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Influence of Rice Husk Ash in Geopolymer Concrete– a Review

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Abstract: *The production of portland cement leads to the pollution of the environment by the release of large amount of CO_2 to the atmosphere. This give rise to the extensive research work on materials with low carbon footprint as substitute to port land cement. Geopolymer concrete is presently studied extensively as a substitute to Portland cement. This paper briefly reviews the influence of rice husk ash in Geopolymer concrete, its strength and potential application. From the review, it was concluded that RHA improves the mechanical properties of Geopolymer concrete at optimum curing temperature of 75 ºC and completed within 7 days to obtain the maximum strength. GPC exhibits better mechanical properties when compared to Portland cement concrete and has a good resistance to sulphate attack which makes it useful in marine structures. The addition of RHA in Geopolymer concrete enhances durability, compressive and tensile strength of concrete. The increase in the percentage of RHA reduces the workability of Geopolymer concrete but can be improved upon by the addition of super-plasticizers.*
Keywords: *Geopolymer concrete, Rice husk ash, Workability, Durability, Curing, Fly ash.*

I.INTRODUCTION

Proper management of wastes materials is very important because both agricultural wastes and industrial by-products pollute the environment and also pose a great challenge of disposal. With growing environmental consciousness, the health hazards associated with concrete and cement industries are under intense scrutiny (Mohammad, 2013). The cement manufacturing industry nearly contributes about 7% of total CO_2 emitted into the space annually (McCaffrey, 2002). This gives rise to extensive research work on Geopolymer concrete as a full replacement of cement in concrete production using agricultural or industrial wastes such as- fly-ash, rice husk ash, GGBS, Met kaolin etc.

Allahverdi et al., (2008) revealed that Geopolymer cements exhibit better engineering properties compared to port land cement in concrete production. It enhances properties such as compressive strength, durability and resistance against aggressive media compared to Portland cements. Geopolymer has the advantages of early hardening, high compressive strength and corrosion resistance, but defects such as high brittleness affects the application of Geopolymer materials. Geopolymer materials can be modified by adding specific modified fillers to the raw materials of Geopolymer (Bernal et al.,2010). Geo-polymer is produced through alkali activation of source materials rich in silica and alumina, forming an inorganic alumino–silicate polymer product with polymeric Si –O –Al –O bonds (Daniel et al., 2017).

II.LITERATURE REVIEW

Geopolymer s are of two main components which are the source materials and the alkaline liquids. The source materials that is suitable for use should be rich in silicon (Si) and aluminum (Al). These could be natural minerals like kaolinite, clays, etc. or by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc. The choice of the source materials for making Geopolymer s may be dependent on some factors such as its availability, cost of the material, type of application, and specific demand of the end users.

Geopolymer is very important to recycle bulk industrial solid waste, develop green building materials and also can meet the urgent needs of sustainable development in the building materials industry (Chu, 2021). The negative environmental impacts associated with cement production provides a need to find sustainable way of reducing the carbon footprint of the cement industry through production of low-carbon cement by replacing the ordinary Portland cement (OPC) with alternative materials, such as rice husk ash, blast furnace slag, coal fly ash, natural pozzolanic materials such as kaolin and geopolymers. Open dumping or burning rice husks can be combusted under controlled conditions to generate rice husk ash with a high silica content (80%–90%) with properties desired in geo-polymer production (Detphan and Chindaprasirt, 2009). For instant, combusting rice husks at temperatures below 700 °C and above 800 °C, the amorphous and crystalline forms of ash are obtained, respectively. The main difference between the crystalline form and amorphous form is that crystalline form is less reactive, while the amorphous form exhibits high pozzolanicity under normal conditions (Nair et al., 2008). Therefore, amorphous form of the rice husk ash is more suited, as compared with its crystalline counterpart in the production of

Geopolymer . Comparing rice husk ash with other silica sources like sand, betonies and diatomaceous earth, rice husk ash has little amounts of contaminants with high purity of ash which affect its performance in applications.

2.1. Rice Husk Ash

Ikenwa, (2019) reported that Nigeria is a major rice producing country and the largest producer of rice in West Africa. He stated states where rice is cultivated mostly as Benue, Borno, Cross River, Enugu, Bauchi, Kaduna, Kano, Taraba, Niger, Kwara and Kebbi etc. Rice husk is an agricultural residue and rice husk ash is about 25% by weight of rice husk when burnt. Rice husk is transported from the mill to the furnace where it is used as fuel for burning. The produced ash is rich in highly reactive silica. RHA does not contain Al_2O_3, it needs to be mixed with an alumina-rich source material before the alkali-activation. Rice husk is usually calcined at similar temperatures to that of the dihydroxylation of kaolin, i.e. about 750°C (Chandrasekhar et al., 2006).

There are two types of RHA, crystalline and amorphous. Burning RHA at temperature below 750ºC generates amorphous silica while when burnt at temperature greater than 800ºC, it will generate crystalline silica (Surya, 2012). Researchers have previously combined Rice husk ash with different alumina source materials to produce geopolymer. For instance, rice husk ash and red mud (He et al., 2013), rice husk ash was combined with fly ash by (Hwang and Huynh, 2015), rice husk ash and met kaolin were used in a research conducted by (Sore et al., 2016).

When Rice husk is burnt under controlled temperature up to 700ºC, it produces RHA of a very high SiO_2content in amorphous form (Mehta, 1992). Due to the abundance of silica content in it. RHA shows pozzolanic properties which makes it a source -material in Geopolymer concrete. In other conditions a ‘‘residual RHA’’ is produced has lower quality, usually presenting residual carbon and part of the silica in crystalline state. Kaolin and rice husk can also be mixed and calcined simultaneously. After calcinations, the product that is produced is a mixture of RHA and MK which is well suitable for subsequent alkaline activation.

Various studies were conducted on Geopolymer using RHA as an additive. Wen et al. (2019) investigated the viability of Geopolymer derived from non-calcined sludge and rice husk ash blend. Yom thong et al. (2019) improved the compressive strength of fly ash-based Geopolymer with an addition of RHA at 3 wt%.

According to research conducted by Pratap (2013), Geopolymer specimens possess better durability and thermal stability properties. The chemical composition of GPC and the curing conditions play important roles in its mechanical properties. GPC is becoming increasingly popular as an environmentally friendly sustainable construction material. Other properties of Geopolymer concrete over OPC concrete are higher tensile strength, higher bond strength with reinforcement and good resistance to sulphate attack, fire and good resistance to acids. GPC has low creep and low drying shrinkage.

Mrema and Mboya (2016) investigated the influence of RHA/Lime ratio on the strength properties of sand mortars. The binder contained 40/60, 50/50, 60/40, 70/30 and 80/20 RHA/Lime ratios. The compressive strength result was seen to have increased when the rate of RHA was increased from 40 to 60 wt% while it was decreased when RHA was increased from 60 to 80 wt%. The result of the study showed that the optimum proportions are 60% RHA and 40% lime gave the best ratio for RHA/Lime.

2.2. Properties of Rice Husk Ash

Zaki and Sola, (2020) reported that RHA has high silica content of 94to 95% as the main reason for using it in Geopolymer concrete as a substitution material which qualifies it to be used as pozzolan. Bezerra et al. (2011) have observed the pozzolanicity of RHA and concluded that the mortars with incorporated RHA had superior values for physical and mechanical performance compared to the reference mixtures due to pozzolanicity of RHA.

2.2.1. Physical Properties of Rice Husk Ash.

The Rice Husk Ash is a very fine and porous material (Mehta, 2002). The Physical properties of RHA as referred by some researchers are given in the table below.

Table 1:Physical Properties of RHA

Physical Properties	Mehta et al (2002)
Mean Particle Size	-----
Specific Gravity	2.06
Fineness Passing 45 µm	99%

The physical properties of RHA depend on burning conditions. Nagasaki, (1994) said that the period and temperature of burning affect the microstructure and characteristics of RHA depends on the period and temperature of burning.

Hwang & Chandra (1997) suggested that burning rice husk at temperatures below 700°C produces amorphous silica which has a high surface area as shown in Table-2.

Table 2: Rice husk ash properties produced from different burning conditions (Hwang and Chandra, 1997).

Burning Temperature	Hold Time	Furnace Environment	Properties Of Rice Husk Ash	
			Silica Form	Surface-Area (m2/g)
500-600º C	1min	Moderately Oxidizing	Amorphous	122
	30 min			97
	2hr			76
700-800º C	15min-1hr			100
	>1hr	Highly Oxidizing	Partially crystalline	6-10
>800º C	>1hr		Crystalline	<5

2.2.2 Chemical Properties of Rice Husk Ash

The RHA contains a large amount of amorphous silica which consist of 50% cellulose, 25-30% lignin, and 15-20% silica (Humayatul, 2015). The different chemical composition of RHA by different authors are given below in the table below.

Table 3: Composition of Rice Husk Ash (Fapohunda et al., 2017).

Constituents	Average percentages based on 30 studies/authors between 1992 to 2016
Silica (SiO_2)	87.90
Alumina (Al_2O_3)	0.69
Iron Oxide (Fe_2O_3)	0.55
Calcium Oxide (CaO)	1.00
magnesium Oxide (MgO)	0.54
Sulphur Oxide (SO_3)	0.34
Sodium Oxide (Na_2O)	0.56
Potassium Oxide (K_2O)	2.26
Loss of Ignition (LOI)	5.52

2.3 Alkaline Activator

Alkaline activator speeds up the rate of reaction in Geopolymer ization of materials to form Geopolymer binder. The alkaline activators mostly used in Geopolymer s are sodium hydroxide (NaOH), potassium hydroxide (KOH), sodium silicate (Na_2SiO_3) and potassium silicate (K_2SiO_3) (Singh et al., 2015). Abdullah et al., (2011) said recommended the mixing of sodium silicate solution and sodium hydroxide (NaOH) solution as alkaline liquid and mixed together for 24 hours prior to use.

Waijarean et al. (2014) studied the effect of Si/Al ratios on the compressive strength of water treatment residue and rice husk ash based Geopolymer s. Finely ground water treatment residue (45µm retaining) was mixed with rice husk ash (45µm retaining) in different proportions so as to achieve Si/Al ratios 2.0, 3.0, 4.0 and 5.0. The mixtures were then activated by sodium hydroxide solution. The samples were cured at ambient conditions and stored in plastic bags until testing at 3, 7, 28 and 60 days. It was reported that the Geopolymer with Si/Al ratio 2.0 showed the highest compressive strength (almost 19 MPa) whereas the values decreased as the ratios were increased up to 5.0.

Thokchom et al. (2012) studied the strength and micro structural properties of low calcium fly ash based Geopolymer pastes. The activator used was sodium hydroxide solutions. Different mixes of Si/Al ratios 1.7, 1.9 and 2.2 were prepared. The pastes were moulded and cured at a temperature of 85°C for 24 hours. After 7 days, the specimens were subjected to elevated temperatures of 300, 600 and 900°C for 2 hrs and tested for compressive strength. Three unexposed specimens were tested for initial strength reference purposes. It was observed that the specimens with Si/Al ratio 2.2 retained 63% of the compressive strength after it was exposed at 900°C. The lowest residual strength (about 50%) was reportedly shown by the sample with least Si/Al ratio of 1.7. The loss of strength at lower Si/Al ratios at elevated temperatures was due to weaker Si-O-Si bonds, shrinkage and microstructure disruption of the specimens.

2.4 Curing of Geopolymer Concrete

Hardijito and Rangan (2004) revealed that longer curing time and also increase in curing temperature from the range of 30 to 90 °C helps to increase the compressive strength of Geopolymer concrete.

Tests conducted by Lloyd and Rangan (2009) showed that the inclusion of a 24 h period before curing helped to increase the compressive strength of GPC. Curing at ambient condition will produce low early strength concrete but a significant strength improvement was observed on using high temperature.

Nurrudeen (2018) noted that extended curing time enhanced the Geopolymer ization mechanism and consequently the strength but however, longer duration of curing at an elevated temperature will lead to failure of the concrete. In general, higher initial curing temperature and duration result to higher compressive strength of concrete.

Joseph and Mathew (2012) indicated 100ºC as the best temperature. The optimum time of curing at 60ºC observed by Chindaprasirt et al. (2007) was 3 h. Most of the researchers found that the optimum curing temperature is 75 ºC and the reaction was completed at 7 days to obtain the maximum strength.

Hamid (2016) reported that engineering properties of Geopolymer concrete such as compressive strength depends on curing time and curing temperature.

2.5 Effect of the Rice Husk Ash Addition On Geopolymer Concrete

The study conducted by Kabirova and Uysal (2022) investigated the usability of rice husk ash (RHA) in metakaolin-based Geopolymer mortars. RHA was used at 25%, 50% and 75% in the sand. The results showed that RHA could be much useful as a filling material in metakaolin-based Geopolymer mortars. And also, it was suggested that metakaolin-based Geopolymer mortar containing 50 wt% RHA can be used as an alternative to pure metakaolin-based mortar. It will help in terms of the economic use of aggregate/sand.

Andi et al., (2017) reported that Hybrid composite rice husk ash (RHA)-Geopolymer s based on Class-C fly ash. It was synthesized through alkali activation method at temperature of 60ºC for 1 hour. The addition of 10% RHA improved the engineering properties such as compressive strength, fire and acid resistance of Geopolymer s. The results gotten from the study also suggest that hybrid composite RHA-Geopolymer s can be suitable to be used as material for bricks bearing building.

Paulo (2016) stated that RHA can be mixed with MK to produce an alternative material for the production of geopolymers. Addition of RHA to MK up to 30%, no changes was observed in the mechanical strength but was dropped to about a half when 40% RHA was used in the formulations. Therefore, further addition of RHA substantially reduces the mechanical strength of metakaolin based Geopolymer s.

Sangeetha (2015) reported that the replacement of cement with Supplementary Cementing Materials improves the engineering properties of concrete. In the study, increase in strength and good durability of concrete was observed when subjected to different temperatures and atmospheric conditions. It was observed that up to 30% replacement of Rice husk ash mixed with 50% replacement with GGBS in concrete give good increase in strength.

Mohammed and Senthil (2015) presented the study that was conducted on rice husk ash and fly ash based Geopolymer concrete with steel fibre. The experimental study on the behavior of Geopolymer concrete fully replaced cement by fly ash and rice husk ash. The mixture was activated by alkaline solution and followed by casting of specimens. The specimens were cured by steam curing at 60º C for 24 hours in an accelerated curing tank. The test result shows that compressive strength decreases with increase in percentage of rice husk ash above 10%. It was suggested that 10% replacement of fly ash by RHA was suitable for production of Geopolymer concrete.

Ammar et al., (2020) assessed the compressive strength of Geopolymer mortar containing rice husk ash (RHA) and metakaolin (MK). Sodium Silicate in powder form was adopted and used as activator for the Geopolymer . Water to binder ratio was constant at 0.5 for each sample. 2% super plasticizer by weight of binder was added in mortar mix and samples were casted. The casted samples were cured in oven at 70°C for first 24 hours and then at ambient temperature of 19°C for 7, 14 and 28 days. Compressive strength of RHA/MK mass ratio of 10/90 gave the highest result among all mixes. In conclusion, the results showed that increase in RHA more than 10 percent showed reduction in the compressive strength result.

Yun et al., (2014) carried out an in-depth experimental investigation on rice husk ash based Geopolymer concrete. The resulting concrete was based on alkali-activated rice husk ash (RHA) by sodium hydroxide with sodium silicate. The effect on method of curing, optimum mix proportion of Geopolymer mortal and concentration of NaOH on compressive strength were investigated. 10M alkali-activated Geopolymer mortal were casted, cured for 24hours at 60ºC and tested at 7 and 28 days of casting. The final result showed a compressive strength of 31N/mm2 and 45N/mm2 respectively. The results indicated that increase in compressive strength as a result of increase in curing period and concentration of alkali activator.

In an experimental research carried out by Stephen and Jeffrey (2022) revealed the potential adoption of coal fly ash

(CFA) and rice husk ash (RHA) Geopolymer binders to serve as a partial substitute for cement in varying proportions up to 25%. Cupola furnace slag (CFS) was also used in the research as a partial substitute of crushed granite from 0% to 35% at an interval of 5% in the production of Geopolymer concrete (GPC). Alkaline solution was used to synthesised the Geopolymer binders. The findings revealed that integrating 75%OPC, 20%CFA, 5%RHA, 100%RS, 20%CFS, and 80%CG results in optimal compressive strength of 19.68 N/mm2 and 21.49 N/mm2 at 28 days and 56 days of curing with w/b of 0.50, respectively.

Hamed et al., (2019) conducted an investigation on metakaolin based Geopolymer concrete with rice husk ash as a forming agent. It focused on an in-depth investigation of formation of pores in the structure of lightweight Geopolymer cements and mortars. The hardener used was sodium water glass. Metakaolin was replaced at 0, 10, 20, 30 and 40 % by mass of husk to produce lightweight Geopolymer cements and mortars. X-ray diffractometry and infrared spectroscopy were used to monitor the formation of pores in the light-weight Geopolymer cements while that of mortars were monitored using apparent density and compressive strength measurements, mercury intrusion porosimetry and scanning electron microscopy. The results showed a decrease in the values of compressive strength and apparent density of Geopolymer mortars while cumulative pore volume increased with increases in the metakaolin replacement level. Stereomicroscopic and scanning electron microscopic images showed that rice husk can be used as a forming agent in the production of sustainable lightweight Geopolymer mortals due to the presence of rice husk and fibres of rice husk in the networks.

Yahya et al. (2017) conducted a research using rice husk as an additive in fly ash-based Geopolymer mortars. They investigated the effects of rice husk on the engineering properties of fly ash-based Geopolymer mortars. Tests were conducted on compressive strength, density and water absorption. The result of the research showed that rice husk can be used to produce lightweight geopolymer concretes.

Paulo (2016) conducted an in-depth investigation on the effect of the RHA addition on compressive and flexural strength of the Geopolymer s. At 30% RHA addition to metakaolin based Geopolymer concrete, there was no significant drop in either the flexural or compressive strength of Geopolymer s. However, both the flexural and compressive strength dropped by half when 40% RHA addition. Although, the results for this level of replacement are 25 MPa compressive strength and 3MPa flexural strength are acceptable. The strength of Geopolymer s containing 50% and 60% RHA addition was too low to be tested. Their properties significantly changed due to the high SiO2 content. It showed a plastic behavior under compression (i.e. deformation instead of brittle crushing) further indicated that the Geopolymer s made with high amounts of RHA are not acceptable as structural materials.

Prasanna et al. (2015) used RHA as a source material in addition to ground granulated blast furnace slag (GGBS) Geopolymer concrete. At 20% replacement, the target strength was surpassed, compressive strength value was as high as 51 MPa at 28 days. The split tensile and flexural strengths of the concrete also showed a trend similar to that of compressive strength with respect to the RHA proportion.

Dara and Bhogayata (2015) revealed some of their findings on the addition of rice husk ash in Fly ash based Geopolymer concrete. Fly ash was replaced by rice husk ash from 0% to 25%, the compressive strength value was increased from 2.24% to 1.78% and the maximum increase observed at 25% was 5.40% compared to result gotten from normal concrete test.

Mohamed and Senthil (2015) in their research stated that the compressive strength of the fly-ash based Geopolymer concrete gradually decreased with increase in the percentage of RHA. 10% replacement of fly ash by RHA decreases the value of the compressive strength by 10.2% when compared to normal Geopolymer concrete.

Compressive strength of Geopolymer concrete is higher than ordinary Portland cement concrete. Geopolymer concrete also showed a very high early strength. It has about 1.5 times more than that of the compressive strength with OPC concrete for the same mix. Geopolymer Concrete showed good workability compared to the ordinary Portland Cement Concrete.

Oladapo et al., (2021) concluded in his experimental research that the durability of geopolymer concrete is much better in comparison with conventional Portland cement concrete.

2.6 Chemical Resistance and Durability of Geopolymer

Durability of reinforced concrete structures is very important and affects the entire lifetime of structures. Geopolymer concrete has been proved to have more sulphate resistance than Ordinary Portland Cement concrete.

Oladapo et al., (2021) encouraged the use of Geopolymer concrete because of its high resistance to sulphate attack, environmental protection and high workability. Geopolymer cement has good properties within both acid and salt environments. It is especially suitable for use in tough environmental conditions. According to Hamid (2016), Geopolymer specimens possesses better durability and thermal stability characteristics. The penetration of aggressive chemical substances into the concrete will damage concrete and corrode steel reinforcement. GPC had been shown better resistance against aggressive environments by studies conducted by many researchers. As a result, GPC can be used to build reinforced structures that are exposed to marine conditions (Reddy et al. 2011). Most researchers were focused on aggressive substance such as sulphate, acid and chloride. Wallah and Rangan (2006) investigated the effect of immersing low calcium fly ash GPC concrete in 5 % sodium sulphate solution. The specimens were studied under various time durations up to one year and it was concluded that the specimens have an excellent resistance to sulphate attack.

All specimens showed no change in appearance and no cracking when compared to the condition before they were exposed.

An experimental investigation by Sanni and Khadiranaikar (2012) was conducted on GPC immersed in sulphuric acid and magnesium sulphate and the result showed that the mass loss of GPC specimens was about 3 % for 45 days exposure while OPC samples have the mass loss observed to be 20 to 25 % for 45 days of exposure. Furthermore, GPC showed less compressive strength loss with an average of 15 % compared to a huge strength loss of about 25 % for OPC.

III.CONCLUSION

From the review, it can be concluded that

(1) RHA improves the mechanical properties of Geopolymer concrete at 20% replacement of pure Met kaolin, GGBS and Fly ash based Geopolymer concrete.

(2) The optimum curing temperature is 75 ºC and the reaction will be completed within 7 days to obtain the maximum strength.

(3) Geopolymer has a good resistance to sulphate attack which makes it useful in marine structures.

(4) Geopolymer cements exhibit better engineering properties when compared to port land cement in concrete production and also it is well suited for high strength concrete

(5) Considering economic and eco-friendly concrete, Geopolymer concrete is the most effective way to replace conventional concrete.

(6) The steam curing achieves a very good strength at 24 hours of curing in accelerated curing tank.

(7) High early strength property of Geopolymer cement makes it a very important material in precast industries to make huge production in short duration.

(8) The addition of RHA in Geopolymer concrete enhances durability, compressive and tensile strength of concrete.

(9) Increase in the percentage of RHA reduces the workability of Geopolymer concrete but addition of super-plasticizers helps to improve on it.

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