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Development of eco-friendly concrete in Oman

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Abstract
This project is a study on the development of eco-friendly (geopolymer) concrete. Concrete made with Portland cement is the most widely used material on earth. The production of Portland cement clinker is expensive and ecologically harmful. The emissions generated by Portland cement productions are principal contributors to the greenhouse gas (GHG) effect where, 1 Ton of CO_2 produced for every Ton of OPC. Geopolymer binder is an innovative construction material and a real alternative to conventional cement. Geopolymer binder is a combination of alumina silicate as source material and alkaline solution.
This study mainly focusing on development of mix proportions of C30 grade of Geopolymer concrete with 8 Molar, 10 Molar and 12 Molar were obtained. The mix proportion of Eco friendly of various concrete molarity obtained based on the mix proportions given in ACI Committee 211.1-91 with hundred percent replacement of cement by fly ash. The compressive strength of geopolymer concrete is achieved by adjusting the concentration of sodium hydroxide in the alkaline solution. Alkaline solution is combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). Totally 27 cubes of geopolymer concrete, of which 9 cubes for 8M, 9 cubes for 10 M and remaining 9 cubes for 12 M of C30 grade concrete were cast and tasted in the laboratory. For conventional cement concrete cubes 9 nos were cast and tasted for 7 days, 14 days and 18 days strength. The strength of geopolymer concrete is achieved in 24 hours after casting of specimens by heat curing. The results obtained are encouraging and similar to the corresponding strength of conventional cement concrete. Hence, the geopolymer technology can be effectively used in the construction industry in terms of saving energy consumption and resources and ultimately to save the ecosystem of earth.

Key words: Geopolymer concrete, compressive strength, sodium hydroxide, sodium silicate, alkaline solution

1. Introduction
Concrete is a widely used material in the construction industry. Ordinary Portland Cement (OPC) is generally used as the primary binder of the concrete and in addition to that coarse aggregates, fine aggregates and water are also used in concrete construction. As the requirement for development in infrastructure increases the demand for the OPC concrete also increases. On the other hand, a major emphasis is given for the sustainable development in the construction industry [1]. In order to comply with sustainable development concept, it is very important to minimize the negative environmental impacts of all construction works. The negative environmental impacts associated with the OPC production are much noticeable [2]. During the manufacturing process of one ton of OPC, it releases a ton of Carbon Dioxide (CO_2) gas to the environment due to the process of calcination of limestone and combustion of fossil fuels. On the other hand, the amount of energy required for the manufacture of OPC is only second to the requirement of energy for manufacturing of steel and aluminum. In such a situation, these negative impacts will lead us to think of better alternatives and substitutes for OPC concrete. One of the alternatives which have been discussed as a substitute for OPC concrete is the geopolymer concrete. The main objective of this research was to develop of geopolymer concrete withe fly ash which can be substitution for OPC concrete and is much more environmental friendly [3].

1.1 Global Pollution due to Cement Industry
Cement production increases at about 3% per year. This rate is set to increase as developing nations rapidly become richer, and spend proportionately more cement intensive infrastructures [4]. The production of one ton of Portland cement contributes approximately one ton of CO_2 to the atmosphere.

Globally, the world's Portland cement production contributes about 2.5 billion tons of CO_2 or about 7% of the global loading of carbon dioxide into the atmosphere. In order to address the environmental effect associated with Portland cement, there is a need to use other binders to make concrete. One of the efforts to produce more environmental friendly concrete is to replace the amount of Portland cement in concrete with by-product materials such as fly ash. An important achievement in this regard is the development of high volume fly ash concrete that utilizes up to 60 percent of fly ash, and yet possesses excellent mechanical properties with enhanced durability performance [5].

1.2 Cement Concrete

Concrete is the most widely used construction material in the world. It is used in many different structures such as dam, pavement, building frame or bridge. Also, it is the most widely used material in the world, far exceeding other materials. Its worldwide production exceeds that of steel by a factor of 10 in tonnage and by more than a factor of 30 in volume. The present consumption of concrete is over 10 billion tons a year, that is, each person on earth consumes more than 1.7 ton of concrete per year. It is more than 10 times of the consumption by weight of steel. The partial replacement of cement by a pozzolanic mineral admixture reduces the production cost of concrete. The reduction of excess $Ca(OH_2)$ due to pozzolanic reaction improves durability of concrete by making cement paste more dense and impervious. The addition of admixtures acts as scavengers for penetration of chloride ions, which prevents corrosions of steel in the concrete. The reduction of compressive strength of concrete, flexural strength of concrete at early ages and increasing carbonation of concrete are found on some of the drawbacks in the partial replacement of cement by fly ash in concrete.

2. Methodology

2.1 Aggregates

Coarse and fine aggregates used by the concrete industry are suitable to manufacture geopolymer concrete. The aggregate grading curves currently used in concrete practice are applicable in the case of geopolymer concrete [6]. The properties of aggregates used are listed below:

- Specific gravity of fine aggregate (G) = 2.70
- Specific gravity of coarse aggregate (G) = 2.65
- Fineness modulus = 2.77 (medium sand)
- Fineness modulus = 2.21 (coarse aggregate of size ranging from 12.5 to 5mm)

2.2 Fly Ash

Fly ash, also known as "pulverised fuel ash" is one of the Coal combustion products, and is composed of the fine particles that are driven out of the boiler with the flue gases. Ash that falls in the bottom of the boiler is called bottom ash [7].

2.3 Alkaline Solution

Alkaline liquids in this research were in pellet form with 97-98% purity. 8 Molar, 10 Molar and 12 Molar Sodium Hydroxide (NaOH) solutions were used for all mix proportions in this research. The sodium silicate solution with sodium hydroxide ratio by mass of 2.5 is used [8].

2.4 Mixing, Casting and Curing

The fresh fly ash classified as low calcium, dry ash collected from Thermal Power Station, India was used. The aggregates were prepared in saturated surface dry condition (Fig. 1). The liquid part of the mixture, i.e. the sodium silicate solution, the sodium hydroxide solution (Figs. 2 and 3) mixed twenty four hours earlier for thorough mixing and reaction. The solids constituents of the fly ash based geopolymer concrete, i.e. the aggregates and the fly ash were dry mixed by a Pan mixer for about three minutes. The wet mixing of liquid and dry mixture of aggregates usually continued for another four minutes (Fig. 4). Total 18 GPC cubes and 6 OPC cubes were cast and tested in the laboratory. On the 18 GPC cubes 8 molarity -6 cubes (7days, 14 days and 28 days strength), 10 molarity -6 cubes and 12 molarity 6 cubes were cast.

The wet mixing usually is in cohesive condition. The workability of the fresh concrete was measured by means of the conventional slump test. The slump measured was 50 mm. The prepared concrete specimens kept in moulds are shown in Fig.5.

After casting the specimens were covered using vacuum bagging film. Heat curing was done at 65° C- 24 hours in heat curing chamber. Curing process in the heat curing chamber is shown in Fig.6. The compressive test on hardened fly ash-based geopolymer concrete was performed on a 1000kN capacity UTM. All GPC and OPC cubes were tested to find their compressive strength is shown in Fig.7.

Fig 1: GPC materials

Fig 2: Sodium Hydroxide (NaOH)

Fig 3: Sodium Silicate (Na_2SiO_3)

Fig 4: GPC mixing in pan mixer

Fig 5: Casting of GPC cubes

Fig 6: Heat – curing chamber

Fig 7: Compressive strength test

3. Results and Discussion

The minimum grade of concrete shall be not less than C30 in reinforced concrete work. Design mix concrete is preferred to nominal mix. In this study same mix ratio has been investigated for Geopolymer concrete with different ratios of alkaline solutions which is one of the main ingredients. These cubes were tested 7 days, 14 days &28 days only in air curing. The constituents of geopolymer concrete and strength properties are given in the Tables 1 and 2.

Table 1: Constituents of Geopolymer concrete (C30 grade)

Sl. No.	Mix Ratio	Molarity of NaOH Solution	Slump mm	Curing Method	Curing Time in Hours	Curing Temp.	Average Comp. Strength N/mm^2			Number of Cubes Total 18 Nos.
							7 day	14 day	28 day	
1	C30	8 M	50	Heat	24	65ºC	19.00	20.00	22.00	9
2	C30	10 M	55	Heat	24	65ºC	15.00	16.50	18.00	9
3	C30	12M	35	Heat	24	65ºC	11.00	13.00	14.00	9

Table 2: Constituents of conventional concrete cubes (C30 grade)

Sl. No.	Mix Ratio	Average Comp. Strength N/mm^2			Number of cubes
		7 day	14 day	28 day	
1	C30	29.75	32.15	35.75	9

The compressive strength tests are making on hardened concrete specimens. Test specimens are concrete cubes, cured for 7 days, 14 days and 28 days. The OPC cube size is 150x150x150mm. The Universal Testing machine (UTM) was used to apply load on the test cubes and the results are presented in Figs. 8 to 11.

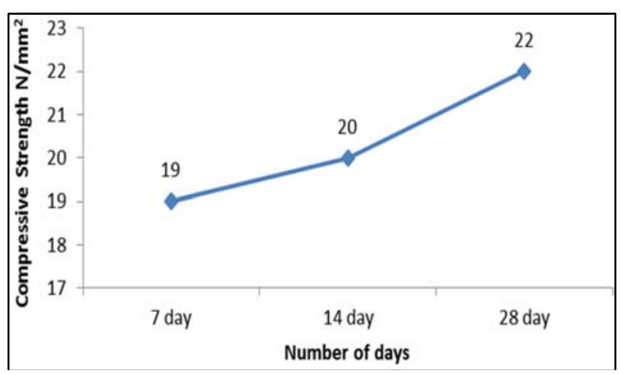

Fig 8: Compressive strength for 8M

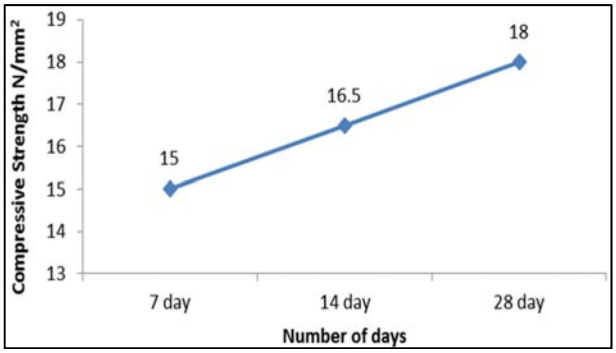

Fig 9: Compressive strength for 10M

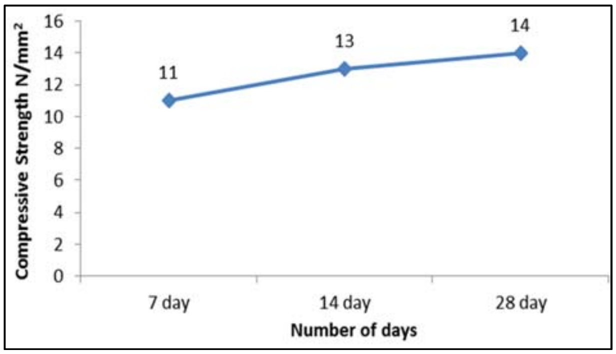

Fig 10: Compressive strength for 12M

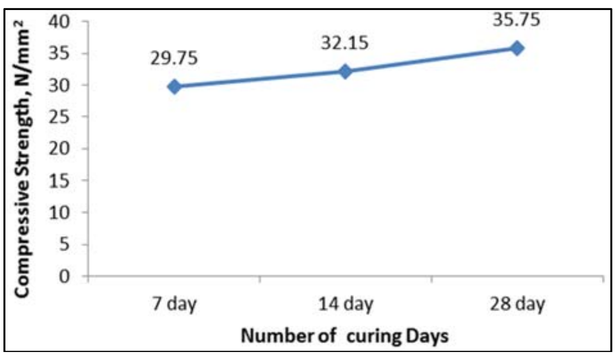

Fig 11: Compressive strength for cement concrete

4. Conclusion

Based on the experiments the following conclusions are drawn:

i) The ratio of alkaline liquid to fly ash, by mass does not much affect the compressive strength of the geopolymer concrete.
ii) The compressive strength of the geopolymer concrete increases with decrease of concentration in terms of molarities of sodium hydroxide.
iii) The compressive strength of the geopolymer concrete increases with increase in the curing time.
iv) One day rest period for alkaline solution increases the compressive strength of the geopolymer concrete as compared to that of concrete without the rest period.
v) From the test result 8 M shows better result compared to 10 M and12 M.
vi) The 8M achieved 70% of strength with respect to conventional concrete.
vii) The 10 M & 12 M proved a strength around 51% and 31% with respect to conventional concrete.

5. References

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