RICE HUSK ASH AND GRINDED RICE HUSK EFFECT ON THE COMPRESSIVE STRENGTH AND WORKABILITY OF CONCRETE

BY

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ABSTRACT

The importance of concrete in modern society cannot be underestimated. There is no escaping from the impact of concrete on everyday life. Concrete is a composite material which is made of filler and a binder. Typical concrete is a mixture of fine aggregate (sand), coarse aggregate (rock), cement, and water. Nowadays the usage of concrete is increasing from time to time due to the rapid development of construction industry. The usage of concrete is not only in building construction but also in other areas such as road construction, bridges, harbor and many more. Thus technology in concrete has been developing in many ways to enhance the quality and properties of concrete. This study was made to investigate the nature of partial replacement of rice husk ash and grinded rice husk and its influences on the strength properties of concrete. Properties of hardened concrete like compressive strength and workability was determined for different mix combinations of materials and these values are compared with the corresponding values of conventional concrete. Ordinary Portland cement (OPC) was replaced with Rice Husk Ash (RHA) by weight at 0%, 10%, 20% and 30% and Grinded rice husk (GRH) by weight at 10%, 20% and 30%. The slump value obtained from the control mix was 50 mm while cement partially replaced by RHA at 10 %, 20%, and 30% were 60 mm, 68 mm, and 76 mm respectively and cement partially replaced by GRH at 10 %, 20% and 30% were 32 mm, 15 mm, and 5 mm respectively. The control mix at 40 days has a peak compressive strength of 49.07 N/mm^2 while cement partially replaced by RHA at 10 %, 20%, 30% were 50.24 N/mm^2, 40.53 N/mm^2, and 40.20 N/mm^2 respectively and cement partially replaced by GRH at 10 % was 45.47 N/mm^2 at 40 days. The cement partially replaced by GRH at 20 % and 30% failed at the casting stage. This research concludes that 10% RHA is the optimum content for getting nearly equal strength at 40 days. Replacement of cement with Rice Husk Ash leads to increase in the compressive strength improved the workability and achieved the target strength at 10% replacement for the grade of concrete.

Keywords

Rice Husk Ash (RHA), Grinded rice husk (GRH), Compressive Strength, and workability.

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DEDICATION

This project is dedicated to Jehovah, the giver of all life and to all those I hold dear.

CERTIFICATION

This is to certify that this report was written by OGUNLALU Ademola Oluwasesan (CVE/11/0371) under my supervision and is approved for its contribution to knowledge and literary presentation. All sources of information are specifically acknowledged by means of references, impartial requirements for the award of Bachelor of Engineering (B.Eng.) degree in Civil Engineering, Federal University Oye-Ekiti, Ekiti, Nigeria.

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LIST OF ABBREVIATIONS

Rice Husk Ash (RHA)

Grinded rice husk (GRH)

Food and Agricultural organization (FAO)

Silica Fume (SF)

Ground Granulated Blast Furnace Slag (GGBFS)

American Concrete Institute (ACI)

Fly Ash (FA)

Pulverized fuel ashes (PFA)

Super plasticizer (SP)

American Society if the International Association for Testing and Materials (ASTM)

Ordinary Portland cement (OPC)

Saturated calomel electrode (SCE)

Scanning electron microscope (SEM)

CHAPTER 1

INTRODUCTION

1.1 General Preamble and Background

Recent work carried out on the formulation and manufacture of concrete has led to the development of various classes with improvement in its quality and properties. Typical concrete is a mixture of fine aggregate (sand), coarse aggregate (rock), cement, and water. Cement is a material with cohesive and adhesive properties when mixed with water, which makes it capable of bonding material fragments into a compact whole (Neville, 1996). Cement gives off lime as it hardens and this lime will inevitably react with silica (silicates or alumino-silicates). The aggregate in the concrete is basically silica, but unfortunately it reacts too slowly, due to its reduced total surface area. The use of pozzolans in concrete helps the lime produced in the hardening of the concrete to slowly react with the aggregate, producing gels. These gels are expansive, and they just fill the voids with a slight pressure thus avoiding water penetration and leaching.

A pozzolan can therefore be defined as a siliceous/ aluminous material which in itself has little or no cementitious value, but which will in finely divided form and in the presence of moisture, chemically reacts with calcium hydroxide liberated during the hydration of Portland cement to produce stable, insoluble cementitious compound which contributes to its strength and impermeability (Sima, 1974). Rice husk ash (RHA) is one of the promising pozzolanic materials that can be blended with Portland cement for the production of durable concrete and at the same time it is a value added product. Addition of rice husk ash to Portland cement does not only improve the early strength of concrete, but also forms a calcium silicate hydrate (CSH) gel around the cement particles which is highly dense and less porous, and may increase the strength of concrete against cracking (Saraswathy and Hawon, 2007). Rice husk ash is the byproduct of burned rice husk at higher temperature from paper plant artificial fibers [Doa *et al.*2008]. It constitutes about one fifth of the 690 million According to Food and Agricultural organization [FAO 2002], Nigeria is the 17th largest producer of rice in the world with over 3.3 million tonnes of paddy rice produced annually and 63,400 tonnes of rice husk generated with a potential for production of at least 121,212 tonnes of rice husk ash from rice husk generated.

This enormous waste is presently not being harnessed productively in the country other than burning, which is a major air pollution activity and indiscriminate dumping that cause environmental hazard. Rice husk ash has been found to be rich in silica. When completely incinerating the husk in appropriate conditions, the residue, RHA, contains 90-96% silica in an amorphous form. RHA is also classified in the same category of highly active pozzolans as Silica Fume [Mehta 1983]. According to Dale *et al.* (2009) rice husk ash is a highly reactive pozzolanic material produced by controlled burning of rice husk. The mean particle size of RHA generally ranges from 5 to 10 μm [Siddique 2008]. However, RHA has a very high specific surface area ranging from 20 to 260 m^2/g [Bui 2001] which is attributed to its porous structure [Cook 1986; Mehta 1994]. Rice husk are being put into various uses from the manufacture of refractory bricks to use as light weight insulating boards. Conversion of wastes to wealth is the new vogue all over the world.

1.2 Problem Statement

Pollution arising from wastes is a cause of concern for many developing nations such as India, Nigeria. Also, handling and transportation of RH is problematic due to its low density. Due to this reasons considerable efforts are being taken worldwide to utilize natural waste and bye-product as supplementary cementing materials to improve the properties of cement concrete; this is not only to reduce environmental degradation and pollution but also to effectively put these wastes into use that would be beneficial to mankind. Reducing environmental pollution and alleviating poverty in less developed countries are important goals of sustainable development. The challenge that poses to Civil Engineeringprofession is to execute projects in harmony with nature using the concept of sustainable development involving the use of high performance economic friendly materials produced at reasonable cost with lowest possible environmental impact. In the context of concrete as building material, it is necessary to identify less expensive cement substitutes. It can therefore be said that recycling of such waste into new building materials could be a viable solution not only to the problem of the high cost of building materials currently facing these nations, but also to the pollution problem.

In this paper a preliminary analysis of the numerous reported properties and uses of rice husk and its ash as well as when blended has been discussed. Attempt has been made to collect data and information from various research work related to RH and RHA.

1.3 Aim and Objectives

The particular aim of this project is to investigate the feasibility of using rice husk ash and grinded rice husk as a partial replacement of cement to produce concrete. With this aim, the research focuses on the following aspects;

Objectives

a. To determine the effect of Rice Husk Ash and Grinded rice husk on the compressive strength of concrete.

b. To determine the effect of Rice Husk Ash and Grinded rice husk on the workability of concrete.

c. To compare the result of different tests with varying proportion of rice husk ash and grinded rice husk on the concrete compressive strength and workability with 0% concrete (control mix).

1.4 Justification

Rice husk ash is a by-product which can be abundantly found in this country. Therefore, using rice husk ash should promise some advantages in reduce the environmental problems

Also due to high exchange rate in Nigeria cement has become more expensive and continues to increase in price. The partial replacement of cement with pozzolans brings about a reduction in construction cost which makes construction more economical.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews concrete with properties such as mechanical properties, and durability, in terms of the mix composition, requirements, and principles of production. When both cement and supplementary cementing material used in concrete mixtures, concrete mixtures show a high autogenous shrinkage because of this. Some of the commonly used supplementary cementing materials are fly ash, Silica Fume (SF), Ground Granulated Blast Furnace Slag (GGBFS) and Rice Husk Ash (RHA) etc. Due to the limitations in terms of cost and availability, RHA has been considered a very promising candidate amongst others mentioned above.

A summary of the properties of RHA, the effect of RHA on the hydration and the formation of the microstructure of cement paste, and its utilization in concrete are discussed in the third main part of this chapter.

2.2 Concrete

2.2.1 Definition

Concrete is a synthetic construction material made by mixing cement, fine aggregate (usually sand), coarse aggregate (usually gravel or crushed stone), and water in the proper proportions. The product is not concrete unless all four of these ingredients are present (Zongjin Li 2011)

2.2.2 Constituents of Concrete

The fine and coarse aggregates in a concrete mix are the inert, or inactive, ingredients. Cement and water are the active ingredients. The inert ingredients and the cement are first thoroughly mixed together. As soon as the water is added, a chemical reaction begins between the water and the cement. The reaction, called hydration, causes the concrete to harden. This is an important point. The hardening process occurs through hydration of the cement by the water, not by drying out of the mix. Instead of being dried out, concrete must be kept as moist as possible during the initial hydration process. Drying out causes a drop in water content below that required for satisfactory hydration of the cement. The fact that the hardening process does not result from drying out is clearly shown by the fact that concrete hardens just as well underwater as it does in air (Peterman *et al.,* 1986).

2.2.3 Concrete as Building Material

Concrete may be cast into bricks, blocks, and other relatively small building units, which are used in concrete construction. Concrete has a great variety of applications because it meets structural demands and lends itself to architectural treatment. All important building elements, foundations, columns, walls, slabs, and roofs are made from concrete. Other concrete applications are in roads, runways, bridges, and dams (Peterman *et al.,* 1986).

2.2.4 Properties of Concrete

Properties of concrete are divide into two major groups,

1 Properties of Fresh Concrete

2 Properties of Hardened Concrete

2.2.4.1 Properties of Fresh Concrete

Concrete remains in its fresh state from the time it is mixed until it sets. During this time the concrete is handled, transported, placed and compacted. Properties of concrete in its fresh state are very important because the influence the quality of the hardened concrete. The fresh concrete has the following properties (The History of Concrete 2013).

i. Consistency

Consistency of a concrete mix is a measure of the stiffness or sloppiness or fluidity of the mix. For effective handling, placing and compacting the concrete, consistency must be the same for each batch. It is therefore necessary to measure consistency of concrete at regular intervals. Slump test is commonly used to measure consistency of concrete (ACI 1999).

ii. Workability

The workability of a concrete mix is the relative ease with which concrete can be placed, compacted and finished without separation or segregation of the individual materials. Workability is not the same thing as consistency. Mixes with the same consistency can have different workability, if they are made with different sizes of stone – the smaller the stone the more workable the concrete.

It is not possible to measure workability but the slump test, together with an assessment of properties like stone content, cohesiveness and plasticity, gives a useful indication.

iii. Settlement and Bleeding

Cement and aggregate particles have densities about three times that of water. In fresh concrete they consequently tend to settle and displace mixing water which migrates upward and may collect on the top surface of the concrete. This upward movement of mixing water is known as bleeding; water that separates from the rest of the concrete is called bleed water.

iv. Plastic Shrinkage

If water is removed from the compacted concrete before it sets, the volume of the concrete is reduced by the amount of water removed. This volume reduction is called plastic shrinkage. Water may be removed from the plastic concrete by evaporation or by being absorbed by dry surfaces such as soil or old concrete or by the dry wooden form work.

v. Slump Loss

From the time of mixing, fresh concrete gradually loses consistency. This gives rise to the problems only if the concrete becomes too stiff to handle, place and compact properly. Slump loss in concrete is caused due to the following reasons.

- **i)** Hydration of cement (generating more heat)
- **ii)** Loss of water by evaporation Absorption of water by dry aggregates
- **iii)** Absorption of water by surfaces in contact with the concrete.

2.2.4.2 Properties of Hardened Concrete

Fully cured, hardened concrete must be strong enough to withstand the structural and service loads which will be applied to it and must be durable enough to withstand the environmental exposure for which it is designed. If concrete is made with high-quality materials and is properly proportioned, mixed, handled, placed and finished, it will be the strongest and durable building material. Below are the properties of hardened concrete (Naik *et al.*, 1998; Pala *et al.*, 2007):-

i. Strength

When we refer to concrete strength, we generally talk about compressive strength of concrete. Because, concrete is strong in compression but relatively weak in tension and bending. Concrete compressive strength is measured in pounds per square inch (psi). Compressive strength mostly depends upon amount and type of cement used in concrete mix. It is also affected by the water-cement ratio, mixing method, placing and curing. Concrete tensile strength ranges from 7% to 1 2% of compressive strength. Both tensile strength and bending strength can be increased by adding reinforcement.

ii. Creep

Deformation of concrete structure under sustained load is defined as concrete creep. Long term pressure or stress on concrete can make it change shape. This deformation usually occurs in the direction the force is applied.

iii. Durability

This might be defined as the ability to maintain satisfactory performance over and extended service life. The design service life of most buildings is often 30 years, although buildings often last 50 to 100 years. Most concrete buildings are demolished due to obsolescence rather than deterioration. Different concretes require different degrees of durability depending on the exposure environment and properties desired. Appropriate concrete ingredients, mix proportions, finishes and curing practices can be adjusted on the basis of required durability of concrete.

iv. Shrinkage

Shrinkage is the volume decrease of concrete caused by drying and chemical changes. In another word, the reduction of volume for the setting and hardening of concrete is defined as shrinkage.

v. Modulus of Elasticity

The modulus of Elasticity of concrete depends on the Modulus of Elasticity of the concrete ingredients and their mix proportions. As per ACI code, the modulus of Elasticity to be calculated using following equation:

$Ec = 33\omega_c 1.5\sqrt{f'_c}$ (psi)

Where, ω_c = unit weight of concrete, lb/ft^2

f'_c = 28 days compressive strength of concrete

For normal weight concrete (90 lb/ft^3 to 1 60 lb/ft3), we assume that formula

$Ec = 57000\sqrt{f'_c}$

vi. Water tightness

Another property of concrete is water tightness. Sometime, it's called impermeability of concrete. Water tightness of concrete is directly related to the durability of concrete. The lesser the permeability, the more the durability of concrete. Now the question is, what is the permeability of concrete? In simple word, the capability of penetrating outer media into concrete is the permeability of concrete. Outer media means water, chemicals, sulphates, etc.

2.3 Pozzolan

2.3.1 Definition

A "pozzolan" is defined as "a siliceous or siliceous and aluminous material, which in itself possesses little or no cementing property, but will in a finely divided form - and in the presence of moisture - chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties." Depending upon the particle size, chemical composition and dosage, different pozzolans will affect the concrete strength differently and at different times during curing.

Typically pozzolans are used as cement *replacements* rather than cement *additions*. Adding pozzolans to an existing concrete mix without removing an equivalent amount of cement increases the paste content and decreases the water/cement ratio. In other words, adding more pozzolans to a mix changes the mix proportions. Replacing some of the cement with pozzolans preserves the mix proportions. Pozzolans replace cement pound for pound.

2.3.2 Origin of Pozzolan

The term pozzolan is derived from the name of the town Pozzuoli, Italy. It is situated near Mt. Vesuvius and is the place where the Romans more than 2,000 years ago mined the ashes deposited by the occasional eruptions of this volcano. Adding these ashes at a ratio of 2:1 to aged lime putty (aged 2+ years) they were able to construct those sturdy buildings we still admire today. Given this mineral origin, some purists consider only volcanic ashes, pumice, tuffs, etc, as pozzolans (Spence *et al.,* 1983). But as the ashes of organic origin, like pulverized fuel ashes (PFA, mostly coal ashes) and rice husk ashes (RHA) also show enhancing properties when mixed with cement or lime, most of the times the origin is irrelevant. What counts are the properties, primarily particle size and purity (absence of carbon), and the results (Schneider *et al.*, 2011).

2.3.3 Pozzolanic Materials

The general definition of a pozzolan embraces a large number of materials which vary widely in terms of origin, composition and properties. Both natural and artificial (manmade) materials show pozzolanic activity and are used as supplementary cementitious materials. Artificial pozzolans can be produced deliberately, for instance by thermal activation of kaolin-clays to obtain metakaolin, or can be obtained as waste or by-products from high-temperature process such as fly ashes from coal-fired electricity production. The most commonly used pozzolans today are industrial byproducts such as fly ash, silica fume from silicon smelting, highly reactive metakaolin, and burned organic matter residues rich in silica such as rice husk ash. Their use has been firmly established and regulated in many countries. However, the supply of high quality pozzolanic by products is limited and many local sources are already fully exploited. Alternatives to the established pozzolanic by-products are to be found on the one hand in an expansion of the range of industrial by-products or societal waste considered and on the other hand in an increased usage of naturally occurring pozzolans (Idorn and M.G. 1997).

2.3.4 Benefit of Pozzolans

Pozzolans not only strengthen and seal the concrete, they have many other beneficial features you will realize the moment you purchase them or add them to the mix. All of the below benefits apply to fly ash and rice husk ash, and most of them to silica fume as well. Spherical Shape: Fly ash (FA) and rice husk ash (RHA) particles are almost totally spherical in shape, allowing them to flow and blend freely in mixtures (Schneider *et al.*, 2011).

i. **Ball Bearing Effect:** The "ball-bearing" effect of FA and RHA particles creates a lubricating action when concrete is in its plastic state.
ii. **Economic Savings:** Pozzolans replace higher volumes of the more costly cement, with typically less cost per volume.
iii. **Higher Strength:** Pozzolans continue to combine with free lime, increasing structural strength over time.
iv. **Decreased Permeability:** Increased density and long-term pozzolanic action, which ties up free lime, results in fewer bleed channels and decreases permeability.
v. **Increased Durability:** Dense pozzolan concrete helps keep aggressive compounds on the surface, where destructive action is lessened. Pozzolan concrete is also more resistant to attack by sulfate, mild acid, soft (lime hungry) water, and seawater.
vi. **Reduced Sulfate Attack:** Pozzolans tie up free lime that otherwise could combine with sulfate to create destructive expansion.
vii. **Reduced Efflorescence:** Pozzolans chemically bind free lime and salts that can create efflorescence. Denser concrete, due to pozzolans, holds efflorescence-producing compounds on the inside.
viii. **Reduced Shrinkage:** The largest contributor to drying shrinkage is water content. The lubricating action of FA and RHA reduces the need for water and therefore also drying shrinkage.
ix. **Reduced Volume:** As pozzolans can in certain cases substitute for up to four times the mass of cement, besides making the same amount of concrete harder than without pozzolans, less voluminous structures are able to bear the same load.

x. **Reduced Heat of Hydration:** The pozzolanic reaction between pozzolan and lime generates less heat, resulting in reduced thermal cracking when pozzolans are used to replace Portland cement.

xi. **Reduced Alkali Silica Reactivity:** Pozzolans combine with alkalis from cement that might otherwise combine with silica from aggregates, which would cause potentially destructive expansion.

xii. **Workability:** Concrete enhanced with FA and RHA is easier to place, with less effort, responding better to vibration to fill forms more completely.

xiii. **Ease of Pumping:** Pumping of FA and RHA concrete requires less energy, therefore longer pumping distances are possible.

xiv. **Improved Finishing:** Sharp, clear architectural definition is easier to achieve with FA and RHA concrete, with less worry about in-place integrity.

xv. **Reduced Bleeding:** Fewer bleed channels decreases porosity and chemical attack. Bleed streaking is reduced for architectural finishes. Improved paste to aggregate contact results in enhanced bond strengths.

xvi. **Reduced Segregation:** Improved cohesiveness of pozzolan concrete reduces segregation that otherwise could lead to rock pockets and blemishes.

xvii. **Reduced Slump Loss:** More dependable concrete allows for longer working time especially important in hot weather.

xviii. **Very low Chloride Ion Diffusion:** Pozzolans make concrete more resistant to salt water (seawater).

xix. **Improved Water Tightness:** The formation of expansive gels effectively seals the concrete.

xx. **Resistance to Freeze-Thaw:** As water doesn't penetrate the hardened concrete, freezing can't cause destructive expansion.

xxi. **Resistance to Adverse Chemical Reactions:** The example of Dynastone shows how pozzolans can protect against strong acids.

2.4 Rice Husk Ash

2.4.1 Definition

Rice plant is one of the plants that absorbs silica from the soil and assimilates it into its structure during the growth (Smith et al., 1986). Rice husk is the outer covering of the grain of rice plant with a high concentration of silica, generally more than 80-85% (Siddique 2008). It is responsible for approximately 30% of the gross weight of a rice kernel and normally contains 80% of organic and 20% of inorganic substances. Rice husk is produced in millions of tons per year as a waste material in agricultural and industrial processes. When rice husk is incinerated, ash is obtained called rice husk ash. It can contribute about 20% of its weight to Rice Husk Ash (RHA) after incineration (Anwar *et al.*, 2001). RHA is a highly pozzolanic material (Tashima *et al.,* 2004). The non-crystalline silica and high specific surface area of the RHA are responsible for its high pozzolanic reactivity. RHA has been used in lime pozzolana mixes and could be a suitable partly replacement for Portland cement (Smith *et al.*, 1986; Zhang *et al.*, 1996; Nicole *et al.*, 2000; Sakr 2006; Sata *et al.*, 2007; etc). RHA concrete is like fly ash/slag concrete with regard to its strength development but with a higher pozzolanic activity it helps the pozzolanic reactions occur at early ages rather than later as is the case with other replacement cementing materials (Molhotra, 1993).

2.4.2 The use of RHA in concrete

The use of RHA in concrete was found very early with two German patents from 1924 [Swamy 1986]. However, the utilization of RHA as a pozzolanic material in cement and concrete was significantly advanced after the 1970s when many positive results were achieved [Mehta 1994]. It was recognized that RHA provides several advantages, such as improving compressive and flexural strengths [Ismaila and Waliuddin 1996; Zhang and Malhotra 1996; Rodríguez 2006; Sata *et al.* 2007; Habeeb and Fayyadh 2009], reducing the permeability [Zhang and Malhotra 1996; Ganesan *et al.* 2008], increasing the resistance to chemical attack [Chindaprasirt and Rukzon 2008], increasing the durability [Coutinho 2003; Mahmud *et al.* 2009], reducing the effects of alkali-silica reactivity (ASR) [Nicole *et al.* 2000], reducing the shrinkage, and making concrete denser [de Sensale *et al.* 2008; Habeeb and Fayyadh 2009]. Besides, from an economical and environmental point of view, RHA can reduce costs due to cement savings, and has environmental benefits related to the disposal of waste materials and reduction of carbon dioxide emissions.

2.4.3 Advantages of using rice husk ash in concrete

The use of RHA in concrete has been associated with the following essential assets:

a. Increased compressive and flexural strengths (Zhang *et al.*, 1996; Ismaila 1996; Rodriguez 2005)
b. Reduced permeability (Zhang *et al.*, 1996; Ganesan *et al.*, 2007)
c. Increased resistance to chemical attack (Chindaprasirt *et al.*, 2007)
d. Increased durability (Coutinho 2002)
e. Reduced effects of alkali-silica reactivity (ASR) (Nicole *et al.*, 2000)
f. Reduced shrinkage due to particle packing, making concrete denser (Habeeb *et al.*, 2009)
g. Enhanced workability of concrete (Coutinho 2002; Habeeb *et al.*, 2009; Mahmud *et al.*, 2004)
h. Reduced heat gain through the walls of buildings (Lertsatitthanakorn *et al.*, 2009)
i. Reduced amount of super plasticizer (Sata *et al.*, 2007)
j. Reduced potential for efflorescence due to reduced calcium hydracids (Chindaprasirt *et al.*, 2007)

2.4.4 Properties of RHA

The utilization of rice husk for use as a cementitious material in cement and concrete depends on the pozzolanic property of its ash. The pozzolanic reactivity of the ash is closely related to the form of silica present and the carbon content. Since the physico-chemical properties of silica in RHA are strongly influenced by the temperature and the duration of thermal treatment, the yield of a highly reactive ash requires a burning method that can remain a low firing temperature and a short retention period in order to give ash with a low carbon content and a high surface area [Bui 2001; Nair 2006].

2.4.4.1 RHA production

For every 1000 kg of milled paddy, about 200 kg (20%) of husk is produced. When this husk is completely burnt, about 50 kg (25%) of RHA is generated. The husk contains about 50% cellulose, 25-30% lignin, and 15-20% of silica. Upon burning, cellulose and lignin are removed, leaving behind silica ash. The use of RHA as a supplementary cementing material requires silica in an amorphous reactive form. Crystalline phases of silica have a negligible pozzolanic reactivity with lime. Generally, the quality of RHA relates to the amorphous $SiO2$

content, the porous structure of ash particles and the specific surface area. The amorphous SiO2 content and the porous structure of RHA depend on the temperature, the duration, and the environment of thermal treatment, as well as the pretreatment of husk before combustion [Bui 2001]. Analysis of the reports on the influence of combustion conditions on the nature of silica suggests that temperatures below 750°C will be sufficiently safe to produce rice husk ash with high reactivity [Boateng and Skeete 1990; Bui 2001]. There are several methods to convert rice husks to ash that have been suggested by some authors, such as a cyclone-type furnace developed by Mehta-Pitt in 1976, a fluidized bed system by Takuma, a tub-in basket type rice husk burner designed by Kapur in 1981, a brick incinerator by the Cement Research Institute of India, and a drum incinerator by the Pakistan Council of Specific and Industrial Research (PCSIR) in 1979 [Cook 1984; Bui 2001; Bui *et al.* 2005; Nair 2006].

2.4.4.2 Chemical and physical composition of RHA

RHA is a very fine material with a mean particle size ranging from 5 to 10 μm [Siddique 2008]. The physical properties and chemical composition of RHA, as reported by several authors, are given in Table 2.1 and Table 2.2 (Mehta 1992; Bui *et al.*, 2005; Zhang *et al.*, 1996), respectively. It also can be seen that RHA is very rich in silica content and has a high alkali amount (mainly K2O). For RHA to be used as a pozzolan in cement and concrete, it should satisfy requirements for chemical composition of pozzolans as ASTM C618, in which the combined proportion of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3) in the ash should not be less than 70%, and loss on ignition (LOI) should not exceed 12% [Siddique 2008].

Table 2.1: Chemical properties of RHA (*Wt. %)*

Chemical properties									
Constituent	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**Na_2O**	**K_2O**	**Loss on ignition**
Mehta (1992)	87.2	0.15	016	0.55	0.35	0.24	1.12	3.68	8.55
Zhang *et al.* (1996)	87.3	0.15	0.16	0.55	0.35	0.24	1.12	3.68	8.55
Bui *et al.* (2005)	86.98	0.84	0.73	1.40	0.57	0.11	2.46	-----	5.14

Table 2.2: Physical properties of RHA (*Wt. %)*

Physical properties			
	Specific gravity (g/cm^3)	**Mean particle size (μm)**	**Fineness: passing 45μm (%)**
Mehta (1992)	2.06	-----	99
Zhang *et al.* (1996)	2.06	-----	99
Bui *et al.* (2005)	2.10	7.4	---

2.4.4.3 Fresh properties of mortar/concrete

a. Workability

Usually typical concrete mixtures contain too much mixing water because of two reasons: Firstly, the water demand and workability are significantly influenced by particle size distribution, particle packing effect, and voids present in the solid system. Typical concrete mixtures do not have an optimum particle size distribution, and this accounts for the undesirably high water requirement to achieve certain workability. Secondly, to plasticize a cement paste for achieving an acceptable consistency, much larger amounts of water than necessary for the hydration of cement have to be used because Portland cement particles, due to the presence of electric charge on the surface, tend to form flocks that trap volumes of the mixing water (Mehta 1997, 1999). Studies by Owen (1979) and Jiang et al. (2000) have indicated that with high volume fly ash concrete mixtures, up to 20% reduction in water requirements can be achieved. However, there is the possibility of water reduction higher than 20% in the presence of RHA. This is because fine particles of rice husk ash get absorbed on the oppositely charged surfaces of cement particles and prevent them from flocculation. The cement particles are thus effectively dispersed and will trap large amounts of water meaning that the system will have a reduced water requirement to achieve a given consistency. The particle packing effect is also responsible for the reduced water demand in plasticizing the system (Mehta 2004). Laskar et al. (2007) examined the effects of RHA on the rheological behavior of high performance concrete. In their study RHA was used to replace cement on mass basis at rates of 5%, 10%, 15% and 20%. Based on their test results, plastic viscosity increases tremendously with the increase in replacement level of RHA. RHA particles have the highest surface area and fineness and lower reaction ability than cement (Shetty 2004). RHA particles fill into the spaces made by larger cement particle, decrease frictional forces of RHA-ordinary Portland cement (OPC) system and improve packing ability thereby reducing yield stress. The steep increase in plastic viscosity with the replacement levels suggests that fineness and shape of RHA play critical role. The more the fineness the more is the number of contacts among the particles and hence the more is the resistance to flow. In addition, any deviation from a spherical shape implies an increase in plastic viscosity for the same phase volume (Nedhi et al., 1998).

b. Setting time

Initial and final setting time tests were shown to yield different results on plain cement paste and pastes having rice husk ash (Dakroury et al., 2008). The studies by Ganesan et al. (2008), Cook (1986), and Bhanumathidas et al. (2004) showed that RHA increases the setting time of pastes. Just like other hydraulic cement, the reactivity of rice husk ash cement depends very much upon the specific surface area or particle size. The rice husk ash cement with finer particles exhibits superior setting time behavior. Research has shown the increase in the initial setting time by raising the RHA level in the cement mixture over those of plain cement paste. Dakroury et al. (2008) contended that this may be due to the slower pace of heat induced evaporation of water from the cement–RHA (Figure 2.1).

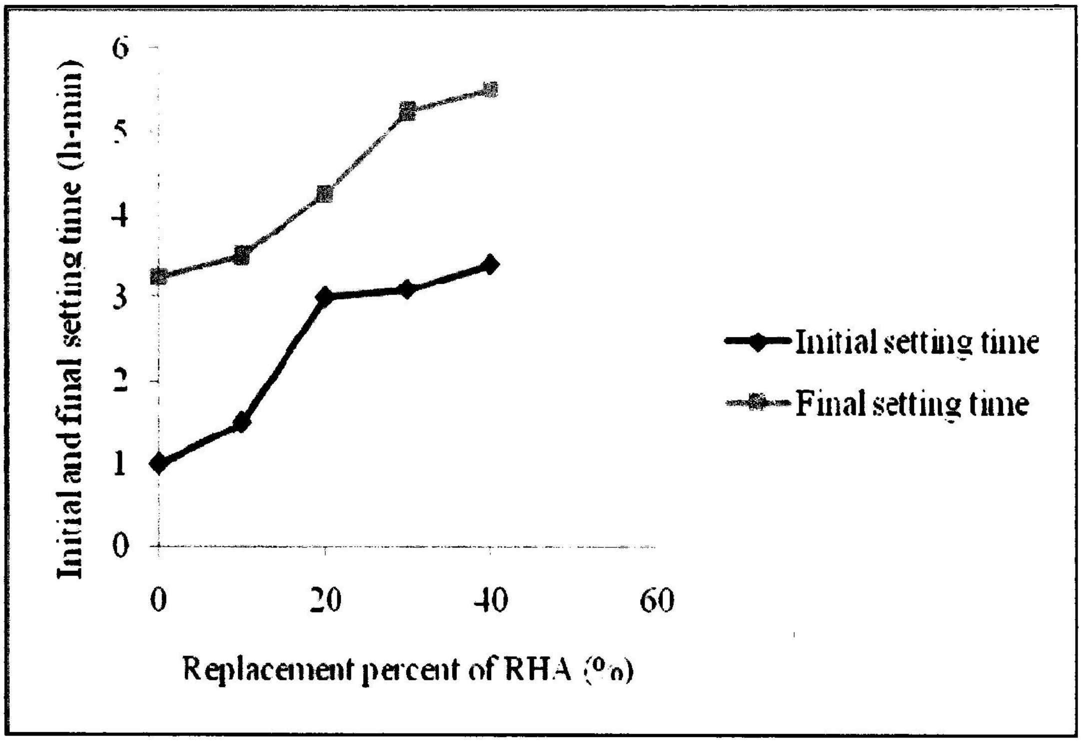

Fig 2.1: Initial and final setting times of RHA with different replacement percentages

Source: Rice husk ash (RHA) as cement admixture for immobilization of liquid radioactive waste at different temperatures (Dakroury et al., 2008)

2.4.4.4 Properties of hardened mortar/concrete

a. Pore size distribution

There is a consensus among several researchers that with partial replacement of cement by pozzolans, porosity decreases in concrete. Blended (or pozzolanic) cements are being used worldwide to produce more homogenous hydration products by filling and segmentation of the capillary voids and produce ultimately more denser and impermeable concrete (Guneyisi et al., 2007). Figure 2.2 shows the effect of RHA content on the total porosity of RHA-hardened cement paste. When the percent of the RHA is increased, the total porosity is decreased.

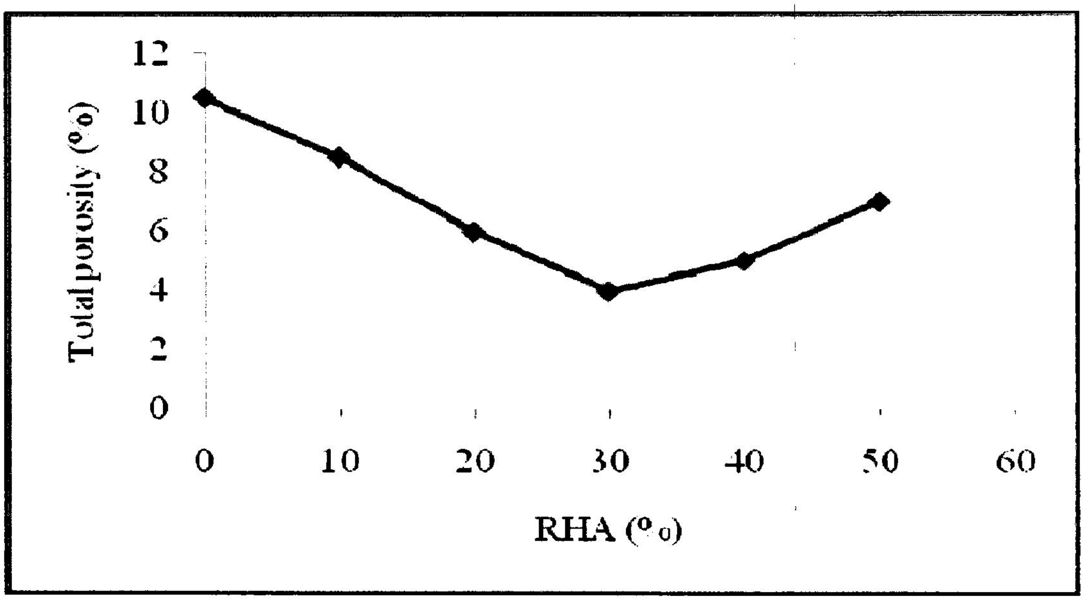

Fig 2.2: Total porosity of RHA hardened cement paste

Source: Rice husk ash (RHA) as cement admixture for immobilization of liquid radioactive waste at different temperatures (Dakroury et al., 2008)

This decrease in the total porosity is attributed to the change occurring in the pore size distribution as a result of using RHA which could react with the calcium hydroxide to form C-S-H gel (Dakroury et al., 2008). Results due to the intensification mechanism of RHA blended concrete confirmed that the average pore size of concrete incorporating RHA is decreased compared to that of control concrete (Sugita et al., 1997).

b. Water absorption and sorptivity

One of the main sources of contamination of concrete in structures is water absorption which influences durability of the concrete and also has the risk of alkali aggregate reactions (Ithuralde 1992). The more impermeable the concrete, the greater will be its resistance to deterioration. The incorporation of pozzolan such as fly ash reduces the average pore size and results in a less permeable paste (Poon et al., 1997; Chindaprasirt et al., 2005). Literature studies have identified that commonly permeability of blended cement concrete is less than plain cement paste. It was observed that the incorporation of RHA in the composites could cause an extensive pore refinement in the matrix and in the interface layer, thereby decreasing water permeability (Rodrigues et al., 2006). The radial expansion of Portland cement hydration products in pozzolanic particles would have a pore modification effect therefore reduces the interconnectedness among pores (Cook et al., 1987). This occurrence can be coupled with perfection on the interfacial transition zones among the cement matrix and aggregate (Toutanji et al., 2004). The permeability will decrease rapidly with the progress of the hydration. The presence of pozzolan leads to greater precipitation of cement gel products (Feng et al., 2004) than occurs in Portland cement alone, which more effectively block the pores helping to reduce permeability. Saraswathy et al. (2007) studied the effect of partial replacement of cement with RHA at different replacement levels on the porosity and water absorption of concrete and reported that the coefficient of water absorption for rice husk ash replaced concrete at all levels was less than control concrete.

c. Compressive strength

Inclusion of RHA as partial replacement of cement enhances the compressive strength of concrete, but the optimum replacement level of OPC by RHA to give maximum long term strength enhancement has been reported between 10% up to 30%. All these replacement levels of RHA are in percentage by weight of the total binder material. Mahmud et al. (1996) reported 15% cement replacement by RHA as an optimal level for achieving maximum strength. Zhang et al. (1996) suggested 10% RHA replacement exhibited upper strength than control OPC at all ages. Ganesan et al. (2008) concluded that concrete containing 15% of RHA showed an utmost compressive strength and loss at elevated content more than 15%. Dakroury et al. (2008) reported that using 30% RHA as a replacement of part of cement could be considered optimum for all content of W/C ratios in investigated mortars because of its high value of compressive strength. Zhang et al. (1996) reported that achieving higher compressive strength and decrease of permeability in RHA blended concrete is perhaps caused by the reduced porosity, reduced calcium hydroxide content and reduced width of the interfacial zone between the paste and the aggregate. The development of more CS-H gel in concrete with RHA may progress the concrete properties due to the reaction among RHA and calcium hydroxide in hydrating cement (Yu et al., 1999). It is apparent from the literature that generally RHA blended cement compared to OPC cement exhibited higher compressive strength than OPC. According to Rodriguez (2006) the RHA concrete had higher compressive strength at 91 days in comparison to that of the concrete without RHA. The increase in compressive strength of concretes with residual RHA may also be justified by the filler (physical) effect. It is concluded that RHA can provide a positive effect on the compressive strength of concrete at early ages. Besides, in the long term, the compressive stresngth of RHA blended concrete produced by controlled incineration shows better performance.

d. Tensile and Flexural Strength

Habeeb et al. (2009) investigated the effects of concrete incorporating 20% RHA as partial replacement of cement at three different particle sizes. In their study the tensile strength of concrete increased systematically with increasing RHA replacement. The results of tensile and flexural strength are shown in Table 2.3.

Table 2.3: Mechanical properties of concrete (Habeeb et al., 2009)

	Flexural Strength (MPa)			Tensile Splitting (MPa)		
Mix	Age (days)			Age (days)		
	28	90	180	28	90	180
CM [a]	4.5	4.9	5.1	2.6	2.8	2.9
20F1 [b]	4.9	5.4	5.5	2.9	3.0	3.2
20F2 [c]	5.0	5.4	5.7	3.2	3.3	3.5
20F3 [d]	5.2	5.7	6.1	3.2	3.5	3.9

[a] Control mix [b] RHA with average particle size of 31.3

[c] RHA with average particle size of 18.3 [d] RHA with average particle size of 11.5

The use of RHA also resulted in significant improvement in flexural strength (De Sensale 2006, Sakr 2006). Habeeb et al. (2009) reported that the coarser RHA particle mixture showed the least improvement in tensile and flexural strength. Zhang et al. (1996) concluded that the addition of RHA to concrete exhibited an increase in the flexural strength and the higher strength was for the finer RHA mixture due to the increased pozzolanic reaction and the packing ability of the RHA fine particles.

2.4.4.5 Durability properties of concrete containing RHA

a. Alkali-silica reaction

Pozzolanic materials are used to prevent or minimize cracking in concrete due to the expansive gel formed by the alkali—silica reaction. Silica fume and RHA have been classified as highly active pozzolans. Hasparyk et al. (2000) studied the expansion of mortar bars made with different levels of cement replacement with rice husk ash (RHA). They reported that incorporation of high reactivity RHA as a partial cement replacement between 12% and 15% may be sufficient to control deleterious expansion due to alkali-silica reaction in concrete, depending on the nature of the aggregate. The mechanism by which RHA may suppress expansion due to alkali-silica reaction appeared to be entrapment of alkalis by the supplementary hydrates and a consequent decrease in the pH of pore solutions because the expansion of the mortar bar is sensitive to the pH level of the solution (Cao et al., 1997).

b. Chloride-ion diffusion

It is approved that the long term deterioration of concrete and corrosion of reinforcing steel commonly occurs by entrancing the chloride ions into body of concrete structures. It is also well known that the rate of chloride ion diffusion into concrete is related to the permeability and pore size distribution. Concretes made with blended cements generally have lower permeability and more discontinuous pore structure than plain Portland cement concrete. Therefore, the diffusivity of chloride ions in blended cement concretes tends to be lower (Cook 1989). The ability of RHA mixtures to reduce the potential detrimental effects of chloride intrusion into concrete was reported by Anwar et al. (2001). They demonstrated that RHA outperform the specimen containing OPC alone and the levels of total and soluble chloride ions had large reductions as the depth of concrete zones surveyed increased. They also determined that for concretes studied, the first 10 mm of concrete cover provides little barrier to chloride ion penetration and underscores the importance of concrete cover to the reinforcement. On the other hand, all the results of zone 20-30 mm show lower values of total chloride ions content than the limits of reinforcement corrosion threshold. Therefore it can be concluded that there are significant reductions in chloride ions permeability due to replacing the OPC with RHA. As the replacement level of the RHA increases from 10% to 20% by weight the results are affected and low chloride ions contents are obtained. Consequently, they concluded that concrete containing RHA may require less depth of cover to protect the reinforcing steel than those concretes using OPC alone. Moreover, Anwar et al. (2001) contended that the soluble chloride ions contents of zone (20, 30 mm) for RHA concretes are smaller than the limits of threshold for corrosion of steel.

Gaynor (1987) reported that one half or three fourths of penetrated chlorides ions in hardened concrete are soluble in water and free to contribute to corrosion, but some studies demonstrated that the RHA concrete mixes show lower percent than the one reported by Gaynor. For instance, Anwar et al. (2001) have reported that the presence of RHA in concrete shows lower ratio of soluble/total chloride ions content than those of OPC concretes. It is shown that proportions of no ground RHA did not significantly change rapid chloride penetrability classification of concrete. However, using finely ground RHA reduced the rapid chloride penetrability of concrete from a moderate rating to low or very low ratings depending on the type and addition level of RHA (Nehdi et al., 2003). Salas et al. (2009) reported that the reduction in the average pore diameter of cement paste caused by the incorporation of rice husk ash in the mix will effectively reduce the pore sizes, permeability, and diffusivity of chloride ions in concrete.

c. Sulfate resistance

The role of RHA on the sulfate resistance of heavyweight concrete has been investigated by some researchers. Sakr (2006) immersed the 100mm cubes in a 5% MgSO4 solution at specific times (1, 3, and 6 months) and found out that the failure occurs in compressive strength of concrete cubes as a result of sulfate attack. The results of this study revealed that concrete mixed with RHA had good resistance to sulfate attack. He concluded that reductions in compressive strength of concrete incorporating 15% of RHA when immersed in a sulfate solution for 28 days was much lower than concrete without RHA and compressive strength was generally increased as the immersion time in the sulfate solution increased. From his reported results it can be concluded that the incorporation of fly ash and ground rice husk ash with Portland cement resulted in a significant improvement in the resistance to attack by 5% sodium sulfate solution. Similar results have been reported by Chindaprasirt et al. (2007). They reported that better dimension stability is obtained with blended cements containing fly ash and RHA. From literature study it can be concluded that despite having higher water demand characteristics, RHA at a dosage of up to 40% cement replacement is very effective in providing sulfate resistance. Also Chindaprasirt et al. (2007) found that fly ash and rice husk ash mortar are of lower pH levels and thus less susceptible to sulfate attack and up to

40% of Portland cement could be replaced with fly ash and RHA to make blended cement mortar with reasonable strength development and good sulfate resistance.

d. Corrosion resistance and drying shrinkage

Saraswathy et al. (2007) investigated the corrosion performance of concrete made with 0, 5, 10, 15, 20, 25, and 30% RHA as partial replacement of cement. They have monitored the open circuit potential measurements with reference to saturated calomel electrode (SCE) periodically with time as per ASTM C876. From their study it can be observed that the time of cracking were 42, 72, and 74 hours for concretes made with 0, 5, and 10% RHA. However, no cracking was observed for concretes with 15, 20, 25, and 30% RHA ever after 144 hours of exposure. These findings indicate that there was no crack in concretes made with 15, 20, 25 and 30% rice husk even after 144 h of exposure. In contrast, ordinary Portland cement concrete, the specimen was cracked after only 42 h of exposure in 5% NaCl solution. Saraswathy et al.'s (2007) study indicated that the concrete specimens containing 5 and 10% rice husk ash also failed within 72 and 74 hours of exposure. It can be concluded from their study that the replacement of rice husk ash refined the pores and thereby reducing the permeability .Moreover, the study by Saraswathy and her colleagues (2007) suggests that the incorporation of RHA up to 30% replacement level reduces the chloride penetration, decreases permeability, and improves strength and corrosion resistance properties. Finally, they have recommended the replacement level of up to 25%. In the same vein, Chindaprasirt et al. (2008) studied the effect of RHA and fly ash on corrosion resistance of Portland cement concrete and concluded that both fly ash and RHA are very effective in improving the corrosion resistance of mortars indicating better contribution of RHA to corrosion resistance in comparison to that of fly ash.

Similarly, Habeeb et al. (2009) studied the effect of RHA on shrinkage of concrete mixtures containing 20% of RHA at three different average particle sizes. They concluded that the drying shrinkage was significantly affected by RHA fineness. The addition of micro fine particles of RHA to concrete would increase the drying shrinkage. While coarser particles of RHA exhibited lower values than the plain cement based concrete. These contributions can be justified by the pozzolanic and the filler effects.

2.4.5 Microstructure and fineness of RHA

Upon combustion, the cellulose-lignin matrix of the rice husk burns away leaving behind a porous silica skeleton. The highly porous structure (see Plate 2.1 and Plate 2.2) of the ash gives rise to a large surface area. The actual specific surface area determined by the BET nitrogen absorption method of RHA ranges from 20 to 270 m2/g [Bui 2001]. Rice husk ash, being porous in nature, has an extremely high surface area, while its average size is still fairly high. Compared to SF with a mean particle size of 0.1-1 μm [Swamy 1986; Malhotra *et al.* 1987], RHA with a mean particle size around 45 μm has a three times higher surface area [Chandrasekhar *et al.* 2003]. Mehta [1994] suggested that since RHA derives its pozzolanicity from its internal surface area, grinding of RHA to a high degree of fineness should be avoided. This means that there is an appropriate fineness of RHA which is not only advantageous to the enhancement of its pozzolanic activity, but also economically beneficial. Unfortunately, this value has been investigated very little [Bui *et al.* 2005; Habeeb and Fayyadh 2009].

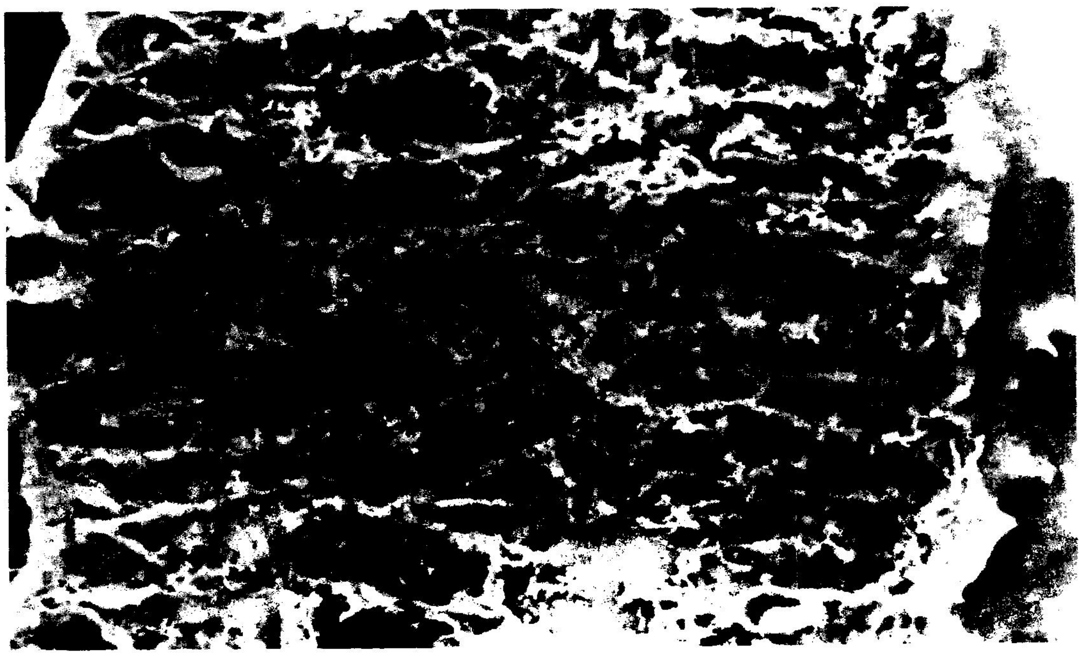

Plate 2.1 Skeletal structure of RHA particle (736×)

Source: Rice husk ash cements: their development and applications (Cook 1984)

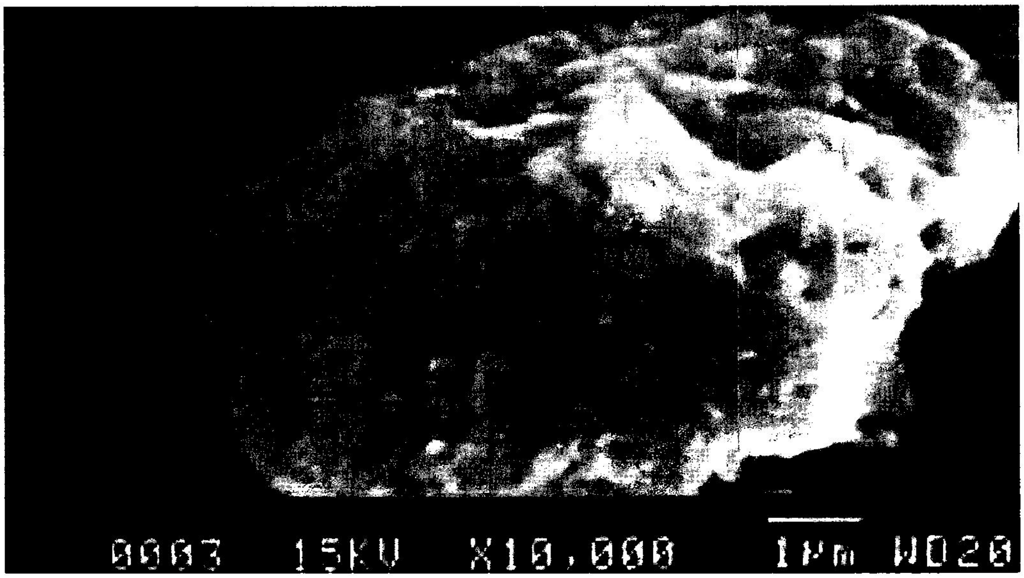

Plate 2.2 SEM image of RHA

Source: Ricehusk ash paste and concrete: Some aspects of hydration and the microstructure of the interfacial zone between the aggregate and paste.[Zhang and Malhotra 1996]

With respect to the porous structure of RHA, Sugita *et al.* [1997] revealed that the specific pore volume of coarse RHA is as much as 0.16 cm3/g, and the pores in it are mainly distributed in the region of 2–40 nm with an average radius of 12.3 nm. The authors suggested that with so many such pores, RHA has a characteristic of high water absorption and this high demand for water is a drawback for RHA mixtures. In fact, the pore structure of RHA will be changed with the degree of grinding [Sugita *et al.* 1992; Bui 2001]. According to Sugita *et al.* [1997] and Real *et al.* [1996], the pore size distribution of the ground RHA is small with a range of 2–5 nm and an average radius of 4 nm. Also, the specific pore volume of this RHA is decreased to 0.13 cm3/g. The reductions in pore volume and pore size will decrease the ability of water absorption of RHA and therewith change the resulting properties of RHA mixtures.

2.4.6 Microstructure of cement blended with RHA

Adding of RHA changes the microstructure development of Portland cement paste. This can normally be observed by means of a scanning electron microscope (SEM). From SEM observations, Hwang and Wu [1989] revealed that a CH crystal in the cement paste containing RHA appears between anhydrous cores, and that the CSH gel appears after 5 hours. The size of this crystal will increase up to 4, 8 and 26 times after 6.5, 7.5 and 12.5 hours, respectively, compared to that after 5 hours. However, such a phenomenon does not occur in cement paste without RHA. Also from SEM observations, Sivakumar and Ravibaskar [2009] found that after just 1 hour, the surface of RHA particles are covered by hydration products. After 1 day, most of the CH may have reacted with RHA; some hexagonal plates (about 0.1 μm) grow on the surface of RHA particles similar to that of monosulfoaluminate (AFm). The ettringite (AFt) needles disappear and the CH crystals diminish due to the pozzolanic reaction. After 3 days, the dense fibers bond with the matrix within large pores, and in 1 week, these pores are filled with the CSH gel [Hwang and Chandra 1997]. After 4 weeks, the matrix has become denser and the non-decomposed CH crystal clogs the matrix. After 60 days, the matrix bonds together, and the presence of CH becomes unclear [Hwang and Wu 1989; Sivakumar and Ravibaskar 2009]. Regarding the interfacial zone between the aggregate and paste in concrete, normally both the hydration and the microstructure of ITZ is partly influenced by the 'wall effect' within the vicinity of aggregate surfaces. In normal concrete, this region may extend some 50 μm from the interface into the cement paste [Maso 1996]. In fact, the addition of RHA was found to improve both the hydration and microstructure of this zone [Zhang *et al.* 1996], in which the porosity and the Ca(OH)2 amount is reduced, as well as the thickness of this zone, compared to that in the Portland cement paste.

2.4.7 Reaction mechanism

2.4.7.1 Pozzolanic reaction

A pozzolanic reaction occurs when a siliceous or aluminous material get in touch with calcium hydroxide(CH) in the presence of humidity to form compounds exhibiting cementitious properties (Papadakis *et al.*, 2002). In the cement hydration development, the calcium silicate hydrate (C-S-H) and calcium hydroxide (Ca (OH) 2, or CH) are released within the hydration of two main components of cement namely tricalcium silicate (C3S) and dicalcium silicate (C2S) where C, S represent CaO and SiO2 (Omotosoa *et al.*, 1995). Hydration of C3S, C2S also C3A and C4AF (A and F symbolize Al2O3 and Fe2O3) respectively, is important. Upon wetting, the following reactions occur (Englehardts *et al.*, 1995):

$$2(3CaO\text{-}SiO_2) + 6H_20 \rightarrow 3CaO.2SiO_2.3H_20 + 3Ca\,(OH)_2 \quad (1)$$

$$2(2CaO.SiO_2) + 4H_20 \rightarrow 3CaO.2SiO_2.3H_20 + Ca\,(OH)_2 \quad (2)$$

$$3CaO.A1\,_20_3 + 31H_20 + 3CASO_4 \rightarrow 3CaO.\ A1\,_20_3.\ 3CaSO_4.31\ H_20 \quad (3)$$

$$4CaO.A1_20_3.Fe_20_3 + 10H_20 + 2Ca\,(OH)_2 \rightarrow 6CaO.Al_20_3.Fe_20_3.12H_20 \quad (4)$$

The C-S-H gel generated by the hydration of C3S and C2S in equations (1) and (2) is the main strengthening constituent. Calcium hydroxide and Ettringite ($3CaO.3CaSO_4.31H_20$, equation 3) that are crystalline hydration products are randomly distributed and form the frame of the gel-like products. Hydration of C_4AF (equation 4), consumes calcium hydroxide and generates gel-like products. Excess calcium hydroxide can be detrimental to concrete strength, due to tending the crystalline growth in one direction. It is known that by adding pozzolanic material to mortar or concrete mix, the pozzolanic reaction will only start when CH is released and pozzolan/CH interaction exist (Villar Cocina *et al.*, 2003). In the pozzolan-lime reaction, OH- and Ca 2+ react with the SiO2 or Al203-SiO 2 framework to form calcium silicate hydrate (C-S-H), calcium aluminate hydrate (C-A-H), and calcium aluminate ferrite hydrate:

Tobermorite gel:

$$SiO_2 + Ca\,(OH)_2 + H_20 \rightarrow CaO.SiO_2.H_20 \quad (5)$$

Calcium aluminate hydrate:

$$Ca\,(OH)_2 + H_20 + Al_20_3 \rightarrow aO.A1_20_3.Ca\,(OH)_2.H_2O \quad (6)$$

Calcium aluminate ferrite hydrate:

$$Ca\,(OH)_2 + Fe_20_3 + A1\,_20_3 + H_20 \rightarrow Ca\,(OH)_2.A1\,_20_3.Fe_20_3.H_20 \quad (7)$$

The crystallized compound of C-S-H and C-A-H, which are called cement gel, hardened with age to form a continuous binding matrix with a large surface area and are components responsible for the development of strength in the cement paste (Kassim *et al.*, 2004). Pozzolan-lime reactions are slow, generally starting after one or more weeks (Englehard *et al.*, 1995). The behavior of the delay in pozzolanic reaction will result in more permeable concrete at early ages and gradually becomes denser than plain concrete with time. This behavior is due to two reasons: Firstly, pozzolan particles become the precipitation sites for the early hydration C-S-H and CH that hinders pozzolanic reaction. Secondly, the strong dependency of the breaking down of glass phase on the alkalinity of the pore water which could only attain the high pH after some days of hydration. Pozzolan can partially replace cement in mortar or concrete mix without affecting strength development. The effect of the pozzolanic reaction produces more cement gel (i.e. C-S-H and C-A-H) reducing the pore size, blocks the capillary and produces denser concrete thus making it stronger and more durable.

2.4.7.2 Pozzolanic reaction of RHA

Data from reaction results between RHA and CH indicates that the amount of CH by 30% RHA in cement paste begins to decrease after 3 days, and by 91 days it reaches nearly zero, while in the control paste, it is considerably enlarged with hydration time (Yu *et al.*, 1999). The addition of pozzolan decreases the formed CH by the pozzolanic reaction to produce more C-S-H gel that can improve the strength and durability of concrete (Aziz *et al.*, 2004). Amorphous silica that is found in some pozzolanic materials (Habeeb *et al.*, 2009) reacts with lime more eagerly than those of crystalline form (Lin *et al.*, 2003). The most essential asset of RHA that identifies pozzolanic activity is the amorphous phase substance. The production of rice husk ash can lead to the formation of approximately 85% to 95% by weight of amorphous silica (Della *et al.*, 2002). As a consequence of this characteristic, RHA is an extremely reactive pozzolanic substance appropriate for use in lime-pozzolan mixes and for Portland cement substitution. The reactivity of RHA associated to lime depends on a combination of two factors: namely the non-crystalline silica content and its specific surface (Dakroury *et al.*, 2008). Cement replacement by rice husk ash accelerates the early hydration of C3S. The increase in the early hydration rate of C3S is attributed to the high specific surface area of the rice husk ash (Feng *et al.,* 2004). This phenomenon specially takes place with fine particles of RHA. Although the small particles of pozzolans are less reactive than Portland cements (Mehta *et al.*, 1990), they produce a large number of nucleation cites for the precipitation of the hydration products by dispersing in cement pastes. Consequently, this mechanism creates the more homogenous and denser paste as for the distribution of the finer pores due to the pozzolanic reactions among the amorphous silica of the mineral addition and the CH (Isaia *et al.*, 2003). Mehta (1987) reported that the finer particles of RHA speed up the reactions and form smaller CH crystals. Berry *et al.* (1994) revealed that high volume of not completely reacted pozzolanic particles in the cement paste may fill up the voids and enhance density of the paste. Cabrera *et al.* (2001) have exposed that pozzolanic reaction can be characterized by the Jander diffusion equation based on Fick's parabolic law of diffusion assuming the interface is a contracting sphere. The Jander equation for three dimensional diffusion in a sphere is;

$$(1-(1-x)^{1/3})^2 = (D/r^2)\,kt$$

Where x is the fraction of the sphere that has reacted, r is initial radius of the starting sphere, and k is the diffusion constant.

2.5 Conclusion

The objective of this work is therefore to investigate into the mechanical strength of concrete by mixing with rice husk ash since the use of these by-products is an environmental-friendly method of disposal of large quantities of materials that would otherwise pollute the land, water and air. And to serve as a partial replacement to cement which will provide an economic use of the by – product and consequently produce strong and durable concrete at a cheaper cost.

CHAPTER 3
METHODOLOGY

3.1 Introduction

The work presented in this paper reports an investigation on the behavior of concrete produced from partial replacement of cement with RHA and GRH at various proportion. The physical and chemical properties of RHA, GRH and OPC are first investigated. Mixture proportioning was performed to produce high workability concrete for the control mix. The effects of RHA and GRH on concrete properties were studied by means of the mechanical property of concrete i.e. compressive strength and workability.

It was also expected that the final outcome of the project will have an overall beneficial effect on the utility of rice husk ash concrete in the field of Civil Engineeringconstruction work. Following parameters influences behavior of the rice husk ash concrete, so these parameters were kept constant for the experimental work.

a. Percentage replacement of cement by rice husk ash
b. Fineness of rice husk ash
c. Chemical composition of rice husk ash
d. Water to cement material ratio (w/c ratio)
e. Type of Curing

Also from the literature survey, it was observed that the parameters suggested by different researchers and their results were not matching with each other. It was due to variation in properties of different materials considered in the work. Therefore the percentage replacement of cement by rice husk ash and grinded rice husk with method of mix design was fixed after preliminary investigation.

3.2 Flow Chart

According to Fig 3.1 the whole research process went as followed;

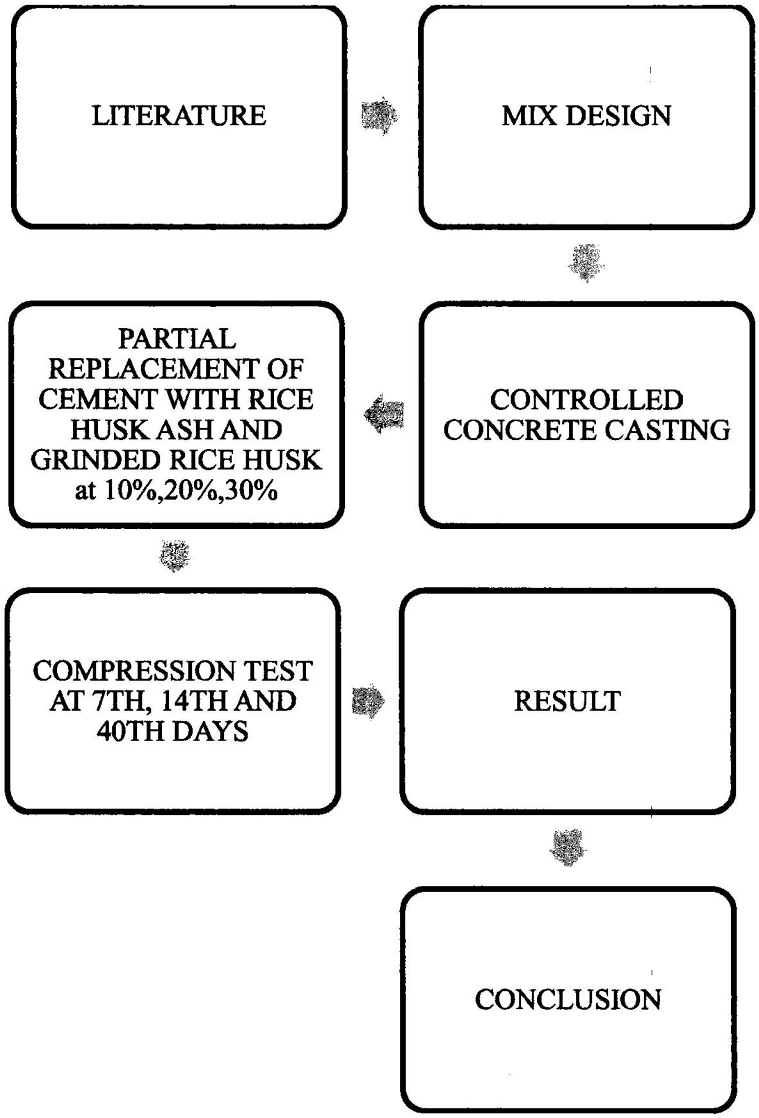

Fig 3.1 Flow chart depicting the methodology

3.3 Experiment Materials

The materials used for the research study are as followed;

a. Rice Husk Ash (RHA)

b. Grinded rice husk (GRH)

c. Cement

d. Fine Aggregates

e. Coarse Aggregates

3.4 Production of RHA and GRH

The rice husk used in this work was collected from rice paddy industry in Ikole, Ekiti, Nigeria. To obtain it's ash it was then burnt in the laboratory by using a Ferro-cement furnace (Plate 3.2) with incinerating temperature of about 700°C. The ash was then collected and sieved.

The grinded rice husk was blended using a grinding machine (Plate 3.1). Plate 3.3, 3.4 and 3.5 show the pictures of RHA before grinding, when burnt and after grinding respectively.

Plate 3.1 Grinding machine

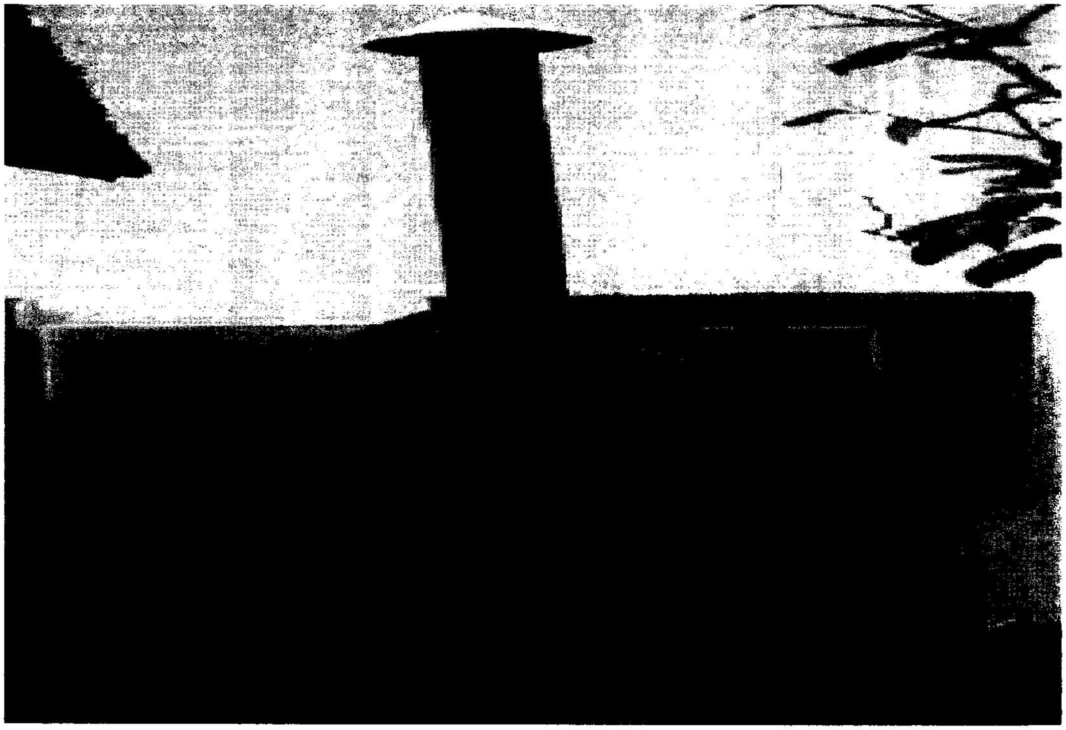

Plate 3.2 Ferro-cement furnace

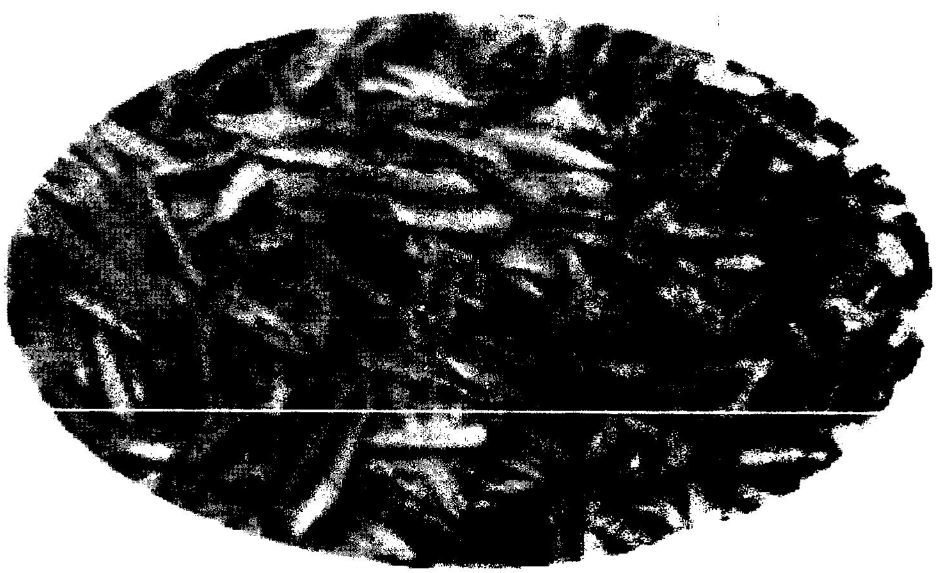

Plate 3.3 Rice Husk before grinding

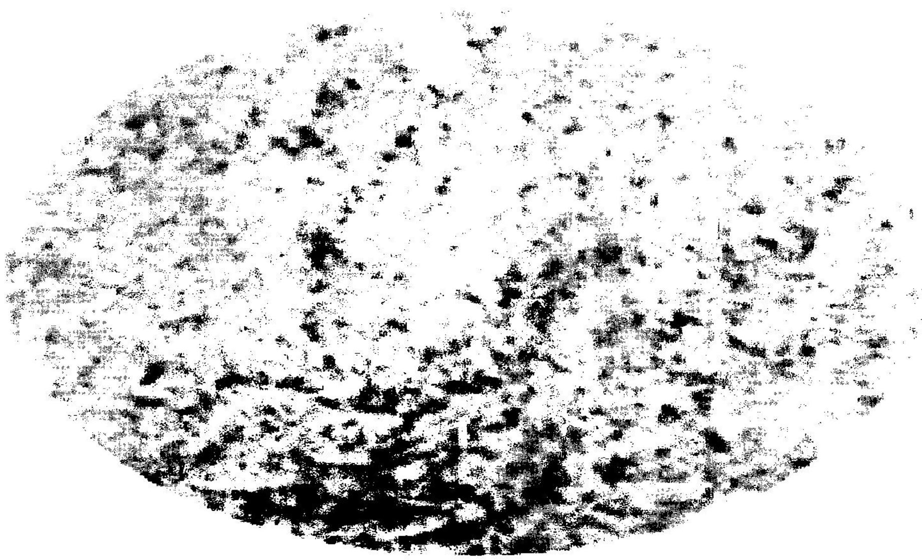

Plate 3.4 Rice Husk after grinding

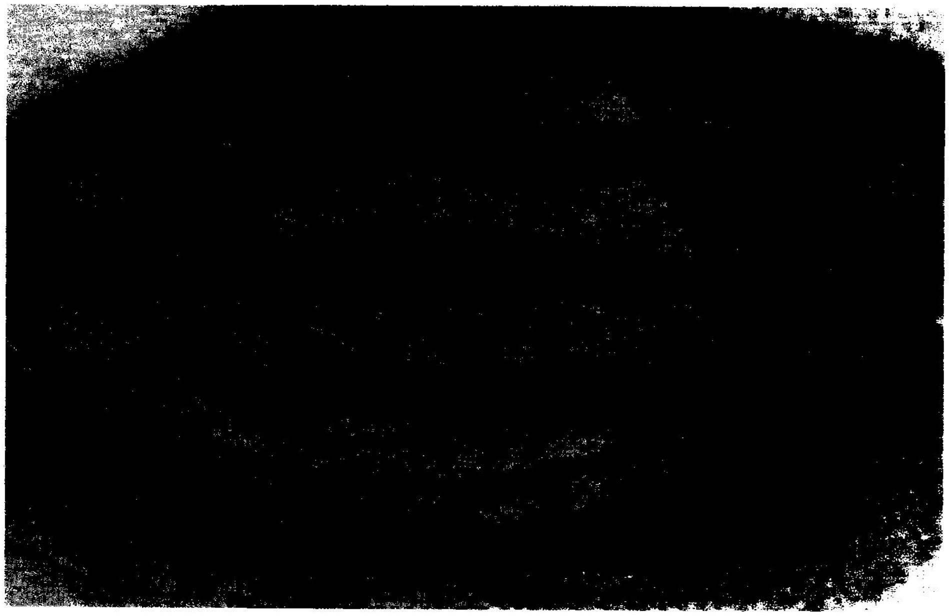

Plate 3.5 Rice Husk Ash

3.5 Mix proportions of concrete cubes mixed with RHA and GRH

In this work, seven batches of concrete were produced with varying amounts of Rice Husk Ash (RHA) and Grinded rice husk (GRH) substituted for Ordinary Portland Cement (OPC). There was a control group with no RHA i.e. 0 % replacement (also known as control mix), then followed by 10% replacement, 20% replacement, and 30% replacement of RHA and GRH respectively as shown in table 3.1. This is important because it fits the conditions of rural and developing countries, where cement is expensive and rice cultivation is predominant.

Table 3.1 Quantities of Materials per Cubic meter of Concrete for various Batch

Mix No	**% Replacement**	**Cement (kg)**	**RHA (kg)**	**GRH (kg)**	**CA (kg)**	**FA (kg)**	**Water-cement Ratio**
1	0%	14.46	-	-	33.12	25.31	0.45
2	10% RHA	13.19	1.80	-	30.9	24.53	0.45
3	20% RHA	10.96	3.85	-	33.37	24.3	0.45
4	30% RHA	10.20	5.38	-	34	23.31	0.45
5	10% GRH	11.46	-	3.63	33.2	24.6	0.45

3.6 Preparation of concrete cubes for crushing

The steps required for the casting and the preparation of concrete cubes for casting are as follows;

3.6.1 Hand mixing

Concrete was mixed using the following procedure

i. The cement was mixed with the fine aggregate on a water tight none-absorbent platform until the mixture was thoroughly blended and of uniform color.
ii. The coarse aggregate was added and mixed with cement and fine aggregate until the coarse aggregate was uniformly distributed throughout the batch.
iii. Water was then added and mixed until the concrete appears to be homogeneous and of the desired consistency

3.6.2 Casting

Concrete cubes were casted using the following procedure

i. The moulds were cleaned and oil was applied.
ii. The concrete was filled into the moulds in layers approximately 50 mm thick.
iii. Each layer was compacted with not less than 35strokes per layer using a tamping rod (steel bar 16mm diameter and 60cm long, bullet pointed at lower end) so as not to have any voids.
iv. The top surface was leveled and smoothened with a trowel by putting cement paste and spreading smoothly on whole area of specimen.
v. The specimens were marked for identification during crushing.

3.6.3 Curing

The test specimens were stored in moist air for 24hours and after this period removed from the moulds and kept submerged in clear fresh water until taken out prior to test.

Plate 3.6 Weighing of the materials for casting

Plate 3.7 Casting of concrete

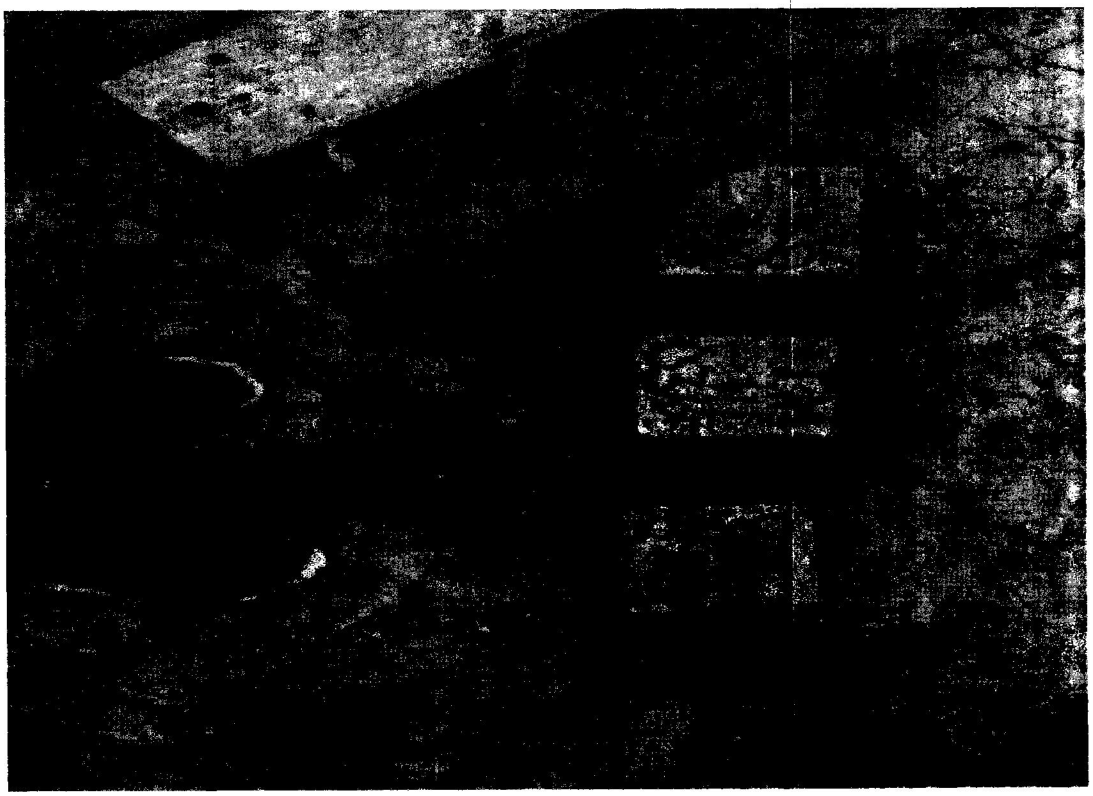

Plate 3.8 Concrete cubes casted

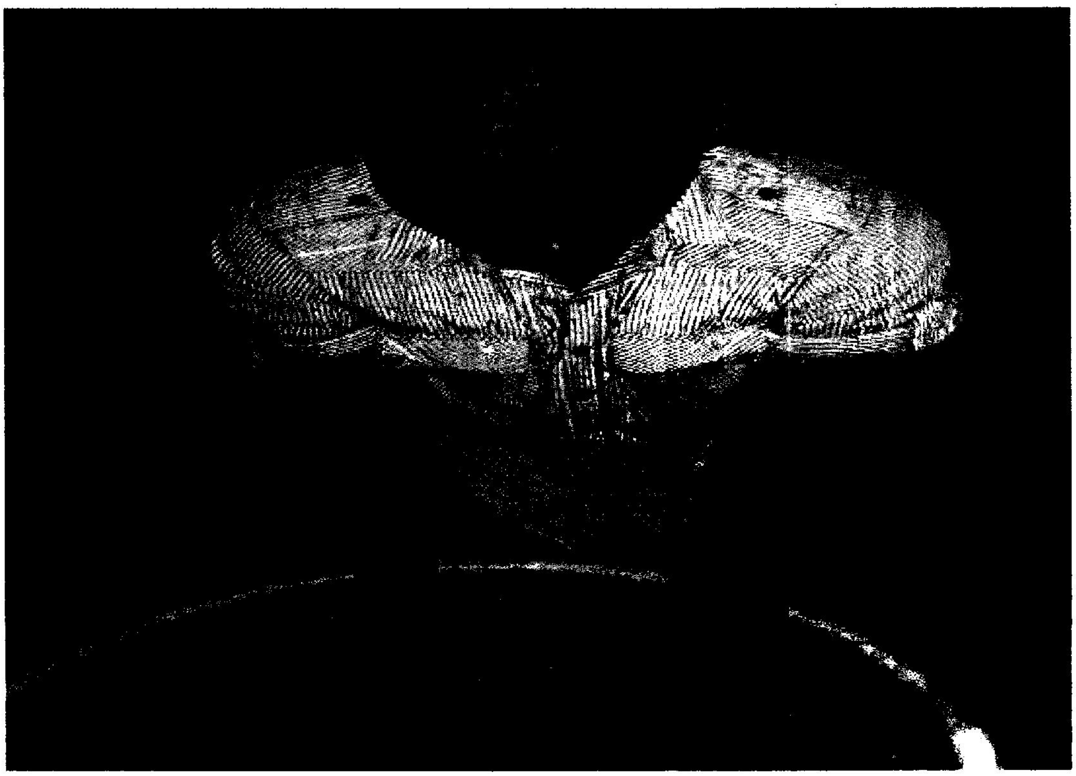

Plate 3.9 Cubes being cured 24 hours after casting

3.7 Concrete Test

The following test were carried out before and after casting of the concrete cubes.

3.7.1 Workability (Slump test)

The slump test is a means of assessing the consistency of fresh concrete. It is used, indirectly, as a means of checking that the correct amount of water has been added to the mix. The test was carried out in accordance with BS EN 12350-2. The steel slump cone was placed on a solid, impermeable, level base and filled with the fresh concrete in three equal layers. Each layer was rodded 25 times to ensure compaction. The third layer is finished off leveled with the top of the cone. The cone was carefully lifted up, leaving a heap of concrete that settles or 'slumps' slightly. The upturned slump cone was placed on the base to act as a reference, and the difference in level between its top and the top of the concrete was measured and recorded to the nearest 5 mm to give the slump of the concrete. When the cone was removed, the slump may take one of three forms. In a true slump the concrete simply subsides, keeping more or less to shape. In a shear slump the top portion of the concrete shears off and slips sideways. In a collapse slump the concrete collapses completely. Only a true slump is of any use in the test. If a shear or collapse slump is achieved, a fresh sample should be taken and the test repeated. A collapse slump will generally mean that the mix is too wet or that it is a high workability mix.

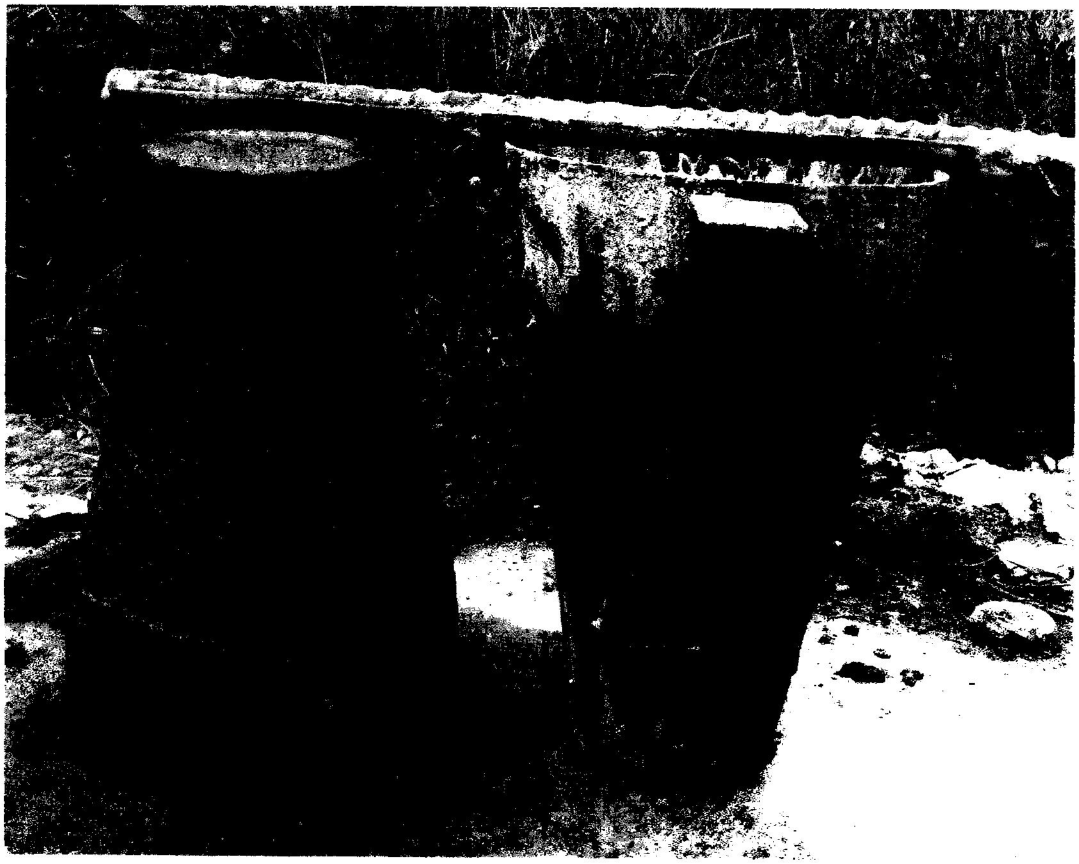

Plate 3.10 Slump Test

3.7.2 Compressive strength of concrete

Out of many test applied to the concrete, this is the utmost important which gives an idea about all the characteristics of concrete. By this single test one judge that whether Concreting has been done properly or not. For cube test two types of cubical moulds of either 150mm X 150 mm X 150 mm or 100 mm X 100 mm x 100 mm depending upon the size of aggregate are used. For most of the works cubical moulds of size 150 mm x 150 mm x 150 mm are commonly used and for this project, that was what was used. These specimens are tested by compression testing machine after 7 days, 14 days and 40 days curing. Load was applied gradually at the rate of 1 40 kg/cm2 per minute till the Specimens fails. Load at the failure divided by area of specimen gives the compressive strength of concrete.

Procedure

The crushing procedure is as follows;

- **i** The specimen were removed from water after specified curing time and wiped off of excess water from the surface.
- **ii** The dimension of the specimen was taken to the nearest 0.2m.
- **iii** The bearing surface of the testing machine were cleaned.
- **iv** The specimen were placed in the machine such that the load shall be applied to the opposite side of the cube cast.
- **v** The specimen were aligned centrally on the base plate of the machine.
- **vi** The movable portion of the machine was rotated gently by hand so that it touches the top surface of the specimen.
- **vii** Load was applied gradually without shock and continuously at the rate of 140kg/cm^2/minute till the specimen fails.
- **viii** The maximum load was recorded and any unusual features in the type of failure were noted

Plate 3.11. The compression testing machine.

CHAPTER FOUR

RESULT

4.1 Workability

From table 4.1 below, it can be observed that the increase in partial replacement of cement at 10%, 20% and 30% Rice Husk Ash respectively in concrete leads to a gradual increase in the slump value of concrete which increases the workability of concrete. This occurs because fine particles of rice husk ash get absorbed on the oppositely charged surfaces of cement particles and prevent them from flocculation. The cement particles are thus effectively dispersed and will trap large amounts of water meaning that the system will have a reduced water requirement to achieve a given consistency.

Increase in partial replacement of Grinded rice husk at 10%, 20% and 30% on the other hand results in a reduction in workability of concrete compared to the control mix.

Table 4.1 Effect of RHA on Workability of Concrete (Slump Test)

Percentage Replacement	RHA (0%)	RHA (10%)	RHA (20%)	RHA (30%)	GRH (10%)	GRH (20%)	GRH (30%)
Slump Value (mm)	50	60	68	76	32	15	5

4.2 Weight and Compressive Strength of Concrete

The 40 days strength obtained for M40 grade Control concrete is 49.07 N/mm^2. The strength results are reported in table 4.2. From the table, it is clear that as the age advances, the strength of Control concrete increases. It can also be observed from the table that as the age advances, the weight of concrete cube increases respectively.

Table 4.2 Weight and compressive strength of concrete (control mix) at 7, 14, and 40 days

Age (days)	7	14	40
Weight (N)	78.48	81.62	84.07
Compressive Strength (N/mm^2)	40.44	43.02	49.07

Table 4.3 to Table 4.6 represents the variation of compressive strength with age for M40 grade RHA concrete and GRH concrete, in each table, variation of compressive strength with age is depicted separately for each replacement level of RHA considered namely 10%, 20% and 30% and GRH namely 10%. Along with the variations shown for each replacement, for comparison, similar variations is also shown for control concrete i.e., for 0% replacement in figure 4.1. In each of these variations, it can be clearly seen that, as the age advances, the compressive strength also increases. Therefore the following observations are made;

The maximum increase in the compressive strength has occurred at 40 days with 10% replacement, whereas the compressive strength of RHA concrete is found to be decreased by 6.17% at 7 days and 1.27% at 14 days with 10% RHA replacement. Due to institutional circumstances, the concrete compressive strength test at 14 days of GRH (Table 4.5) was not conducted. Therefore, a theoretical value was calculated using interpolation. Table reveals a decrease in compressive strength in comparison to the control mix for 7 days, 14 days and 40 days having a percentage in reduction of 12.74%, 13.48% and 7.91% respectively. Although there was an increase in compressive strength of the 10% GRH over the number of days having its compressive strength at 40 days clearly higher than 20% and 30% RHA concrete mixes, with a compressive strength of 45.57 N/mm^2 it is clearly not as high as that of the control mix (50.24 N/mm^2).

During casting, the 20% and 30% partial replacement of cement with GRH failed, lacking enough cohesion to be removed from the concrete mould, the samples exhibited flakiness, softness, containing numerous voids and took a longer number of days to attain considerable hardness and dryness for demoulding and subsequently curing. Therefore they were discarded.

It can also be observed from table 4.7 that as the age advances, the weight of concrete cube increases respectively whereas there occurs a reduction in weight of concrete cube as it is being replaced partially with the various percentage of RHA and GRH. The concrete cube with the lowest weight is 30% RHA at 7 days having a weight of 63.08N.

Table 4.3 Weight and compressive strength of concrete at 10% RHA for 7, 14, and 40 days

Age (days)	7	14	40
Weight (N)	71.62	75.83	77.2
Compressive Strength (N/mm²)	38.09	42.58	50.24

Table 4.4 Weight and compressive strength of concrete at 20% RHA for 7, 14, and 40 days

Age (days)	7	14	40
Weight (N)	67	69.51	68.96
Compressive Strength (N/mm²)	33.24	35.42	40.53

Table 4.5Weight and compressive strength of concrete at 30% RHA for 7, 14, and 40 days

Age (days)	7	14	40
Weight (N)	63.08	64.45	66.71
Compressive Strength (N/mm²)	29.47	33.69	40.20

Table 4.6 Weight and compressive strength of concrete at 10% GRH for 7, 14, and 40 days

Age (days)	7	14	40
Weight (N)	68.47	69.62*	73.87
Compressive Strength (N/mm²)	35.87	37.91*	45.47

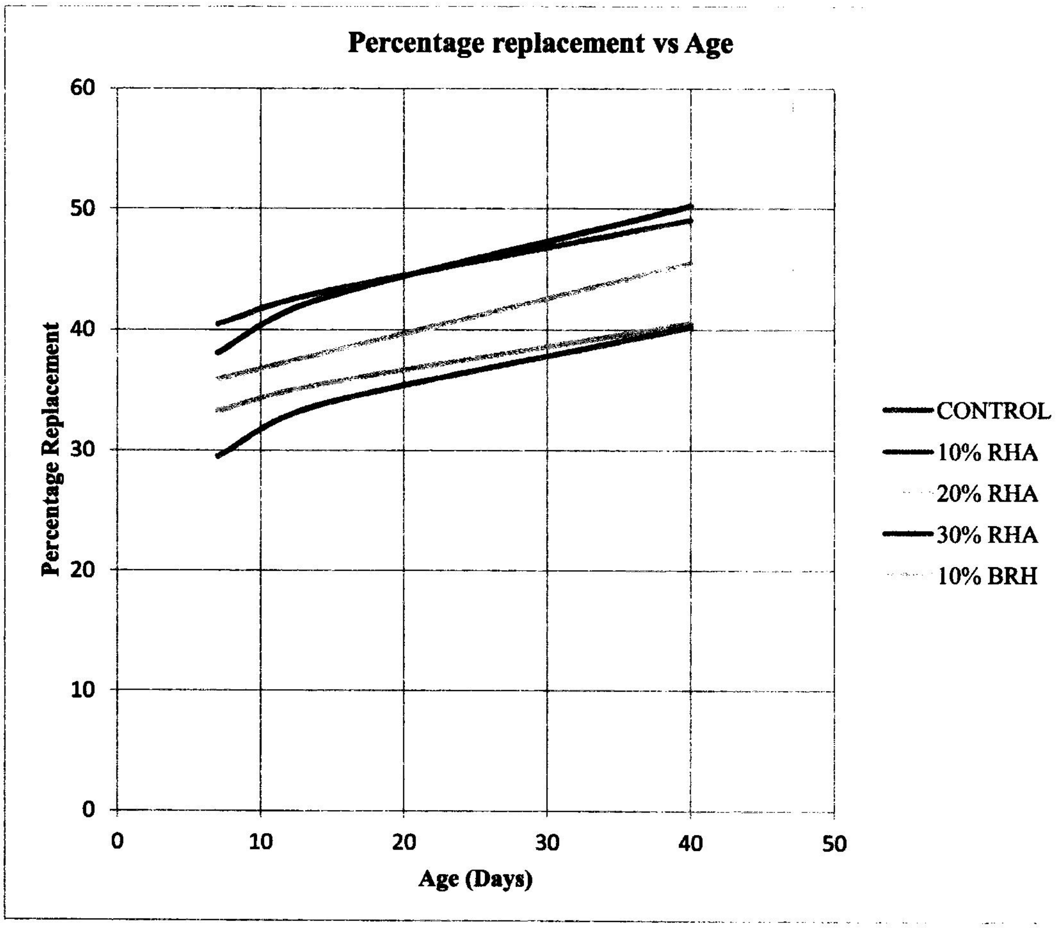

Figure 4.1. Percentage Replacement vs. Age (Compressive strength)

Table 4.7 Percentage Replacement vs. Age (Weight in N)

Percentage Replacement					
		RHA (%)			GRH (%)
Age (days)	**0**	**10**	**20**	**30**	**10**
7	78.48	71.62	67	63.08	68.47
14	81.62	75.83	69.51	64.45	69.62*
40	84.07	77.2	68.96	66.71	73.87

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Based on the limited study carried out on properties of fresh & hardened concrete the following conclusions are drawn;

At all the cement replacement levels of RHA and GRH; there is significant increase in compressive strength from 7 days to 40 days. A partial replacement up to 10% of RHA provides a compressive strength higher than that of the control mix which makes it the best option. GRH on the other hand does not meet up with the required margin and therefore is not suitable.

The partial replacement of cement in concrete using rice husk ash concrete leads to a more cohesive and more plastic mix and thus permits easier placing and finishing of concrete. It also increases the workability. However greater workability can be achieved by the addition of super plasticizer to Rice Husk Ash. Grinded rice husk on the other hand gives less cohesive mix.

By using this Rice husk ash in concrete as partial replacement the self-weight of concrete can be reduced significantly and also the emission of greenhouse gases can be decreased to a greater extent. As a result there is greater possibility to gain more number of carbon credits.

The utilization of RHA holds promising prospects in the country because it softens the impact on the environment & capital cost of the structure. As the RHA is a waste material, it reduces the cost of construction. It helps in reducing the pollution in environment.

5.2 RECOMMENDATION

After completing my research and testing various samples, it is recommended that rice husk ash be used as partial replacement for Ordinary Portland Cement up to 10% in areas where rice production is prevalent and cost of cement is high. This will help decrease the weight of the finished project, reduce the cost, and dispose of the rice husk waste product to prevent environmental degradation. Although grinded rice husk may not exhibit higher compressive strength properties than rice husk ash, it can still be used to fuel brick kilns and complement cement in building materials. The various applications of rice husk transforms it from prevalent waste product into an abundant resource and step towards national development.

The technical and economic advantages of incorporating RHA in concrete should be exploited by the construction and rice industries in Nigeria.

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