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A Review on Geopolymer Concrete

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Abstract: Portland cement is universally accepted binder in concrete. The manufacturing of one ton cement liberates around one ton of CO2 to the atmosphere due to the calcinations of lime stone and combustion of fossil fuel. The production of cement is highly energy intensive and it consumes a substantial amount of natural resources. Geopolymer is found to be an excellent alternative construction material to the concrete produced using OPC. Davidovits (1978) proposed that binders can be produced by polymeric reaction of alkaline liquid with alumino-silicate materials such as fly ash, blast furnace slag, rice husk ash etc. Geopolymer also has the ability to form a strong chemical bond with rock based aggregates. This paper reviews the several studies on geopolymer concrete, its strength, durability and various aspects for being an environmental friendly concrete. The test results demonstrate the geopolymer concrete to be a material of choice for the future.
Keywords: Geopolymer, Environmental Friendly Concrete, Strength, Durability.

1. Introduction

Geopolymer cement is being developed and utilised as an alternative to conventional Portland cement for use in transportation, infrastructure, construction and offshore applications. It relies on minimally processed natural materials or industrial byproducts to significantly reduce its carbon footprint, while also being very resistant to many common concrete durability issues. Attention on geopolymer composites is gaining because consumption of energy and pollution free in its production unlike cement Portland cements.

In the past few decades, geopolymer binders have emerged as one of the possible alternative to OPC binders due to their reported high early strength and resistance against acid and sulphate attack apart from its environmental friendliness. Since geopolymers depends on alumina-silicate rather than CSH bonds for structural reliability, they are regarded as acid resistant. Davidovits reported that metakaoline based geopolymer has very low mass loss when immersed in 5% sulphuric acid solutions. Geopolymer composites possess excellent durability.

In a way, the curing temperature is considered as an unconfined factor regarding compressive strength of geopolymer (1, 2). The incorporation of calcium is much important to consider as an alkali cation which may act as a charge compensator of aluminium to form an amorphous geopolymeric gel rather than any part of a basic geopolymeric structure. The composition and temperature on the properties of fly ash based geopolymer has a remarkable effect on the compressive strength.

The presence of calcium in source material in larger amount disturbs the polymerization process and also the microstrucure of concrete [3]. The source material with alkaline liquid subjected to thermal curing at temperature 60º to 100ºC increases the compressive strength also the compressive strength value not only depends upon chemical reaction but also depends upon the concentration of sodium hydroxide (NaOH) solution [4].

The Black Rice Husk Ash (BRHA) is an agro-industrial waste generated in the rice milling industry. The use of BRHA as a building material is very limited, even though it has a high silica content of about 87-97 % [5]. But several researchers reported that the addition of BRHA in concrete has improved its durability properties [6, 7].

By adding the recycled coarse aggregate as a partial or full replacement of normal coarse aggregate the sustainability of the existing geopolymer concrete containing natural aggregates can further be extended which together address the environmental issues of greenhouse gas emission by the manufacturing of OPC, the depletion of natural aggregate resources and the dumping problems of wastes as landfill.

Extensive research has been conducted on various mechanical and durability properties of geopolymer concrete containing natural aggregates and the same for OPC concrete containing recycled aggregates. However, a few researches on mechanical and durability properties of geopolymer concrete containing recycled coarse aggregates were reported.

2. Objective

The main aim of this study is to analyze the different materials used, optimum temperature of thermal curing, proportioning of Na_2SiO_3/NaO, the ratio of alkaline liquid to solids, the ratio of silicate to hydroxide (SiO_3/OH), various mechanical properties and durability properties and their effects on geopolymer concrete.

3. Literature Review

Suresh Thokchom et al., (2009) carried out an experimental program to study the effect of water absorption, apparent porosity and sorptivity on durability of fly ash based geopolymer mortar specimens in sulphuric acid solution. Low calcium Class F fly ash was activated by a mixture of NaOH and Na_2SiO_3 containing 5% to 8% Na_2O with water to fly ash ratio of 0.33 and river sand was used as fine aggregate. From the observations, geopolymer mortar specimen manufactured with 8% Na_2O resulted in lesser values of water absorption, apparent porosity and sorptivity The residual compressive strength after acid exposure also was found maximum for specimen which contained 8% Na_2O. It was concluded that higher alkali content in the mix gives better reactivity with the fly ash resulting in denser microstructure and the specimen with higher porosity would allow more sulphuric acid solution to enter the geopolymer mortar specimen and hence causing greater damage.

Temuujin et. al., (2011) intended to study the acid and alkaline resistance of class F fly ash based geopolymer pastes. Geopolymer pastes were prepared by mixing fly ash with the alkaline liquids to achieve a composition Si:Al=2.3, Na:Al=0.88 and water:geopolymer solid = 0.19. The alkaline compounds were 14 M NaOH and D-grade sodium silicate solution. To know the surface crystallisation of non-reacted fly ash spheres, the geopolymer pastes were calcined at 600^0C and 1000^0C. The results showed that the calcination of the geopolymers at 600^0C caused about 12% weight reduction. The acid and alkali resistance of fly ash based geopolymer pastes can be increased by calcination at 600^0C.Calcining geopolymer has reduced compressive strength by approximately 30%, because of crack appearance and loss of the structural water. It was observed that the acid or alkali resistance behaviour of the geopolymers can also be improved by regulating the amount of quartz impurity and level of iron oxides in the fly ash thus assisting the geopolymer calcination process.

Monita Olivia et al., (2011) presented a study on the strength development, water absorption, water permeability and AVPV (Apparent Volume of Permeable Voids) of low calcium fly ash geopolymer concrete. Investigations were carried out with variations of water/binder ratio, aggregate/binder ratio, aggregate grading, and alkaline/fly ash ratio. The strength of fly ash geopolymer concrete was improved to a certain extent by decreasing the water/solids ratio, the aggregate/solids ratio, and the alkaline to fly ash ratio. The water absorption of fly ash geopolymer was less than 5%. The water absorption got decreased by decreasing the water/solids ratio, increasing the aggregate/solids ratio, and increasing the alkaline/fly ash ratio. The overall percentage of AVPV and Water absorption were less than 12%. The values can be improved by decreasing the water/solids ratio, increasing the aggregate/solids ratio, and increasing the alkaline/fly ash ratio. The water permeability test and void content revealed that the concrete had “average” quality, varying from 8.2% to 13%. It was inferred that the water/solids ratio is the most influential parameter to increase strength, and to decrease the water absorption/AVPV and water permeability. The alkaline/fly ash ratio of 0.30 was found to increase strength and reduce porosity. It was found that an optimum aggregate/binder ratio of 3.50 contributed to the high strength of the concrete; however, to obtain a low porosity of fly ash geopolymer, the ratio should be increased to 4.70.

Nisha Khamar et al., (2013) analysed the properties of hybrid fibre reinforced geopolymer concrete under ambient curing Crimped steel fibres with aspect ratio 60 were added in the mix at percentages of 0, 0.25, 0.5, 0.75 and 1. As the percentage of polypropylene increased, the fresh properties got decreased. From the compressive strength test, in comparing to GPC, HFRGPC has showed an increase in strength of 40% at 28 days and 37% at 56 days and comparing to SFRGPC, HFRGPC has showed an increase in strength of 20% at 28 days and 24% at 56 days. Percentage increase in splitting tensile strength of HFRGPC was 70% when compared to GPC and 7% compared to SFRGPC. Percentage increase in flexural strength of HFRGPC was 49 % when compared to GPC and 23% compared to SFRGPC.

Prakash R. Vora and Urmil V. Dave, (2013) investigated on compressive strength of geopolymer concrete. It was observed that longer curing time has improved the polymerisation process resulting in development of higher compressive strength. Rapid rate of increase in the strength has been observed up to the curing time of 24 hours. Due to the addition of superplasticiser there was improved workability and higher dosage of the admixture up to 4% has resulted into reduction of the compressive strength of the geopolymer concrete. It was stated that compressive strength of geopolymer concrete reduces with increase in the ratio of water to geopolymer solids which gives reduction in compressive strength of 33%. It was found that with 14 M concentration of sodium hydroxide solution higher compressive strength was achieved.

Maria Rajesh et al.,(2014) studied the strength of geopolymer concrete with alkaline solution of varying molarity. From the experimental results it was found that the optimum compressive strength, split tensile strength, flexural strength was obtained in 12M at 28 days after ambient curing. The compressive strength, split tensile strength and flexural strength of GPC specimens with 12M was 1.25 times, 1.18 times and 1.058 times more than that of GPC with other molarities after 28 days of hot curing.

Debabrata Dutta et al., (2014) made study to predict the ideal curing temperature for fly ash based geopolymer blended with blast furnace slag. The curing temperature was from 55^{o}C-85^{o}C for GP (without any calcium compound) and sample GB (with 15% of blast furnace slag). Sodium hydroxide and sodium silicate solution were used as activators and the silicate modulus was varied from 0.5 to 1.5. The samples were subjected to compression and observed that the strength values vary a lot at different temperature of curing and the strength value was also increased with the increment of curing temperature over 65^{o}C for GP. However the optimal strength is achieved at 65^{o}C temperature for sample GB. From the results the compressive strength of GB was 47.09 MPa at 65^{o}C curing temperature, whereas non-blended geopolymer GP was 9.98 MPa. It was found that contribution of calcium plays a major role for the faster dissolution of reactive species than that of curing temperature for GB specimens and concluded that higher curing temperature has little impact on further strength of GB specimens rather it disturbs the stable geopolymeric structure with excessive water pressure.

Marlene A. Jenifer et al., (2015) analyzed the fracture behaviour of fibre reinforced geopolymer concrete to know the impact of with and without steel fibres on compression, split tension, flexural strength and bond strength of hardened geopolymer concrete. Crimped stainless and crimped mild steel fibres of aspect ratio (a/d) 60 with volume fraction of 0.75% were used in the mix. It was found that the fracture energy tend to be higher for GPC concrete as the compressive strength increased. It can also be seen that critical stress intensity factor tend to increase with compressive strength in GPC and the crack resistance of GPC was higher to that of its compressive strength.

Sreenivasulu et al., (2015) made a study on mechanical properties of geopolymer concrete (GPC) using granite slurry (GS) as sand replacement.The different replacement levels were (0%, 20%, 40% and 60%) and the fly ash and ground granulated blast furnace slag (GGBS) were used at 50:50 ratio as geopolymer binders. Compressive strength and splitting tensile strength properties were studied at ambient room temperature. From the results, it was observed that compressive strength values and splitting tensile strength values of GPC mixes were increased with the increasing replacement levels of GS from 20% to 40% at all ages as in the case of 20% GS + 80% sand and 40% GS + 80% sand. But these values were decreased at the 60% replacement level of GS. It was concluded that optimum replacement level (40%) of GS can be used in place of sand.

Prasanna Venkatesan Ramani et al., (2015) conducted an experimental study on the strength and durability properties of geopolymer concrete prepared using the ground granulated blast furnace slag and black rice husk ash. Test results reveals that the addition of BRHA beyond 20% is not beneficial for geopolymer concrete. The 30% BRHA replaced specimens neither achieved significant strength nor proved durable. The strength results showed that an optimum proportion of BRHA that can be used in geopolymer concrete is 20%, considering the target strength of 30 MPa. It can also be seen from the durability studies that the geopolymer concrete performed remarkably well with regard to chloride penetration and corrosion resistance for up to 20 % BRHA replacement.

Chien-Chung Chen et al., (2015) made an experimental study on ground granulated blast slag (GGBFS) / Class C fly ash-based geopolymer concrete to investigate material properties and the slag/fly ash ratios were taken as 25/75, 50/50, and 75/25. Results revealed that the setting time could be extended to about 20 minutes for slag/fly ash ratios of 50/50 and 75/25. Air contents and unit weights were ranging from 1.5 to 1.9, and the unit weights ranging from 2,387 kg/m^3 to 2,393 kg/m^3. It was observed the 7-day compressive strength increased with the increase of the slag/fly ash ratio, but for 28-day similar trend was not observed and also for the highest slag content, there were severe micro cracks on the surface. The studies indicated that the dry shrinkage of the slag concrete was affected by the curing conditions and alkaline solutions.

Minju Jo et al, **(2015)** made a study to find out the optimum mix design of fly ash geopolymer paste and its use in pervious concrete for removal of fecal coliforms and phosphorus in water. The four factors considered were the percentages of liquid-to-binder (L/B), FA-to-binder (FA/B), NS-to-binder (NS/B) and the concentrations of NaOH solution (NH). The Response Surface Methodology (RSM) was utilized to optimize the mix design. It was found that optimum mix was at 50% L/B, 60% FA/B, 0.04% NS/B and 1.71 M NH, with a maximum 7-day compressive strength at 22.2 MPa and the targeted flow of the fresh paste at 110%. At the contact time of 8, 3, 0.5 and 0.5 h, pervious geopolymer concrete achieved an average FC removal at 100%, 89.5%, 43.1% and 53.9% and an average P removal at 100%, 47.0%, 21.9% and 24.9%, respectively. For the removal of fecal coliforms FC and phosphorus P lower NH and greater L/B, the higher flow of paste were observed. The greatest compressive strength was observed when L/B, FA/B and/or NH were at lower levels. On the contrary, NS/B did not show a significant effect on the 7-day compressive strength. A greater FC and P removals were achieved at a higher pH.

Kumaravel et al., (2015) studied the durability performance of various grade of geopolymer concrete to resistance of acid and salt. HCl and $MgSO_4$ were used as chemicals to know the durability of geopolymer and alumina-silicate is taken as the binder in GPC and the molarity of sodium hydroxide was taken as 8, 12 and 14 for mix proportions of "M20, M30, M40, M50 and M60. The compressive strength loss for the specimens exposed in magnesium sulphate were in the range of 4 to 10% in GPC.

Suriya Prakash et al., (2015) experimented a study on geopolymer concrete using steel fibres. The in compressive strength was about 8.2% and 25.9 and decrease in compressive strength was about 18.1%. The increase in split tensile strength was about 26.9% and 57.4% and decrease in split tensile strength was about 44.2% It was concluded that the compressive strength and split tensile strength of 1% steel fiber geopolymer concrete were found to be 5% increase in strength and found that 1% concentration of steel fibers to be the optimum dosage.

Rajarajeswari and Dhinakaran (2016) attempted to produce ground granulated blast furnace slag (GGBFS) based geopolymer concrete and to find out its compressive strength characteristics by considering the parameters such as ratio of alkaline liquid (AL) to (GGBFS), ratio of silicate to hydroxide (SiO_3/OH) and the age of geopolymer concrete with different temperatures of thermal curing. The result showed that there was an increase in compressive strength with increase in Na_2SiO_3/NaOH ratio and with increase in age of concrete. It was also observed that rate of increase of compressive strength was more for Na_2SiO_3/NaOH ratio from 0.5 to 1.5 than 1.5 to 2.5. It was also noted that the optimum values in preparing GGBFS based geopolymer concrete was with the temperature of 100°C and Na_2SiO_3/NaOH = 1.5. Hence replacement of 100% of cement with GGBFS is made possible without compromise in compressive strength.

Faiz Uddin Ahmed Shaikh (2016) presented the mechanical and durability properties of geopolymer concrete containing recycled coarse aggregate (RCA). The results showed that the compressive strength, indirect tensile strength and elastic modulus of geopolymer concrete decrease with an increase in RCA contents. It was noted that the measured durability properties increase with an increase in RCA contents. From the comparison with OPC, it was found that there was a excellent correlations of compressive strength with indirect tensile strength and elastic modulus are also observed in geopolymer concrete containing RCA and also very good correlations of compressive strength with volume of permeable voids and water absorption of geopolymer concrete containing RCA, while the correlation between the compressive strength and the sorptivity is not that strong.

Anil Ronad et al., (2016) studied the mechanical properties of geopolymer concrete reinforced with basalt fiber, both fly ash and GGBS were utilized in making geopolymer concrete. Alkaline solution used was sodium silicate and sodium hydroxide in the ratio of 2.5. Fibers were added to the geopolymer concrete in the range of 0.5% to 2.5% at 0.5% increments. The compressive strength of the GPC was observed to be enhanced by 34.74 % on the addition of the fibers. The percentage increase in tensile strength of the GPC was found to be 47.5% with the incorporation of basalt fibers. Hence it was concluded that addition of basalt fibers at 2% to the geopolymer concrete can increase both compressive and tensile strength and also basalt fiber act as a crack arrestors and prevent sudden failure of the structure.

Francis N. Okoye et al., (2017) investigated the effect of silica fume on durability properties of fly ash based geopolymer by conducting chemical attack and measuring the change in the weights and percent losses in compressive strength at different intervals of time. Low calcium fly ash (FA) was used as base material. Sodium hydroxide and sodium silicate were used as alkali activators and naphthalene sulfonate was used as chemical admixture. The experiments were carried out with 2% Sulphuric acid (H_2SO_4) and 5% sodium chloride (NaCl) solutions and with mixes of 0,10 and 20% silica fume named as GPC1, GPC2 and GPC3along with fly ash. It was found that 20% incorporated silica fume GPC exposed to 2% H_2SO_4 for 90 d showed no deterioration in acid solution nor erosion of surface and the weight loss was lower as compared to 0, 10% silica fume. GPC3 showed minimum loss in compressive strength on exposure to 2% H_2SO_4 for 90 d. The results for the exposure in 5% NaCl solution showed that there was no deterioration or erosion of surface GPC particularly GPC3 and only a slight weight loss in all the GPC samples and for the compressive strength there was a slow decrease in compressive strength in the case of GPC1 and GPC2 and practically no decrease in GPC3. Geopolymer concrete in presence of 20% silica fume possessed excellent long term durability properties capable of resisting chemical attack.

Abhilash et al., (2017) made an experimental study to evaluate the resistance of geopolymer concrete to acid environment. The materials used were Low-calcium fly ash, slag as fine aggregate, crushed stone up to 70% by weight as coarse Aggregate and remaining 30% was replaced by Coal washery rejects. M 25 grade concrete was designed and 6M molarity was adopted. It was concluded that the weight of geopolymer concrete decreases when the acid concentration increases and the reduction in compressive strength of geopolymer concrete was 0.61% were as in cement concrete it was 0.69%. Hence it has been proven that geopolymer concrete has a good wear and tear resistance to acidic environment.

Boopalan et al., (2017) made an investigation of bond strength of reinforcing bars in fly ash and GGBS based geopolymer concrete. 12 and 16 mm dia. bars were embedded in fly ash and GGBS based geopolymer concrete and conventional Portland Pozzolana cement concrete specimens. Bond stress increases with increase in compressive strength for both GPC and PPCC. Bond stress in GPC was more than that of PPCC at similar strength levels. The peak bond stress obtained from investigation were found to be 4.3 times more than the design bond stress as per IS:456-2000 for GPC mixes and the same is 3.6 times more for PPCC mixes. Hence, it is concluded that GPCs was found to possess higher bond strength compared to conventional Portland cement concretes.

Lakshmi Prasad et al., (2017) studied the properties of GGBS and Phosphogypsum blended geopolymer concrete. The results showed that the strength of geopolymer concrete made by blending with GGBS has increased with increase in GGBS percentage and in case of Phosphogypsum the strength has increased upto certain limit and then the strength decreased with increase in Phosphogypsum percentage.

4. Conclusion

From the literature review on the various research articles in the field of geopolymer concrete, it had shown to be a good alternative to cement and thus it reduces the harmful effects caused by cement. By considering the factors such as materials used, sodium silicate to sodium hydroxide ratio or potassium silicate to potassium hydroxide ratio, molarity of sodium hydroxide or potassium hydroxide, Alkali to binder ratio, curing temperature, curing period, geopolymer possessed excellent mechanical and durability properties, both in short term and long term.

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