasticity of specimens prepared with 10% RHA was slightly higher than for those prepared with 20% RHA.

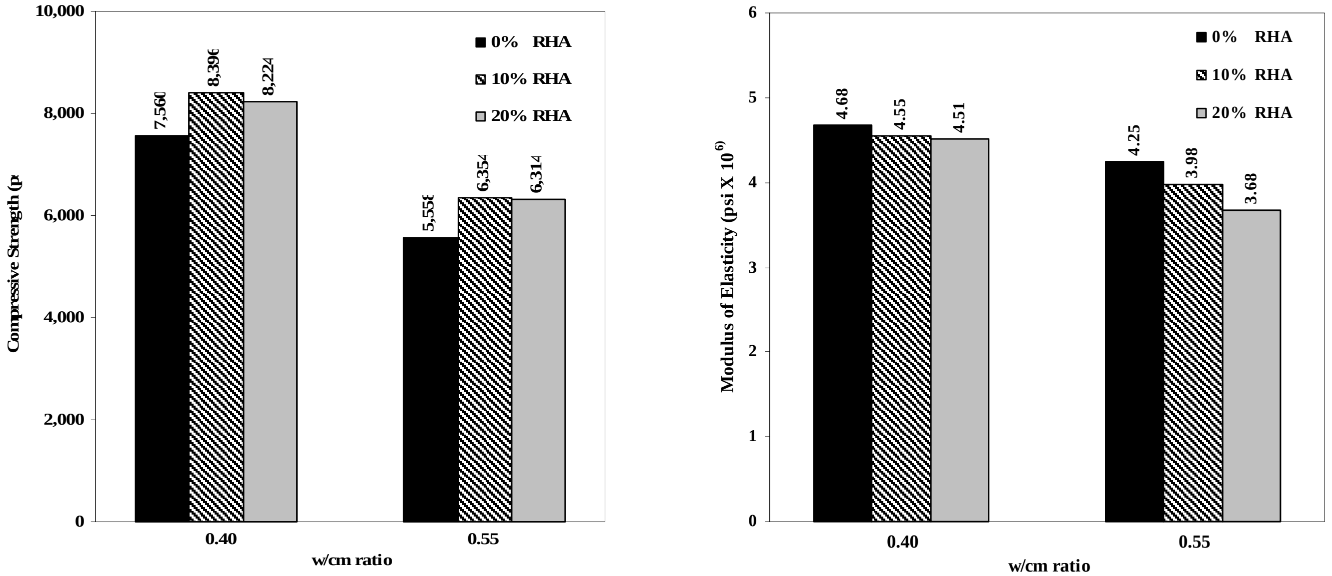

Figure 1: Average compressive strength and modulus of elasticity at 28 days

The comparison of the results for splitting tensile strength and flexural strength of the six mixes is shown in Figure 2. . The splitting tensile strength of the specimens ranged from 45 1 psi (3.1 1 MPa) to 541 psi (3.73 MPa). For the same w/cm ratios, the splitting tensile strength of RHA modified concrete was somewhat lower than normal concrete prepared with Portland cement only. The average splitting tensile strength of specimens prepared with 10% and 20% RHA is similar.

The flexural strength of the specimens ranged from 177 psi (1.22 MPa) to 506 psi (3.49 MPa). For similar w/cm ratios, the flexural strength of RHA modified concrete was lower than that for normal concrete prepared with Portland cement only. The average flexural strength of specimens prepared with 10% and 20% RHA was similar.

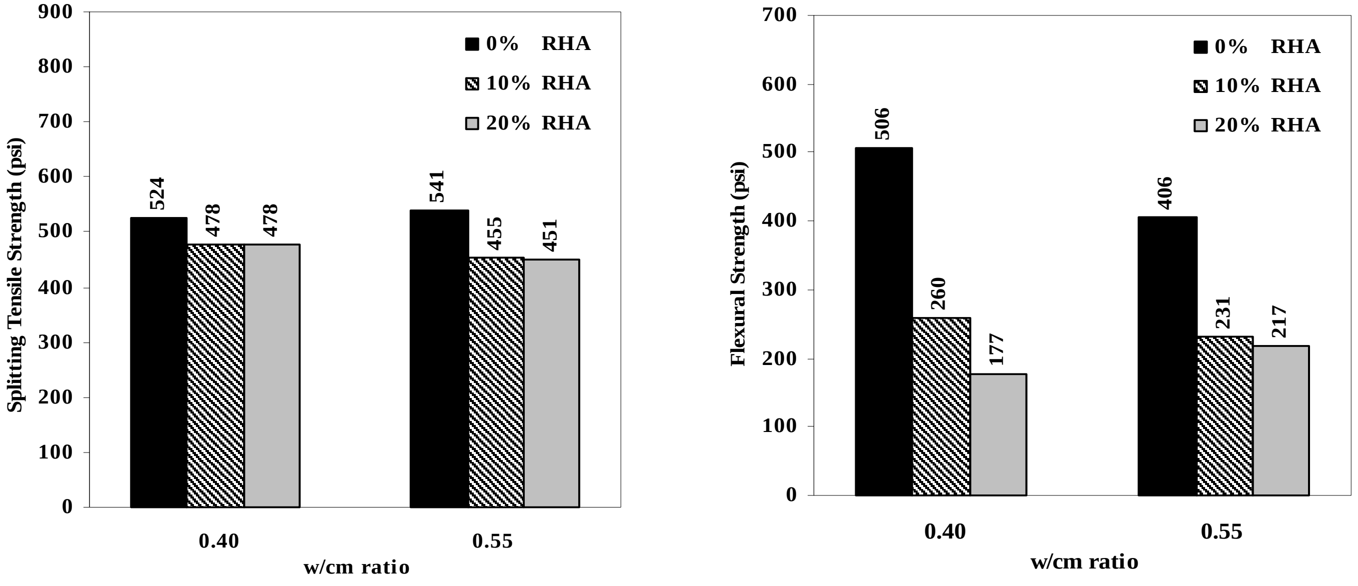

Figure 2: Average splitting tensile strength and flexural strength at 28 days

For the unrestrained shrinkage test, the specimens cast were prisms of size 3 in. height x 3 in. width x 11.25 in. length. A specimen installed in the test set up is shown in figure 3, below.

Figure 3: Shrinkage test setup and digital length comparator

The comparison of the results for drying unrestrained shrinkage of the six mixes, is shown in Figure 4. For similar w/cm, the shrinkage strain of RHA modified concrete was lower than normal concrete. The average shrinkage strain of specimens prepared with 10% RHA was lower than for those prepared with 20% RHA. The drying shrinkage of RHA modified concrete, ASTM C 157 and C 490, is lower than that of normal concrete.

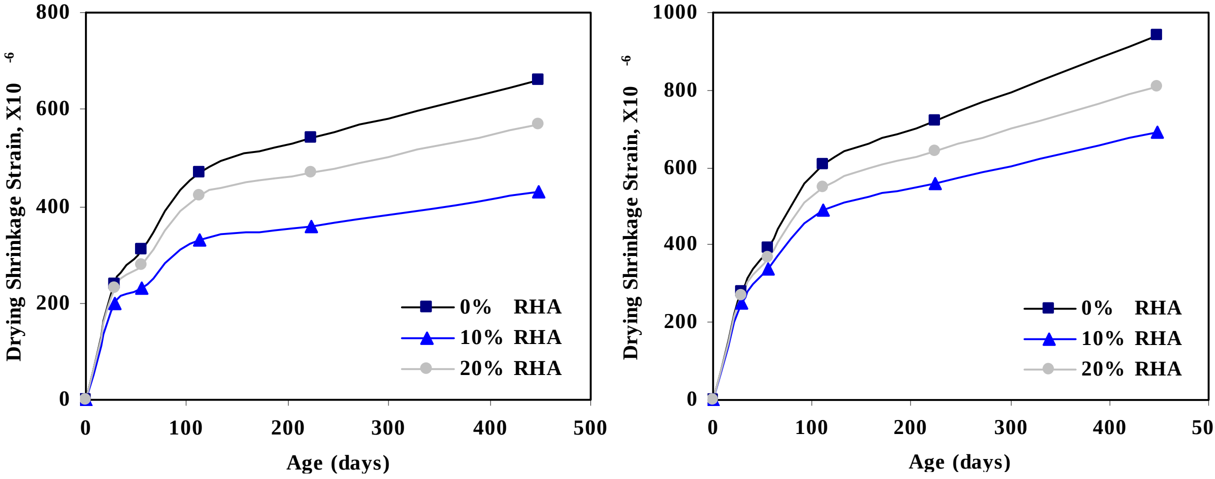

Figure 4: Average drying shrinkage strain for w/cm = 0.40 and w/cm = 0.55

The comparison of the results for average compressive strength and modulus of elasticity after 150 and 300 Cycles of exposure to a marine environment is shown in Figure 5. For similar w/cm ratios, after 150 cycles of marine exposure, the average compressive strength of specimens prepared with 10% RHA was higher than the average compressive strength of the specimens prepared with 20% RHA**.**). After 300 cycles, the % reduction in compressive strength of RHA modified concrete was lower than normal concrete. Also, the specimens prepared with mixes containing lower w/cm ratio had a lower % reduction in compressive strength.

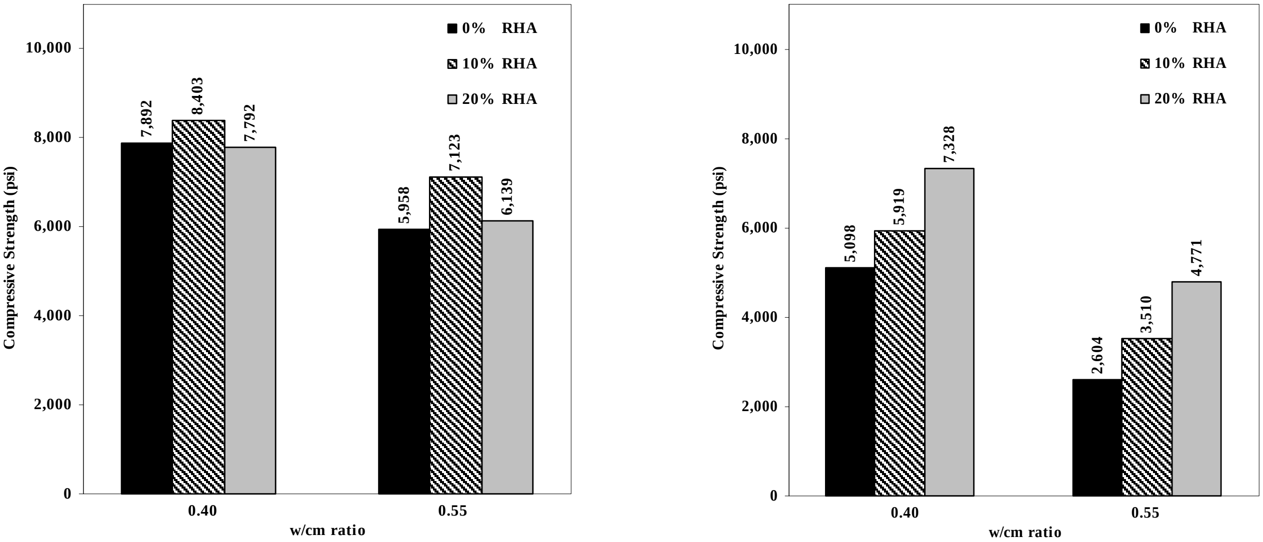

Figure 5: Average compressive strength after 150 cycles of exposure and after 300 cycles of exposure

The results for modulus of elasticity and for splitting tensile strength after 150 and 300 cycles of exposure was lower than for those of the control specimens The average static modulus of elasticity of specimens prepared with 10% RHA was higher than those with 20% RHA. The average splitting tensile strength of the specimens with 20% RHA was slightly higher than the average splitting tensile strength of the specimens with 10% RHA.

The comparison of the results for average chloride ion permeability and a schematic of the chloride ion penetration test setup are shown in Figure 6. These results show a significant reduction in the chloride ion permeability of the mixed with RHA.

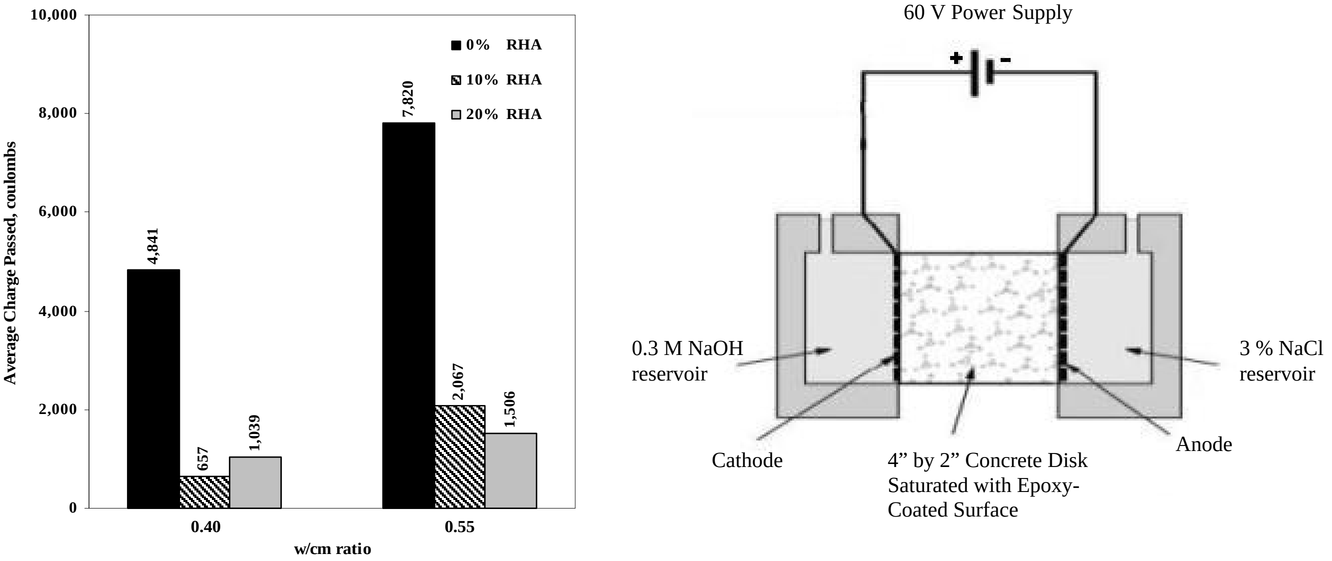

Figure 6: Average chloride ion permeability and schematic of Chloride Ion Penetration Test Setup

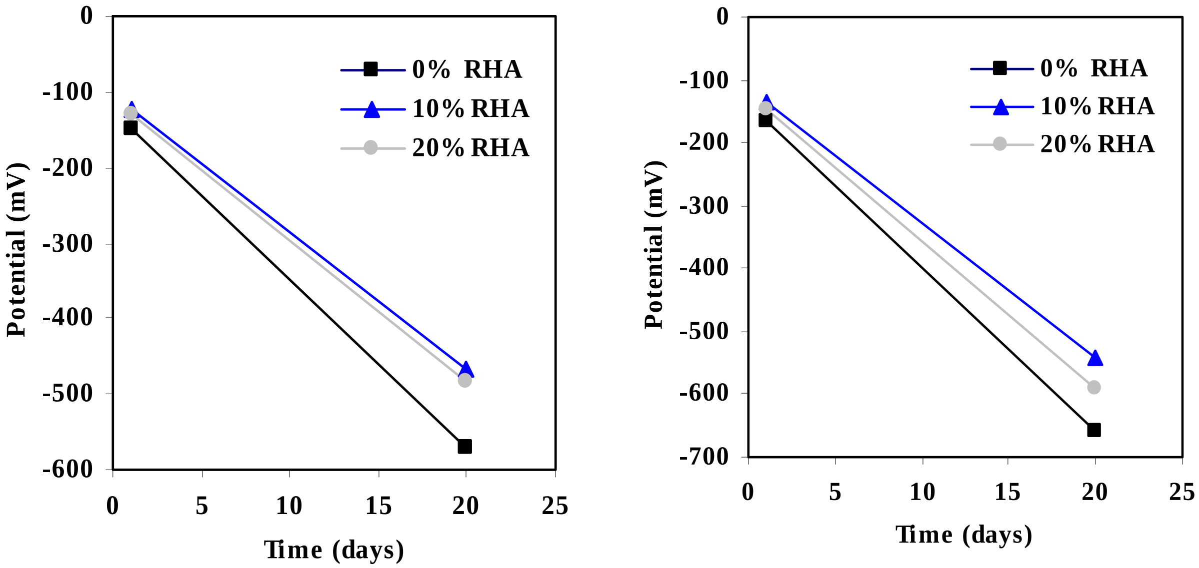

Figure 6: Average Corrosion Potential of the specimens for w/cm ratio = 0.40 (left) and w/cm ratio = 0.55 (right)

For similar w/cm ratios, the corrosion potentials of the specimens prepared with normal concrete were higher than for the specimens prepared with RHA modified concrete. The specimens prepared with normal concrete showed cracks and localized corrosion after the exposure, but the RHA modified concrete showed minor visible corrosion, with no visible cracks. The specimens with RHA modified concrete had higher load capacities after corrosion than those made of normal concrete. After failure, it could be observed that the reinforcement embedded in the specimens made with normal concrete, showed a higher level of corrosion than those embedded in RHA modified concrete.

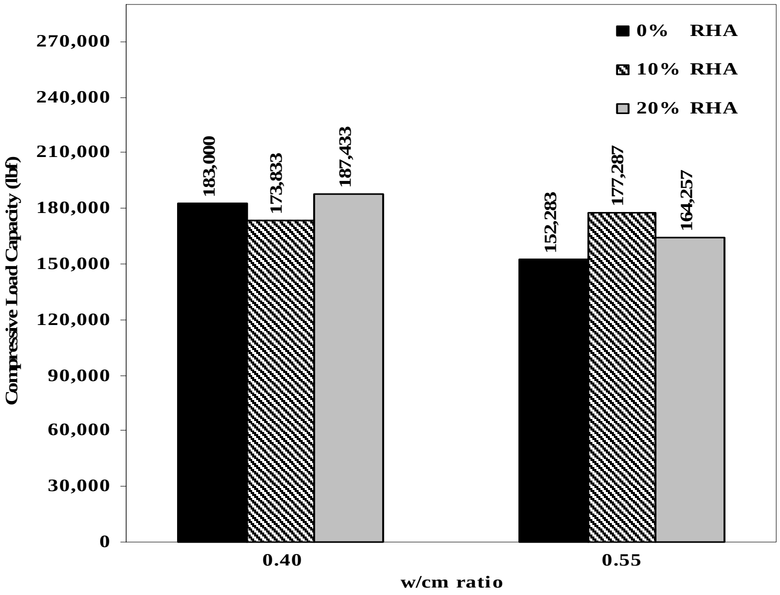

Figure 7: Average Load Capacity after Corrosion of Test specimens

5. CONCLUSIONS

In general, the mixes containing 10% and 20% RHA showed better performance characteristics than the normal concrete mixes. The mixes with lower w/cm ratios performed better than the mixes with higher w/cm ratios. Marine exposure has a detrimental effect on concrete and the longer the exposure the greater the damage induced in the concrete. The high silica content of RHA makes it an efficient alternative to more costly silica fume and blast furnace slag for corrosion control, and also because RHA is a renewable resource, unlike fly ash, which is fossil-based. The cost-effectiveness, enhanced durability, and the supply from a renewable resource, coupled with its energy efficient contribution to "Turning Down the Global Thermostat," make RHA a significant contributor to a holistic approach of the concrete industry to the global issue of environmental sustainability. Further research is ongoing to determine the optimum RHA-other admixture combinations to be used as partial replacements for the cement. Additional experiments, involving tidal cycle simulation of the marine environment for corrosion testing, as well as restrained shrinkage testing, comprise the new tasks.

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REFERENCES

Bouzoubaa, N. and Fournier, B. (2001), *Concrete Incorporating Rice-Husk Ash: Compressive Strength and Chloride-Ion Penetrability*, International Centre for Sustainable Development of Cement and Concrete (ICON), CANMET, Natural Resources Canada, Ottawa,Canada.

Velupillai, L., Mahin, D. B., Warshaw, J.W., and Wailes, E.J. (1997), *A Study of the Market for Rice Husk-to-Energy Systems and Equipment*, Louisiana State University, Baton Rouge, Louisiana, USA. ASTM Standard C 618-94a, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete*. Loo, Y.C., Nimityongskul, P., and Karasudhi, P. (1984), "Economical Rice Husk-Ash Concrete," *Proc. Ninth CIB Congress*, Stockholm, Sweden.

Mehta, P.K. and Folliard, K.J. (2002), "Rice Husk Ash - A Unique Supplementary Cementing Materia*l" Durability Aspects, Recent Advances in Cementitious Materials*, University of Wisconsin, Milwaukee, Wisconsin, USA.

Sugita, S., Yu, Q., Shoya, M., Sukinaga, Y.T., and Isojima, Y. (1997), "The Resistance of Rice Husk Ash Concrete to Carbonation, Acid Attack and Chloride Penetration", *High Performance Concrete*, ACI Int. Conf.,Kualalumper, Malaysia, 29-43.

Wada, I., Kawano, T., Kawakami, M., and Maeda, N. (2000), "Effect of Highly Reactive Rice Husk Ash on durability of concrete and Mortar", *Durability of Concrete*, CANMET/ACI, Barcelona, Spain, 205-222.

Gjorv, O.E., Ngo, M.H., and Mehta, P.K. (1998), "Effect of Rice Husk Ash on the Resistance of Concrete Against Chloride Penetration", *Concrete in Severe Environment*, Tromso, Norway.

Bhanumathidas, N.,and Mehta, P.K. (2001), "Concrete Mixtures Made with Ternary Blended Cements Containing Fly Ash and Rice-Husk Ash," *Seventh CANMET/ACI Int. Conf. on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete*, 22-27 July, Madras, India, V.M. Malhotra, Ed., ACI SP199, ACI, Michigan, 379-391

ASTM Standard C 143, *Test Method for Slump of Portland Cement Concrete*.

ASTM Standard C 138, *Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete*.

ASTM Standard C 172, *Practice for Sampling Freshly Mixed Concrete*.

ASTM Standard C 39, *Standard Testing Method for Compressive Strength of Cylindrical Concrete Specimens*.

ASTM Standard C 496, *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*.

Zhang, M.H. and Malhotra, V.M. (2002), "High-Performance Concrete Incorporating Rice Husk Ash as a Supplementary Cementing Material", *Recent Advances in Cementitious Materials,* University of Wisconsin, Milwaukee, Wisconsin, USA.

ASTM Standard C 78, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*.

ASTM Standard C 469, *Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression*.

Taylor, C. Peter. (2001), "Mineral Admixtures for Concrete", *Structures,* 8, 36-37

ASTM Standard C 1202, *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*.

ASTM Standard C 666 Procedure A, *Resistance of Concrete to Rapid Freezing and Thawing in water*.

ASTM Standard C 1012, *Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution*.

Mukunda, H.S. (2001), "Precipitated Silica from Rice Husk Ash IPSIT (Indian Institute of Science Precipitated Silica Technology).

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