A Review on Strength and Durability Studies on Geopolymer Concrete Produced with Recycled Aggregates

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Abstract— India, one of the leading producers of ordinary Portland cement in the world and also leads top place in consumption of natural resources to produce OPC. During production of OPC harmful gases are liberated into atmosphere and cause ozone layer depletion and gives signs to global warming effects. Due to the rapid growth in industrialization there is a huge requirement of OPC and natural aggregate in shape of fine and coarse aggregate to meet the need of construction industry leads to environmental pollution due to over utilization of natural resources and liberating of CO2 in to the atmosphere. As a part of reducing environmental pollution a step is laid by Davidovits in the production of concrete without OPC as a binder material. Present paper gives a brief review on properties of Geopolymer concrete produced with available alternate materials without consuming natural resources in huge volume.

Key words: Geo polymer concrete, sodium hydroxide, sodium silicate, hardened and durability properties

I. INTRODUCTION

Joseph Davidovits in 1979 proposed that an alkaline liquid could be used to react with silicon (Si) and aluminium (Al) as source material of geological origin or with by-product materials such as fly ash and rice husk ash to produce binders. Since the chemical reaction that is taking place in this case is a polymerization process and the precursors are of geological origin, these binders were named as 'Geopolymer'.

Geopolymer Concrete is gaining importance world over as the carbon emission and consequent global warming has become the major concern of the entire countries world over. One tone of cement production results in the emission of one tone of carbon dioxide. Many countries are promoting the use of fly ash as building material by granting carbon credit, which will not only reduces the production of cement and emission of carbon dioxide but also promotes the consumption of the waste material fly ash which poses a major problem for disposal world over. In India almost all the states have thermal power plants and abundant availability of fly ash.

on the fly ash based geopolymer concrete dates back to three decades only. Most of the studies are done under heat cured regime since the polymerization process is fast at 60oC to 90oc. Most parts of India come under tropical region where the normal temperature during summer is above 30oC.Geopolymer which is naturally cured at ambient outdoor temperature can be considered as a curing free concrete.

Recycle Concrete Aggregate (RCA) is the main components of old concrete and for many reasons there is a need to re-use them. It is better to the reuse of waste aggregates as recycled aggregates in structural concrete, instead of throwing out as a total waste material. Thus in recent years, the use of recycled concrete aggregate has gained tremendous momentum in constructional engineering. Utilization recycling of waste concrete would benefit into two folds. First, reduce the environmental problem and second reduce the utilization of natural resources. By the production and use of RCA, these advantages include that lower environmental pollution, reduction in valuable landfill space, and savings in natural aggregate resources.

II. LITERATURE REVIEW

''Geopolymer'' is used to describe an amorphous alkali aluminosilicate which is also commonly used as ''inorganic polymers'', ''alkali-activated cements'', ''geocements'', ''alkali-bonded ceramics'', ''hydro ceramics'' etc.

A variety of aluminosilicate materials such as kaolinite, feldspar and industrial solid residues such as fly ash, metallurgical slag, mining wastes etc. have been used as solid raw materials in the geopolymerization technology. The reactivity of these aluminosilicate sources depends on their chemical make-up, mineralogical composition, morphology, fineness and glassy phase content. The main criteria 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 (Na2SiO3) and potassium silicate (K2SiO3) are used to activate aluminosilicate 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 [1]. The properties of geopolymers can be optimised by proper selection of raw materials, correct mix and processing design to suit a particular application [1]. Viewing the importance of the subject, a collaborative project sponsored by the European Commission – BRITE was undertaken jointly by France, Spain and Italy on development of ''Cost-effective geopolymeric cement for innocuous stabilization of toxic elements (GEOCISTEM)''. The project was aimed at manufacturing geopolymeric cement by replacing potassium silicate with cheaper alkaline volcanic tuffs [2]. Geopolymers are synthesized by the reaction of a solid aluminosilicate powder with alkali hydroxide/alkali silicate[3].

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 [1]. Contrary to this, the fly ash-based geopolymer is generally more durable and stronger than that of metakaolin-based geopolymer [1]. The slag-based geopolymer is considered to have high early strength and greater acid resistance than those of metakaolin and fly ash-based systems.

The most important factors affecting the properties of geopolymer pastes are: SiO2/Al2O3 ratio, R2O/Al2O3 ratio, SiO2/R2O ratio (R = Na+ or K+) and liquid–solid ratio.

The majority of research concluded that an amorphous structure of geopolymers is preferable in order to achieve desired mechanical strength [5-10]. The relationship between the compressive strength and SiO2/R2O ratio showed that an increase in alkali content or decrease in silicate content increases the compressive strength of geopolymers attributable to the formation of aluminosilicate network structures [5,6]. Geopolymer activated with NaOH alone with Si/Na of 4/4 or less formed the crystallinezeolite (Na96Al96Sr96O384216H2O) but at a ratio >4/4, nano sized crystals of another zeolite (Na6[AlSiO4]64H2O) were formed [7]. The addition of even small amount of sodium silicate to the NaOH significantly reduces crystallite formation due to templating function of silicate units. At low activator dosage (18%), the pores developed in the fly ash-based paste were larger and exhibited wider distributions whereas at higher activator dosage (30%), the pores were smaller and showed a narrow distribution mainly due to the pore refinement as a result of more dissolution of particles and formation of reaction products. The reduced porosity enhanced the strength of geopolymer pastes [8]. Typically, the optimum geopolymer strength was reported with SiO2/Al2O3 ratio in the range of 3.0–3.8 and Na2O/Al2O3 ratio of 1 [9-10]. Changes in SiO2/Al2O3 ratio beyond this range have been found to result in low strength. The setting time of geopolymer pastes increased with increasing SiO2/Al2O3 ratio of the initial mixture.

Kusbiantora et al. [11] reported from their studies that admixtures such as sucrose and citric acid which act as retarder in OPC have different mechanism in fly ash-based geopolymers. Sucrose acted as a retarder since it is absorbed by Ca, Al and Fe ions to form insoluble metal complexes. On the other hand, citric acid acted as an accelerator reducing the setting time by 9 and 16 min. Conversion of fly ash into geopolymers/concrete. Pore size distribution of fly ash-based geopolymer pastes at different activator dosages respectively. Amongst the commercial superplasticizers, the naphthalene based superplasticizer was effective when single activator was used rendering 136% increase in relative slump without any decrease in compressive strength. Modified polycarboxylate based superplasticizer was efficient one when multi-compound activator was used with a decrease in compressive strength of 29% [12]. However, retarding effect of polycarboxylate based superplasticizer was also reported in fly ash/slag blended system though the improvement in workability was significant compared to naphthalene based superplasticizer.

Several attempts [13-18] have been made to study the effect of different curing conditions on the properties of geopolymer pastes. The curing temperatures were reported in the range between 400C and 850 C for complete geopolymerisation reactions.

Palomo et al. [13] studied curing of alkali activated fly ash (0.25 and 0.30 liquid/solid ratio) at 650 C and 850 C. They indicated that the compressive strength of geopolymers (8–12 M) cured at 850 C for 24 h was much higher than those cured at 650 C. The rise of strength was much smaller when curing time was extended after 24 h. Perera et al.[14] studied the curing of metakaolin-based geopolymers under ambient (21–230 C) and heat conditions (40– 600 C) with a controlled relative humidity (RH) for 24 h and found that curing at 30% RH was preferable to that at 70% RH. Heah et al. [15] concluded that the curing of metakaolin-based geopolymers at ambient temperature was not feasible while increase in temperature (400 C, 600 C, 800 C, 1000 C) favored the strength gain after 1–3 days. However, curing at higher temperature for a longer period of time caused failure of samples at a later age due to the thermolysis of –Si–O–Al–O– bond. Rovnanik [16] reported that curing of metakaolin based geopolymer at elevated temperature (40– 800 C) accelerated the strength development but in 28 days, the mechanical properties deteriorated in comparison with results obtained for an ambient or slightly decreased temperature. Ebrahim and Ali [17] prepared three mixes with different formulations and cured hydrothermally at different temperatures (45, 65, 850 C) and time (5–20 h) after 1 and 7 days of procuring. Longer procuring at room temperature, before the application of heat is beneficial for higher strength development. In general, adequate curing of geopolymeric materials is required to achieve optimal mechanical and durability performance to maintain their structural integrity [18].

Attempts were also made to study behaviour of reinforced fly ash-based GPC beams and columns with respect to longitudinal tensile reinforcement ratio and concrete compressive strength as test variables [22-25]. Sumajouw et al. [22] reported that the flexural capacity of beams increased with the increase in tensile reinforcement (0.64–2.69%) but the effect of concrete compressive strength was marginal. The ductility index increased significantly for beams having longitudinal reinforcement ratio less than 2%. They also studied the strength of reinforced GPC slender columns with respect to the compressive strength of concrete, longitudinal reinforcement ratio and load eccentricity. The design provisions mentioned in the Standards for OPC concrete can be used for designing geopolymer concrete columns also. Dattatreya et al. [23] found that the load carrying capacity of reinforced slag-based GPC beams was 17.7% more than the Portland pozzolana cement concrete beams at 2.68% tension reinforcement. Yost et al. [24] indicated that load–deflection behaviour of GPC beam was identical to OPC beam. The maximum strain obtained for under-reinforced beam was less than 3000 microstrains which is generally assumed for design work. The predicted neutral axis depth was 15% less than the experimentally achieved value for GPC. The Whitney's stress block for strength calculation was found applicable for GPC also. Ng et al. [25] investigated potential use of steel Bond strength of fly ash-based geopolymer concrete as a function of steel bar diameter [24] fibres (up to 1.5 wt%) to replace conventional shear reinforcement in GPC beams of 2250 mm span length.

Davidovits et al. [3] indicated that metakaolin-based geopolymer pastes showed only 7% mass loss when sample was immersed in 5% H2SO4 for 30 days. It was also reported that fly ash-based geopolymer pastes retained a dense microstructure after 3 months exposure in HNO3. Temuujin et al. [26] concluded that acid and alkaline resistance of fly ash-based geopolymer strongly depend on its mineralogical composition. High solubility of Al, Si and Fe ions was obtained in both strong alkali and acid solutions. The performance of fly ash-based geopolymer pastes when exposed to 5% acetic acid and 5% H2SO4 solutions was superior to ordinary Portland cement pastes. The deterioration in pastes was connected to depolymerisation of the aluminosilicate network and formation of zeolites [27].

Sumajouw et al. [22], By adding the RCA as a partial or full replacement of NCA 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 C&D 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.

Anuar et al. [28] studied the compressive strength of geopolymer concrete containing recycled concrete aggregate, where the source material for geopolymer was waste paper sludge ash instead of popularly used fly ash and slag. Results show that the compressive strength is increased by about 10% from 7 days to 28 days and high molarity of sodium hydroxide shows higher compressive strength in geopolymer concrete. Shuang et al. [29] evaluated the mechanical properties of geopolymer concrete containing 50% and 100% recycled coarse aggregate as a replacement of natural coarse aggregate and compared with those of ordinary concrete. Results show that the compressive strength and elastic modulus are all higher in the case of geopolymer concrete containing recycled coarse aggregate than its counterpart OPC concrete containing RCA and the above mechanical properties decrease with an increase in RCA contents. They also reported better interfacial transition zone in the case of geopolymer concrete than the OPC concrete. Recently, Posi et al. [30] studied the mechanical properties of geopolymer concrete containing recycled lightweight aggregates and reported that similar to normal weight recycled coarse aggregate the compressive strength of geopolymer concrete decreases with an increase in recycled light weight aggregate contents. However, mixed results are reported on the modulus of elasticity in their study. Sata et al.[31], also reported a study where crushed concrete and crushed brick were used as a replacement of natural coarse aggregates in geopolymer pervious concrete containing different concentrations of sodium hydroxide solution. Results show that the measured compressive and indirect tensile strengths are lower in geopolymer pervious concrete containing crushed concrete and crushed bricks as coarse aggregates are lower than their counterpart natural coarse aggregates. Results also show that the both compressive and indirect tensile strength of all three types of geopolymer concrete increase with an increase in the concentrations of sodium hydroxide solution. Nukalong et al.[32] also reported a study on geopolymer concrete made by crushed concrete as coarse aggregates and reported reduction in compressive strength due to addition of recycled crushed concrete as coarse aggregate.

III. Conclusion

Literature review on the various research articles in the field of geopolymer concrete, it had shown a significant potential as a good engineering material for the future research, as the GPC is not only environmental friendly but also it possesses excellent mechanical properties, both in short term and long term. Further research is needed to understand the science behind Geopolymer technology like microstructure, rheology of fresh concrete etc. The economic benefits and contributions of Geopolymer concrete to sustainable development are evident.

As a research scholar under my guide supervision, I am planning to work on short term and long term studies on mechanical, durability properties by using recycled aggregate and quarry dust as the basic source materials in production of Geo polymer concrete to minimize the utilization of natural resources.

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