Research Article

Rice Husk Ash Based Geopolymer Concrete – A Review

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Abstract

Environmental issues resulted from cement production have become a major concern today. To develop a sustainable future it is encouraged to limit the use of this construction material that can affect the environment. Cement replacement material was proposed to partially replace cement portion in concrete. Geopolymer is the best solution to reduce the use of cement in concrete. Geopolymer is a hardened cementitious paste made from fly ash, alkaline solution and geological source material. The development of fly ash and rice husk ash (RHA) as the source material for geo polymer concrete was studied through the observation of the hardened specimen strength and durability properties. Rice husk ash is a by-product from the burning of rice husk at a temperature lower than 6000C.this means that it is in a form that is soft and easy to grind. Rice husk ash is rich in silica about 90%, 5% carbon and 2% K_2O. The specific surface of RHA is between 40-100m^2/g. It is extremely prevalent in East and South-East Asia because of the rice production in this area. The addition of RHA as a silica source also had an effect on the strength of Geopolymer. The strength and durability increased with an increase in silica content.

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The RHA forms a calcium silica gel around the cement particles and prevents the cracking of the concrete and protect it from corrosion and make the concrete to be durable one. The study done by Jakrapan Wongpa found that the compressive strength of Geopolymer mortar using RHA as a binder could be as high as 40Mpa and 60Mpa at the ages of 14 and 28 days, respectively. As per the study by Song and Saraswathy found that the incorporation of RHA up to 30% replacement level reduces the chloride penetration, decreases permeability and improve strength and corrosion resistance properties. The strength and durability properties of hardened concrete include compressive strength and durability tests such as acid resistance, water absorption, pull out test, carbonation test, sulphate attack, chloride penetration test, corrosion test for various percentage of replacement of cement by fly ash and RHA have to be study and the results are compared with that of the conventional concrete. Based on the results of the experimental study some important conclusions have been drawn.

Keywords: Geopolymer Concrete, Flyash, GGBS, RHA, Alkaline Activators

1. Introduction

In 1972, Davidovits [8] found the geo polymerization process and had invented the geo polymer high-strength cement in 11 years later. Geopolymer cement is another building material which does not need the Portland cement to develop the strength. However, geo polymer from Davidovits's research needs the raw material which has to contain Al_2O_3 and SiO_2 such as kaolin and blast furnace slag to produce the Si-O-Al bonds. Many years later, some researchers made geo polymer using fly ash as a binder.

However, fly ash also has SiO_2 and Al_2O_3 [4, 10]. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term "Geopolymer" to represent these binders. Geopolymer concrete is concrete which does not utilize any Portland cement in its production. Geopolymer concrete is being studied extensively and shows promise as a substitute to Portland cement concrete. Research is shifting from the chemistry domain to engineering applications and commercial production of geo polymer concrete. There are two main constituents of geopolymers, namely the source materials and the alkaline liquids. The source materials for geopolymers based on alumina-silicate should be rich in silicon (Si) and aluminium (Al). These could be natural minerals such as kaolinite, clays, etc. Alternatively, by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc could be used as source materials. The choice of the source materials for making geopolymers depends on factors such as availability, cost, type of application, and specific demand of the end users. The alkaline liquids are from soluble alkali metals that are usually sodium or potassium based. The most common alkaline liquid used in geo polymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate.

It is well known that RHA can contain non-crystalline silica and that a highly reactive pozzolana is obtained when the rice-husk is burnt under controlled conditions. In other conditions a ‘‘residual RHA’’ is produced with a lower quality, usually presenting residual carbon (which increases the water demand) and part of the silica in crystalline state. However, the residual RHA can be improved by grinding it to an appropriated particle size, although this process comes with a considerable cost, as expected [5]. Both processes imply energy costs and strategies for selection and disposition. Recently, a joint project1 was developed with the aim of analyzing the viability of the use of residual RHA ‘‘as nature’’, without previous grinding, adopting an appropriate sequence for the incorporation of component materials during the mixing process of concrete. An adequate RHA particle size was obtained mixing RHA together with the coarse aggregates during a convenient period of time (near 8 min).

2. Research Significance

This paper deals with the manufacture, materials, testing of rice husk ash geopolymer concrete and the influence of several parameters on the properties of Geopolymer Concrete. The research data review presented in this paper is useful to understand the behaviour of Geopolymer concrete.

3. Experimental Programme

3.1 Preparation of Geopolymer Specimens

Firstly, sodium hydroxide (NaOH) was dissolved in distilled water. Then weighted quantities of raw materials: fly ash, GGBS and rice husk ash were added into the NaOH solution and mixed until the mixtures looks homogeneous. The mixtures were cast in a plastic mould and cured at different temperatures (ambient, Oven, room) for hours. After that, the specimens were cured continuously and tested according to the codes.

3.2 Materials

3.2.1 Fly ash

Coal-burning power plants produce four main byproducts: bottom ash, boiler slag, flue gas desulfurization sludge, and fly ash, which are widely used in making blended cements. Fly ash comprises 75–80% of the total mass of ash produced and is composed of fine, spherical alumina silicate particles generally recovered from the smokestack of the power plant [3]. The exact chemical composition of fly ash depends on the type of coal burned: geologically older (anthracite and bituminous) coals typically produce ASTM Type F fly ash, which has a relatively low calcium content and is a pozzolana Geologically younger (lignite or sub bituminous) coals typically produce calcium-rich ASTM Type C fly ash, which does not always require an activator and will display cementitious properties when exposed to water [6]. The type of coal also determines the chemical composition of less important elements, with substantial variations occurring not just between different types of coal, but between coal samples taken from different parts of the same seam. As with slag, the reuse of fly ash is environmentally friendly in three ways. It reduces the amount of virgin material that needs to be extracted to make Portland cement, as well as displaces the green house gases, and reduces energy consumption, during the processing of that virgin material. The 24.7 Mt of fly ash reused in the U.S. alone in 2009 reduced CO_2 emissions equivalent to the exhaust of roughly 1.3 million automobiles.

3.2.2 Ground Granulated Blast Furnance Slag

It is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy granular product that is then dried and ground into a fine powder. GGBS is used to make durable concrete structures in combination with ordinary portland cement and/or other pozzolanic materials. Concrete made with GGBS cement sets more slowly than concrete made with ordinary Portland cement, depending on the amount of GGBS in the cementitious material, but also continues to gain strength over a longer period in production conditions. This results in lower heat of hydration and lower temperature rises, and makes avoiding cold joints easier, but may also affect construction schedules where quick setting is required. Use of GGBS significantly reduces the risk of damages caused by alkali–silica reaction (ASR), provides higher resistance to chloride ingress — reducing the risk of reinforcement corrosion — and provides higher resistance to attacks by sulfate and other chemicals.

3.2.3 Rice husk ash

Rice husk ash is a byproduct of the cultivation and processing of rice as a foodstuff. Between 20% and 25% of the rice paddy is an indigestible outer husk, which is removed and usually burnt (either in a local power plant, to create steam with which to parboil the rice itself, or in household stoves). Approximately 18% of these husks, when burnt, will become ash, therefore, the production of 1 ton of rice will result in roughly 45 kg (70 lbs) of RHA, which is rich in silica (95%), with a high surface area and substantial pozzolanic properties [11]. The exact amount of RHA produced, its chemical composition, and its crystalline content depends strongly on the burning temperatures and furnace design [24]. Crystalline silica content in RHA is a particular concern, as crystalline silica is a potent inhalation hazard.

As rice is the world's most important grain product (corn is grown more widely, but also has a wide variety of non-food purposes), a large amount of ash is produced every year. Assuming that 3.5% by weight of the rice will eventually become RHA, the four largest (potential) producers of RHA are China (7.2 Mt), India (5.5 Mt), Indonesia (2.2 Mt), and Bangladesh (1.7 Mt); worldwide potential production is around 20 Mt. According to the USA Rice Federation, U.S. rice production exceeds "20 billion pounds" annually; at most, this means that domestic rice husk ash production could reach 0.35 Mt.

Table 1 Chemical Properties of Cement (OPC), Fly ash and Rice husk ash

Materials	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**LOI**	**SO_3**	**K_2O**	**Na_2O_3**
Cement	19.71	5.20	3.73	62.91	2.54	0.96	2.72	0.90	0.25
Fly ash	40	25	6	20	3.71	3.0	1.74	0.80	0.96
GGBS	40	13.5	1.8	39.2	3.6	0.0	0.2	0.2	-
Rice Husk Ash	87.2	0.15	0.16	0.55	0.35	6.55	0.32	3.60	-

First, rice production is a highly localized activity. In the U.S. rice is only produced in two regions: northern California, and along the Mississippi river from southern Missouri to the Gulf Coast. Such localization leads to transport costs, which can rapidly make the material economically or ecologically unviable. In Asia, where the bulk of the world's rice is produced, availability is more widespread, but transport is still a hurdle. Modern combustion furnaces may not be available, especially in rural areas, and simple open-field burning produces only low-quality

RHA (along with especially noxious pollution and relatively large amounts of CO_2). Limited widespread acceptance, or even awareness of the potential for RHA use, continues to be the single largest obstacle, and the fact that RHA is often dark colored (frequently black) leads to aesthetic quality issues.

3.2.4 Alkaline Activators

The most used alkaline activators are a mixture of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate and potassium silicate [8]. The alkaline activated slag reporting an increase in mechanical strength when the concentration of the activator increases. Furthermore, after a study of the geo-polymerisation of sixteen natural Al-Si minerals, they found that generally the NaOH solution caused a higher extent of dissolution of minerals than the KOH solution [3].

3.2.5 Super Plasticizer

In order to improve the workability of fresh concrete, high range water-reducing naphthalene based superplasticizer was added to the mixture. The dosage of super plasticizer also has an effect on the compressive strength of the concrete. As a super plasticizer it substantially improved the workability without increasing the amount of water and hence reducing the risk of segregation. It results in normal set even when overdosed. It gives a good surface finish and as it is chloride free it doesn't attack reinforcement or pre-stressed cables if any. Apart from this, various other superplasticizers, which can be used, are categorized as

- Super Plasticiser A (Naphthalene Formaldehyde Condensate)
- Super Plasticiser B (Sulphonated Melamine Formaldehyde Condensate)
- Super Plasticizer C (Aqueous De Policarboxilato)
- Super Plasticizer D (Aqueous Solution of Ligno Sulphonate

3.3 Testing Methods

3.3.1 Workability

A set of samples were achieved in a desired slump in the range of 80-100mm. To attain the desired slump, the concretes containing RHA required higher water content than those containing only Portland cement. This is due to the high specific surface area and high carbon content of RHA. There slump of RHA concrete mixtures are higher than that of the control mixture. There is the possibility of water reduction higher than 20% in the presence of RHA [1].

3.3.2 Compressive strength

Compressive strength is usually considered as one of the most important properties of concrete and a major indicator of general quality control. Factors influencing the strength of concrete include the types and quality of materials, the mixture proportion, the construction methods, the curing condition, and the test method. From the microscopic point of view, both the degree of hydration and the porosity play important roles. The greater the volume of the pores, the lower the strength of the concrete will be. In addition, with decreasing binder/space ratio (defined as the ratio of the content of C–S–H gel to the original volume of space), the strength will become greater. In the early phase, the addition of ground RHA reduces the amount of cement by 10–20%, the volume of capillary pores then increases, accumulating CH on the interface. As a result, the structure is less compact, causing the strength to be lower than that of the specimen without ground RHA added. After 28 days, pozzolanic reaction starts to proceed, decreasing the amount of CH and improving the densification. The compressive strength of concretes with up to 20% ground RHA added attain values equivalent to that control concrete after 28 days .

3.3.3 Ultrasonic pulse velocity (UPV)

The pulse velocity methods have been used to assess the uniformity and relative quality of concrete, to indicate the presence of voids and cracks, and to evaluate the effectiveness of crack repairs. Generally, high pulse velocity reading in concrete is indicative of concrete of good quality. The concrete has good durability when its pulse velocity value is in the range of 3660–4575 m/s. The trend with regard to the hardening properties of ground RHA concrete is: the lower the w/b ratio the higher the UPV. During the hydration period, the volume of the solid/liquid phase with the high water-to binder ratio is smaller and the distance between grains is a little greater. At the same time, it takes a longer time to fill pore space with hydrates of low cement content than of high cement content.

3.3.4 Air permeability

On concrete cylinders of 150 _ 300 mm at 28 days of age was determined by the ‘‘Torrent Permeability Tester” method according to the Swiss Standard SIA 262/ 1:2003. The particular features of the Torrent method are a two chamber vacuum cell and a pressure regulator, which ensure that air flows at right angles to the surface directed towards the inner chamber; this allows the calculation of the permeability coefficient Kt on the basis of a simple theoretical model.

3.3.5 Chloride ion penetration

Use 10 by 20 cm concrete cylinders at 28 days. All the specimens were cast following the directions of Mercosur Code; then they were labeled and cured in molds for 24 h. afterwards, they were demoulded and cured in a moist-curing room at 21 ± 2 0C and a relative humidity of more than 90–95% until testing. For the chloride ion penetration test, the Italian Standard 79-28 was used; Cl was introduced from the outside of the hardened concrete (external Cl). Seven days after curing, the specimens were immersed in water, having a Cl concentration of 5% for 21 days. After splitting tensile test, a silver nitrate solution was sprayed on the fractured surface to observe the color change boundary. In the zone penetrated by Cl, silver nitrate forms a white precipitate of silver chloride, while in the area not penetrated by Cl it reacts with OH ions to form silver oxide, which appears on the surface as a brown precipitate. Because of the appearance of contrasting colors at the color change boundary, the zone is clearly drawn. Based on this result, each fractured surface was scanned, each Cl depth of penetration was evaluated with statistical analysis, and the diffusion coefficient was calculated.

3.3.6 Acid attack

The influence of RHA in the chemical deterioration of concrete according to ASTM C267 on mortar cylinders of 50x100 mm exposed to 1% HCl solution [20]. The mass of the cylinders from each of the mixtures, after 7 days of moist-curing (temperature of 20 _C and a relative humidity of 100%), was determined in the saturated surface dry (SSD) condition, before immersion in the HCl solution. On a weekly basis, the test cylinders were cleaned by three quick rinses in running cold tap water and quick dried by blotting with a paper towel between each rinse. For each one of the test specimens prepared, the mass was determined after ½ h. The HCl solution was also changed on a weekly basis before re submerging the cylinders. The mass was determined up to 84 days.

3.3.7 Sulphate resistance

A mortar bars were prepared in accordance to ASTM C1012. Ten specimens of 25x25x285 mm were prepared for each mixture. After casting, specimens were covered with moist paper towels (approx. 100% relative humidity) for 24 h, after which they were demolded, marked and placed in a saturated lime–water solution for 28 days. After 28 days of lime–water curing, the initial length was measured and the specimens were divided into two categories for further curing: (a) curing in saturated lime–water (control), (b) curing in a solution of 5% sodium sulphate. The sodium sulfate solution PH was controlled daily and corrected when needed with a 1 N sulphuric acid solution. On a weekly basis, the length change of the prisms was measured over time, up to 200 days (28 weeks). The specimens containing RHA were found to be more resistant to HCl solution and sulfate attack than the specimens without RHA [12]

4. Conclusion

This paper presented a summary on the progress and current status on the development of Geopolymer concrete using by-products such as flyash, GGBS and rice husk ash. From the review of literature it is noted that rice husk ash based geo-polymer concrete has a big importance to play in the near future, in the construction sector. It provides a mature and cost-effective solution to many problems where hazardous residues must be treated and stored under critical environmental conditions. The excellent potential of Geopolymer concrete as a construction material has been exposed. This paper also presented several areas where research is needed to further develop this material, and to make it widely usable in, any applications. The employment of RHA in cement and concrete has gained considerable importance because of the requirements of environmental safety and more durable construction in the future. The use of RHA as partial replacement of cement in mortar and concrete has been extensively investigated in recent years.

It is noted that RHA blended concrete can decrease the temperature effect that occurs during the cement hydration. RHA blended concrete can improve the workability of concrete compared to OPC. It can also increase the initial and also final setting time of cement pastes. Additionally, RHA blended concrete can decrease the total porosity of concrete and modifies the pore structure of the cement, mortar, and concrete, and significantly reduce the permeability which allows the influence of harmful ions leading to the deterioration of the concrete matrix. RHA blended concrete can improve the compressive strength and helps in enhancing the early age mechanical properties as well as long-term strength properties of cement concrete. Partial replacement of cement with RHA reduces the water penetration into concrete by capillary action. RHA replacement of cement is effective for improving the resistance of concrete with sulphate attack.

It can be concluded that the use of rice husk ash based geopolymer concrete leads good results than that of ordinary concrete and it is recommended to use rice husk ash widely in the concrete.

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