A Review on the Mechanical Properties of Different Types of Geopolymer Concrete

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Abstract— The production of Ordinary Portland Cement (OPC) causes drastic effects on the environment with the emission of CO_2 which could be avoided by the use of geopolymer concrete (GPC). It fully replaces OPC in the concrete by other aluminosilicate materials such as fly ash, metakaolin, GGBS and so on, along with the addition of alkaline solutions to it for the commencement of geopolymerisation. Over the years not only fly ash, but also various materials has been used in the manufacture of GPC with improved properties. This paper reviews the various types of GPCs and their properties to suit the needs of the construction industry.

Key words: Geopolymer Concrete, NaOH, Na_2SiO_3, Compressive Strength

I. Introduction

Portland cement is the most commonly used cement all over the world as a basic ingredient of concrete and mortar. Manufacturing of Portland cement releases a large amount of greenhouse gas into the atmosphere. It is reported that nearly 13500 million tons of CO2 is produced from this process worldwide, which accounts for about 7% of the greenhouse gas produced annually [1]. However, the usage of geopolymer in the production of concrete by the replacement of cement overcomes its adverse effects.

Geopolymers are inorganic, ceramic materials that are covalently bonded to form a long chain network, which has a Si-O-Al framework [2]. The exact mechanism of geopolymerisation has not yet been fully understood. However, the most proposed and accepted mechanisms for geopolymerisation include the following stages [3-4]. (i) The Si and Al from the aluminosilicate materials dissolve in the strongly alkaline aqueous solution, (ii) formation of oligomers which are generally the geopolymeric precursors consists of polymeric bonds of Si-O-Si and/or Si-O-Al type, (iii) polycondensation of the oligomers to form a three-dimensional aluminosilicate geopolymeric framework and (iv) bonding of the unreacted particles and filler materials into the geopolymeric framework and hardening of the whole system into a solid polymeric structure.

A clear study of the concrete mix design procedure has not been established yet. Recent works on the Geopolymerisation of fly ash reported concrete with better mechanical properties such as high strength, low water absorption, resistant to fire and acid attack. Because of these properties, they are considered as an alternative for OPC in concrete. A brief research work on geopolymer concrete manufactured using fly ash, Sodium silicate (Na2SiO3) and Sodium hydroxide (NaOH) solution were carried out by Rangan B.V, et al., [5].

Recently, different types of Geopolymer concrete such as basalt fiber reinforced geopolymer concrete (BFRGC) [6], Pervious geopolymer concrete (PGC) [7], Lightweight geopolymer concrete (LGC) [8], Light aggregate foamed geopolymer concrete [9] and various others have been developed. This paper reviews the properties of these different geopolymer concretes so that they could be effectively used based on the strength and other suitable durability requirement and external environmental conditions.

II. Fiber Reinforced Geopolymer Concrete

In contrast to the durability, high early strength, sulfate resistance and low-velocity impact properties of geopolymer concrete materials, the increased strain resistance due to the addition of basalt fiber to the geopolymer composites have not been studied properly. Weimin Li et al. [6] Reported that the addition of basalt fiber to the geopolymer concrete led to their increased deformation and energy absorption capabilities. The impact properties of BFRGC along with the critical compressive strain and dynamic compressive strength increased linearly with the increase in average strain.

Dylmar Penteado Dias et al. [10] investigated the basalt fiber reinforced geopolymer concrete to determine the influence of the volumetric fraction of the basalt fibers on the fracture toughness. The various test results including fracture toughness, critical crack mouth opening displacement and stress intensity factor were determined and showed that the fracture properties of BFRGC were much higher than conventional concrete.

In order to overcome some problems such as brittleness and large shrinkage Zu-Hua Zhang et al. [11] partially replaced the fly ash by calcined kaolin and incorporated polypropylene (PP) fibers into the geopolymer to investigate its mechanical properties and volume stability. The results showed that by steam curing the concrete at 80 oC for 6 days containing a 33.3% fly ash, the compressive strength was significantly increased by 35.5%. Also, an addition of 0.05% polypropylene fiber increased the 3-day compressive strength, flexural strength and impacting energy by 67.8 %, 36.1%, and 6.25%. Furthermore, there was a decrease in shrinkage and modulus of compressibility. The scanning electron microscopy (SEM) results showed that PP fibers could probably reduce the drastic pores and can improve the strength and toughness of the geopolymer concrete.

III. Pervious Geopolymer Concrete

Thwatchai Tho-in et al. [7] prepared PGC from lignite fly ash, sodium silicate (Na2SiO3), sodium hydroxide (NaOH) solution and aggregates and evaluated their properties. The alkali ratio and the fly ash to coarse aggregate ratio were kept constant at 0.5 and 1.8 while alkali to fly ash ratio and molar concentrations were varied between 0.35, 0.4, 0.45 and 10 M, 15 M and 20 M. In order to initiate the geopolymerisation reaction, the curing temperature was kept constant at 60 oC for 48 h. The results of the testing showed that the link between the compressive strength-density, compressive strength-voids ratio, and density-voids content were mostly same as that of the conventional concrete.

The use of recycled aggregates in the making of pervious geopolymer concrete was investigated by Vanchai sata et al. [12]. High calcium fly ash, sodium silicate (Na2SiO3), sodium hydroxide (NaOH) solution and two different recycled aggregates namely crushed structural concrete member (RC) and crushed clay brick (RB) were used in the making of the PGC. The test results of various mechanical properties including compressive strength and splitting tensile strength, total voids ratio and water permeability showed that recycled aggregates both RC and RB had satisfactory properties making it convenient in the production of geopolymer concrete.

IV. LIGHTWEIGHT GEOPOLYMER CONCRETE

The properties of lightweight geopolymer concrete made from recycled lightweight blocks as aggregate were studied by P Posi et al. [8]. The blocks were used as fine, medium and coarse aggregates in the Lightweight geopolymer concrete. The alkali ratio, alkali/fly ash ratio, molarity, aggregate/fly ash ratio and curing temperature were varied and the samples were tested for compressive strength along with the determination of water absorption, porosity, and modulus of elasticity. The test results showed that the compressive strength was in the range of 1-16 MPa with a density of 860-1400 kg/m3 and the water absorption, porosity and modulus of elasticity were between 10-31%, 12-34% and 2.9-9.9 GPa respectively. From the test results, it can be seen that LGC could be used in the construction of walls and partitions.

Using foam in the production of lightweight geopolymer concrete was attempted by MMAB Abdullah et al. [13]. Class C fly ash, alkali including NaOH and Na2SiO3, aggregates and foam was used in the production of LGC. Fly ash and alkali solution were first mixed and then foam was added to the matrix and mixed to form a homogenous mixture to make lightweight concrete. The samples were cured at 60 oC for 24 h and then at room temperature for 28 days. The compressive strength at 1, 7 and 28 days was found to be 11.03 MPa, 17.5 MPa, and 18.19 MPa respectively. The results, including SEM analysis, X-ray diffraction showed that the samples cured at a temperature of 60 oC than samples at normal temperature had better results.

D.M.A. Huiskes et al. [14] used industrial by-product minerals as raw materials in the production of ultra-lightweight geopolymer concrete. A very low concentration 2-3 M of NaOH was used as the alkali activator along with a special additive as superplasticizer. The addition of a waste glass produced expanded lightweight material was used as aggregate to make the concrete ultra-lightweight. It was noted that the packing of raw solid ingredients strongly affected the performance of the concrete. The results showed a very low thermal conductivity of 0.07 W/(m.K) was achieved at a compressive strength of 8 MPa. This proves that it can be replaced in the place of conventional materials.

V. FLY ASH AND SLAG BASED GEOPOLYMER CONCRETE

Gum Sung Ryu et al. [16] investigated the mechanical properties of fly ash based geopolymer concrete with alkaline activators. The effects of chemical changes of alkaline activators of the compressive strength and the microstructure were analyzed with the help of SEM, XRD and FT-IR. The results showed that the alkaline activators played an important role in the high early strength of the GPC. Furthermore, an empirical relationship between the compressive and splitting tensile strength of fly ash based GPC was also proposed.

Tianyu Xie and Togay Ozbakkalolgu [15] studied the behavior of fly and bottom ash based geopolymer concrete cured at ambient temperature. Totally 10 batches of GPC and one batch of cement concrete were prepared and tested for compressive strength, flexural strength, workability, shrinkage, energy absorption and modulus of elasticity including the parameters such as fly ash to bottom ash ratio, alkali to binder ratio. The results showed that bottom ash and fly ash showed a lesser polymerization than fly ash based geopolymer concrete, which made it inferior in the mechanical and durability properties.

The influence of recycled aggregate on fly ash geopolymer concrete properties was studied by Peem Nuaklong et al. [17]. High calcium fly ash, sodium silicate (Na2SiO3), sodium hydroxide (NaOH) solution and two different coarse aggregates namely recycled concrete aggregate and crushed limestone coarse aggregate were used in the production of GPC. The comparative test results showed that the compressive strength of high calcium GPC with crushed limestone aggregate was slightly higher than GPC with recycled concrete aggregate. Also, GPC manufactured with a higher molarity of 12 M and 16 M showed increased strength and durability.

Moruf Olalekan Yusuf et al. [18] developed ground granulated blast furnace slag (GGBS) – ultrafine palm oil fuel ash based geopolymer concrete (UPOFA). Two pozzolanic solid wastes (PMs) GGBS and UPOFA were used in the manufacture of high strength GPC. NaOH and Na2SiO3 were used as alkali activators and their ratio to PMs was kept between 0.45-0.55 while the curing time and temperature were varied between 6-24 h and 25-90 oC, respectively. An early high compressive strength of about 69.13 MPa in 3 days and a strength of 71.2 Mpa in 28 days was observed for an optimum GGBS/PM, alkali/PM, curing temperature and duration of 0.2, 0.5, 60 oC and 24 h.

VI. CONCLUDING REMARKS

Various types of GPC with improved properties are produced with locally available waste materials. The type of GPC to be adopted may depend on the properties needed for the construction and on the availability of the materials. As reviewed above the major restriction on practical applications of GPC is the proper curing technique to be adopted for the activation of geopolymerisation. Since, oven dried curing technique is widely adopted, the significant use of it in the casting of longer structural members is by far challenging. If this problem is overcome the above-discussed GPCs can replace the conventional concrete to profit for an environmentally sustainable construction.

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