**Advances in Concrete Construction**, *Vol. 7, No.* 2 *(2019) 107-115*
DOI: https://doi.org/10.12989/acc.2019.7.2.107


# An experimental study on effect of Colloidal Nano-Silica on tetranary blended concrete

Avuthu Narender Reddy[a] and T. Meena*

*Department of Structural and Geo-Technical Engineering, School of Civil Engineering (SCE), Vellore Institute of Technology (VIT-Vellore), Vellore, Tamil Nadu, 632014, India*

*(Received August 10, 2018, Revised March 13, 2019, Accepted March 17, 2019)*

**Abstract.** The possibility of using a combination of mineral admixtures as a replacement for cement may reduce the $CO_2$ emission which causes global warming and climatic changes on the environment. By using the combination of different by-products from various industries, for replacing cement in concrete leads to saving in energy and natural resources. In this article, an attempt has been made to study the mechanical and water absorption properties of concrete incorporated with combination of Fly ash (FA), Alccofine (ALC) and Collodial Nano Silica (CNS) at 7, 28 and 56 days curing period. Cement has been partially replaced by combination of FA at 25%, ALC at 10% and CNS at 0.5%, 1%, 2% and 3% with water cement ratio of 0.43. The result indicates that the incorporation of combination of FA, ALC and CNS can be very effective in improvement of mechanical and water absorption properties of concrete. The Mix with a combination of 25% FA, 10% ALC and 1% CNS is most effective in improvement of mechanical and water absorption properties as compared with all other mixes.

**Keywords:** fly ash; Alccofine; Collodial Nano Silica; tetranary blended concrete

## 1. Introduction

Now-a-days cement is being used on large scale in the production of concrete worldwide. Due to this the global demand of cement has reached about 5 billion metric tons. Due to which the large amount of raw material is consumed for the production of cement, which causing huge amount of $CO_2$ release into the atmosphere (Andrew *et al.* 2018, Reddy *et al.* 2018, Varun Teja *et al.* 2017, Aly *et al.* 2012, Gopala Krishnan *et al.* 2011, Zhang *et al.* 2011). About 5% to 7% of manmade $CO_2$ gas emission is released during the production of cement (Andrew *et al.* 2018, Bala *et al.* 2017, Malhotra 2002). The lot of research is being done to find the supplementary cementitious material in order to safeguard the environment. Efforts are being made for usage of industrial by products as cementitious materials possessing pozzolanic properties (Varun Teja *et al.* 2017, Bala *et al*. 2017, Martin *et al*. 2015). The pozzolanic materials such as the Silica Fume (SF), Ground Granulated Blast Furnace Slag (GGBS), Rice Husk Ash (RHA), Fly Ash (FA) etc, which are by-product from various industries are being used as replacing material for cement (Varun Teja *et al.* 2017, Saha *et al.* 2016, Li 2007, Shi *et al.* 2012, Morsy *et al.* 2012, Nazari *et al.* 2011, Yuvaraj *et al.* 2012, Barbhuiya *et al.* 2014, Singh *et al.* 2013, Kupwade-Patil *et al.* 2016, Martin Antonia *et al.* 2015). The utilization of pozzolanic materials diminishes the cement consumption and furthermore expands the strength and durability of concrete (Kupwade-Patil *et al.* 2016, Martin Antonia *et al.* 2015).

Recently some of the researchers have reported that the micro fine material namely Alccofine (ALC), obtained as a by-product from iron ore industry in India also possess pozzolanic nature and can be used as a partial replacement of cement in concrete (Jariwala *et al.* 2016). By using ALC as an admixture a significant improvement in workability and mechanical properties of concrete was observed (Jindal *et al.* 2016, Jindal *et al.* 2017). Due to the ultrafine particle size, ALC improves the micro pore filling ability and offers resistance to segregation which helps in enhancing fresh, mechanical and durability properties of concrete significantly. It is very much economical than all other micro pozzolanic materials like SF, MK (Varun Teja *et al.* 2017, Bala *et al.* 2017, Reddy *et al.* 2017). However, very little work has been reported on the use of ALC in concrete and mortars.

From the past few years, the nanotechnology had a potential use of particles at the nanometre scale (Shaikh *et al.* 2014, Oltulu *et al.* 2011, Nazari *et al.* 2010, Jalal *et al.* 2012). Nano particles plays a major job in the enhancement of mechanical and durability properties of concrete by giving incredible surface area, which prompts increasing acceleration of pozzalanic reactions (Bhuvaneshwari *et al.* 2012, Oltulu *et al.* 2011, Quercia *et al.* 2010, Quercia *et al.* 2012). They also additionally fill pores with nonreactive particles within the presence of cement. All these improvements influence the mechanical and toughness qualities of concrete. These improvement leads to extend the lifespan of concrete structures and a reduction in expense for repair of such structures as a result (Oltulu *et al.* 2011, Quercia *et al.* 2010, Quercia *et al.* 2012). A few kinds of nano particles are utilized in concrete, for example nano

*Corresponding author, Associate Professor
E-mail: meena14473@gmail.com
[a]Research Scholar


http://www.techno-press.org/?journal=acc&subpage=7
ISSN: 2287-5301 (Print), 2287-531X (Online)

Table 1 Physical properties of Ordinary Portland Cement (OPC)

| Characteristics | Test Results | Values as per BIS:12269 - 2013 |
|---|---|---|
| Grade | 53 | 53 |
| Fineness modulus | 6.5% | < 10% |
| Specific gravity | 3.12 | 3.15 |
| Standard consistency | 32% | 30% - 35% |

Table 2 Chemical properties of Ordinary Portland Cement (OPC)

| Characteristics | Result by Mass (%) |
|---|---|
| Silicon dioxide | 21.1 |
| Calcium oxide | 62.4 |
| Ferric oxide | 2.49 |
| Aluminium oxide | 4.50 |
| Loss on ignition | 2.40 |

Table 3 Properties of fine aggregate

| Characteristics | Test Results | Values as per BIS:383 - 2016 |
|---|---|---|
| Specific gravity | 2.682 | 2.1 - 3.2 |
| Fineness modulus | 2.71% | 2% - 4% |
| Water absorption | 1.023% | <5% |

Table 4 Properties of coarse aggregate

| Characteristics | Test Results | Values as per BIS:383 - 2016 |
|---|---|---|
| Specific gravity | 2.781 | 2.1 - 3.2 |
| Fineness modulus | 7.22 % | 6.5% - 8% |
| Water absorption | 0.83% | <5% |

silica, nano aluminium, nano titanium etc, there are many research provides details regarding the usage of nano particles in building materials.

However, the most widely recognized and important Nano material in the production of concrete is Nano Silica (NS). From past few years, NS has transformed into an effective material for the enhancement of mechanical and durability properties of concrete (Reddy *et al.* 2017, Ghaseni *et al.* 2010). It is also found that the use of NS in concrete had two advantages, the first one is the NS can produce a pozzolanic reaction with free calcium hydroxide crystals to form more C-S-H gel in the concrete and the second one is due to the nano size particles, NS has an ability to fill the micro pores which helps to improve the density of Interfacial transition zone (ITZ) of concrete (Li *et al.* 2007, Beera *et al.* 2012, Erdem *et al.* 2012, Reddy *et al.* 2017). NS can either be used as a replacement of cement or as an additive to concrete, mortar and cement paste. In all cases, NS enhances the performance of concrete in fresh and hardened states (Senff *et al.* 2012, Naji *et al.* 2010, Ltifi *et al.* 2011).

The main intension of this work is to find out at the effect of combination of FA at 25%, AL at 10% and various percentages (0%, 0.5%, 1%, 2% and 3%) of NS as replacement of cement on properties like Compressive Strength, Split Tensile Strength, Flexural Strength and Water Absorption of Tetranary Blended Concrete. The paper moreover moreover focuses at the effects of using the combination of FA, ALC, and CNS on initial stage and long-time properties of TBC. Hence the efforts are to address the improvement in TBC and examine some of the hardened properties which lead to a sustainable construction.

## 2. Research significance

The ordinary portland cement which is a major constituent of conventional concrete plays a significantly important role in attaining the strength properties. But now-a-days cement had become a major source for pollution which compels the researchers to replace cement by some alternative pozzolanic materials which can provide the desirable mechanical and durability properties to concrete as well as address the pollution menace such as dumping of industrial waste. Previous researchers have focused on the use of combination of Fly Ash and Nano silica in concrete mix to improve the properties of concrete. In the present study, an attempt has been made to study the effect of combination of different pozzolanic materials like Fly Ash, Alccofine and Colloidal Nano Silica as partial replacement of cement on mechanical and water absorption properties of concrete so that their scope to address environmental pollution caused by industrial by-products.

## 3. Materials

### *3.1 Cement*

Ordinary Portland Cement (OPC) of 53 grade confirming to BIS: 12269-2013 was used for preparation of various mixes.

### *3.2 Fine aggregate*

Locally available river sand passing through 4.75 mm sieve with fineness modulus of 2.71%, falling under Grading Zone II confirming to BIS: 383-2016 was used as fine aggregate.

### *3.3 Coarse aggregate*

Locally available crushed rocks passing through 20 mm sieve confirming to BIS: 383-2016 was used as coarse aggregate.

### *3.4 Water*

Tap water with pH value ranging from 7 to 8 was used.

### *3.5 Mineral admixtures*

FA, ALC and CNS were used as mineral admixtures.

Table 5 Physical properties of mineral admixtures

| Characteristics | Test Results |
|---|---|
| **Fly Ash** | |
| Fineness modulus | 1.19% |
| Specific gravity | 2.3 |
| **Alccofine** | |
| Specific gravity | 2.9 |
| Specific surface area [$m^2$/kg] | 1200 |
| Bulk density [kg/$m^3$] | 680 |
| Particle Size | |
| $D_{10}$ | 1.5 micron |
| $D_{50}$ | 5 micron |
| $D_{90}$ | 9 micron |
| **Colloidal Nano Silica** | |
| Grade | CemSyn |
| Nano solids | 29.4-40.5% |
| Particle size | 10-20 nanometer |
| Specific gravity | 1.21 |
| Viscosity | 4-7 centipoises |

Table 6 Chemical properties of mineral admixtures

| Characteristics | Fly Ash Result by Mass (%) | Alccofine Result by Mass (%) |
|---|---|---|
| Silicon Dioxide | 59.14 | 34.83 |
| Aluminum Oxide | 24.08 | 21.44 |
| Iron Oxide | 12.02 | 1.39 |
| Calcium Oxide | 2.22 | 33.91 |
| Sulphur Trioxide | 0.15 | 0.10 |
| Magnesium Oxide | 0.43 | 6.81 |
| Loss of ignition | 0.63 | 1.42 |

FA was acquired from Dr. NTR Vijayawada Thermal Power Station (VTPS), Vijayawada, Andhra Pradesh. Low calcium FA (class F type) confirming to BIS: 3812-2013 was used. ALC is a specially processed slag based secondary cementitious material with high glass content with a higher reactivity and lower silicate content obtained from controlled granulation. Due to its ultra fine particle size, ALC is generally used as a water reducer to improve mechanical properties along with high workability. ALC 1203 was acquired from Ambuja Cement Ltd, Goa confirming to ASTM C989-1999**.** CNS which is a nanometric particle size solution of silica particles in water was acquired from Beechems Chemicals, Kanpur.

### *3.6 Superplasticizer*

A poly-carboxylic ether based superplasticiser with brand name Master Glenium Sky 8233 which is a new generation chlorides free, super plasticizing admixture confirming to ASTM C494-2017 was used.

## 4. Research methodology

### *4.1 Mix proportions*

Table 7 Properties of superplasticizer

| Characteristics | Test Results |
|---|---|
| Appearance | Brown liquid |
| Specific gravity | 1.08 |
| Chloride content | <0.2% |
| Water reduction | 24% |

Table 8 Mix proportions of controlled conventional concrete mixture and concrete with FA, ALC and CNS

| Mix ID | Cement (kg/$m^3$) | FA (kg/$m^3$) | ALC (kg/$m^3$) | CNS (kg/$m^3$) | Fine Aggregate (kg/$m^3$) | Coarse Aggregate (kg/$m^3$) | Water (kg/$m^3$) |
|---|---|---|---|---|---|---|---|
| CM | 350.22 | - | - | - | 721.51 | 1273.86 | 150.59 |
| N0 | 236.41 | 87.55 | 26.26 | - | 721.51 | 1273.86 | 150.59 |
| N1 | 235.22 | 87.55 | 26.26 | 1.19 | 721.51 | 1273.86 | 150.59 |
| N2 | 234.04 | 87.55 | 26.26 | 2.37 | 721.51 | 1273.86 | 150.59 |
| N3 | 231.68 | 87.55 | 26.26 | 4.73 | 721.51 | 1273.86 | 150.59 |

Mix Proportion =1: 2.06: 3.63: 0.43
CM: Conventional Concrete Mix; N0-N4: Tetranary Blended Concrete (TBC) Mix; SD: Standard Deviation

In the present investigation, M30 grade concrete mix design was carried out according to BIS: 10262-2009 (reaffirmed in 2014). The details of the mix design are as shown in Table 8. The cement content was partially replaced with a combination of FA, ALC and CNS. FA and ALC that were kept constant at 25% and 10% respectively, totally 35% of cement. The CNS content was varied as 0, 0.5%, 1%, 2% and 3% by weight of cement content. The CNS was mixed with water and added to the concrete. The effect of CNS on the mechanical and durability properties of TBC is evaluated. The water/binder ratio of 0.43 was used throughout the mix design. The mix proportions for conventional concrete mix (CM) and TBC are shown in Table 8, respectively.

### *4.2 Casting and curing*

All the concrete mixes were prepared at room temperature i.e., 27℃±10. Dry mixing of cement, FA, ALC, fine aggregate and coarse aggregate was done for approximately for 3 minutes. Water, CNS, and super-plasticizer were mixed for 2-3 minutes prior to mixing with dry mix. The cube samples of size 100 mm×100 mm×100 mm, cylindrical samples of size 200 mm×100 mm diameter and beam samples of size 500 mm×100 mm×100 mm were cast and de-molded after 24 hours. The concrete specimens so prepared were cured under water at room temperature.

### *4.3 Testing procedure*

The mechanical properties of concrete like compressive strength, splitting tensile strength and flexural strength were determined according to BIS: 516-1959 (reaffirmed in 2013). The water absorption test was performed according to ASTM C642-2013. Concrete gains more than 90% of its targeted compressive strength by 28 days of curing period and further the rate of gain in strength becomes very slow.

Literature study reveals that fly ash based concrete may gain more compressive strength in comparison to conventional concrete till a long term curing period (Sabarish *et al.* 2017, Bala *et al.* 2017, Sigh *et al.* 2015). Therefore in the present study 7, 28 and 56 days curing period were adopted for all mechanical and water absorption tests.

### 4.3.1 Testing procedure for compressive strength

The cube samples of size 100 mm×100 mm×100 mm were placed in between the steel plates the without packing. The load applied was increased constantly at 1.4 N/mm$^2$/ minute till the cube failed. From the dial, the maximum load reading is noted.

### 4.3.2 Testing procedure for split tensile strength

The cylindrical specimens of size 200 mm×100 mm diameter were placed horizontally between the loading surface of compression testing machine and the load was applied at a nominal rate of 1.2 N/ mm$^2$/ minute without any shock until the failure of the sample occurs.

### 4.3.3 Testing procedure for flexural strength

The beam samples of size 500 mm×100 mm×100 mm were placed in the flexural testing machine and three point loading was applied at a nominal rate of 0.7 N/mm$^2$/minute without any shock or vibration. The load was increased until the specimen failed and the failure load was recorded. The appearance of the fractured faces of concrete and any unusual features in the type of failure were noted.

### 4.3.4 Testing procedure for water absorption

The water absorption test was performed according to ASTM C642-2013. Water absorption tests were conducted on cube samples for 7, 28 and 56 days curing period. The samples were allowed to complete the curing under room temperature and allowed to dry in open sky for 2-3 hours, so that the surface moisture content will get evaporated. Now the specimens are kept in oven at 110℃. After 24 hours the samples were removed from oven and allowed to cool upto room temperature. Weights of samples (A) were measured after cooling of samples upto room temperature. After measuring the weight-A, samples were again immersed in water. After 48 hours the samples were removed from the water and they were weighed as weight-B. The water absorption percentage of samples was calculated by using the formula.

$$\text{Water Absorption \%} = [(B\text{-}A)/A]\times 100 \quad (1)$$

$A$=Weight of the oven dried sample at 110℃ for 24 hours,

$B$=Weight of the sample after 48 hours of immersion in water.

## 5. Results and discussions

The test results of compressive strength test, split tensile strength test, flexural strength test and water absorption test on Tetranary Blended Concrete with varying percentage of CNS are explained in the subsequent sub-sections.

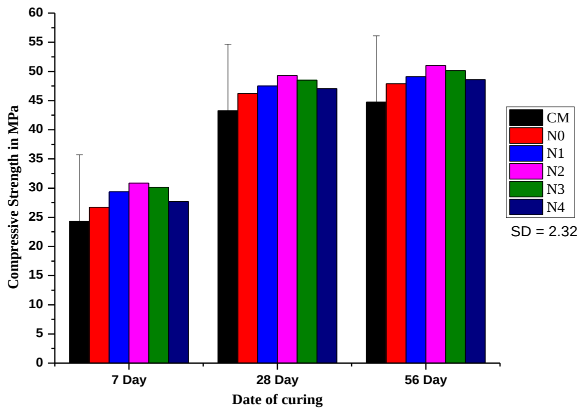


Fig. 1 Graphical representation for compressive strength of TBC mixes

### 5.1 Compressive strength test

Fig. 1 compares the compressive strength of conventional concrete mix and TBC mixes.

From the results, it is clearly observed that the Tetranary Blended Concrete mixes made with Colloidal Nano Silica showed higher compressive strength than conventional concrete mix. The early age (7 days) compressive strength of mixes N0, N1, N2,N3 and N4 was improved by 9.86%, 20.68%, 26.84%, 23.97%, and 14.10% respectively, in comparison to conventional concrete mix. It was also noticed that the compressive strength of Tetranary Blended Concrete samples were enhanced when cement content was replaced up to 1% Colloidal Nano Silica and declined slightly on increasing the CNS material. The improvement in early age compressive strength of Tetranary Blended Concrete mix might be due to the accelerated hydration reaction on addition of Alccofine and Colloidal Nano Silica (Li *et al.* 2007, Reddy *et al.* 2017, Jindal *et al.* 2016, Jindal *et al.* 2017). Similar types of results were observed at the age of 28 and 56 days. For 28 days curing period the mixes with Colloidal Nano Silica, Fly Ash and Alccofine i.e., N0, N1, N2 and N3 showed an improvement in compressive strength by 7.08%, 9.78%, 14.10%, 12.17% and 8.78% respectively with respect to the conventional concrete mix. The later age strength (56 days) showed a negligible change with respect to 28 days strength is may be due to the acceleration of heat of hydration by CNS and ALC in concrete lead to dense micro structure, from the results it has been observed that maximum percentage of the hydration is completed at 28 days, the rest negligible percentage of hydration will be very very slow and keep going with the time so it had showed the negligible change of strength for 56 days curing period. From the above results, it was observed that the percentage strength gain is higher for 7 days of curing when compared with other ages of curing. Therefore it can be concluded that the rapid development of the compressive strength of Tetranary Blended Concrete at early age shows that the Alccofine and Colloidal Nano Silica not only serves as a filler to increase the density of the micro and nanostructure of concrete but also serves as an activator in the hydration process. The decrease in strength on addition of Colloidal Nano Silica

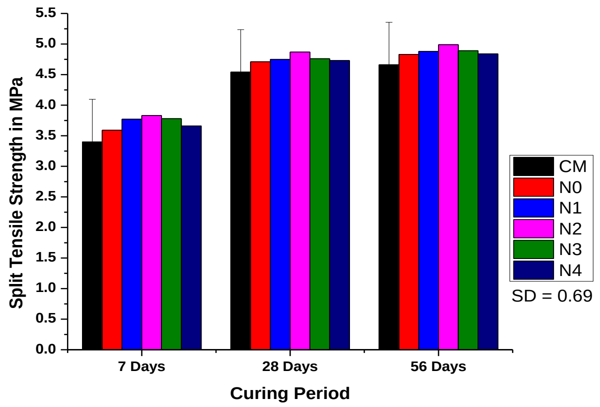


Fig. 2 Graphical representation of the split tensile strength of TBC mixes

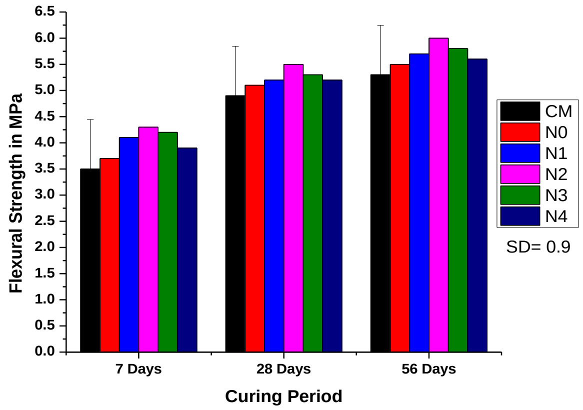


Fig. 3 Graphical representation of the flexural strength of TBC mixes

beyond 1% is attributed to the reason that the quantity of Colloidal Nano Silica particles is higher than the of liberated lime quantity in the hydration process resulting in leaching out of excess silica that leads to decrease in pore bonding strength (Li *et al.* 2007, Chitra *et al.* 2016). Thus, at this stage the combination of Fly Ash, Alccofine and Colloidal Nano Silica acts as cement replacement materials used for filling the pores but does not involve in the hydration process (Li *et al.* 2007, Chitra *et al.* 2016). The inclusion of Fly Ash, Alccofine and Colloidal Nano Silica enhanced the compressive strength for all the employed cases, in comparison with the conventional concrete mix.

### *5.2 Split tensile strength test*

The variation in split tensile strength for CM and TBC mixes are shown in Fig 2.

From the results, it is clearly observed that the Tetranary Blended Concrete mixes made with Colloidal Nano Silica showed higher Split tensile strength than conventional concrete mix. The early age (7 days) Split tensile strength of mixes N0, N1, N2, N3 and N4 was improved by 4.03%, 9.53%, 11.07%, 9.84% and 6.15% respectively, in comparison to conventional concrete mix. Similar types of results were observed at the age of 28 and 56 days. The mixes with CNS and ALC i.e., N0, N1, N2 and N3 showed an improvement in split tensile strength by 3.73%, 4.62%, 7.24%, 4.90% and 4.20% respectively compared to conventional concrete mix for 28 days curing period. At 56 days curing period Tetranary Blended Concrete mixes showed a negligible change in tensile strength compared 28 days strength is may be due to the acceleration of heat of hydration by CNS and ALC in concrete lead to dense micro structure. From the results it has been observed that maximum percentage of the hydration is completed at 28 days, the rest negligible percentage of hydration will be very very slow and keep going with the time so it had showed the negligible change of strength for 56 days curing period. This increase in tensile strength may be attributed to the improved properties of the concrete matrix and the strong inter-phase bond between the binders (i.e., between cement, Fly ash, Alccofine and Collodial Nano Silica) and the aggregates used (Chitra *et al.* 2016). The Interfacial Transition Zone (ITZ) plays a key role in the development of split tensile strength. By utilizing micro and nano particles like Alccofine and Colloidal Nano Silica, the ITZ becomes denser resulting in improvement of split tensile strength (Sanchez *et al.* 2010, Said *et al.* 2012). It was also noticed that the Split tensile strength of Tetranary Blended Concrete samples was enhanced when cement content was replaced up to 1% CNS and declined slightly on increasing the Colloidal Nano Silica content. The decrease in tensile strength with greater than 1% CNS replacement is attributed to the reason that the quantity of Colloidal Nano Silica particles is higher than the of liberated lime quantity in the hydration process resulting in leaching out of excess silica that leads to decrease in strength (Li *et al.* 2007, Chitra *et al.* 2016).

### *5.3 Flexural strength test*

The variation in flexural strength for CM and TBC mixes are shown in Fig. 3.

From the results, it is clearly observed that the Tetranary Blended Concrete mixes made with Colloidal Nano Silica showed higher flexural strength than conventional concrete mix. The early age (7 days) flexural strength of mixes N0, N1, N2,N3 and N4 was improved by 5.71%, 17.14%, 22.85%, 20%, and 11.42% respectively, in comparison to conventional concrete mix. Similar types of results were observed at the age of 28 and 56 days. The mixes with CNS and ALC i.e., N0, N1, N2 and N3 showed an improvement in flexural strength by 4.08%, 7.41%, 12.24%, 9.18% and 6.12% respectively with respect to the conventional concrete mix for 28 days curing period. The later age flexural strength (56 days) showed a negligible change with respect to 28 days flexural strength. It was also noticed that the flexural strength of Tetranary Blended Concrete samples was enhanced when cement content was replaced up to 1% CNS and declined slightly on increasing the Colloidal Nano Silica content. From the above results, the inclusion of Fly ash, Alccofine and Colloidal Nano Silica enhanced the strength for all the employed cases, in comparison with the conventional concrete mix. However the compressive strength, splitting tensile strength and flexural strength for all the samples were closer to each other.

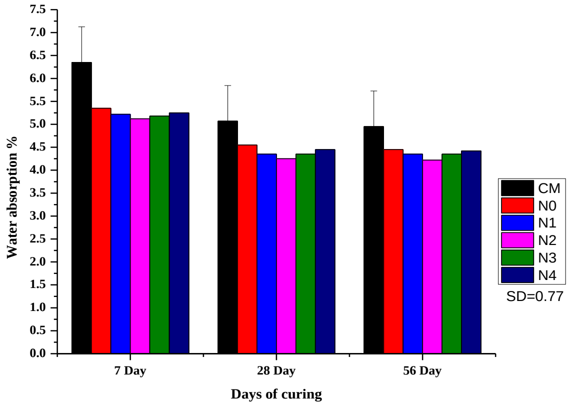


Fig. 4 Graphical representation of the water absorption test of TBC mixes

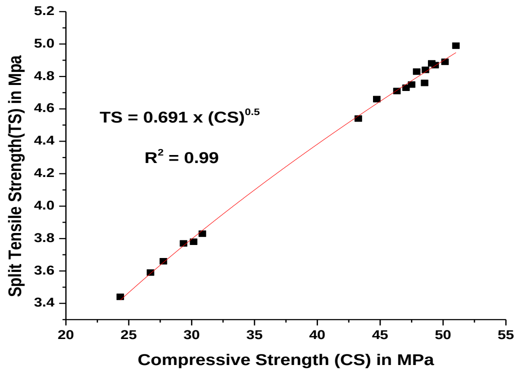


Fig. 5 Graphical representation of the relationship between compressive strength (CS) and splitting tensile strength (TS) of TBC mixes

### *5.4 Water absorption test*

The impact of combination of FA, ALC and CNS on the water absorption of TBC mixes at the age of 7, 28 and 56 days are shown in Fig. 4.

From the results, it is clearly observed that the Tetranary Blended Concrete mixes made with Colloidal Nano Silica showed lower water absorption percentage than the conventional concrete mix. The early age ($7^{th}$ day) water absorption percentage was decreased by 4.68%, 4.37%, 4.24%, 4.34% and 4.50% respectively for N0, N1, N2, N3 and N4 mixes compared to conventional concrete mix. Similar types of results were observed at the age of $28^{th}$ and $56^{th}$ days. The mixes with CNS and ALC i.e N0, N1, N2 and N3 showed decrease in water absorption percentage of 3.40%, 3.11%, 2.84%, 2.91% and 3.17% respectively with respect to the conventional concrete mix for $28^{th}$ day and on $56^{th}$ day the water absorption showed a decrease in percentage by 2.99%, 2.67%, 2.42%, 2.61% and 2.74% respectively for N0, N1, N2, N3 and N4 mixes compared to conventional concrete mix. The low water absorption percentage results in Tetranary Blended Concrete mixes may be due to occurrence of higher pozzolanic effect by Alccofine and Colloidal Nano Silica due to their micro and nano particle size which made the concrete more denser, more compacted and also improved the pore structure of the concrete which helped to reduces the water absorption percentage (Chitra *et al.* 2016, Li *et al.* 2007). It was also noticed that the water absorption percentage of Tetranary Blended Concrete samples was decreased up to 1% CNS as replacement for cement and increased slightly on increasing the Colloidal Nano Silica content. The decrease in water absorption percentage with greater than 1% CNS replacement is attributed to the reason that the quantity of Colloidal Nano Silica particles is higher than the of liberated lime quantity in the hydration process resulting in leaching out of excess silica which my leads to effect pore structure of concrete that leads to increase in water absorption slightly (Li *et al.* 2007, Chitra *et al.* 2016).

### *5.5 Regression analysis*

In the present study, the correlation between compressive strength and splitting tensile strength as well as between compressive strength and water absorption percentage was also developed for Tetranary Blended Concrete.

#### *5.5.1 Relationship between compressive strength and split tensile stength*

Fig. 5 illustrates the relationship between compressive strength (CS) and split tensile strength (TS) for Tetranary Bended Concrete which can be represented by Eq. (2).

$$TS = 0.691 \times (CS)^{0.5} \quad (2)$$

It can be noted that the relationship between compressive strength and split tensile strength of TBC is very similar to that recommended by BIS:456-2000 for conventional concrete. From the results it clearly seen that, as the split tensile strength of TBC concrete increased as the compressive strength increased. It also indicate that the Split tensile strength of TBC concrete increased as the time until testing increased from 7 to 56 days (Chitra *et al.* 2016). The analysis in Fig. 5 shows that the best fit line representing the relationship between split tensile strength with compressive strength at all the ages of curing. The $R^2$ value was found to be 0.99. It is clearly seen that the regression line for Tetranary Blended Concrete does not depend on variables like binders used and other parameters. The coefficient of correlation, $R^2$=0.99 indicates very good level of correlation. $R^2$ value is replicating a good relation between compression and split tensile strength with the replacement of cement with combination of FA, ALC and CNS.

#### *5.5.2 Relation between compressive strength and water absorption (%)*

Fig. 6 illustrates the relationship between Water absorption and compressive strength (CS) for Tetranary Bended Concrete which can be represented by Eq. (3).

$$y=-22.631x+147.43 \quad (3)$$

A good relationship was found between water absorption and compressive strength for Tetranary Blended Concrete. The correlation coefficient $R^2$=98.7% indicates the strong relation between the water absorption and

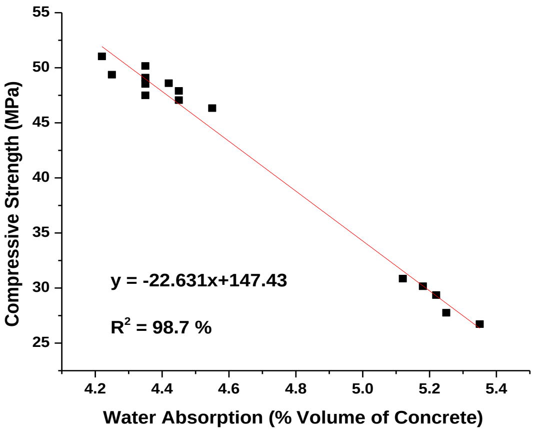


Fig. 6 Graphical representation of the relationship between compressive strength and water absorption percentage of TBC mixes

compressive strength of TBC. By this relation it is possible to predict the water absorption behavior by knowing the trend of compressive strength for Tetranary Blended Concrete. Therefore it can be concluded that as the compressive strength increases, the water absorption percentage decreases (Jindal *et al.* 2016, Jindal *et al.* 2017).

## 6. Conclusions

Based on the experimental investigation carried out on Tetranary Blended Concrete mixes, it can be concluded that the mechanical and water absorption properties of TBC increased due to higher specific surface area and high pozzolanic activity nature of ALC and CNS resulting in high production of C-S-H gel which helps in formation of compact structure in the concrete and also helps in improving the early strength gaining capacity and pore filling effect making the concrete denser and compacted. From the above studies it is concluded that 25% FA, 10% ALC and 1% CNS in concrete was found to be more beneficial and better performance in mechanical and water absorption properties when compared with all other mixes. Beyond 1% CNS content the strength and water absorption properties tends to decrease due to the higher quantity of CNS particles than that of liberated lime quantity in the hydration process resulting in leaching out of excess silica which may leads to effect pore structure of concrete. Using the combination of FA, ALC, and CNS as a replacement for cement leads to eco-friendly and sustainable concrete.

## Acknowledgments

The authors acknowledge the Vellore Institute of Technology (VIT deemed to be University), Vellore providing laboratory testing facility. The authors further highly thankful to Dr. Bharat Bhushan Jindal, Assistant Professor, School of Civil Engineering at Shri Mata Vaishno Devi University, Katra, India for his valuable guidance. The authors are further thankful for the Mrs. Sapna Devendra, Regional Manager- South at Ambuja Cements Ltd and Mr. Vijayant, Beechems chemicals, Kanpur for providing required materials.

## References

Ahmed Abubakar, J., Dhaduk, D., Abhishek, R., Rathod, J.S. and Pritesh. (2016), "Experimental study on the enhancement in concrete due to the ultra-fine particles", *Global Res. Develop. J. Eng.*, **138**, 120-135.

Aly, M., Hashmi, M.S.J., Olabi, A.G., Messeiry, M., Abadir, E.F. and Hussain, A.I. (2012), "Effect of colloidal nano-silica on the mechanical and physical behavior of waste-glass cement mortar", *Mater. Des.*, **33**, 127-135.

Andrew, R.M. (2018), "Global $CO_2$ emissions from cement production", *Earthq. Syst. Sci. Data*., **10**, 195-217.

ASTM C494 (2017), Standard Specification for Chemical Admixture for Concrete, West Conshohocken, USA.

ASTM C642 (2013), Standard Test Method for Density, Absorption, and Voids in Hardened Concrete, West Conshohocken, USA.

ASTM C989 (1999), Standard Specification for Ground Granulated Blast-furnace Slag for Use in Concrete and Mortars, West Conshohocken, USA.

Barbhuiya, S., Chow, P. and Das, A. (2014), "Nanomechanical properties of cement paste containing silica fume", *Proced. Int. Conf. Arct. Civil Eng., (ICAACE'14)*, 25-26.

Berra, M., Carassiti, F., Mangialardi, T., Paolini, A.E. and Sebastiani, M. (2012), "Effects of nanosilica addition on workability and compressive strength of Portland cement pastes", *Constr. Build. Mater.*, **35**, 666-675.

Bharat, B., Jindal, D.S., Sanjay, K., Deepankar, K.A. and Parveen. (2017), "Improving compressive strength of low calcium fly ash geopolymer concrete with alccofine", *Adv. Concrete Constr.*, **5**(1), 17-29.

Bhuvaneshwari, B., Sasmal, S., Baskaran, T. and Nagesh, R.I. (2012), "Role of nano oxides for improving cementitious building materials", *J. Civil Eng. Sci*., **1**, 52-58.

BIS 10262 (2009), Concrete Mix Proportioning-Guidelines, New Delhi, India.

BIS 12269 (2013), Ordinary Portland Cement 53 Grade-Specification, New Delhi, India.

BIS 3812 (2013), Pulverized Fuel Ash-Specification, Part 1 for Use as Pozzolana in Cement, Cement Mortar and Concrete, New Delhi, India.

BIS 383 (2016), Specification for Coarse and Fine Aggregates from Natural Sources for Concrete, New Delhi, India.

BIS 456 (2000), Plain and Reinforced Concrete-Code of Practice is an Indian Standard Code of Practice for General Structural Use of Plain and Reinforced Concrete, New Delhi, India.

BIS 516 (1959), Methods of Tests for Strength of Concrete, New Delhi, India.

Chithra, S., Senthil Kumar, S.R.R. and Chinnaraju, K. (2016), "The effect of Colloidal Nano-silica on workability, mechanical and durability properties of High Performance Concrete with Copper slag as partial fine aggregate", *Constr. Build. Mater.*, **113**, 794-804.

Erdem, S., Dawson, A.R. and Howard Thom, N. (2012), "Influence of the micro-and nano-scale local mechanical properties of the interfacial transition zone on impact behaviour of concrete made with different aggregates", *Cement Concrete Res.*, **42**, 447-458.

Gnanasoundarya, S., Varun Teja, K. and Meena, T (2017), "Experimental study on ternary blended concrete under elevated temperature", *Int. J. Civil Eng. Tech.*, **8**(5), 895-903.

Gopalakrishnan, K., Birgisson, B., Taylor, P. and Nii, O.A.O. (2011), *Nanotechnology in Civil Infrastructure*, Springer, Berlin, Heidelberg, Germany.

Jalal, M., Mansouri, E., Sharifipour, M. and Pouladkhan, A.R. (2012), "Mechanical, rheological, durability and microstructural properties of high performance self-compacting concrete containing $SiO_2$ micro and nanoparticles", *Mater. Des*., **34**, 389-400.

Jalal, M., Mortazavi, A.A. and Hassani, N. (2012), "Thermal properties of $TiO_2$ nanoparticles binary blended cementitious composites", *J. Am. Sci*., **8**(7), 391-394.

Jalal, M., Pouladkhan, A.R., Ramezanianpour, A.A. and Norouzi, H. (2012), "Effects of silica nanopowder and silica fume on rheology and strength of high strength self-compacting concrete", *J. Am. Sci*., **8**(4), 270-277.

Jindal, B.B., Anand, A. and Badal, A. (2016), "Development of high strength fly ash based geopolymer concrete with alccofine", *IOSR J. Mech*. *Civil Eng*., 55-58.

Jindal, B.B., Singhal, D., Sharma, S.K. and Parveen. (2017), "Prediction of mechanical properties of alccofine activated low calcium fly ash based geopolymer concrete", *ARPN J. Eng*. *Appl*. *Sci*., **12**(9), 3022-3031.

Jindal, B.B., Singhal, D., Sharma, S.K. and Parveen. (2017), "Suitability of ambient-cured alccofine added low-calcium fly ash-based geopolymer concrete", *Ind. J. Sci*. *Technol*., **10**(12), 1-10.

Krishna, C.B.R. and Jagadeesh, P. (2017), "Influence of admixtures on plastic wastes in an eco-friendly concrete a review", *Int. J. Civil Eng. Tech*., **8**(6), 388-397.

Kupwade-Patil, K., Al-Aibani, A.F., Abdulsalam, M.F., Mao, C., Bumajdad, A., Palkovic, S.D. and Buyukozturk, O. (2016), "Microstructure of cement paste with natural pozzolanic volcanic ash and Portland cement at different stages of curing", *Constr. Build. Mater*., **113**, 423-441.

Li, H., Zhang, M.H. and Ou, J.P. (2007), "Flexural fatigue performance of concrete containing nano-particles for pavement", *Int. J. Fatig*., **29**, 1292-1301.

Ltifi, M., Guefrech, A., Mounanga, P. and Khelidj, A. (2011), "Experimental study of the effect of addition of nano-silica on the behaviour of cement mortars", *Procedia Eng*., **10**, 900-905.

Malhotra, V. (2002), "Introduction: Sustainable development and concrete technology", *Concrete Int*., **24**(7), 235-242.

Martin, A., Pastor, J.Y., Palomo, A. and Jiménez, A.F. (2015), "Mechanical behaviour at high temperature of alkali-activated aluminosilicates (geopolymers)", *Constr. Build. Mater*., **93**, 1188-1196.

Morsy, M.S., Al Salloum, Y.A., Abbas, H. and Alsayed, S.H. (2012), "Behavior of blended cement mortars containing nano-metakaolin at elevated temperatures", *Constr. Build. Mater*., **35**, 900-905.

Naji Givi, A.R., Abdul Rashid, S. and Nora, A.A.F. (2010), "Salleh A. M. M. Experimental investigation of the size effects of $SiO_2$ nano-particles on the mechanical properties of binary blended concrete", *Compos*. *Part B-Eng*., **41**, 673-677.

Narender Reddy, A. and Meena, T. (2017), "A comprehensive overview on performance of nano-silica concrete", *Int. J. Phar. Tech.*, **9**(1), 5518-5529.

Narender Reddy, A. and Meena, T. (2017), "An experimental investigation on mechanical behaviour of eco-friendly concrete", *IOP Conf. Series: Mater. Sci. Eng*., **263**, 032010.

Narender Reddy, A. and Meena, T. (2017), "Behavior of ternary blended concrete under compression", *Int. J. Civil Eng Tech*., **8**(4), 2089-2097.

Narender Reddy, A. and Meena, T. (2018), "A study on compressive behavior of ternary blended concrete incorporating alccofine", *Mater. Today Proc*., **5**, 11356-11363.

Narender Reddy, A. and Meena, T. (2018), "Study on effect of colloidal nano silica blended concrete under compression", *Int. J. Eng. Tech*., **7**(10), 210-213.

Nazari, A. and Riahi, Sh. (2010), "Microstructural, thermal, physical and mechanical behavior of the self-compacting concrete containing $SiO_2$ nanoparticles", *Mater. Sci. Eng. A-Struct*., **527**, 7663-7672.

Nazari, A. and Riahi, Sh. (2010), "The effect of $TiO_2$ nanoparticles on water permeability and thermal and mechanical properties of high strength self-compacting concrete", *Mater. Sci. Eng. A-Struct*., **528**, 756-763.

Nazari, A. and Riahi, Sh. (2011), "Splitting tensile strength of concrete using ground granulated blast furnace slag and $SiO_2$ nanoparticles as binder", *Energy Build*., **43**, 864-872.

Nazari, A. and Riahi, Sh. (2011), "The effects of $SiO_2$ nanoparticles on physical and mechanical properties of high strength compacting concrete", *Compos*. *Part B-Eng*., **42**, 570-578.

Oltulu, M. and Sahin, R. (2011), "Single and combined effects of nano-$SiO_2$, nano-$Al_2O_3$ and nano-$Fe_2O_3$ powders on compressive strength and capillary permeability of cement mortar containing silica fume", *Mater. Sci. Eng. A-Struct*., **528**, 7012-7019.

Quercia, G. and Brouwers, H.J.H. (2010), "Application of nano-silica (nS) in concrete mixtures", *8th fib PhD Symposium in Kgs*, Lyngby, Denmark.

Quercia, G., Hüsken, G. and Brouwers, H.J.H. (2012), "Water demand of amorphous nano silica and its impact on the workability of cement paste", *Cement Concrete Res*., **42**, 344-357.

Raiess Ghasemi, A.M., Parhizkar, T. and Ramezanianpour, A.A. (2010), "Influence of colloidal nano-$SiO_2$ addition as silica fume replacement material in properties of concrete", *Sec. Int. Conf. Sus. Const. Mater. Tech.*, University of Politecnica delle Marche, Ancona.

Sabarish, K.V., Venkat Raman, R., Ancil, R., Wasim Raja, R. and Selva Surendar, P. (2017), "Experimental studies on partial replacement of cement with fly ash in concrete elements", *Int. J. Civil Eng. Tech*., **8**(9), 293-298.

Saha, S. and Rajasekaran, C. (2016), "Mechanical properties of recycled aggregate concrete produced with Portland pozzolana cement", *Adv*. *Concrete Constr*., **4**(1), 27-35.

Said, A.M., Zeidan, M.S., Bassuoni, M.T. and Tian, Y. (2012), "Properties of concrete incorporating nano-silica", *Constr. Build. Mater*., **36**, 838-844.

Sanchez, F. and Sobolev, K. (2010), "Nanotechnology in concrete - a review", *Constr. Build. Mater*., **24**, 2060-2071.

Senff, L., Hotza, D., Lucas, S. and Ferreira, V.M. (2012), "Effect of nano-$SiO_2$ addition on the rheological behavior and the hardened properties of cement mortars and concrete", *Mater. Sci. Eng. A-Struct*., **532**, 354-361.

Shaikh, F.U.A., Supit, S.W.M. and Sarker, P.K. (2014), "A study on the effect of nano silica on compressive strength of high volume fly ash mortars and concretes", *Mater. Des*., **60**, 433-442.

Shi, X., Xie, N., Fortune, K. and Gong, J. (2012), "Durability of steel reinforced concrete in chloride environments (An overview)", *Constr. Build. Mater*., **30**, 125-138.

Singh, L.P., Karade, S.R., Bhattacharyya, S.K., Yousuf, M.M. and Ahalawat, S. (2013), "Beneficial role of nanosilica in cement based materials - A review", *Constr. Build. Mater*., **47**, 1069-1077.

Singh, V.K., Srivastava, V., Agarwal, V.C and Harison, A. (2015), "Effect of fly ash as partical replacement of cement in PPC cement", *Int. J. Res. Sci. Eng. Tech*., **4**, 6212-6217.

Varun Teja, K., Purna Chandra, P. and Meena, T. (2017), "Investigation on the behaviour of ternary blended concrete with SCBA and SF", *IOP Conf. Series: Mater. Sci. Eng*., **263**,

032012.
Yuvaraj, S., Sujimohankumar, D., Dinesh, N. and Karthic, C. (2012), "Experimental research on improvement of concrete strength and enhancing the resisting property of corrosion and permeability by the use of nano silica flyashed concrete", *Int. J. Emer. Tech. Adv. Eng*., **2**, 105-110.
Zhang, M.H. and Li, H. (2011), "Pore structure and chloride permeability of concrete containing nano-particles for pavement", *Constr. Build. Mater*., **25**, 608-616.

*CC*