INTERNATIONAL RESEARCH JOURNAL OF MULTIDISCIPLINARY TECHNOVATION (IRJMT)

http://www.mapletreejournals.com/index.php/IRJMT
Received 18 August 2019ISSN 2582-1040
Accepted 06 October 2019 2019; 1(6); 432-438
Published online 02 November 2019

Strength and Structural Properties of Geopolymer Concrete with Natural Fibers -A Review

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Doi: https://doi.org/10.34256/irjmtcon60

ABSTRACT

As the infrastructure development growing worldwide, the demand for ordinary Portland cement (OPC) increases exponentially. Studies revealed that the production of one ton cement releases one ton of CO2 to the atmosphere due to the calcinations of lime stone and combustion of fossil oil. The production of cement is highly energy intensive and it consumes a substantial amount of natural resources. 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 etc., Geopolymer also has the ability to form a strong chemical bond with rock based aggregates. Fiber reinforced geopolymer concrete is relatively a new composite material in which fibers are introduced in the matrix as micro reinforced to improve the strength properties. This paper presents a new review on various research works done in the area of geopolymer concrete and the effect of fiber on their mechanical properties.

Keywords: Fly ash, GGBS, Geopolymer concrete, Glass fiber, Micro Reinforcement, Polypropylene fiber.

1. INTRODUCTION

The demand for concrete as a construction material increases exponentially and thereby, there is an increase in the demand for the production of OPC. The environmental issues associated with the production of cement are well known. The production of one ton cement releases around one ton of carbon dioxide to the atmosphere due to the calcinations of lime stone and combustion of fossil fuel and causes the global warming condition. In addition, the production of cement is highly energy intensive and it consumes a large amount of natural resources.

To reduce these problems, it is necessary to find out an alternative material for cement. Many researches were carried out to find a replacement for cement. Partial replacement and high volume replacement of OPC with materials having binding property were studied. In 1978, Davidovits proposed that binders can be produced by polymeric reaction of alkaline liquid with alumino-silicate materials such as fly ash, rice husk ash, blast furnace slag etc. and termed these binders as Geopolymers. Geopolymer can be considered as a green material, because it relies on minimally processed natural materials or industrial byproducts, thus reducing its carbon footprint.

Geopolymers have gained considerable attention for their rapid strength attainment, corrosion resistance, and chemical stability, low rate of shrinkage and freeze thaw resistance.

Even though the geopolymer possess many advantages over OPC, they also show tension failure behavior similar to that of OPC. Incorporation of fibers in concrete has been found to improve several properties of concrete like cracking resistance, ductility and fatigue resistance, impact and wear resistance.

II. PROPERTIESOFGEOPOLYMER CONCRETE

The term geopolymer was coined by Davidovits to represent a broad range of materials characterized by chains or networks of inorganic molecules. The schematic representation of geopolymer concrete. Geopolymer concrete is an innovative and eco-friendly construction material and an alternative to Portland cement concrete. Use of geopolymer reduces the demand of Portland cement which is responsible for high CO_2 emission.

The drying shrinkage of is much less compared to cement concrete. This makes it well suited for thick and heavily restrained concrete structural members. It has low heat of hydration in comparison with cement concrete.

A) Composition of geopolymer concrete

- Fly ash – A byproduct of thermal power plant
- GGBS – A byproduct of steel plant
- Fine aggregate and coarse aggregates as required for normal concrete.
- Alkaline activator solution for GPCC as explained above. Catalytic liquid system is used as alkaline activator solution.
- It is a combination of solutions of alkaline silicates and hydroxides, besides distilled water. The role of alkaline activator solution is to activate the geopolymeric source materials containing Si and Al such as fly ash and GGBS.

B) Advantages of geopolymer concrete

Geopolymer cement concrete is produced with various waste materials like fly ash and ground granulated blast furnace slag (GGBS). Fly ash is a debris that is mostly used in thermal power plant and ground granulate blast furnace slag is applied as debris in steel plant.

- Low permeability
- Eco-friendly
- The price of fly ash is low
- Resistance to heat and cold
- Chemical resistance
- Very low creep and shrinkage
- Better compressive strength
- Excellent properties within both acid and salt environments.

III. REVIEWOFLITERATURE

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. The residual compressive strength after acid exposure also was found maximum for specimen which contained 8% Na_2O.

Termuujin et. Al., (2011) Intended to the study the acid and alkaline resistance of class F fly ash based geopolymer pastes. Geopolymer were prepared by mixing fly ash with the alkaline liquids to achieve a composition of Si: Al=2.3, Na:Al=0.88 and water geopolymer solids=0.19. The alkaline compounds were 14 M NaOH and D- grade sodium silicate solution. To know the surface crystallization of non-reacted fly ash spheres, the geopolymer pastes were calcined at 600^{o}C and 1000^{0}C. It was observed that the acid or alkali resistance behavior of the geopolymer 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.

Nisha Khamar et al., (2013) Analyzed the properties of hybrid fiber reinforced geopolymer concrete under ambient curing crimped steel fiber with aspect ratio 60 were added in the mix at percentages of 0, 0.25, 0.5, 0.7and 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% and 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% compared to GPC and 23% compared to SFRPC.

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 polymerization process resulting on 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 what 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^{0}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. It was found that contribution of calcium plays a major role for the faster dissolution a 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 behavior of fiber reinforcement geopolymer concrete to know the impact of with and without steel fibers on compression, split tension, flexural strength and bond strength of hardened geopolymer concrete. Crimped stainless and crimped mild steel fibers 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 a 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 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% of 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 furnace slag (GGBS). Class C fly ash based geopolymer concrete to investigate material properties and the slag/fly ash ratio 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 ratio of 50/50 and 758/25. Air contents and unit weights were ranging from 1.5 to 1.9, and the units 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 flag content, there were severe cracks on the surface. The studies indicated that the dry shrinkage of the slag concrete was affected by the curing condition and alkaline solutions.

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 alumino-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 fibers. The compressive strength was about 8.25% and 25.9% decrease in compressive strength was about 18.1%. The increase in split tensile strength was about 26.9% and 57.4% 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 is 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^{o}C and Na_2SiO_3/NaOH = 1.5. Hence replacement of 100% of cement with GGFBS 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 decreases 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 an 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 basalt fiber act as a crack arrestors and prevent sudden failure to the structure.

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, crush stone up to 70% by weight as coarse aggregate and remaining 30% was replaced by coal washery rejects. M25 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 stresses 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 that 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 GPC was found to possess higher bond strength compared to conventional Portland cement concrete.

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 up to certain limit and then the strength decreased with increase in phosphogypsum percentage.

IV CONCLUSION

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 effect of cement. By considering the factors such as materials used natural fibers. Alkali to binder ratio, curing temperature, curing period, geopolymer possessed excellent mechanical and durability properties, both in short and long term.

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Conflict of Interest

None of the authors have any conflicts of interest to declare.

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