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# Marine Durability Characteristics of Rice Husk Ash-Modified Reinforced Concrete

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## Abstract

This paper addresses the potential use of Rice Husk Ash (RHA) as a cementitious material in concrete mixes. RHA is produced from the burning of rice husk which is a by- product of rice milling. The ash content is about 18-22% by weight of the rice husks. Research has shown that concrete made with RHA as a partial cement substitute to levels of 10% to 20% by weight of cement has superior performance characteristics compared to normal concrete. Also, the use of RHA would result in a reduction of the cost of concrete construction, and the reduction of the environmental greenhouse effects. This paper reviews the research investigations during the past three decades. The significant findings from these include higher compressive strength, and the lower chloride-ion penetrability of RHA modified concrete compared to normal concrete. Further research is being conducted by the authors to determine the resistance to accelerated corrosion in the marine environment, shrinkage and durability, and resistance to chloride ion penetrability of concrete mixes with different percentages of RHA and different water-binder ratios. This project, funded by the National Science Foundation, is a joint effort with a parallel investigation of restricted scope, at Chulalongkorn University, Bangkok, Thailand.

## KEYWORDS

Concrete**,** RHA, Durability, Environment, Sustainability.

## INTRODUCTION

Global production of rice is approximately 580 million tones a year, and this is rising as the world population and the consumption of rice increases. Table 1 shows the most rice-growing countries in the world and the potential husk and ash production. The milling of rice produces rice husk, which is a waste material. Rice husk is generated on average 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. Prior to 1970, RHA was usually produced by uncontrolled combustion, and the ash so produced was generally crystalline and had poor pozzolanic properties. 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 tons of rice husks 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. In the USA the following three power plants use rice husk as fuel: A 10.5 MW and a 1.5 MW Agrilectric Power plant at Lake Charles, Louisiana in service since 1984 and 1995 respectively. A 28.7 MW United America Energy Corporation plant at Williams, California. Also, there are two plants in Thailand, at Nakorn Ratchasima, 2.5 NW capacity, and in Pathumthani, 1.5 MW capacity. Recognizing that the potential for using the renewable resource of rice husk, three 22 MW production plants are being set up in Central Thailand in the period 2004-2005 by a Bangkok-based company, A.T. Biopower Co. Limited, at three of the following locations: Nakorn Pathorn, Nakorn Sawa, Pichit, and Singburi.

## LITERATURE REVIEW

The use of RHA will contribute not only, to the production of concrete of a higher quality and lower cost, but also the reduction of carbon dioxide ($CO_2$) emissions from the production of cement. The partial replacement of cement by RHA will result in lower energy consumption associated with the production of cement. The market potential for rice husk-to-energy systems and equipment has been studied by Velupillai et al. (1997). The reference also addresses 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.

## RICE HUSK ASH PROPERTIES

Studies have shown that RHA resulting from the burning of rice husks at control temperatures have physical and chemical properties that meet ASTM (American Society for Testing and Materials) Standard C 618-94a. At burning temperatures of 550 $^0$C – 800 $^0$C, amorphous silica is formed, but at higher temperatures crystalline silica is produced. The silica content is between 90 and 96%. The particular chemical and physical properties are given in Table 2, and Fig. 1 shows the X-ray diffraction analysis, which indicates that the RHA mainly consists of amorphous materials (Bouzoubaa, and Fournier 2001). Grinding for producing high quality RHA was studied by (Loo et al. 1984). Studies have shown that to obtain the required particle size, the RHA needs to be grown to size 45 µm – 10 µm.

## 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). The concept of using RHA as a substitute for cement has been explored for the past three decades. During this period several tests have been carried out in research laboratories. From the research on concrete mixes with different percentages of RHA as a substitute for cement and different w/c ratios, the following information has been gathered:

## FRESH CONCRETE

Following ASTM standards C 143, C 138, and C 172, mixes prepared with different percentages of RHA were compared to mixes containing cement only and the following was found: 1) RHAMC (Rice Husk Ash-Modified Concrete) mixes have similar to slightly higher slump, and unit weight than those containing cement only, 2) RHAMC mixes have similar to slightly lower air content than those containing cement only. Table 3 shows these properties (Bouzoubaa and Founier, 2001).

## HARDENED CONCRETE

The use of Rice Husk Ash (RHA) in the production of high-performance and highly durable concrete has been presented in several papers. The significant findings were as follows:

***Compressive Strength*** The early strength of RHAMC, ASTM C 39, is lower than normal concrete, but in general the strength at 28 days is higher. Fig. 2 shows the strength at different ages for concrete with different contents of RHA (Bouzoubaa and Founier, 2001).

***Indirect Tensile Strength*** The strength in tension of RHAMC, ASTM C 496, is higher than that of normal concrete. Table 3 shows the splitting tensile strength at 28 days of cylinders made with concrete containing 10% RHA as a substitute for cement compared to normal concrete cylinders (Zhang and Malhotra, 2002).

***Flexural Strength*** The flexural strength of RHAMC, ASTM C 78, is higher than concrete containing cement only. Table 4 shows the Flexural Strength at 28 days of prisms made with concrete containing 10% RHA as a substitute for cement compared to prisms made with normal concrete (Zhang and Malhotra, 2002).

***Modulus of Elasticity*** The modulus of elasticity of RHAMC, ASTM C 469, is similar than concrete containing cement only. Table 4 shows the modulus of elasticity at 28 days of cylinders made with concrete containing 10% RHA as a substitute for cement, compared to those made with normal concrete (Zhang and Malhotra, 2002).

***Shrinkage*** The drying shrinkage of RHAMC is similar to that of concrete containing silica fume and normal concrete. Fig. 3 shows the drying shrinkage strain of concrete made with 10% RHA compared to concrete made with 10% silica fume, and normal concrete, after 7 days of initial curing in lime-saturated water (Zhang and Malhotra, 2002).

## DURABILITY

The capacity of concrete to resist deterioration from freezing and thawing, heating and cooling, the action of chemicals such as deicers and fertilizers, abrasion, or any other environmental exposure will determine its service life. The use of supplementary cementing materials can alter the pore structure of concrete to reduce its permeability, thus increasing its resistance to water penetration and water-related deterioration such as frost damage, reinforcement corrosion and sulfate and acid attack. Using a suitable supplementary cementing material in the appropriate amount also can prevent detrimental alkali-silica reactions (Taylor, 2001). The use of highly reactive RHA has been found to produce high strength and high durability concrete (Wada et al., 2000).

***Resistance to Chloride Ion Penetration*** Testing of concrete disks in the laboratory, ASTM C 1202, at 28 days and 90 days, has shown that RHAMC has excellent resistance to chloride ion penetration and the charge passed in coulombs was below 1000, which is well below that of normal concrete (Zhang and Malhotra, 2002).

***Resistance to Freezing and Thawing*** Following ASTM C 666, Procedure A, testing in the laboratory has shown that RHAMC exhibited significantly higher frost resistance compared to mixes containing silica fume. Also, the durability of MRHAC subjected to freeze and thaw in saline environment is considerably higher than that of normal concrete (Mehta and Folliard, 2002).

***Sulfate Attack*** Sulfate attack occurs when the sulfates contained in soil and seawater react with the calcium hydroxide and aluminates in the cement. This reaction produces ettringite which expands the concrete leading to cracking and deterioration of concrete. Following ASTM standard C 1012, testing has shown that RHAMC has lower expansion compared to normal concrete due to sulfate attack (Mehta and Folliard, 2002).

## TERNARY RICE HUSK ASH 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) At 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) At the same w/cm, the compressive strength at 28 days of mixes containing RHA and HVFA was higher than the mixes with HVFA only. 4) At 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.

## ENVIRONMENTAL IMPACT

The majority of rice husk goes into landfills since 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 USA and around the world. The manufacturing of cement produces carbon dioxide ($CO_2$), which is a prime contributor to the global warming. Typically, cement production results in $CO_2$ emissions of about 0.8 – 1.2 tonnes/tonne of cement product depending on the production process and the fuel used. Also, 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.

## RESEARCH CONDUCTED BY THE AUTHORS OF THIS PAPER

Following ASTM standards, the authors of this paper are conducting research to determine properties of RHA modified concrete. The RHA was obtained from Agrilectric Power Plant in Lake Charles, Louisiana, USA. The ash received from the power plant was ground to obtain a particle size of 7 to 45μm. Six different concrete mixes will be tested to determine compressive strength, splitting tensile strength, and flexural strength at 28 days. The experimental work also includes testing of accelerated corrosion damage with induce current, chloride ion permeability, shrinkage, and durability testing. The eight mixes contain 0%, 10%, and 20% of RHA as a substitute for cement and water/binder ratios of 0.40 and 0.55. This experimental work is still ongoing, and is expected to be completed by the end of September of this year. The typical results for compressive strength at 28 days have shown that the RHA modified concrete has higher strength than that for normal concrete. The splitting tensile strength of RHA modified concrete was lower than that for normal concrete.

## RECENT DEVELOPMENTS

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).

## CONCLUSIONS

The cost-effectiveness and enhanced durability, coupled with its energy efficient contribution to "Turning Down the Global Thermostat", make RHA a significant contributor to a holistic approach by the concrete industry to the global issue of environmental sustainability.

## ACKNOWLEDGEMENTS

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**Table 1 Rice Paddy, and Potential Husk and Ash Production in the 20 Highest Producing Countries 2002**

| Country | Rice, Paddy Production in 2002 (t) | Percentage of Total Paddy Production (%) | Husk Produced (20% of total) (t) | Potential Ash Production (18% of husk) (t) |
|---|---|---|---|---|
| China | 177,589,000 | 30.7 | 35,517,800 | 6,393,204 |
| India | 123,000,000 | 21.2 | 24,600,000 | 4,428,000 |
| Indonesia | 48,654,048 | 8.4 | 9,730,810 | 1,751,546 |
| Bangladesh | 39,000,000 | 6.7 | 7,800,000 | 1,404,000 |
| Viet Nam | 31,319,000 | 5.4 | 6,263,800 | 1,127,484 |
| Thailand | 27,000,000 | 4.7 | 5,400,000 | 972,000 |
| Myanmar | 21,200,000 | 3.7 | 4,240,000 | 763,200 |
| Philippines | 12,684,800 | 2.2 | 2,536,960 | 456,653 |
| Japan | 11,264,000 | 1.9 | 2,252,800 | 405,504 |
| Brazil | 10,489,400 | 1.8 | 2,097,880 | 377,618 |
| USA | 9,616,750 | 1.7 | 1,923,350 | 346,203 |
| Korea | 7,429,000 | 1.3 | 1,485,800 | 267,444 |
| Pakistan | 5,776,000 | 1.0 | 1,155,200 | 207,936 |
| Egypt | 5,700,000 | 1.0 | 1,140,000 | 205,200 |
| Nepal | 4,750,000 | 0.8 | 950,000 | 171,000 |
| Cambodia | 4,099,016 | 0.7 | 819,803 | 147,565 |
| Nigeria | 3,367,000 | 0.6 | 673,400 | 121,212 |
| Sri Lanka | 2,794,000 | 0.5 | 558,800 | 100,584 |
| Colombia | 2,353,440 | 0.4 | 470,688 | 84,724 |
| Laos | 2,300,000 | 0.4 | 460,000 | 82,800 |
| Rest of the World | 29,091,358 | 5.0 | 5,818,272 | 1,047,289 |
| Total (World) | 579,476,722 | 100 | 115,895,344 | 20,861,162 |

**Table 2: Physical and Chemical Properties of Rice-Husk Ash - From Bouzoubaa and Fournier, 2001**

| Physical Properties | Values |
|---|---|
| Specific gravity | 2.05 |
| Fineness – median particle size, m | 8.3 |
| Nitrogen absorption, $m^2/g$ | 20.6 |
| Water requirement, % | 104 |
| Pozzolanic activity index, % | 99 |
| Chemical Properties | |
| Silicon dioxide ($SiO_2$) | 90.7 |
| Aluminium oxide ($Al_2O_3$) | 0.4 |
| Ferric oxide ($Fe_2O_3$) | 0.4 |
| Calcium oxide (CaO) | 0.4 |
| Magnesium oxide (MgO) | 0.5 |
| Sodium oxide ($Na_2O$) | 0.1 |
| Potassium oxide ($K_2O$) | 2.2 |
| Equivalent alkali ($Na_2O$+0.658$K_2O$) | 1.5 |
| Phosphorous oxide ($P_2O_5$) | 0.4 |
| Titanium oxide ($TiO_2$) | 0.03 |
| Sulphur trioxide ($SO_3$) | 0.1 |
| Loss of ignition | 4.8 |

**Table 3: Properties of Fresh Concrete - From Bouzoubaa and Fournier, 2001**

| Rice Husk Ash (%) | Unit Weight ($kg/m^3$) | Slump (mm) | Air Content (%) |
|---|---|---|---|
| 0 | 2432 | 120 | 2.5 |
| 7.5 | 2446 | 130 | 1.6 |
| 10 | 2432 | 150 | 2.0 |
| 12.5 | 2432 | 155 | 1.6 |

**Table 4: Mechanical Properties of Hardened Concrete (w/c = 0.40) - From Zhang and Malhotra, 2002**

| Rice Husk Ash (%) | Age (Days) | Splitting tensile (MPa) | Flexural (MPa) | E, modulus (GPa) |
|---|---|---|---|---|
| 0 | 28 | 2.7 | 6.3 | 29.6 |
| 10 | 28 | 3.5 | 6.8 | 29.6 |

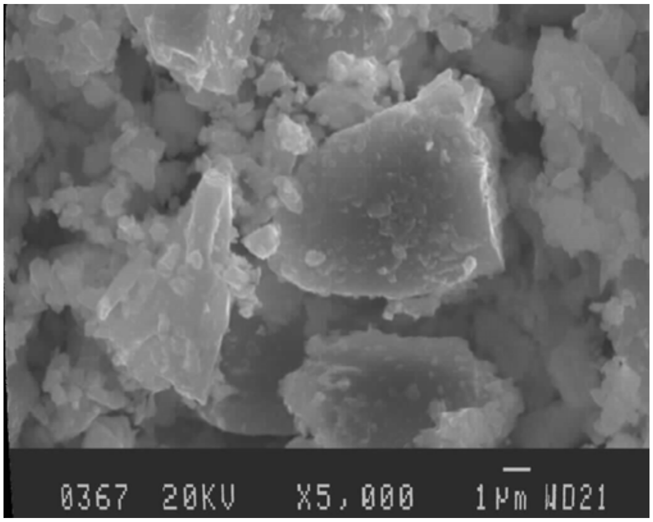


**Figure 1: X-ray spectrum of RHA**
**- Reproduced from Bouzoubaa and Fournier, 2001**

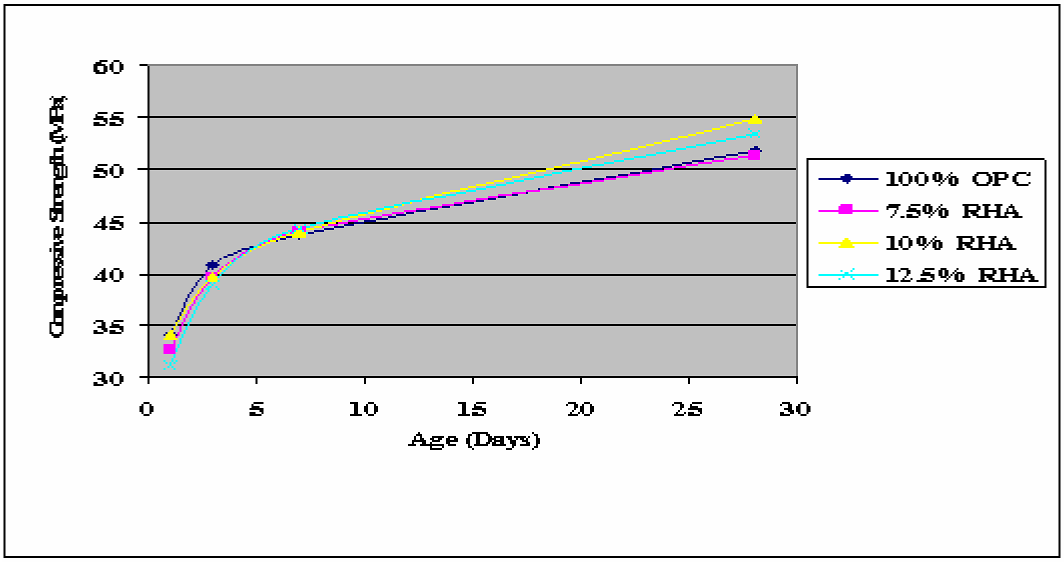


**Figure 2: Compressive strength at different RHA% and w/cm= 0.40**
**- Reproduced from Bouz oubaa and Fournier, 2001.**

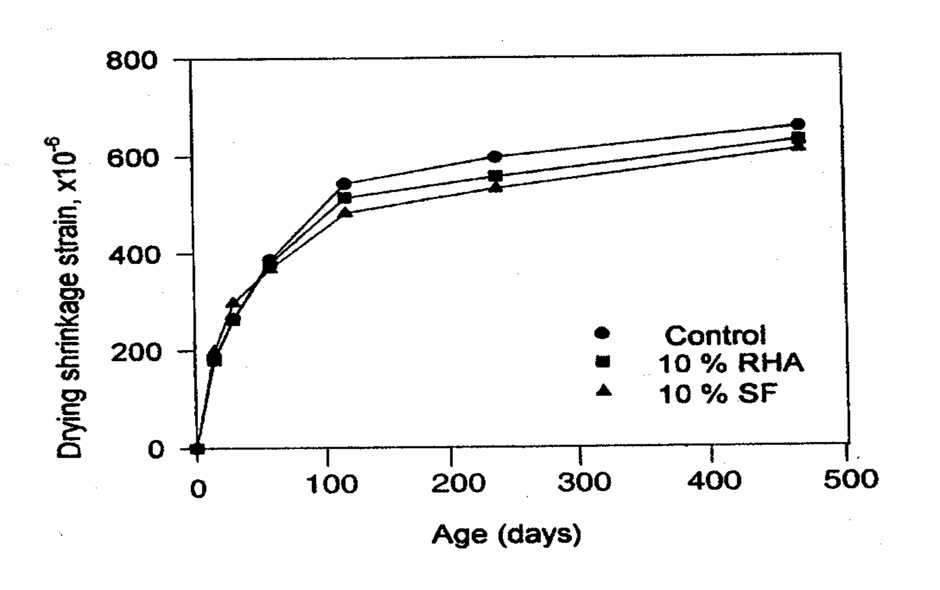


**Figure 3: Drying Shrinkage of Concrete**
**- Reproduced from Zhang and Malhotra, 2002**