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Reduction in environmental problems using rice-husk ash in concrete

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ABSTRACT

The production of cement (key binding component of concrete) is costly, consumes high energy, depletes natural resources and emits huge amounts of greenhouse gases (1 ton of cement production emits ~1 ton of CO_2). Consequently, environmental degradation, serious pollution and health hazards associated with cement and concrete industries, have come under intense scrutiny from environmentalists and the governments.

Developed and some developing nations, are already using industrial and agricultural wastes in concrete. These wastes also pose several environmental problems. Partial inclusion of waste instead of 100% cement has been found to be environmentally safe, stable, durable as well as economical.

The present study used rice-husk ash (RHA) as a partial replacement of cement in concrete. X-ray diffraction analysis, scanning electron microscopic examination, compressive strength (without and with superplasticizers), flexural strength, resistance to aggressive chemicals and cost analysis were carried out. Concrete and mortars containing 25% RHA as a replacement of cement, exhibited same or better results compared to conventional concrete. Moreover, it leads to substantial cost savings not to mention benefits to the environment.

1. Introduction

With growing environmental consciousness at all levels of society, the pollution and health hazards especially associated with the concrete, cement and clay-bricks industries, are coming under intense scrutiny from environmentalists and the governments. The developed countries are farther ahead in tackling the problem by using industrial and agricultural wastes in their industries. These industrial and agricultural wastes are mostly the by-products of oil and coal burning by-products, slag, rice husk ash, bagasse, fly ash, cement dust, stone crusher dust, marble dust, brick dust, sewer sludge, glass, tires, etc. Million tons of these waste materials are abundantly available and discarded every year in the world. They pose environmental problems like air pollution and leaching of hazardous and toxic chemicals (arsenic, beryllium, boron, cadmium, chromium, chromium(VI), cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, and vanadium, along with dioxins and polycyclic aromatic hydrocarbon compounds, etc.) when dumped in landfills, quarries, rivers and oceans [1,2]. Consequently air and water pollution have been inextricably linked to environmental problems and climate change.

Increasing concern for environmental protection, energy conservation with minimal impact on economy have been motivating researchers to look for other alternatives of cement in the concrete industry. Studies have shown that waste materials can be successfully used in all kinds of existing and future concrete structures, by replacing cement sometimes up to 70%. They provide environmentally safe, stable, and more durable and low cost construction materials [3–5]. It is well known that production of cement (key binding component of concrete) is costly, consumes high energy, depletes natural resources and emits large amounts of greenhouse gases (GHGs mostly CO_2). It has been reported that the production of 1 ton of cement consumes about 4GJ of energy and requires about 1.7 tons of raw materials (limestone and shale) which leads to environmental degradation and pollution problems [6–8]. Therefore concrete technology has focused on other alternatives which can be used as cement replacement materials in concrete. Researchers have been searching all the time for cheap and easily available cement replacement materials, like industrial and agricultural wastes which are pozzolanic in nature. Rice-husk ash (RHA), is one of the agricultural wastes and pozzolanic. It can be used as a partial replacement of cement in concrete. On the other hand, concrete consumes more than 8 billion tons of aggregates (mostly limestone) every year, which also depletes the natural resources, such as forests, hills, and mountains, thus creating additional problems to the environment, to humans and wild habitats, and climate change.

Rice husk is an agricultural residue generated by the rice milling process. During milling, about 78% of weight is received as rice, broken rice and bran and the rest of the 22% is received as husk

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[9]. This husk contains about 75% organic volatile matter and the balance 25% of the weight is converted into ash, known as rice husk ash (RHA), during the burning process. This RHA in turn contains around 85–90% silica which is mostly in amorphous state, but depends on the burning temperature and time.

The annual global paddy production estimates for the year 2010 are 678 million tons which implies 149.16 million tons of rice husk production that year from which 37 millions of tons of RHA can be obtained [10]. In the absence of its utilisation, this huge quantity of RHA goes waste and becomes a great threat to the environment causing damage to the land and the surrounding areas in which it is dumped. If most of the RHA were to be used in concrete, it would not only get rid of dumping RHA but would also have decreased the CO_2 emissions to atmosphere by bringing down the cement production. The annual global production of RHA, being very small in comparison to the enormous quantity of cements produced worldwide (2.65 billion metric tons in year 2009), cannot wipe out cement completely [11]. However, by replacing cement partially with RHA, it will bring a substantial reduction in the amount of CO_2 emitted every year in the atmosphere.

The chemical composition of rice husk is found to vary from sample to another due to the differences in the type of paddy, crop year, climate and geographical conditions. Burning the husk under controlled temperature below 800 °C can produce ash with silica mainly in amorphous form [12,13].

It is estimated that 90% of rice is produced and consumed in Eastern and Western Asia. Pakistan is also located in the same region and is a major rice producing country. The annual paddy production of Pakistan has been 9.5 million tones for the year 2009 meaning a substantial amount of RHA production of 0.53 million tones [14]. If used wholly in the construction industry as pozzolanic material it would bring about a marked reduction of CO_2 emission associated with the manufacturing of cement. It would not only decrease the level of pollution in the atmosphere but will also eradicate a major land pollutant as RHA is dumped as waste in quarries. Therefore, using it in concrete as a cement replacement material will make a waste material into one of value. Moreover, it may be a viable alternative to its disposal as waste which has a damaging effect on the environment.

Pakistan is a developing country with 85% of its population comprising in the middle and lower income groups. About six hundred thousand dwellings are required per annum to cope with present population growth rate of 3%. Keeping in view the main problem of shelter, low cost housing is the right solution. In low cost construction, the major component that affects the economy is ordinary Portland cement (OPC). As mentioned earlier, its production depletes natural resources, requires high energy use and emits a large amount of CO_2 and causing environmental problems. The abundance of rice husk offers a very useful solution. This study was carried out with the following main objectives:

- to explore the cementing properties of RHA and its possible use as a low cost construction material by partially replacing OPC in concrete. Such use would provide a useful means of disposing it off, by utilisation as an agricultural waste. This would improve rural economy and generate employment as well;
- to transform rice husk from an environmental concern to a useful resource for the production of a highly effective supplementary cementing material.

2. Experimental program

2.1. Materials

2.1.1. Cement

Locally available OPC conforming to the ASTM C150 was used. Table 1 summarises its chemical composition.

2.1.2. Rice-husk ash

Rice-husk from the Province of Punjab, Pakistan, was selected to evaluate its suitability as ash for OPC replacement in concrete. Rice-husk was burnt in a controlled atmosphere at 800 °C in the laboratory. The ash thus produced was cooled rapidly as well as slowly. Rapid cooling was carried out by spreading the ash in trays at the laboratory ambient temperatures of 21 ± 1 °C after achieving the required temperature of 800 °C. Slow cooling, on the other hand, was carried out by leaving the ash, as is, in the incinerator, after achieving the required burning temperature. Only 22% of the ash was obtained after burning the rice husk. It was ground through rod mill and sieved through 200 or 325 μm mesh. Its specific gravity was 2.1. Table 1 presents the chemical analysis of both the rapid cooled as well as slow cooled RHA.

Table 1 shows that:

- The amount of chemical constituents significantly differ in the rapid and slow cooled RHA samples.
- Silica content in both the rapid cooled and slow cooled RHA is high. In rapid cooled RHA, the silica is about 5% less than that of slow cooled RHA. The reason for this anomaly could not be explained as yet.
- Similarly, the loss on ignition in both the rapid cooled and slow cooled RHA is high. The high loss on ignition could be due to the volatile organics as well as the moisture content in the ash [15].

2.1.3. Aggregates

The fine aggregate used was natural silica river sand with a fineness modulus 2.3. The coarse aggregate used was crushed limestone. It had a maximum aggregate size of 19 mm and a bulk specific gravity of 2.66.

2.1.4. Superplasticizer

Superplasticizer (SP) was used to control the water to cement or water to binder (OPC + RHA) ratio (W/B) in order to achieve the desired workability of the concrete mixture. Since the addition of RHA increased W/B, obviously the strength of finished product was decreased due to its high surface area. It was; therefore, appropriate to study the behaviour of rice-husk ash cement (RHAC) concrete by keeping the W/B constant by using the SP.

2.1.5. Tests

Tests carried out on RHA and RHAC concrete were: reactivity with sodium hydroxide (NaOH), X-ray diffraction analysis (XRD), scanning electron microscopic analysis (SEM), compressive strength (with and without SP), flexural strength and chemical resistance, etc.

3. Results and discussion

3.1. Reactivity of RHA

One gram of RHA was dispersed in 200 ml of 0.5 M sodium hydroxide (NaOH) solution and was allowed to stay for 48 h with constant stirring. It was then filtered and the filtrate was titrated against 0.5 M HCl solution. The amount of NaOH neutralised by the dispersed ash (reactivity) was estimated from the difference in the concentration of NaOH solution before and after this treatment.

Table 1
Physical and chemical properties of OPC and RHA.

Materials	Specific gravity	Chemical analysis (%)						
		SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	LOI
OPC	3.12	19.80	3.85	6.9	62.45	2.35	2.95	–
Rapid cooled RHA	2.1	84.00	2.01	1.39	0.60	0.85	–	5.85
Slow cooled RHA	2.1	89.50	2.86	0.40	0.30	0.25	–	4.0