

# A study on the strength development of geopolymers concrete using fly ash

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## Abstract

Cement consumption is increasing day by day due to the tremendous development in the infrastructure facilities. The production of one ton of cement emits approximately one ton of carbon dioxide to the atmosphere. In order to reduce the use of cement a new-generation concrete has been developed such as geopolymer concrete (GPC). Geopolymer is a new material which has the potential to replace ordinary Portland cement. It is an inorganic material synthesized by alkali activation of amorphous aluminosilicates at ambient or slightly increased temperatures having an amorphous to semi-crystalline polymeric structure. In this study, low calcium fly ash from Tuticorin was used to produce geopolymer concrete. The geopolymer was synthesized with sodium silicate and sodium hydroxide solutions. The sodium hydroxide pellets were dissolved in the distilled water to make free from mixing water contaminants. The ratio of sodium silicate and sodium hydroxide ratio was kept as 2.5. The concentration of sodium hydroxide solution is 12 Molarity (12M). Other materials used are locally available coarse aggregate and fine sand in surface dry condition. A polycarboxylate HRWRA La Hypercrete S25 was used. Cubes of size 100mm were cast for six mix proportions of 450kg/m<sup>3</sup> fly ash+0.35W/B, 500 kg/m<sup>3</sup> fly ash+0.35W/B, 550kg/m<sup>3</sup> fly ash+0.35W/B, 450kg/m<sup>3</sup> fly ash+0.40 W/B, 500kg/m<sup>3</sup> fly ash+0.40W/B and 550kg/m<sup>3</sup> fly ash+0.40W/B. The specimens after casting in moulds were kept in oven at 60°C for 6 hours and left to air dry at room temperature and tested at 7 and 28 days. The test results revealed the compressive strength of 30 Mpa was achieved. There was not much significant difference in strength development at 28 days between the mixes due to the increase of fly ash content. The microstructural images at 28 days revealed that there was not much difference in the microstructure due to the variation in fly ash content from 450 kg/m<sup>3</sup> to 550 kg/m<sup>3</sup>.

**Keywords:** Flyash; Geopolymer; Sodium Silicate; Sodium Hydroxide; Compression.

## 1. Introduction

Cement consumption is increasing day by day for satisfying the need of development of infrastructure facilities. The production of one ton of cement emits approximately one ton of carbon dioxide to the atmosphere. In order to reduce the use of cement a new-generation concrete has been developed such as geopolymer concrete (GPC). Geopolymer is an excellent alternative material for cement concrete as it is produced from industrial by-products such as Flyash and GGBS replacing 100% of cement in concrete [1]. Geopolymers are formed by alkaline activation of an aluminosilicate material like fly ash, GGBS, metakaolin, rice husk ash, activated bentonite, clay, red mud, etc.[2]. It is noted that most of these raw materials are industrial wastes or byproducts, and significant environmental and economic benefits can be achieved if the waste-based geopolymer is produced and used in practice. Geopolymer provides not only performance comparable to conventional Portland cement concrete, but also additional advantages, including rapid development of mechanical strength, small drying shrinkage, high fire resistance, superior acid resistance, effective immobilization of toxic and hazardous materials and significantly reduced energy and greenhouse emissions [3].

## 2. Literature review

Daniel and Sanjayan [4] used fly ash as precursor and synthesized geopolymer with sodium silicate and potassium hydroxide solutions. They examined various experimental parameters such as specimen sizing, aggregate sizing, aggregate type and super plasticizer type. They studied the effect of elevated temperature on geopolymer paste, mortar and concrete. They found that aggregate sizes larger than 10 mm resulted in good strength performances in both ambient and elevated temperatures. Also strength loss in geopolymer concrete at elevated temperatures is attributed to the thermal mismatch between the geopolymer matrix and the aggregates. Benny Joseph et al [5] conducted experiments using fly ash(Class F Type), Sodium hydroxide, Sodium Silicate, coarse aggregate and fine aggregate of nominal size of 20mm and 4.5mm respectively. Also they used naphthalene based water reducing admixture and tested the mechanical properties of geopolymer concrete and concluded that the compressive strength of geopolymer concrete increases with increase in curing temp upto 100 °C and beyond which it decreases. Tawatchai Tho-in et al [6] conducted tests and studied the properties of pervious concrete made of high-calcium fly ash geopolymer binder. They used lignite fly ash, sodium silicate sodium hydroxide solution, and coarse aggregate. They concluded that the high-calcium fly ash geopolymer

binder could be used to produce pervious concrete with satisfactory mechanical properties. Also the relationships of the density-void content, compressive strength-density and compressive strength-void content of the PGCs proved to be similar to those of conventional pervious concrete. Gun Sung Ryu et al [7] examined the effects of chemical changes of alkaline activators on the compressive strength of mortar and analyzed its micro structure by conducting SEM, EDS, XRD, FT-IR and by porosity assessment tests using Fly ash (Class F type), alkaline activator of sodium hydroxide and sodium silicate solutions. They concluded that higher Molarity of NaOH used as an alkaline activator provided higher compressive strength together with a considerable effect on the early strength. Also, geopolymer concrete is most suitable for precast concrete products as the compressive strength of geopolymer concrete can be developed above 60 °C. Vanchai Sata et al [8] developed pervious geopolymer concrete by using recycled aggregates of crushed structural concrete member, crushed clay brick, high calcium fly ash, sodium silicate solution, sodium hydroxide solution and conducted tests on compressive strength, splitting tensile strength, void ratio and permeability coefficient. They concluded that both recycled aggregates could be used as coarse aggregates for making pervious geopolymer concrete using high calcium fly ash as a source material. Prabir K Sarkar et al [9] studied the effect of the geopolymer binder on fracture characteristics of concrete by three points bending test of RILEM TC 50 – FMC type notched beam specimens and found the failure modes of the heat cured GPC specimens were more brittle than those of the OPC concrete specimens. Furthermore, fracture energy was increased with compressive strength in both types of concrete and the difference in fracture behaviors of GPC and OPC concrete is because of the higher bond and tensile strengths of GPC. Navid Ranjbar et al [10] performed XRF, XRD, TGA/DTG and FESEM analysis for finding the compressive strength behaviour of palm oil fine ash and fly ash based mortar and found all the fly ash based geopolymer mixtures gained strength when exposed to 500°C and all the specimens lost strength when exposed to temperatures above 500 °C. The materials used in the test are fly ash, activator of sodium hydroxide and sodium silicate solutions. Pradip Nath et al [11] studied the effect of geopolymer concrete without heat curing. The geopolymer concrete was developed with fly ash (Class F type), activator of mixture of sodium hydroxide and sodium silicate solutions and small part of ground granulated blast-furnace slag (GGBFS) as a binder. Tests were conducted for workability, setting time and compressive strength and concluded that fly ash based geopolymer with GGBS is found to be a suitable binder for low to moderate strength concrete production at ambient curing condition, as it eliminates the necessity of heat curing. Tianu Xie and Togay Ozbakkaloglu [12] carried out tests for Compressive strength, elastic modulus, flexural strength, workability, drying shrinkage to determine the properties of fresh concrete and durability-related properties of hardened concrete and found no significant exothermic reactions were observed during the curing of GPC at the ambient temperature and also compressive strength of coal ash based GPC increases with a decrease in the liquid to binder ratio.

### 3. Materials used

#### 3.1. Fly ash

Fly ash from Tuticorin thermal power plant was used for the entire study. The specific gravity of fly ash was determined as per IS 4031 and was found to be 2.1. X-Ray Diffraction (XRD) was used to determine the chemical composition of the fly ash, and the peak obtained was shown in Fig.1.

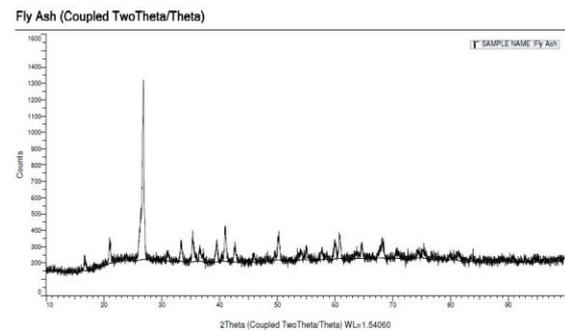


Fig. 1: X-Ray Diffraction Pattern of the Flyash.

#### 3.2. Fine aggregate

Locally available river sand was used in the study and the properties were tested as per IS 2386 – 1968 Part III and are as follows.

Specific gravity – 2.65.

Fineness Modulus – 2.58.

Water absorption – 1.4%.

The sieve analysis of the fine aggregate was tabulated in Table 1

**Table 1: Sieve Analysis of Fine Aggregate**

IS Sieve	Weight retained (g)	Cumulative % retained	Cumulative % passing
4.75 mm	25	2.5	97.5
2.36 mm	25	5	95
1.18mm	96	14.6	85.4
600 μ	313	45.9	54.1
300 μ	448	90.7	9.3
150 μ	86	99.3	0.7
Pan	7	--	--
Fineness modulus		258/100=2.58	

#### 3.3. Coarse aggregate

Locally available coarse aggregate was used in the study and the properties were tested as per IS 2386- 1968 Part III and are as follows

Specific gravity -2.80

Water absorption-0.40%

The maximum size of the coarse aggregate was 20mm and the coarse aggregate was blended in the ratio 60:40 of 20mm and 12.5 mm respectively. The sieve analysis of 20mm and 12.5mm aggregate was tabulated in Table 2 and 3 respectively.

**Table 2: Sieve Analysis of Coarse Aggregate (20Mm)**

IS Sieve	Weight Retained g	Cumulative Percentage	
		Retained	Passing
40 mm	0.00	0.00	100.00
20 mm	1406.00	46.87	53.13
10 mm	1520.00	97.53	2.47
4.75 mm	74.00	100.00	0.00
Pan	0.00		

**Table 3: Sieve Analysis of Coarse Aggregate (12.5 mm)**

IS Sieve	Weight Retained g	Cumulative Percentage	
		Retained	Passing
16 mm	0.00	0.00	100.00
12.5 mm	85.00	2.83	97.17
10 mm	1995.00	69.33	30.67
4.75 mm	850.00	97.67	2.33
Pan	70.00		

#### 3.4. Activator solution

Sodium hydroxide and sodium silicate solution was obtained from a local vendor. A mixture of sodium hydroxide and sodium silicate solution was used as the activator solution. Sodium hydroxide

solution of 12M concentration was prepared by mixing NaOH pellets with distilled water. The concentration of NaOH solution was kept 12M for all the mixtures. The solution were mixed together one day prior to casting.

**3.5. Admixture**

A polycarboxylate based high range water reducing admixture (HRWRA) La Hypercrete S25 was used in concrete mixtures to obtain the necessary workability.

**4. Mix proportions**

Six different mix combinations were tried for achieving geopolymer concrete of M30 viz; 450kg/m<sup>3</sup> fly ash+0.35 w/c (GPC 450-1), 500kg/m<sup>3</sup> fly ash+0.35 w/c (GPC 500-1), 550 kg/m<sup>3</sup> fly

ash+0.35 w/c (GPC 550 -1), 450kg/m<sup>3</sup> fly ash+0.40 w/c (GPC 450-2), 500kg/m<sup>3</sup> fly ash+0.40 w/c (GPC 500-2), 550 kg/m<sup>3</sup> fly ash+0.40w/c (GPC 550-2). The mix proportions for all the six mixes were tabulated in Table 4. Cubes of size 100 x 100 x 100 mm size were cast to determine the compressive strength at 7 and 28 days. The specimens after casting were placed in hot air oven for a period of 6 hours at 60°C and kept in room temperature till the date of testing. Compressive strength tests were carried out using a Compression Testing Machine (CTM) as per IS: 516 – 1959. The compressive strength results discussed in the following sections were the average value of three readings. Fig. 2 shows the pan mixer used for mixing geopolymer concrete. Fig. 3 represents the hot air oven used for placing the specimens at hot air oven at 60 C for 6 hours. Fig. 4 shows the compression testing machine used to test the compressive strength of geopolymer concrete.

**Table 4:** Mix Proportions of Geopolymer Concrete in Kg/M<sup>3</sup>

Mix ID	Fly ash kg/m <sup>3</sup>	Na <sub>2</sub> SiO <sub>3</sub> kg/m <sup>3</sup>	Na OH kg/m <sup>3</sup>	20mm kg/m <sup>3</sup>	12mm kg/m <sup>3</sup>	Sand kg/m <sup>3</sup>	Admixture kg/m <sup>3</sup>
GPC 450-1	450	113	45	664	501	609	4.5
GPC 500-1	500	125	50	627	473	574	5
GPC 550-1	550	138	55	590	445	540	5.5
GPC 450-2	450	129	51	648	488	593	4.5
GPC 500-2	500	143	57	608	459	557	5
GPC 550-2	550	157	63	569	429	521	5.5



**Fig. 2:** Pan Mixer for Mixing Geopolymer Concrete.



**Fig. 3:** Cube Specimens in Hot Air Oven.



Fig. 4: Testing of Geopolymer Concrete Specimen.

## 5. Results and discussion

### 5.1. Effect of fly ash

Three different flyash content has been used to study the effect of flyash quantity on the compressive strength development of geopolymer concrete. Fig. 5 and 6 depicted the effect of flyash content on the compressive development of geopolymer concrete at 7 and 28 days respectively. The compressive strength increased about 10% for every increase of 50kg/m<sup>3</sup> flyash content from 450 kg/m<sup>3</sup> at 7 days at w/c 0.35. But on the other hand there was not much improvement in the strength at 28 days due to the increase of flyash content from 450 kg/m<sup>3</sup> to 550kg/m<sup>3</sup>. With 0.4 w/c, the compressive strength increased 5% for 500 kg/m<sup>3</sup> and 15% for 550 kg/m<sup>3</sup> when compared to 450kg/m<sup>3</sup> flyash content. But in this mix also, there was not much significant difference between the compressive strength due to the increase in flyash content.

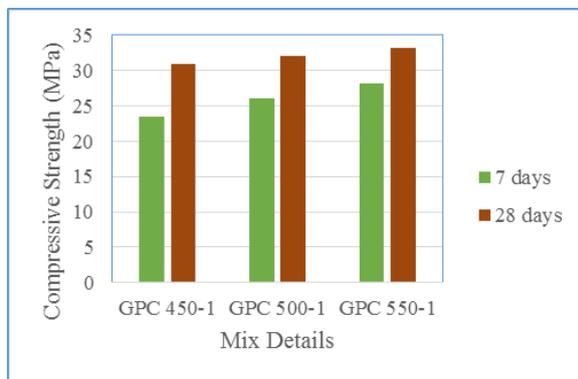


Fig. 5: Compressive Strength of Geopolymer Concrete with 0.35 W/C.

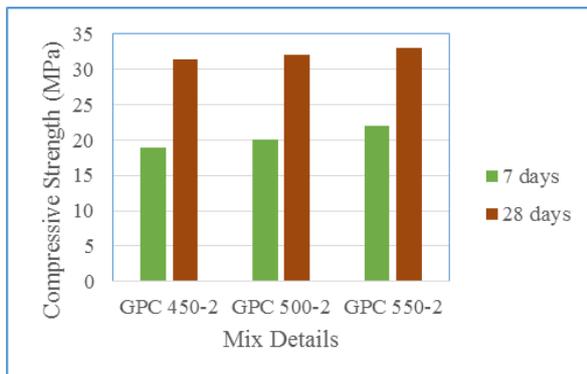


Fig. 6: Compressive Strength of Geopolymer Concrete with 0.35 W/C.

### 5.2. Effect of w/c

Two different w/c ratios has been used to study the effect of w/c on the compressive strength development of geopolymer concrete. Fig. 7 and 8 depicts the effect of w/c ratio on the compressive strength of geopolymer concrete at 7 and 28 days respectively. It has been noticed that at 7 days there was an increase of around 20% in compressive strength when there was a decrease of w/c from 0.4 to 0.35 at all flyash content mixtures. But on the other hand there was not much significant difference between the 28 days compressive strength.

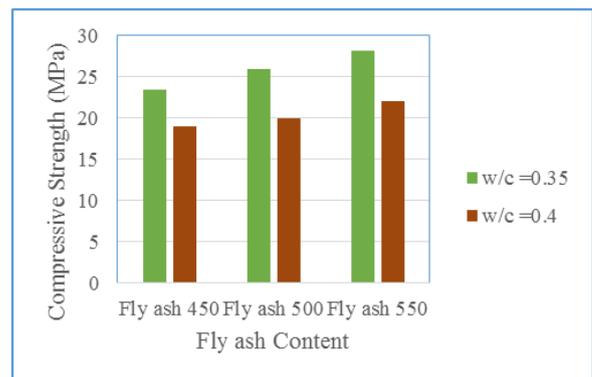


Fig. 7: Compressive Strength of Geopolymer Concrete at 7 Days.

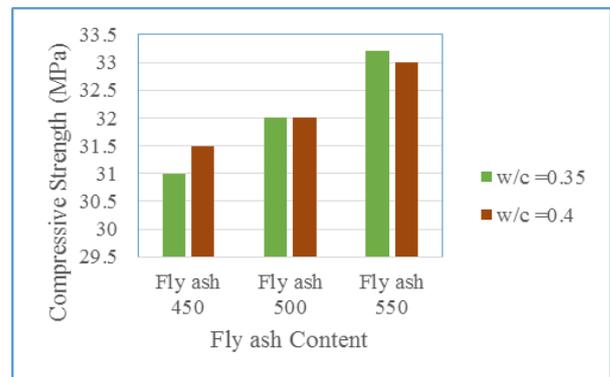


Fig. 8: Compressive Strength of Geopolymer Concrete at 28 Days.

## 6. Microstructural investigations

Fig. 9 and 10 reveals the microstructure of GPC 450-1 and GPC-550-1 mixtures at 28 days. It is been noted that there was not much difference in the microstructure which is in line with the compressive strength of these concretes at 28 days.

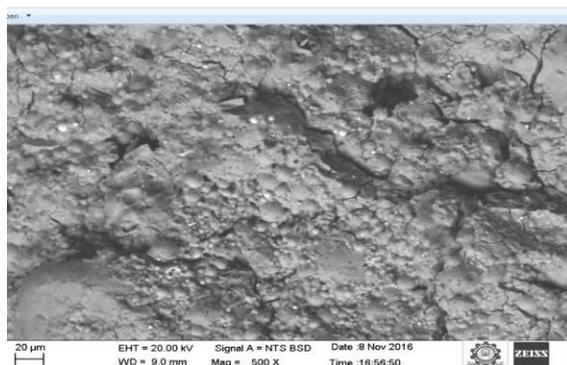


Fig. 7: SEM Image of Geopolymer Concrete GPC 550-1.

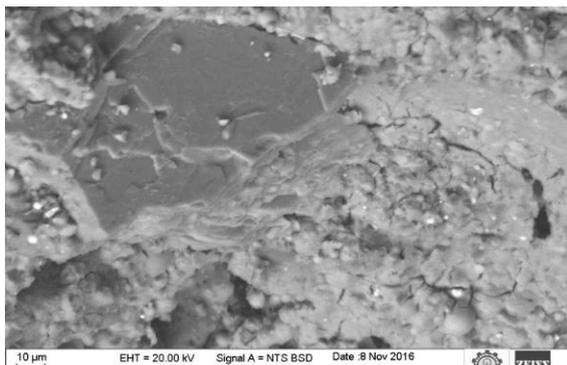


Fig. 8: SEM Image of Geopolymer Concrete GPC 450-1.

## 7. Conclusions

Based on the work done, the salient conclusions arrived are

- The Compressive strength increases with the increase in fly ash content at 7 days for both the water cement ratio
- The compressive strength increase was about 10% for every 50 kg/m<sup>3</sup> increase in flyash content, when the w/c is fixed at 0.35
- There was only a marginal increase in the strength at 28 days by varying the fly ash content.
- There was not much increase in the compressive strength by varying the w/b ratio.
- The ratio of sodium silicate to sodium hydroxide ratio and the Molarity of the solution might have influence on the strength of concrete.
- The initial hot curing plays a major role in the strength development of the geopolymer concrete.

## References

- [1] MCG. Juenger, F. Winnefeld, J.L. Provis and J.H. Ideker, "Advances in alternative cementitious binders," *Cement and Concrete Research*. vol. 41, pp. 1232-1243, 2010. <https://doi.org/10.1016/j.cemconres.2010.11.012>.
- [2] J. Davidovits, "Geopolymer chemistry and application," 2nd edition, Saint-Quentin (France); Institut Geopolymere; 2008.
- [3] Hardjito, Djwantoro and B. Vijaya Rangan, "On the development of flyash based geopolymer concrete", *ACI Materials Journal*, 101, pp. 467-472, 2004
- [4] Daniel L.Y. Kong, Jay G. Sanjayan, Effect of elevated temperatures on geopolymer paste, mortar and concrete, *Cement and Concrete Research* 40 (2010) 334-339 <https://doi.org/10.1016/j.cemconres.2009.10.017>.
- [5] Benny Joseph, George Mathew, Influence of aggregate content on the behavior of fly ash based geopolymer concrete, *Scientia Iranica A* (2012) 19(5), 1188-1194 <https://doi.org/10.1016/j.scient.2012.07.006>.
- [6] Tawatchai Tho-in, Vanchai Sata, Pervious high calcium fly ash geopolymer concrete, *Construction and Building Materials* 30 (2012) 366-371 <https://doi.org/10.1016/j.conbuildmat.2011.12.028>.
- [7] Gum Sung Ryu, Young Bok Lee, Kyung Taek Koh, oung Soo Chung, The mechanical properties of fly ash based geopolymer concrete with alkaline activators, *Construction and Building Materials* 47 (2013) 409-418 <https://doi.org/10.1016/j.conbuildmat.2013.05.069>.

- [8] Vanchai Sata, Ampol Wongs, Prinya Chindaprasit, Properties of pervious geopolymer concrete using recycled aggregates, *Construction and Building Materials* 42 (2013) 33-39 <https://doi.org/10.1016/j.conbuildmat.2012.12.046>.
- [9] Prabir K. Sarkar, Rashedul Haque, Karamchand V. ramgolan Fracture behavior of heat cured fly ash based geopolymer concrete, *Materials and Design* 44 (2013) 580-586 <https://doi.org/10.1016/j.matdes.2012.08.005>.
- [10] Navid Ranjbar, Mehdi Mehrabi, Compressive strength and micro structural analysis of fly ash/palm oil fuel ash based geopolymer mortar under elevated temperatures, *Construction and Building Materials* 65 (2014) 114-121 <https://doi.org/10.1016/j.conbuildmat.2014.04.064>.
- [11] Pradip Nath, Prabir Kumar Sarkar, Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition, *Construction and Building Materials* 66 (2014) 163-171 <https://doi.org/10.1016/j.conbuildmat.2014.05.080>.
- [12] Tianyu Xie, Togay Ozbakkaloglu, Behavior of low calcium fly ash and bottom ash based geopolymer concrete cured at ambient temperature, *Ceramics International* 41 (2015), 5945-5958 <https://doi.org/10.1016/j.ceramint.2015.01.031>.
- [13] Rasoul Shadnia, Liyang Zhang, Peiwen Li, Experimental study of geopolymer mortar with incorporated PCM, *Construction and Building Materials* 84 (2015) 95-102 <https://doi.org/10.1016/j.conbuildmat.2015.03.066>.
- [14] Moser R.D., Allison P.G, Williams B.A, Weiss Jr C.A, Diaz A.J, Gore E.R, Malone P.G, Improvement in the geopolymer-to-steel bond using a reactive vitreous enamel coating, *Construction and Building Materials* 49 (2013) 62-69 <https://doi.org/10.1016/j.conbuildmat.2013.08.001>.
- [15] Chindaprasit P, Chalee W, Effect of sodium hydroxide on chloride penetration and steel corrosion of fly ash based geopolymer concrete under marine site, *Construction and Building Materials* 63 (2014) 303-310 <https://doi.org/10.1016/j.conbuildmat.2014.04.010>.
- [16] Ganesan N, Ruby Abraham, Deepa Raj S, Divya Sasi, Stress-strain behavior of confined Geopolymer concrete, *Construction and Building Materials* 73 (2014) 326-331 <https://doi.org/10.1016/j.conbuildmat.2014.09.092>.
- [17] Part Wei Ken, Mahyuddin Ramli, Cheah Chee Ban, An overview on the influence of various factors on the properties of geopolymer concrete derived from industrial by-products, *Construction and Building Materials* 77 (2015) 370-395 <https://doi.org/10.1016/j.conbuildmat.2014.12.065>.
- [18] Singh B, Ishwarya G, Gupta M, Bhattacharyya, Geopolymer concrete: A review of some recent developments, *Construction and Building Materials* 85 (2015) 78-90 <https://doi.org/10.1016/j.conbuildmat.2015.03.036>.
- [19] Wahid Ferdous, Allan manalo, Amar Khennane, Obada kayali, Geopolymer concrete- filled pultruded composite beams Concrete mix design and application, *Cement & Concrete Composites* 58 (2015) 1-13 <https://doi.org/10.1016/j.cemconcomp.2014.12.012>.
- [20] Mijarsh M.J.A, Megat Johari, Zainal Arifin Ahmad, Compressive strength of treated palm oil fuel ash based geopolymer mortar containing calcium hydroxide, aluminium hydroxide and silica fume as mineral additives, *Cement & Concrete Composites* 60 (2015) 65-81 <https://doi.org/10.1016/j.cemconcomp.2015.02.007>.
- [21] Habert G, d'Espinose de Lacaillerie J.B, Roussel N, An environmental evaluation of geopolymer based concrete production: reviewing current research trends, *Journal of Cleaner Production* 19 (2011) 1229-1238 <https://doi.org/10.1016/j.jclepro.2011.03.012>.
- [22] Prakash R. Vora, Umil V.Dave, Parametric Studies on Compressive Strength of Geopolymer Concrete, *Procedia Engineering* 51 (2013) 210-219 <https://doi.org/10.1016/j.proeng.2013.01.030>.
- [23] Kolli Ramujee, Potharaju M, Abrasion Resistance of Geopolymer Composites, *Procedia Materials Science* 6 (2014), 1961-1966.
- [24] Djwantoro Hardjito, Steenie E. Wallah, Dody M.J. Sumajouw and Vijaya Rangan B, On the development of Fly ash - Based Geopolymer Concrete, *ACI Material Journal*, November-December(2004), 467-472.
- [25] Khadiraikaikar R.B, Shankar H. Sanni, Experimental Investigations of Reinforced Geopolymer Concrete Beams, *ICI Journal /July- September* (2016) 29-37.
- [26] Indian Standard Code of practice for Methods of test for strength of concrete IS: 516 - 1959, Bureau of Indian Standards, New Delhi.
- [27] Indian standard Code of practice for specifications for coarse and fine aggregates from natural sources for concrete IS: 383-1970, Bureau of Indian Standards, New Delhi.
- [28] Parthiban K., Saravanrajmohan K., Shobana S., and Anchal Bhaskar A., Effect of replacement of slag on the mechanical properties of flyash based geopolymer concrete, *International Journal of Engineering and Technology*, (2013), Vol5, No.3, 2555-2559.