Construction and Building Materials 135 (2017) 430–439

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

# Structural performance of nano-silica modified fly-ash based geopolymer concrete

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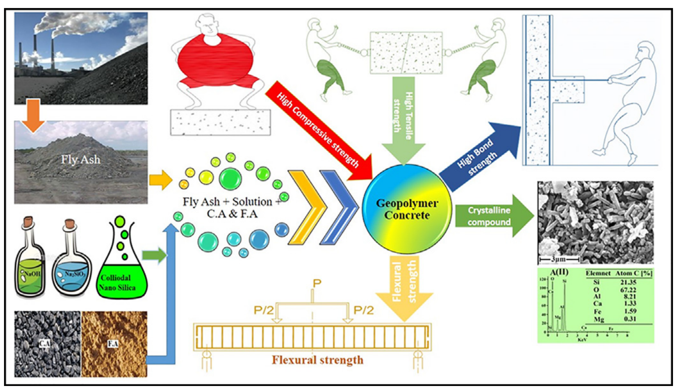
## HIGHLIGHTS

- Nano silica based geopolymer concrete shows excellent strength at room temperature.
- Flexural strength of 12GC6 reinforced concrete beam is higher than 12GC0H and CC.
- Bond performance of rebar with 12GC6 concrete is better than that of 12GC0H and CC.
- Nano silica enhances the geopolymerization process at ambient temperature.

## GRAPHICAL ABSTRACT




## ARTICLE INFO

*Article history:*
Received 20 April 2016
Received in revised form 2 November 2016
Accepted 21 December 2016
Available online 12 January 2017

*Keywords:*
Fly ash
Nano silica
Geopolymer concrete
Structural performance
Micro structure

## ABSTRACT

The fly ash based geopolymer concrete generally requires heat activation of different temperatures, which has been considered as an important limitation for its practical application. Such limitation can be overcome by the addition of appropriate amount of nano-silica in the mixture. Therefore, a fly ash based geopolymer concrete can be developed using 6% nano silica replacing fly ash. The structural performance of such geopolymer concrete in terms of bond strength, flexural strength and micro structural behaviour has been explored. Such nano silica modified fly ash based geopolymer concrete shows appreciable improvement in structural behaviour at different ages without any heat activation. The bond strength between reinforcement bars (deformed or mild steel) and surrounding geopolymer concrete materials (with/without nano silica) has been also compared to the conventional cement concrete. The nano silica modified geopolymer concrete exhibits better structural performance than heat cured geopolymer concrete (without nano silica) and conventional cement concrete samples. The microstructural properties of such geopolymer concrete (with/without nano silica) and cement concrete have been analyzed through Field Emission Scanning Electron Microscope (FESEM) with Energy Dispersive X-ray Spectroscopy (EDS), Fourier Transform Infrared Spectroscopy (FTIR) analysis and X-ray Diffraction (XRD) techniques. The enhancement of structural performance is mainly due to the transformation of amorphous phase to crystalline phase in the geopolymer concrete matrices in the presence of nano-silica.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http://dx.doi.org/10.1016/j.conbuildmat.2016.12.111
0950-0618/

## 1. Introduction

Geopolymer is a novel inorganic polymer binding material produced from the reaction of fly ash with the alkaline activator fluid; to ensure strength, durability and environmental sustainability. It is emerging as a greener alternative to Ordinary Portland Cement (OPC) in the construction field over the last two decades as the cement industry is the second largest producer of the greenhouse gas. The production of 1.0 ton Ordinary Portland Cement produces about 1.0 ton of carbon dioxide into the atmosphere [1]. Total $CO_2$ production attributed to cement production contributes around 8% of global $CO_2$ emission to the atmosphere [2].

The larger uses of the cement are becoming the global threats to the living organism day by day. The scientists and the researchers are trying to reduce the uses of cement as well as $CO_2$ production. The alternative products like nanomaterial, admixtures, chemicals, microorganisms are used in cementitious materials to enhance the strengths and to reduce the cement consumption [3–6]. However, their uses have some drawbacks and finally fail to reach the desired result. On the other hand, total coal combustion products in the form of fly ash were approximately 780 Mt in the year of 2011–2012 all over the world. Although effective utilization of fly ash was limited to only 415 Mt or 53% of total production and excess remains as an industrial hazard [7]. Thus, low calcium contain fly ash based geopolymer concrete are emerging as an alternative low emission binding material compared to OPC [8].

Fly ash are normally amorphous spherical particles, in addition to unburnt carbon, crystalline mullite, quartz and hematite. The mineralogical and chemical composition of fly ash, in general, depends on the source of coal and types of power plants [9]. The higher molarity of NaOH in fly-ash based geopolymer appeared to provide higher compressive strength together with a considerable effect on the early strength cured at 60 °C for 48 h [10,11].

It was already established that to accelerate the polymerization process, heat activation is generally needed for the development of physical and mechanical properties of geopolymer concrete [12–14]. The structural behaviour of heat cured fly ash based geopolymer concrete shows better performance than the conventional cement concrete [15–18]. The scope of such concrete is limited to the precast members due to the requirement of the heat activation after casting unlike conventional concrete. Thus, the exploration/investigation is required to develop the fly ash based geopolymer concrete cured at an ambient temperature [19,20]. The geopolymer paste made of the mechanically activated fly ash (vibration mill with milling media to powder ratio of 10:1) leads to an 80% increase in compressive strength when compared with the geopolymer made from raw fly ash [21]. The compressive strength of high volume fly ash mortars with the addition of nano-silica has significantly improved at room temperature curing [22]. The early strength is also achieved in geopolymer mortar (fly-ash + rice husk ash) having a different percentage of nano-silica and nano aluminum oxide with heat activation for 2, 4 and 8 h at different temperatures [23]. Also, the addition of nanoparticles in fly ash geopolymer mortar shows the appreciable strength at ambient temperatures curing [24–27]. The addition of colloidal nano-silica (6% w/w) in low calcium fly ash based geopolymer mortar at room temperature exhibited the maximum improvement of strength and durability [28].

The aim of this present exertion is to elucidate the effect of the addition of nano-silica on the structural behaviour (compressive strength & split tensile strength) of fly ash based geopolymer concrete cured at ambient temperature and to compare with heat cured fly ash based geopolymer concrete as well as conventional cement concrete. The flexural behaviour of reinforced concrete beams (with/without nano silica modified geopolymer concrete and control cement concrete) has been studied at different percentages of reinforcement (tension, compression and shear). Also, this study includes the bond strength between reinforcement bars and surrounding concrete matrices (both geopolymer concrete and control cement concrete). Microstructural properties of nano silica modified geopolymer concrete, and other type of concretes has been assessed through Field Emission Scanning Electron Microscope (FESEM) with Energy Dispersive X-ray Spectroscopy (EDS), Fourier Transform Infrared Spectroscopy (FTIR) analysis and X-ray Diffraction (XRD) test.

## 2. Materials & methods

### 2.1. Ingredients

Fly ash from National Thermal Power Corporation Ltd, Farakka plant in India has been used as the base material [29,30]. The basic properties of the fly ash and the grain size distribution are presented in Tables 1A and 2 respectively. Locally available sand (Specific gravity 2.52, water absorption 0.50%, and fineness modulus of 2.38) and 12 mm down coarse aggregates (Specific gravity 2.78, water absorption 0.42%, and fineness modulus of 4.89) have been used for the present study. The sodium hydroxide (NaOH) pellet of 99% purity and liquid sodium silicate ($Na_2SiO_3$) (specific gravity 1.53 gm./cc) having 45% solid content are used as an activator fluid [31]. The basic properties of nano silica used are represented in Table 3. The Ordinary Portland Cement (OPC) of 43 grade (Refer Table 1B) has been used for the conventional cement concrete mixture. The mild steel (yield stress = 250 MPa) and the deformed steel bar (0.2% proof stress = 500 MPa) of 20 mm diameter are used for bond strength test. The deformed steel bar of 6 mm and 8 mm diameter have been used as longitudinal (tension and compression) and shear reinforcement for reinforced concrete flexural members.

**Table 1B**
Chemical analysis report of OPC 43 grade cement.

| Material | Chemical composition (in percentage) |
|---|---|
| *OPC (43 grade):* | |
| Los in ignition | 1.55 |
| Insoluble residue | 2.00 |
| Magnesium Oxide | 1.40 |
| Lime saturation factor | 0.87 |
| Alumina Iron ratio | 1.00 |
| Sulphuric Anhydride | 1.90 |
| Alkalis | 0.60 |
| Chlorides | 0.01 |

**Table 1A**
Chemical analysis report of fly ash.

| Material | Chemical composition (in percentage) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fly Ash | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | $SO_4$ | LOI |
| | 64.97 | 26.64 | 5.69 | 0.33 | 0.85 | 0.49 | 0.25 | 0.33 | 0.45 |