STRUCTURAL BEHAVIOUR OF REINFORCED GEOPOLYMER CONCRETE MEMBERS AND EFFECT OF FIBRES INCLUSION – A REVIEW

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ABSTRACT:-Due to the advantage of carbon footprint decline with the use of cement-less geopolymer concrete, researchers had focused towards the study of the behaviour of geopolymer concrete on micro- and macro-scales. The widely used application of concrete in building construction is reinforced concrete structural members. The objective of this review is to summarize and discuss the reported findings on the structural behaviour of geopolymer concrete members in order to give a clearer understanding of effects of such concrete in structural elements and to present the influence of Fibres inclusion in geopolymer concrete members. Among the geopolymer concrete members highlighted in this review include reinforced concrete beams and columns. It is found that generally there is no detrimental effect of using geopolymer concrete as structural member in terms of its load-carrying capacity. Also inclusion of fibres increases the flexural capacity and delayed the shear crack formation.It is suggested that more detailed researches may be carried out on other structural members like slabs, panels, piles and pre-stressed members. Also probably of inclusion of Natural fibres and their influence on structural members is to be explored.

Keywords –Geopolymer concrete, fly ash, slag Geopolymer Concrete Beams and Columns, Shear behavior, Durability.Fibres ,

1. INTRODUCTION

The construction sector faces challenges to meet the raising demand of Portland Cement due to limited resources of limestone, slow growth in manufacturing and increasing carbon ash. The demand in India is likely to reach 550 million tonnes by 2020 with 58% shortage i.e, 230 million tonnes [1].To encounter this shortage, development of alternatives to Cement is inevitable. The objective is to reduce the environmental effect of construction, use of higher proportion of waste pozzolona and to improve the performance of concrete. Investigation are being made on several substitutes like alkali activated cement, calcium sulphoaluminate cement, magnesium oxy carbonate cement, supersulphated cement etc [2]. The category of alkali activated cement is emerging in recent years. The alkaline cement is based on a phase composition of hydratic products R-A-S-H [R-Na^+ or K^+] in the aluminosilicate based systems and R-C-A-S-H in the alkali activated slag or alkaline Portland cements [3].

Geopolymer is a promising alternative to ordinary Portland Cement, because of its early compressive strength, low permeability, good chemical resistance and excellent fire resistance behavior [4-9]

The term Geopolymer is coined by a French Professor Davidovits in 1978 to represent a broad family of material characterized by networks of inorganic molecules [Geopolymer Institute 2010] [10,11].The Geopolymer basically depends on thermally activated natural materials like Metakaolinite or industrial by-products like Flyash or Slag to provide a source of Silicon and Aluminium. The Silicon and Aluminium is chlorinised in an alkaline activating solution and get polymerized into molecular chains and become the binder.

2. GEOPOLYMER CONCRETE- OVERVIEW

Geopolymer is the third generation cement after lime and ordinary Portland cement. The term ‘‘geopolymer’’ is used to mention alkali aluminosilicate which is also commonly known as inorganic polymers, alkali-activated cements,and geocements. [4]. It consists of a repeating unit of sialate monomer (–Si–O–Al–O–).

Aluminosilicate materials such as kaolinite, feldspar and industrial solid residues such as fly ash, mining wastes and metallurgical slag shall be used as base raw materials in the geopolymerization process. The reactivity of the aluminosilicate sources depends on their chemical make-up, mineralogical composition, morphology, fineness and glassy phase content [12]. The main requirements for developing stable geopolymer are that the source materials should be highly amorphous and possess sufficient reactive glassy content, low water demand and be able to release aluminium easily. The alkaline activators such as sodium hydroxide (NaOH), potassium hydroxide (KOH), sodium silicate (Na_2SiO_3) and potassium silicate (K_2SiO_3) are used to activate aluminosilicate [12] materials. Compared to NaOH, KOH showed a greater level of alkalinity. But in reality, it has been found that NaOH possesses greater capacity to liberate silicate and aluminate monomers [4].. Research is being carried out aiming at manufacturing geopolymeric cement by replacing potassium silicate with cheaper alkaline volcanic stuffs [9]. Geopolymers are synthesized by the reaction of a solid aluminosilicate powder with alkali hydroxide/alkali silicate [8]. A schematic representation on formation of fly ash-based geopolymers/concrete is shown in Fig. 1. [12]

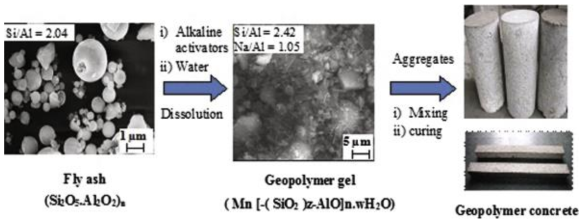
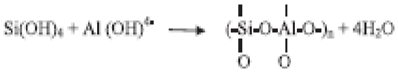


Fig. 1. Conversion of fly ash into geopolymers/concrete.[12]

Under highly alkaline conditions, polymerisation takes place when reactive aluminosilicates are dissolved and free $[SiO4]^-$ and $[AlO4]^-$ tetrahedral units are released in solution. The tetrahedral units are linked to polymeric precursor by sharing oxygen atom, thus forming polymeric Si–O–Al–O bonds. The following reactions occur during geopolymerisation [12].

$(Si_2O_{5.}Al_2O_2)_n + H_2O + OH^- \text{-->} Si(OH)_4 + Al(OH)^{4-}$



[12]

Water is released in this reaction that is normally consumed during dissolution and provides workability to the mixture during handling. This is in contrast to the chemical reaction of water in Portland cement mixture during the hydration process where water is absorbed and heat is generated. The hydration products of metakaolin/fly ash activation are zeolite type. Sodium aluminosilicate hydrate gels is with different Si/Al ratio whereas the major phase produced in slag activation is calcium silicate hydrate with a low Ca/Si ratio. Many physical properties of geopolymers prepared from various aluminosilicate sources may seem to be similar but their microstructures and chemical properties vary to a large extent. The metakaolin-based geopolymer has an advantage that it can be manufactured consistently, with predictable properties both during the preparation and development. However, its plate-shaped particles lead to rheological problems, increasing the `complexity of processing as well as the water demand of the system [6]. Whereas the fly ash-based geopolymer is generally more durable and stronger than that of metakaolin-based geopolymer [4]. The slag-based geopolymer is found to have high early strength and greater acid resistance than those of metakaolin and fly ash-based systems. [12]

3.1. STRUCTURAL BEHAVIOUR REINFORCED GEOPOLYMER CONCRETE BEAMS:

Research Works Structural behaviour of fly ash based geopolymer concrete beams were initiated by Sumajouw et al. [13]. A total of six under-reinforced concrete beams with varying reinforcement ratios (0.64–2.69%) were tested for flexural failure. The flexural load-carrying capacity increased with the increased tensile reinforcement ratio [14], The test-to-prediction ratio were between 0.98 and 1.28. In the investigation by Sumajouw et al. [15] sixteen reinforced geopolymer concrete beams (Fig. 2) with varying tensile reinforcement ratio (0.64–2.69%) and concrete compressive strength (37–76MPa) were tested.

Fig. 2. Geopolymer concrete beams by Sumajouw et al. [15].

In short, Sumajouw et al. [15] reported that the effect of tensile reinforcement ratio on flexural capacity and ductility index of the geopolymer concrete beams was similar to conventional cement based concrete beams.

In various investigations, it was also reported that under-reinforced fly ash-based geopolymer concrete beams behaved similarly (first cracking load, crack width, load-deflection relationship, flexural stiffness, ultimate load and failure mode) as conventional reinforced concrete beams subjected to flexural loading [16-20]. Whereas, Dattatreya et al. [16] observed lower post peak ductility of geopolymer concrete beams and this was refevted by Yost et al. [17] who found a more brittle failure during concrete crushing compared to conventional cement-based concrete. In contrast, Jeyasehar et al. [21] found higher first crack load, midspan deflection and ultimate load as well as smaller crack width for the case of reinforced geopolymer concrete beams as compared to conventional cement-based concrete beams. Similar to the previous investigation in Sumajouw et al. [15], Sumajouw et al. [16] evaluated the flexural load capacity of the sixteen reinforced geopolymer concrete beams and the average test-to-prediction ratio was found to be 1.11. Considering that the beams were under-reinforced, the effect of the geopolymer concrete compressive strength was marginal..

As per IS 456 [22], although there is fair agreement between predicted and experimental values of the cracking, service ultimate moment capacity and deflection of the reinforced geopolymer concrete beams, Dattatreya et al. [16] suggested that improvement could be made to predict the structural behavior of the geopolymer concrete beams. Prachasaree et al. [23] observed this and introduced equivalent stress block parameters meant for fly ash-based geopolymer concrete which gave good

conformance with experimental findings for geopolymer concrete beams. An average of 13% difference in the nominal moment capacity was observed, reducing the difference between prediction and test results by about 1.4 times.

Kumaravel et al. [19] and Kumaravel and Thirugnanasambandam [18] found good comparison of the predicted and experimental load-deflection relationships. In addition, in the research done by Nguyen et al. [24], although finite element simulation with ABAQUS software gives slight difference in the predicted deflection values, good agreement still existed between the experimental and simulated load-deflection behaviour of reinforced geopolymer concrete beams. Based on these researches, it was suggested that the ANSYS and ABAQUS software could be useful tools in simulating the behaviour of structural members made of geopolymer concrete, and this could benefit design engineers dealing with reinforced geopolymer concrete members in the future.

Researchers also explored the structural behaviour of under reinforced geopolymer concrete beams containing different concrete materials. Andalib et al. [25] incorporated 30% palm oil fuel ash (POFA) into the geopolymer concrete to produce geopolymer concrete beams and they observed similar cracking and ultimate moments as well as crack pattern as conventional reinforced concrete beams. The flexural capacity of the reinforced geopolymer concrete beam was increased by up to 23% with the inclusion of recycled concrete as up to 75% coarse aggregate replacement. Similar first crack load was observed for all cases of recycled concrete content (0%, 25%, 50%, 75% and 100%) [26]. From the same sudy by Kathirvel and Kaliyaperumal [26], the geopolymer concrete beams containing higher amount of recycled concrete aggregate were observed to exhibit increasing deflections and ductility, higher number of cracks as well as greater crack widths.

3.2 DURABILITY REINFORCED GEOPOLYMER CONCRETE BEAMS:

The flexural behaviour of reinforced geopolymer concrete beams subjected to corrosion was also investigated. Under accelerated corrosion in sodium chloride solution, Wanchai [20] found that the reinforced fly ash-based geopolymer concrete beams exhibited greater degradation in the flexural capacity compared to the control beam containing conventional cement-based concrete. When immersed in sulphuric acid and combination of hydrochloric and sulphuric acid solutions for 180 days, Kannapiran et al. [27] observed little reduction (less than 8%) in the flexural capacity of reinforced concrete beams and no significant changes to the load-deflection relationship.

3.3 SHEAR BEHAVIOUR OF REINFORCED GEOPOLYMER CONCRETE BEAMS :

There are few studies carried out to evaluate the shear behaviour of shear-critical reinforced geopolymer concrete beams under flexural loading. Yost et al. [30] reported similar crack shape, failure mode and the shear force transfer in both geopolymer and cement-based concrete beams. Whereas, Mourouganeet al. [28] observed higher shear strength for the reinforced geopolymer concrete beams than the corresponding conventional cement-based concrete beams, in the range of 5–23%.

4. REINFORCED GEOPOLYMER CONCRETE COLUMNS:

One of the most important structural members is reinforced concrete column which are designed to carry compressive axial loading. Several research works have been carried out in the past to promote utilization of geopolymer concrete in reinforced concrete structural members and to evaluate the performance of geopolymer concrete in slender reinforced concrete columns Sujatha et al. [29] tested 12 slender circular reinforced concrete columns made of geopolymer and cement-based concretes of compressive strength grades 30 and 50 MPa. It was found that the geopolymer concrete columns had up to 34% higher load-carrying capacity as well as having greater rigidity compared to the corresponding cement-based concrete columns. Research works were also carried out on slender fly ash-based geopolymer concrete column under load eccentricity carried out in Curtin University of Technology in Australia [15,30,31]. The details and set-up of the column test are shown in Fig 3 [15}

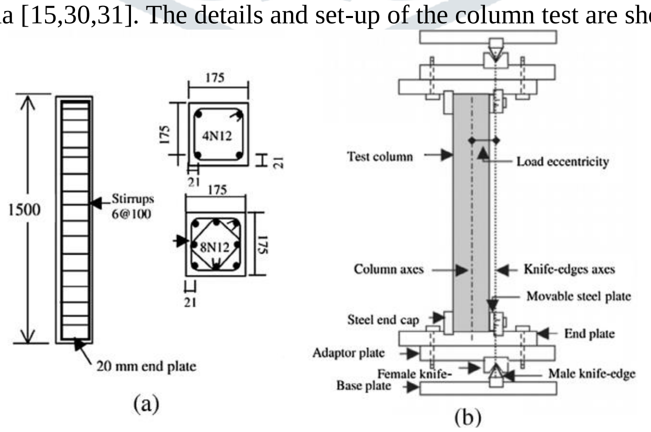


Fig.3. Details of column specimen and test set-up [15]

In these researches, the slender columns tested had longitudinal reinforcement ratios of 1.47% and 2.95% and targeted concrete strength grades of 40 and 60 MPa. The column specimens were tested at specified varying load eccentricities from 15 to 50 mm

The columns had similar failure mode characterized by crushing of concrete in the compressed face near the mid-height of the columns Fig. 4 [15]

Fig. 4. Failure mode of slender geopolymer concrete columns [15].

Brittle failure mode was observed in columns with smaller load eccentricity, higher concrete strength and higher reinforcement ratio [31]. Similarly, the load-carrying capacity of the columns were increased with decrease in load eccentricity, increase in concrete strength and longitudinal reinforcement ratio [15]. On the other hand, the mid-height deflection of the tested geopolymer columns increased with the increase in load eccentricity, decrease in concrete strength and reinforcement ratio [31]. The corner columns in a building frame and columns in a bridge are the most common examples of columns under bi-axial bending. Axial load combined with biaxial bending is also common in internal columns of building frames Rahman and Sarker [32] tested fly ash-based geopolymer concrete columns subjected to axial load and biaxial bending. The columns of reinforcement ratios of 1.74% and 2.95% were tested for different combination of bi-axial load eccentricities, ranging from 15 to 70 mm for each direction . Failure occurred by crushing of concrete on the compression face at the mid-height of the column and similar to the slender column subjected to load eccentricity, a brittle and explosive failure occurred in specimens with smaller load eccentricity and higher concrete strength due to the greater loadcarrying capacity. It was highlighted that the failure and the load-deflection behaviour of the slender geopolymer concrete column was similar with conventional cement-based concrete column. When comparing circular columns reinforced with GFRP bar, Maranan et al. [33] observed that the strength of the column made from geopolymer concrete was higher than that for cement-based concrete, although no significant difference in terms of ductility and confinement efficiency was observed. The ductility of the columns reinforced with GFRP could be improved through the use of spiral-confinement compared to hoop-confinement [33]. In the experimental study conducted by Nagan and Karthiyaini [34] the performances of short reinforced fly ash-based geopolymer concrete columns with and without GFRP wrapping were evaluated. In the research, columns reinforced with 2.89% longitudinal reinforcement ratio were tested under compressive axial loading. The geopolymer concrete column was found to have about 30% higher load-carrying capacity and less deformation compared to conventional cement-based concrete column. When two layers of GFRP wrapping was applied to the short reinforced geopolymer concrete column, good confinement effect was observed, as enhanced load-carrying capacity (up to 69% increase) and ductility

were observed [34].

5. INCLUSION OF FIBRES:

Devika and Deepthi [35] investigated the effects of hybrid steel polypropylene fibre addition into reinforced geopolymer concrete beams. It was found that the flexural load capacity of the geopolymer concrete beam was improved by up to 30% by the inclusion of the hybrid steel-polypropylene fibres in a ratio of 70:30. The

presence of the fibres also significantly enhanced the energy absorption and displacement ductility of the reinforced concrete beams. In another research, Srinivasan et al. [36] evaluated the effects of glass fibre addition on the flexural behaviour of reinforced geopolymer concrete beams. The flexural load capacity of the geopolymer concrete beams was found to be increased by up to 35% in the presence of up to 0.02% volume fibres which was attributed to the increase in tensile strain carrying capacity of the concrete. Further addition of glass fibres to 0.04% led to reduction in the flexural load bearing capacity due to induced voids within the concrete [36] Ng et al. [37] found that as steel fibres were added into the geopolymer concrete, the shear cracking of the resulting reinforced concrete beams was delayed, and more finer cracks were formed in the specimens. As a result, cracking load and ultimate strength of the steel fibre geopolymer concrete beams were increased. In addition, use of straight steel fibres resulted in smaller crack width compared to the addition of hooked-end steel fibres in the geopolymer concrete beams and this was due to the smaller diameter of the straight steel fibres. Ng and Foster [38] also evaluated the shear strength of lightweight steel fibre geopolymer concrete composite beam reinforced with aramid fibre reinforced polymer (AFRP) bars and AFRP strengthened core. The specimen with AFRP strengthened core exhibited increased flexural stiffness and the ultimate shear strength was increased by 40% and 60% for plain and steel fibre reinforced geopolymer concrete beams, respectively. The addition of steel fibres in the geopolymer concrete beam was found to contribute to increase of 139% and 150% in the shear strength compared to the corresponding plain geopolymer concrete beam without and with AFRP strengthened core, respectively. Similar to the observation by Ng et al. [37], there were also higher number of cracks but finer in terms of the crack width for the specimens with the addition of steel fibres in the shear-critical geopolymer concrete beams [38]. Ganesan et al. [39] investigated the effect of steel fibre addition on the behaviour of slender square geopolymer concrete columns with 2.01% reinforcement ratio. In this research, the effects of different volume of steel fibres (up to 1.0%) as well as aspect ratio (l/d) of the slender columns were investigated. The slender columns were tested under monotonic axial loading. It was found that the inclusion of steel fibres columns by up to 56%, and this was due to the fibre-bridging effect which prevented early concrete cover spalling. Increase in strain at the peak axial compressive stress and area under the stress-strain curve suggested that there was considerable improvement in the ductility (up to 29% increase) of geopolymer concrete column when steel fibres were added.

Siva Chidambaram [40] focused on the confining effect of geo-grid on the mechanical properties of concrete under flexure and the effect of geo-grid with the steel fiber reinforced concrete (SFRC) has also been investigated.The axial stress–strain behavior of concrete specimens confined with geo-grid is improved by the use of SFRC. The performance of cylindrical specimens under split tension also proves the significance of geo-grid confinement with and without steel fibers. Joshua Daniel et al [41] fully replaced cement by Ground Granulated Blast Furnace Slag (GGBFS) and supplemented with steel and glass fibres to improve the performance of the concrete. These hybrid fibres are optimised by compression test and split tensile test. The flexural behaviour of the conventional concrete and a geo-polymer concrete is tested under static cyclic loading for the corresponding optimised percentage of hybrid fibres. The experimental test shows significant improvement in the flexural strength, stiffness degradation, cumulative energy dissipation capacity, displacement ductility and the ultimate load with its corresponding deflection

6.DISCUSSION AND SUGGESTIONS:

Based on the literature studies, it is evident that most research on using geopolymer concrete in structural members were mainly focused on reinforced concrete beams and columns.Generally, most of the performance of these reinforced geopolymer concrete members were found to exhibit similar or enhanced load-bearing capacities compared to the corresponding conventional reinforced cement-based concrete members.

Due to the similarity in the general structural behaviours such as load-deflection, cracking characteristics and failure mode of the geopolymer concrete members with conventional concrete members, researchers generally agreed that geopolymer concrete members could be designed in the same way as conventional concrete members. In terms of the ductility behaviour of structural members, researchers found reduced ductility of geopolymer concrete beams compared to conventional cement-based concrete beams. However it is suggested that more research is required to address the ductility of various geopolymer concrete members such that necessary consideration could be taken into account in the structural design stage for geopolymer concrete members.

7. CONCLUSION

Based on the review of the performance of the structural properties of geopolymer concrete members, it is concluded that the general behaviour and failure mode of reinforced geopolymer concrete members were similar with those of conventional reinforced cement-based concrete members, and thus Geopolymer Concrete technology shall be applied for pratical constructions. Further researches are to be carried out to standardize the Codal provisions for mix design of Geoploymer Concrete. Structiral behavior of mebers like slabs, pile, pre-stressed concrete mebers etc., cast by geopolymer concrte are to be explored. Inclusion of natural fibres In Geopolymer is to be tried out and structural behavior, effect of chemical bases on natural fibres is to be studied.

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