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EXPERIMENTAL INVESTIGATION OF FIBRE REINFORCED BASED GEO-POLYMER CONCRETE

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Abstract

Fly ash based Geopolymer is considered as the third generation cement after lime and Portland cement. Geopolymer cements are acid resistant cementitious materials with zeolite properties, developed for the long term containment of hazardous and toxic wastes. The term geopolymer is generally used to describe an amorphous alkali aluminosilicate which was also commonly used for inorganic polymer, alkali- activated cements, geocements, alkalibonded ceramics, hydro ceramics etc. This research is carried to investigate the fresh, hardened, durability and structural behaviour of Fibre Reinforced Geopolymer (FRGP) concrete members. The casting and testing of FRGP concrete specimens were done according to the specifications followed for ordinary Portland cement mortar and concrete. The test specimens were heat-cured in an oven/heat curing chamber. The tests were carried out for the fresh concrete initially. The slump value and percentage of flow for fresh geopolymer concrete with and without polypropylene fibre were tested in accordance with ASTM-C143 and ASTM C1362-09 respectively.

Introduction

Geopolymer is produced by alkali activation of the Alumino silicates present in the source material. These gels can be used to bind aggregates, such as sand or natural rocks, to form aggregates and concrete. In simple terms, Geopolymers are inorganic binders that act like better-known

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Portland cement. Davidovits, a French professor, found that the ancient pyramids had a structure similar to the Zeolite in existence of the three-dimensional silicate-aluminum product, and then named this man-made rock as the product as a "Geopolymer". Industrialization leads to the generation and release of undesirable pollutants in the environment. To keep pace with rapid industrialization, there is a need to select an engineering process that causes minimal pollution to the environment. On the other hand, the construction industry is moving rapidly towards the use of environmentally friendly materials to meet the sustainable aspect required by modern infrastructure. As a result, over the past two decades, the expansion of this concept and the increasing global warming have raised concern over the widespread use of Portland cement due to the high amount of carbon dioxide associated with its production. The development of Geopolymer concrete provides promising indications for changes in the way concrete is produced. However, for consideration critically as Geopolymer Binders is an alternative to Ordinary Portland Cement (OPC), various strength-related factors of this new material should be evaluated in any comparative analysis format. So far, very little published literature has been concerned with the mechanical, durability properties and application of Indian fly ash with polypropylene fibers in the development of Geopolymer concrete.

Geopolymer Concrete

Credits for the development of Geopolymer concrete Prof. Davidovits, who first proposed in 1978 that a Geopolymer could replace the matrix cement binder. The Davidovits solution theory was that an alkaline solution could be added to an Aluminum-Silicon-rich source material to produce the same bind as cement and was called Geopolymer ´binder. Fly ash, a by-product from the coal industry, is the most widely used source material for Geopolymer concrete due to its availability, suitable structure and low calcium content with low loss of ignition. However, other materials rich in Silicon and Aluminum can be used, including rice husk ash, blast furnace slag, metakaolin, and natural Al-Si minerals. Geopolymer concrete is a concrete that does not use any OPC in its production. The primary difference between Geopolymer concrete and OPC concrete is binder. In the case of

Portland cement concrete, coarse and fine aggregate covers about 75% to 80% of the mass of Geopolymer concrete. The effects of aggregates such as grading, angularity, and strength are assumed to be similar in the case of Portland cement concrete (Lloyd and Rangan, 2009). Therefore, this component of the Geopolymer concrete mixture can be designed using the currently available equipment for Portland cement concrete. Fly ash based geopolymer concrete has widely used properties for any construction purpose. Geopolymer concrete develops a shiny surface that can give a nice appearance. Activation by alkali gives rise to materials with different properties of OPC and makes fly ash based geopolymer concrete more fire resistant and resistant to abrasion and cracks. Since fly ash is only a by-product material derived from industrial waste, Geopolymer concrete costs equal to or less than OPC concrete that uses expensive cement as a binder. As in conventional reinforced concrete, GPC needs to be reinforced with steel bars for large-scale utility in civil engineering structural applications.

Source of Geopolymerisation

Source materials may contain natural minerals such as Kaolinite, Calcined Kaolinite (metakaolin) and clay (Davidovits, 1991; Barbosa et al. 2000; Xu & Van Deventer 2002). Alternatively, industry waste products such as fly ash, lava, red clay, rice bran ash and Silica fume can be used as feedstock for the synthesis of Geopolymer. It has been proven that Calcined materials such as slag, flyash, and metakaolin that are mostly amorphous undergo higher reactivity during Geopolymerization than non-calcined materials (Palomo et al. 1999; Xu and Deventer 2000). For flyash-based Geopolymer, the mechanical strength increases due to the formation of an Al-rich Alumino-Silicate gel during the first phase of alkaline activation of flyash particles and can proceed as a result of Si enrichment of the material (Fernandez)-Jiménez et al. 2006). It has also been found that Geopolymer derived from metakaolin may require too much water due to an increase in porosity and therefore becomes very soft for construction application, although for applications such as adhesives, coatings, and hydroceramic, metakaolin Geopolymer remains important in production. Furthermore, the microstructure and properties of Geopolymer strongly depend on the nature of the initial source materials (Duxson et al. 2007). As a result, understanding the reactivity and chemistry of raw materials is important for optimizing both cost and technical performance for some applications. The cement industry seems to have realized the potential of fly ash as a resource and this can be seen from the increasing share of fly ash in mixed cement production in recent years. Recent data from cement manufacturers show that the share of Portland Pozzolana Cement (PPC) has increased dramatically from 26.17% to 44.36% between 2000 and 2004, respectively, to about 70 percent within a period of only four years.

Curing of Geopolymer Concrete

The most important operation in the manufacture of Geopolymer concrete is curing. Unlike OPC concrete, which requires water for curing, Geopolymer concrete requires heat or temperature to activate the chemical reaction occurring in the Geopolymer matrix. Steam curing, dry curing and curing at ambient temperature are the types of curing that can be employed to cure Geopolymer concrete. Steam curing and dry curing are collectively called heat-curing. In India, treatment at ambient temperature is more likely. However, only the summer temperature in India is between 26 ° C to 40 ° C.

The main drawback in adopting ambient temperature is that it takes longer to cure the compressive strength required to fix the concrete and the unavailability of the required temperature in winter. On the other hand, the advantage of heat-curing is the attainment of the compressed power required within several hours and even during all seasons. The need for boilers and firewood to generate steam or electrical energy to produce heat makes it a bit expensive. During this research, dry-curing is adopted to cure Geopolymer concrete elements between 60 ° C to 90 ° C in a heat curing chamber specially designed for this experimental work. Heat curing increases the compressive strength of Geopolymer concrete by 15% (Hardjito and Rangan, 2005) as compared to steam curing and also achieves its full strength in 24 hours.

Polypropylene Added Geopolymer

Inorganic Geopolymers are three-dimensional Si-O-Al materials with ceramic properties. The chemical composition of alkali-based Geopolymers is similar to that of natural Geolytic materials, with the only major difference between these being its microstructure, which shows that the Geopolymer is more amorphous. Polymerization occurs in an alkaline state. During the reaction, water is slowly dividing slowly and tetrahedral units that share oxygen atoms between connected alternatively polymer pioneers who tetrahedral units and services thus more amorphous Geopolymer. However, due to ceramic characteristics, Geopolymer shows a mossy-brittle behavior similar to conventional cement concrete samples with slightly lower corrosive strength in the early stages. Thus improving the strength and durability of the Geopolymer is considered necessary.

Polypropylene fiber is an important material used in concrete to improve strength, performance and durability. Geopolymer concrete usually has many favorable properties such as low strength and high durability; Geopolymer is also used to dissolve toxic metals, improve resistance to acid and fire. With all these observations, Geopolymer is considered as a possible alternative to conventional concrete in the construction industry.

In this study, the Geopolymer binding material is produced with the addition of polypropylene fibers. The study has been attributed to Geopolymer concrete with polypropylene fibers for structural characterization and to study its nano properties. Properties such as pore volume, crystalline nature, surface active material, morphology and surface area are investigated and the obtained results are discussed. The resulting concrete has high compressive strength and capacity for durability.

Significance of the Study

This research is one of the areas of high profile research and commercial interests over the past decade. Geopolymer technology led to the conversion of waste by product material into valuable materials. Some reports outside India state that Geopolymer concrete has good strength and durability aspects. However, so far, only a few published results can be found using Indian fly ash based Geopolymer concrete with polypropylene fibers as secondary reinforcement. The results of this extensive work will provide information and information about the optimization of mixtures and application in structural elements for needy heirs interested in polypropylene fibers.

Objectives of the Study

To study the factors that decide the compressive strength of fly ash based Geopolymer concrete with different ratios of fiber. Experimental investigation of the development and application of “Geopolymer technology” with fiber as well as Indian fly ash and materials as secondary reinforcement. To investigate the crack pattern, deflection, and load carrying capacity of fiber composite Geopolymer reinforced concrete beams and slabs constructed using a dry heat curing process. To investigate the thermal behavior and bond strength of flyash based Geopolymer concrete with fibers as additions.

Literature Review

Yliniemi et al. (2017) studied about lightweight Geopolymer aggregates, which were fabricated from liquefied bed combustion fly ash and mine stitching using high shear granulation and alkali activation. The results showed that Geopolymer aggregates had physical properties compared to commercial lightweight expanded clay aggregates (LECAs).

Peem Nuaklong et al. (2016) conducted a study of the effect of recycled aggregate on the strength and durability of fly ash based Geopolymer concrete. The test results indicate the use of recycled concrete aggregates is to be as coarse aggregates in high calcium fly ash Geopolymer contract, which narrowed the strength of 7-day 30.6 to 38.4 MPa, which crushed limestone stones are. High fly ash Geopolymer were slightly lower than the Concrete. The use of high sodium hydroxide concentrations of 12 and 16 M led to better performance in both strength and durability compared to 8 M.

Salama Banu Luhar et al. (2015) have conducted a durability study on fly ash based Geopolymer concrete. Exposure to sulfuric acid solution (concentrations of 5%) causes damage to the surface of heat-cured Geopolymer concrete test specimens and a large loss of about 0.5% after three months of exposure. The sorptivity curve was found to be less linear than in control concrete, meaning that the rate of water absorption by Geopolymer concrete is low.

Rajini B. et al. (2014) authors concluded that the compressive strength and split tensile of Geopolymer concrete decreased as the amount of fly ash in the mix increased despite the duration of mixing. The compressive strength and split tensile FA of Geopolymer concrete are maximum for 0% - GGBS 100% irrespective of the curing period. The rate of gain in the compressive strength and split tensile strength of Geopolymer concrete is very fast over the 7-day curing period and this rate decreases with age.

C. K. Madheswaran et al. (2014) conducted experimental investigations on the flexible behavior of reinforced GPC beams of size 100 mm x 150 mm x 1500 mm using light-weight sin fa aggregates. The crack pattern observed for the GLWC beam was found to be similar. Reinforcement in the compression zone and crushing of concrete failed all beams in flexural mode.

Shankar H. Sunny et al. (2013) observed that the average compression strength of heatcured samples was 34% higher than that of steam and ambient air treatment, respectively. The average split tensile strength of heat-curing samples was 27% and 52% higher than steam and ambient air curing, respectively.

Ammar Motorwala et al. (2013) conducted an experimental study on alkali activated fly-ash based Geopolymer concrete including workability and mix design. They found that temperature has a significant contribution in regaining strength at 25 ° C; The strength obtained was 0.872 MPa, whereas, for 80 ° C it was 30.95 MPa. Wrapping was treated with a plastic bag as better compressive strength was obtained to preserve moisture.

Derrick Wade Immelmann (2013) has studied the effect of percent replacement on aggregate and concrete properties from the total of commercially produced coarse recycled concrete and concluded that high percentages of RCA negatively affected fresh concrete properties , Though not significantly. Mixtures with 15% RCA exhibited the best fresh solid results.

V. Bhikshma (2012) conducted an experimental investigation on the properties of fly ash based Geopolymer concrete. A completely 5 mixing ratio with alkaline solution was used to blow the ash ratio from 0.30 to 0.50 and tested for the mechanical properties of the concrete. It was concluded that higher concentrations of sodium hydroxide solution and higher proportion of alkaline solution resulted in higher compressive strength.

M. M. A. Abdullah et al. (2011), based on literature review on the mechanism and chemical reaction of fly ash Geopolymer binder, they have observed that the exact Geopolymerization mechanism is not well understood because the Geopolymerization process involves a fairly fast chemical reaction and every material used in Geopolymer is included. Has its own function and role to form a chemical reaction and mechanism.

A. A. Adam et al (2010) have conducted experimental studies on the effect of activation concentration on strength, sorption, and carbonation on alkali activated slag (AAS) and fly ash (FA) based Geopolymer concrete. -70% OPC replacement with ground granular blast-furnace slag (GGBS) with 30%, 50% space, and control concrete. Their report indicated that the alkali modulus has a major impact on the afflictions of both AAS and Geopolymers.

Ka-Hung Ng et al (2006) concrete mix was built using a two-stage mixing approach. (i) Coarse and fine aggregates are added to the mixer and mixed for 60 seconds. (ii) The first half of the water is added to the mixed set, and the second is mixed for 60 seconds. (iii) All cement is added to the mixer and mixed for another 30 seconds. (iv) The remaining half of the water is poured into the mixer and mixed for 120 seconds. This led to better performance in deformity and water soreness. Optimal RCA substitution was found at 20%, giving optimal performance in creep, shrinkage, and water malfunction.

Jarvis R. Black (2012) based on research work on the mix design process or alkalineactivated class *F* fly ash Geopolymer concrete, the author concluded that when the ratio of alkaline liquid ash (AL: FA) increases above a certain point . Instead, the increase in compressed power actually decreases. The ratio of this maximum is found above 0.50 and below 0.65. Water above 0.29 in the Geopolymer solids (W: GPS) ratio is not feasible because the general gain is not reinforced with an increase in the alkaline liquid level. A strength plateau is under continuous heat curing, where GPC will not gain any further strength for longer curing. It is believed that this plateau persists for more than 72 hours of treatment. GPC samples made with 16 M NaOH can produce unexpected and unreliable results, and therefore the concentration of NaOH used is recommended to be a maximum of 12 M.

3.4. Polypropylene Fibre

Polypropylene fibers are made up of crystalline and non-crystalline regions. The spherulites shape developed from a nucleus can range from a fraction of a micrometer to a centimeter diameter. The axis of the crystal unit cell aligns radially and the series axis is distributed in perpendicular planes in this radial direction. Each crystal is surrounded by non-crystalline material. Fiber spinning and drawing may cause orientation of both crystalline and amorphous regions. If the expansion is less than 0.5%, the spherulite deformation is elastic and there is no disruption of the structure, otherwise the spheres are highly oriented in the direction of the force and eventually turn into microfibrils. These are highly anisotropic microfibrillar structure leads to anisotropic fiber properties. Fibers within the following specifications:

Effective diameter : 10 micron – 1.0 mm.

Length : 6-48 mm.

Specific gravity : more than 1.0.

Suggested dosage : 0.6-2.0 kg/cumec (0.23-0.6 % by Weight of cement in mix).

Water absorption : less than 0.45 percent.

Melting point shall not be less than 160˚C

The aspect ratio typically varies from 200 to 2000.

Steel Reinforcement

Hot-rolled, deformed, high yield strength bars in both RC slabs and beams were used as

the main reinforcement. Steel reinforcement bars of different diameters ranging from 8 mm to 16 mm were used in this study. The yield strength of the bars used was 500 MPa. The bars were tightly wrapped in tarpaulin sheets to avoid direct exposure to seasonal variations to prevent corrosion. Strips were made of 6 mm diameter mild steel bars. The reinforcing steel bars were subjected to standard tensile tests in the Universal Testing Machine (UTM) to ascertain the yield strength of the bars.

Flyash

Flyash plays an important role in the manufacture of geopolymer concrete, was sourced from Tuticorin Thermal Power Station, Tamil Nadu, India. The total amount of fly ash required for this work was calculated and the entire volume was sourced from Tuticorin Thermal Power Station and covered with tarpaulin sheet to keep the fly ash in air tight condition.

Water

In this study portable water was used to dilute NaOH flakes, to manufacture OPCs, and to prepare aggressive fluids. The amount of solid was less than the permissible limit as specified by ASTM C1602 / C1602 M-12 standards.

Conclusion

Based on results of the above experimental investigation it is concluded that Geopolymer concrete with Polypropylene Fibre as secondary reinforcement have superior properties and Structural behaviour than conventional GPC. The FRGP Concrete can be used as a substitute in place of conventional reinforced cement concrete.

The results indicated that the workability of fresh FRGP concrete decreases as the percentage addition of Polypropylene Fibre increases. The values of slump cone test on fresh concrete lies between 120 mm to 90 mm which there by ensures medium workability on all mix proportions. The maximum percentage of flow of fresh concrete is observed in control specimen whereas lowest flow percentage is observed in FRGP- 5 specimen. The loss in workability of the FRGP Concrete is due to the addition of Polypropylene Fibre which directly influences the flow in fresh Geopolymer Concrete. The concrete mix prepared using up to 0.6% Polypropylene Fibre addition, shows increase in Compressive Strength of GPC.

The results show that as the ages' increases the variation in strength gain decreases, and normalizes almost after 56 days. The effect of Polypropylene Fibre addition in binding material on splitting tensile strength shows higher strength than that of GP specimen. It is evident that the addition of Polypropylene Fibre increases the splitting tensile strength and this increment is more than that of Compressive Strength increment. The Polypropylene additions increases the flexural strength of plain GPC prisms and are substantially related to the bonding properties and the dispersion of Polypropylene Fibre. UPV results show all the specimen exhibit excellent quality in terms of pulse wave passed through the GPC.

The UPV results also relate with the strength of GPC, higher the pulse velocity shows higher strength. From the UPV results it can be concluded that the quality of GPC is excellent for all mix proportions, especially for Polypropylene Fibre addition upto 0.6%, excellent. This increase in water absorption is due to higher voids in higher percentage of FRGP Concrete.

Therefore it can be concluded that the addition of Polypropylene Fibre reduces the pores in FRGP Concrete. It is evident that the Polypropylene Fibre has a vast influence on its void structures. The drying shrinkage can be reduced by incorporating Polypropylene Fibre as an addition to cement. The values exceed the control specimen values at 1% addition of Polypropylene Fibre. The loss in compressive strength due to chloride attack is less in FRGP-3 specimen this is due to the resistance to penetration of chloride solution into the specimen.

The FEM models for validation of plain Geopolymer Concrete and its respective analysis shows that the concentration of thermal stresses and its impact on the material structure is more for the control specimen when compared to that of Geopolymer specimen. The test on specimens under elevated temperature shows the loss in weight goes on decreasing as the percentage of Polypropylene Fibre addition increases. This shows that resistance towards exposure to high temperature is made possible by incorporating Polypropylene fibre in FRGP Concrete. From the study carried out on fly ash based polymer RC beams and RC cement concrete beams, it can be concluded that the plain fly ash based polymer RC beams were structurally more resistive than control specimen due to its higher molarity(14 M) in this study. But when it comes to addition of Polypropylene Fibre there was no significant increase in load carrying capacity. The addition of fibre increases the flexural toughness of the beams. The volumetric fractional addition of Polypropylene Fibre gives the maximum load carrying capacity at 0.4%, but the toughness was high, attributed to the reduction in deflection. At 0.4% the failure was also sudden when compared to other specimens. Until 0.6% addition of Polypropylene Fibre addition, the load carrying capacity of beams was maintained not lesser than the control specimen. The addition of Polypropylene Fibre gives more resistance toward bending by increasing its flexural resistance. The addition of Polypropylene Fibre also reduces the strain localization of the fly ash based RC beams. Hence the addition of Polypropylene Fibre should be maintained at 0.4% or lesser. From the test results it is observed that Geopolymer Slabs exhibited brittle failure. With the incorporation of Polypropylene Fibre in Geopolymer, the brittle behaviour of Geopolymer Concrete can be brought to ductile.

Scope for Future Works

Polypropylene Fibre can be used in Self Compacting GPC and Special Concrete. Study on GPC with different additives like GGBS, silica fume along with polypropylene fibres.

Polypropylene Fibre can be effectively added in making high performance Geopolymer blocks and porous Geopolymer Pavement Blocks. Study on performance of special structural elements like Deep beam, Corbel, Shear wall etc using Polypropylene fibre based GPC. Precast wall panels with Polypropylene fibre based GPC can be studied. Beam Slab Panels with Polypropylene fibre based GPC can be studied.

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