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# Effect of nano materials in geopolymer concrete☆

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**Summary** In general, cement based concrete can be replaced by low calcium fly-ash based geopolymer concrete regarding the adverse effect of the manufacture of ordinary Portland cement on environment. Nowadays, nano technology has an important role in the field of construction industries. It has been seen that several properties of cement based concrete are affected by different nano materials. As low calcium fly-ash based geopolymer concrete is an alternate option for cement based concrete, nano materials may also have some influence on it. An experimental program has been taken up on low calcium fly-ash based M25 grade geopolymer concrete having 16 (M) concentration of activator liquid. Different percentage of nano materials viz. nano silica, carbon nano tube, titanium di-oxide were also used to investigate the effect of nano materials on geopolymer concrete. Geopolymer concrete with 1% titanium di-oxide shows appreciable improvement in compressive strength although pH remains almost same in all cases.


## Introduction

Concrete for construction has traditionally been based on an ordinary Portland cement binder. The production of 1 ton of cement contributes almost 1 ton of $CO_2$ to the atmosphere. Thus, due to the production of OPC, the $CO_2$ emission has been reported to be about 13,500 million ton, which is almost the amount of 7% of greenhouse gases annually worldwide. Geopolymer as an alternative binder, have potential to lower the carbon footprint of OPC concrete in a significant amount.

In general, geopolymer possess many excellent mechanical properties such as high early strength gain, low creep and shrinkage, and good resistance in acid and sulphate attacks. Most of the research works on fly ash based geopolymer concrete are basically on the strength variation by either changing curing conditions or by changing molar

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concentration of sodium hydroxide (Hardijito et al., 2004; Davidovits, 1994; Pal and Mandal, 2011). There are limited literatures available on effect of nano silica on geopolymer concrete (Shaikh et al., 2014; Zhang and Islam, 2012). It is observed that for cement based concrete, 0.75% nano silica, 0.02% carbon nano tube and 1% titanium di-oxide gives max compressive strength.

This paper examines the effect of different percentage of nano materials addition in low calcium fly ash based geopolymer concrete. The mechanical strength of such geopolymer concrete was analysed by compressive strength. Also durability property based pH test was incorporated. Some non-destructive tests like, rebound hammer and UPV are also performed to verify the applicability of standard charts & graphs mainly used for cement based concrete.

## Materials and methods

Low calcium fly ash from Kolaghat thermal power plant has been used as the base material. Coarse aggregate of different sizes like 20, 16, 12.5, 10, 4.75 mm and locally available sand were mixed in different percentages. The coarse and fine aggregates used for the experiment were in saturated surface dry condition.

The combination of sodium hydroxide and sodium silicate was used as the alkaline liquid. The sodium hydroxide of commercial graded was mixed with distilled water for producing sodium hydroxide solution with 16 molar concentrations. The ratio of sodium hydroxide to sodium silicate ratio was kept as 1:2.5 (by volume).

Colloidal nano silica (nS) with 0.75%, 3% and 6% by weight of fly ash was added to the alkaline liquid. Water present in the colloidal nano silica was adjusted from the activator solution during the preparation of nano silica mixed geopolymer concrete. Multiwall carbon nano tube (CNT) (0.02% by weight of fly ash) was added with polycarboxylate ether (2% by weight of fly ash) and the mixture of CNT and polycarboxylate ether was added during the preparation of CNT mixed geopolymer concrete. In another case titanium dioxide ($TiO_2$) of 1% by weight of fly ash was added during the preparation of geopolymer concrete. Water to geopolymer ratio was adjusted as 0.25 for all M25 grade geopolymer concrete. Mixing of the materials for geopolymer concrete of M25 grade was based on volumetric approach. All types of geopolymer concrete were first air cured for 48 h after casting and then heat cured at 60° C for next 48 h. After that period the samples were kept in air till the test. The controlled concrete samples made with OPC were cured in ambient condition till the test.

## Preparation of samples and testing

### Samples preparation for mechanical strength test and non-destructive test

The standard cube specimens of size 150 mm × 150 mm × 150 mm were cast to determine the compressive strength of geopolymer concrete for different mixes without and with nano materials addition. All the specimens were tested for 7 days and 28 days after casting to determine the compressive strength at different ages. The compressive strength report is shown in Fig. 1.

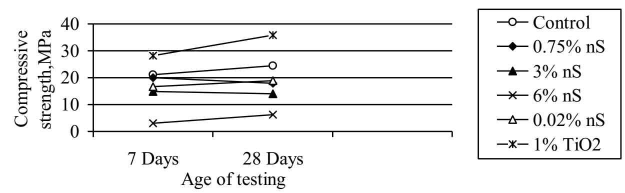


**Figure 1** Compressive strength report of M25 grade geopolymer concrete of various types.

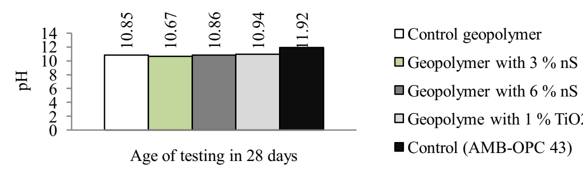


**Figure 2** pH of M25 grade geopolymer concrete (with or without nano materials).

Non-destructive tests like, rebound hammer (for prediction of compressive strength from standard curve) and ultrasonic pulse velocity (for quality of concrete as per IS code) were also performed for that samples. The applicability of standard charts & graphs mainly used for cement based concrete were also verified. The details of non-destructive test results for the different geopolymer concrete samples are shown in Tables 1 and 2.

### Samples preparation for pH test

The geopolymer concrete sample of 10 g passed through the 600 μm IS sieve were mixed with 100 ml distilled water and stirred for 60 min. pH was measured with a pH probe and meter. In that case geopolymer concrete samples with 3% and 6% nano silica addition and with 1% titanium dioxide ($TiO_2$) addition was also tested along with controlled geopolymer concrete samples at 28 days. The pH report is shown in Fig. 2.

## Results and discussion

### Compressive strength test and non-destructive test

Fig. 1 shows the compressive strength of geopolymer concrete with addition of nano silica (0.75%, 3%, 6%), 0.02% multi-walled carbon nano tube (CNT) and also with 1% titanium di-oxide ($TiO_2$). The strength of geopolymer concrete in control condition was also compared.

However, addition of nano materials in the low calcium fly ash based geopolymer concrete seems to provide comparable compressive strength. It was shown that geopolymer concrete with addition of 0.75% nano silica provided almost 80% of the compressive strength at 7 days but at 28 days the strength seemed to be decreased whereas 3% and 6% nano silica addition did not provide satisfactorily compressive strength at 7 and 28 days. In case of 0.02% carbon nano tube addition with geopolymer concrete 7 and 28 days compressive strength was not also quite satisfactorily. Geopolymer

**Table 1** Rebound hammer test report for geopolymer concrete samples.

| Age of rebound hammer test | | Types of geopolymer concrete | | | | | |
|---|---|---|---|---|---|---|---|
| | | Control | 0.75% nS | 3% nS | 6% nS | 0.02% CNT | 1% $TiO_2$ |
| 7 days | Rebound hammer no | 23 | 22 | 24 | <10 | 20 | 27 |
| | Predicted compressive strength | 14 ± 5.1 MPa | 13 ± 4.95 MPa | 16 ± 5.4 MPa | NA | 10 ± 4.5 MPa | 21 ± 6.0 MPa |
| 28 Days | Rebound hammer no | 30 | 25 | 29 | 23 | 25 | 27 |
| | Predicted compressive strength | 25 ± 6.3 MPa | 18 ± 5.7 MPa | 24 ± 6.2 MPa | 14 ± 5.25 MPa | 18 ± 5.7 MPa | 21 ± 6.0 MPa |

**Table 2** Ultrasonic pulse velocity test report for geopolymer concrete samples.

| Age of ultrasonic pulse velocity test | Types of geopolymer concrete | | | | | |
|---|---|---|---|---|---|---|
| | Control | 0.75% nS | 3% nS | 6% nS | 0.02% CNT | 1% $TiO_2$ |
| 7 days | 7.14 | 7.21 | 4.18 | 4.81 | 7.26 | 7.12 |
| 28 days | 7.16 | 6.95 | 4.27 | 4.67 | 6.93 | 6.95 |

concrete with 1% titanium di-oxide addition provided good strength at both of 7 and 28 days. In that case 7 days strength is 32.96% more than M25 grade reference geopolymer concrete and at 28 days that result was 46.65% more than reference concrete.

Tables 1 and 2 show the non-destructive test of geopolymer concrete incorporating nano material and also for control condition. Rebound hammer test shows the predicted compressive strength according to the rebound number and standard curve. It was found that the predicted compressive strength at 7 days was almost similar to the actual compressive strength after crushing whereas at 28 days the result was not similar mainly for 3% and 6% nano silica and 1% $TiO_2$ addition. In case of ultrasonic pulse velocity test, the values were greater than 4.5 km/s. So it can be said the quality of concrete for all cases were excellent as per the IS code which was prepared basically for the cement based concrete.

## pH test

Fig. 2 shows the pH test results of geopolymer concrete with addition of nano silica and titanium di-oxide ($TiO_2$) and also the comparison with geopolymer and OPC samples in control condition. The 28 days test result for pH was noticed as almost same for geopolymer concrete samples with addition of nano materials and also for control condition.

## Conclusion

Based on the present experimental study it can be concluded that nano silica and also titanium di-oxide can be added with low calcium fly ash based geopolymer concrete to get satisfactory amount compressive strength. Predicted compressive strength from Rebound hammer number and standard curve also shows similar results. UPV for all cases of geopolymer concrete gives good value for assessing the quality of concrete as per the table mentioned in IS code which are basically prepared for cement based concrete. The table may be modified for suitability of geopolymer concrete. The pH of geopolymer sample is almost same for all cases due to the use of alkaline solution as the source material.

## Conflict of interest

None declared.


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