Experimental Study on Fresh Properties of Self Compacting GEO Polymer Concrete using Vermiculite as Fine Aggregate at Various Levels of Replacement

P. Yagnasree[1] K. Vasu[2]
[1]PG Student [2]Assistant Professor
[1,2]Department of Civil Engineering
[1,2]Annamacharya Institute of Technology & Sciences, Andhra Pradesh, India

Abstract— This investigation is mainly focused on the preliminary study on fly ash (FA) and ground granulated blast furnace slag (GGBS) based GPC using vermiculite (VM) as fine aggregate replacement at various levels (0%, 10%, 20%,30% ,40% and 50%). In this study, sodium silicate (Na2SiO3) and sodium hydroxide (NaOH) solution is used as alkaline activator. Test results revealed that the increased replacement level of vermiculite decreased the GPC properties. It can be concluded that the replacement levels of VM can be chosen based on the strength requirement GPC as per the requirement. The SCGC is suitably designed for vermiculite replacement with fine aggregate Up to 30% only and remaining percentage of vermiculite is not suitable like 40% and 50% Last and finally we are concluded 10%,20% and also 30% of vermiculite of fine aggregate is suitable for self-compacted geo polymer concrete (SCGC).

Key words: Fly Ash, Ground Granulated Blast Furnace Slag (GGBS), Vermiculite, Self-Compacting Geo Polymer Concrete

I. INTRODUCTION

The cost-effective strength and even scale of civilization of any country is reflected by the growth rate of the infrastructures and highlighted by the production rate of concrete. Concrete is one of the most far used construction materials in the world. Portland an essential constituent of concrete is not an environmentally friendly material. The production of Portland cement not only depletes significant amount of natural resources but also liberates a considerable amount of Carbon dioxide (CO_2) and other greenhouse gases into the atmosphere as a result of de-carbonation of limestone and the combustion of fossil fuels. It is reported that the worldwide cement industry contributes around 1.65 billion tons of the greenhouse gas emissions annually. Due to the production of Portland cement, it is estimated that by the year 2020, the CO_2 emissions will rise by about 50% from the current levels. Therefore, to preserve the global environment from the impact of cement production, it is now believed that new binders are indispensable to replace Portland cement.

Geopolymer concrete is new technology because it utilizes industrial waste and by products. Geopolymer concrete is rising as an innovative environmentally friendly used in the construction material for sustainable development, using Slag and alkali instead of PC as the binding material. This results in two benefits. I.e. reducing CO_2 releases from production of PC and also utilisation of industrial waste like flyash, slag etc. Ground granulated blast furnace slag (GGBS) is a by-product from the blast-furnaces used to make iron. During the process, slag formed and it is then dried and ground to a fine powder. Davidovit s proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term 'Geopolymer' to represent these binders.

Geo-polymers are members of the family of inorganic polymers. The chemical composition of the geo-polymer material is similar to natural zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds.

II. GPC MIX DESIGN

Rangan and Hardjito (2005) have noted that unlike conventional cement concretes GPCs are a new class of construction materials and therefore no standard mix design approaches are yet available for GPCs. While GPC involves more constituents in its binder (viz., FA, GGBS, sodium silicate, sodium hydroxide and water), whose interactions and final structure and chemical composition are under intense research whereas the chemistry of Portland cement and its structure and chemical composition (before and after hydration) are well established due to extensive research carried out over more than century. While the strength of cement concrete is known to be well related to its water-cement ratio, such a simplistic formulation may not hold good for GPCs. Therefore, the formulation of the GPC has to be done by trial and error basis. The role and the influence of aggregates are considered to be the same as in the case of Portland cement concrete. The mass of combined aggregates may be taken to be between 75% and 80% of the mass of geopolymer concrete. The performance criteria of a geopolymer concrete mixture depend on the application. For simplicity, the compressive strength of hardened concrete and the workability of fresh concrete are selected as the performance criteria. In order to meet these performance criteria, the alkaline liquid-to-fly ash ratio by mass, water-to-geopolymer solids ratio by mass, the wet-mixing time, the heat-curing temperature, and the heat-curing time are selected as parameters. With regard to alkaline liquid-to-fly ash ratio by mass, values in the range of 0.30 and 0.45 are recommended. Sodium silicate solution is cheaper than sodium hydroxide solids. Commercially available sodium silicate solution A53 with SiO_2-to-Na_2O ratio by mass of approximately 2, i.e., Na_2O = 14.7%, SiO_2 = 29.4%, and water = 55.9% by mass, and sodium hydroxide solids (NaOH) with 97-98% purity are recommended. Laboratory experience suggests that the ratio of sodium silicate solution-to-sodium

hydroxide solution by mass may be taken approximately as 2.5 (Hardjito and Rangan, 2005).

Mixture proportion of heat-cured low-calcium fly ash-based geopolymer concrete with design compressive strength of 45 MPa is needed for precast concrete products as follows: Assume that normal-density aggregates in SSD condition are to be used and the unit-weight of concrete is 2400 kg/m^3. Take the mass of combined aggregates as 77% of the mass of concrete, i.e. 0.77x2400 = 1848 kg/m^3. The combined aggregates may be selected to match the standard grading curves used in the design of Portland cement concrete mixtures. For instance, the aggregates may comprise 277 kg/m^3 (15%) of 20 mm aggregates, 370 kg/m^3 (20%) of 14 mm aggregates, 647 kg/m^3 (35%) of 7 mm aggregates, and 554 kg/m^3 (30%) of fine sand to meet the requirements of standard grading curves. The fineness modulus of the combined aggregates is approximately 5.0.The mass of low-calcium fly ash and the alkaline liquid = 2400 – 1848 = 552 kg/m^3. Take the alkaline liquid-to-fly ash ratio by mass as 0.35; the mass of fly ash = 552/ (1+0.35) = 408 kg/m^3 and the mass of alkaline liquid = 552 – 408 = 144 kg/m^3. Take the ratio of sodium silicate solution-to-sodium hydroxide solution by mass as 2.5; the mass of sodium hydroxide solution = 144/ (1+2.5) = 41 kg/m^3; the mass of sodium silicate solution = 144 – 41 =103 kg/m^3.Therefore, the trial mixture proportion is as follow: combined aggregates = 1848 kg/m^3, low-calcium fly ash = 408 kg/m^3, sodium silicate solution = 103 kg /m^3, and sodium hydroxide solution = 41 kg/m^3.

The sodium hydroxide solids (NaOH) with 97-98% purity is purchased from commercial sources, and mixed with water to make a solution with a concentration of 8 Molar. This solution comprises 26.2% of NaOH solids and 73.8% water, by mass. For the trial mixture, water-to-geopolymer solids ratio by mass is calculated as follows: In sodium silicate solution, water = 0.559x103 = 58 kg, and solids = 103 – 58 = 45 kg. In sodium hydroxide solution, solids = 0.262x41 = 11 kg, and water = 41 – 11 = 30 kg. Therefore, total mass of water =58+30 = 88 kg, and the mass of geopolymer solids = 408 (i.e. mass of fly ash) +45+11 = 464 kg. Hence, the water-to-geopolymer solids ratio by mass = 88/464 = 0.19. For water-to-geopolymer solids ratio by mass of 0.19, the design compressive strength is approximately 45 MPa, as needed. The geopolymer concrete mixture proportion is therefore as follows: 20 mm aggregates = 277 kg/m^3, 14 mm aggregates = 370 kg/m^3, 7 mm aggregates = 647 kg/m^3, fine sand = 554 kg/m3, low-calcium fly ash (ASTM Class F) = 408 kg/m^3, sodium silicate solution (Na2O = 14.7%, SiO2 = 29.4%, and water = 55.9% by mass) = 103 kg/m^3, and sodium hydroxide solution (8 Molar) = 41 kg/m^3 (Note that the 8 Molar sodium hydroxide solution is made by mixing 11 kg of sodium hydroxide solids with 97-98% purity in 30 kg of water).

Geopolymer concrete can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. It is recommended that the alkaline liquid is prepared by mixing both the solutions together at least 24 hours prior to use. In the laboratory, the fly ash and the aggregates were first mixed together dry in 80-litre capacity pan mixer for about three minutes. The aggregates were prepared in saturated-surface-dry (SSD) condition. The alkaline liquid was mixed with the super plasticiser (SP) and the extra water, if any. The liquid component of the mixture was then added to the dry materials and the mixing continued usually for another four minutes. The fresh concrete could be handled up to 120 minutes without any sign of setting and without any degradation in the compressive strength. The fresh concrete was cast and compacted by the usual methods used in the case of Portland cement concrete (Hardjito and Rangan, 2005). Fresh fly ash-based geopolymer concrete was usually cohesive. The workability of the fresh concrete was measured by means of the conventional slump test.

III. MATERIALS

A. Fly Ash

Most of the thermal power plants use coal-fired boilers which consume coal ground to a fineness of more than 75% particles of 75µm size. In this experimental investigation using of the fly ash is taking from fly ash of brick factory nearby D-mart backside Tirupathi, Andhra Pradesh. It fly ash of specific gravity is 2.12 was used. The physical properties of fly ash as shown in table 1.

B. Ground Granulated Blast Furnace Slag

Ground Granulated Blast Furnace Slag (GGBS) is a by manufactured goods of the steel manufacturing. Blast furnace is obtained in from the metallurgical furnace to produce metals and pig iron supplied above atmospheric pressure. The product is taken from the lanco company which is used as the replacement in the SCGC. The physical properties of ground granulated blast furnace slag as shown in table 1

C. Aggregates

Aggregate is a rough material, such as sand, gravel, crushed stone, used with a hydraulic cementing medium to produce either concrete or mortar. 12.5mm sized coarse aggregates and 4.75mm size of fine aggregate were used.
The physical properties of fine and coarse aggregate as shown in table 1

D. Alkaline Solution

Sodium silicate gel (Na_2SiO_3) and sodium hydroxide (NaOH) solutions were used for fly ash activation. The concentration of NaOH solution can vary in the range between 8M to 12M. In this study, 8M is considered. The NaOH for 8M is 8x40 (Molecular weight) = 320gms should dissolve in 1 litre of water. After mixing the NaOH flakes in water its molecular weight reduces to 320gms for 8 Molarity. The Sodium silicate and Sodium hydroxide solution were mixed in 24 hrs prior to usage. In this investigation used alkaline liquid (sodium silicate solution and sodium hydroxide solution) is taking from Astra chemical, Chennai in INDIA.

E. Vermiculite

Vermiculite is a hydrous phyllosilicate mineral. It undergoes significant expansion when heated. Exfoliation occurs when the mineral is heated sufficiently, and the effect is routinely produced in commercial furnaces. The exfoliated vermiculite is commonly used in the agricultural, construction and also industries. It mainly provides strength to concrete. In this investigation used vermiculite is taking from Astra chemicals, Chennai in INDIA.

The physical properties of fly ash, ground granulated blast furnace slag, fine aggregate, coarse aggregate and also vermiculite as shown inn below.

PARTICULARS	FLY ASH	GGBFS	FINE AGGREGATE	COARSE AGGREGATE	VERMICULITE
Specific gravity	1.93	2.86	2.62	2.66	1.2
Fineness of cement replacement	7.9%	48%	-	-	-
Water absorption	-	-	-	-	2.24%
Bulk density	-	-	0.24%	0.27%	0.62%

Table 1: Physical Properties of Materials

IV. RESULTS & DISCUSSIONS

A. Fresh Properties

The fresh properties required by SCGC are flow ability or filling ability, passing ability. The tests performed on SCGC are Slump flow, T-50cms flow, V-Funnel, L-Box satisfying the EFNARC guidelines. The values are tabulated in below tables.

SL. NO	TEST	PERCENTAGE REPLACEMENT OF FINE AGGREGATE	MOLARITY	SLUMP FLOW IN MM	T_{50CM} SLUMP FLOW IN SEC
1	SLUMP CONE	10	8	692	4
2	SLUMP CONE	20	8	680.5	4.5
3	SLUMP CONE	30	8	660	5
4	SLUMP CONE	40	8	475	5
5	SLUMP CONE	50	8	450	8.5

Table 2: Concrete Mix of Slump Flow Test in mm

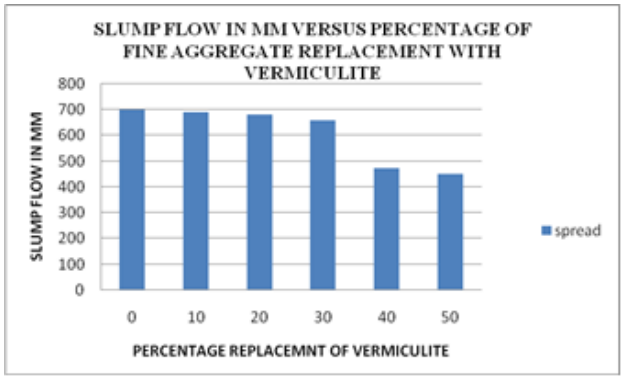

Fig. 1: Effect on Slump Flow on Increase in Replacement of vermiculite

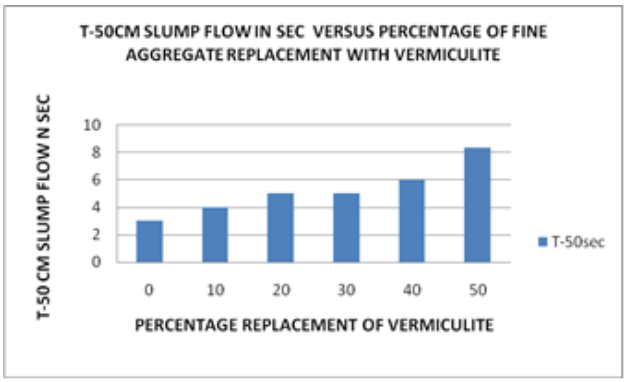

Fig. 2: Effect on T-50cm Slump Flow on Increase in Replacement of Vermiculite

SL.NO	TEST	PERCENTAGE REPLACEMENT OF FINE AGGREGATE	MOLARITY	V-FUNNEL IN SEC
1	V-FUNNEL	0	8	8
2	V-FUNNEL	10	8	10
3	V-FUNNEL	20	8	11
4	V-FUNNEL	30	8	12
5	V-FUNNEL	40	8	14
6	V-FUNNEL	50	8	15

Table 3: Concrete mix of V-Funnel in sec

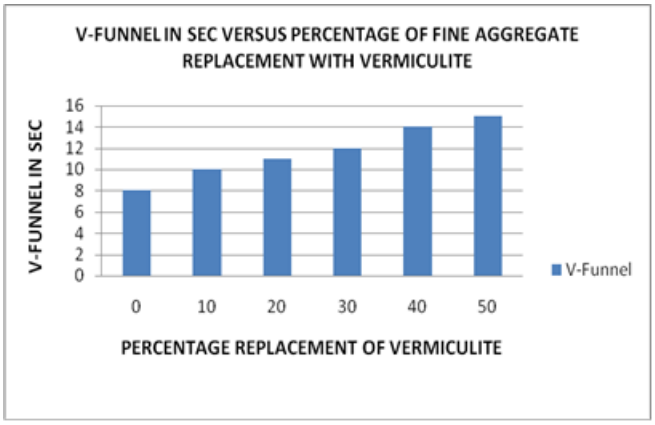

Fig. 3: Effect on V-Funnel in sec on Increase in Replacement of Vermiculite

SL.NO	TEST	PERCENTAGE REPLACEMENT OF FINE AGGREGATE	MOLARITY	L-BOX RATIO (h_2/h_1)
1	L-BOX	0	8	1
2	L-BOX	10	8	0.96
3	L-BOX	20	8	0.87
4	L-BOX	30	8	0.8
5	L-BOX	40	8	1.32
6	L-Box	50	8	1.5

Table 4: Concrete mix of L-box (h_2/h_1) in sec

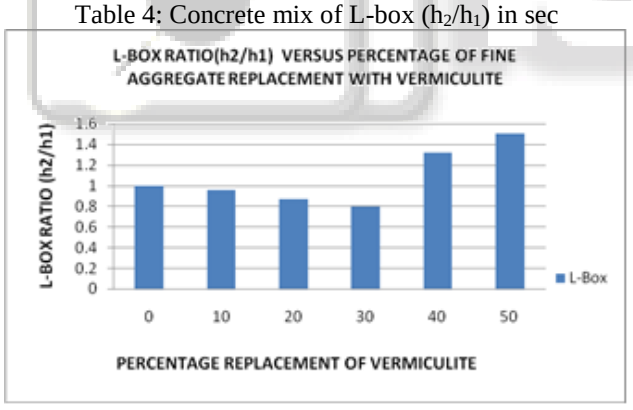

Fig. 4: Effect on L-Box ratio on Increase in Replacement of Vermiculite

V. CONCLUSIONS

This chapter summarizes the overall conclusions drawn from the selection and design of SCGC mix design tool, investigation of fresh properties of self-compacting geo-polymer concrete using fly ash and GGBS based up on vermiculite replaced with fine aggregates. In this study, fresh properties of self-compacting geo polymer concrete (SCGC) using vermiculite as various partial replacement of fine aggregates.

1) The percentage of GGBS and Fly ash in the mix will affects the workability characteristics of SCGC.
2) The inclusion of super plasticizer improved the workability characteristics of fresh concrete.
3) Keeping in view of savings in natural resources, sustainability, environment, production cost, maintenance cost and all other GPC properties, it can be recommended as an innovative construction material for the use of constructions.
4) By adding VERMICULITE to fine aggregate replacement the strength was increasing and adding more VERMICULITE to fine aggregate strength decreases.
5) GGBS, FA based SCGC mixes with replacement of vermiculite at various levels of replacement attained enhanced fresh properties.
6) The SCGC is suitably designed for VERMICULITE replacement with fine aggregate Up to 30% only and remaining percentage of vermiculite is not suitable like 40% and 50% Last and finally we are concluded 10%,20% and also 30% of VERMICULITE of fine aggregate is suitable for self-compacted geo polymer concrete (SCGC).
7) It is also used for thermal resisting structures.

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