A STUDY ON THE EFFECT OF COLLOIDAL NANO-SILICA ON BLENDED CONCRETE CONTAINING FLY ASH AND ALCCOFINE

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Cement is one of the essential constituent for the production of concrete. However, large amounts of carbon dioxide (CO_2), green house gases etc are emitted during the calcinations of limestone; for the production of one tonne of cement, the raw materials of about 2 tonnes is required and it releases approximately 1 tonne of CO_2. Since, the production of cement involves excessive emission of greenhouse gases that leads to damaging of ozone layer and many environmental problems, a substitute or alternative material to cement for a sustainable construction was required. Research works are being carried out for finding out the alternate cementing material which will replace cement partially or fully due to its ill effects on the environment. The present paper reports an attempt in this direction by experimental examination on the hardened properties of concrete by replacing cement with combination of Fly ash (FA), Alccofine (AL) and Colloidal Nano Silica (CNS) in order to form a blended concrete (BC). From the experimental results, it was clearly observed that the combination of FA, AL and CNS had shown a high early age strength gaining property. Incorporation of a combination of these admixtures enhanced the mechanical and water absorption properties of the concrete. BC mix with a combination of 25% FA, 10% AL and 1% CNS with a total of 36% replacement of cement has achieved higher mechanical and water absorption properties as compared with all other mixes. The relationship between compressive strength and splitting tensile strength as well as between compressive strength and percentage water absorption is also investigated.

Keywords: *Colloidal Nano Silica; Fly Ash; Alccofine; Blended Concrete; Compressive Strength; Split Tensile Strength; Flexural Strength and Water Absorption*

1. Introduction

Now a days cement had become a dominant raw material in the manufacture of concrete. The demand for cement is increasing worldwide with a consumption of nearly 4.3 billion tones every year. For the production of cement large amount of energy is consumed and it is one of the largest sources in the emission of CO_2 gas [1-3]. About 13500 million tons of CO_2 gas is released during the production of cement [4]. Therefore, engineers are in search of alternative cementitious materials which can give better performance in all aspects such as fresh and hardened state properties along with durability properties so as to minimize the use of cement in concrete [5].

According to available literatures, the replacement of cement by industrial by-products which posses pozzolanic nature such as Fly ash (FA), Metakoline (MK), Granulated blast furnace slag (GGBS), Rice-husk ash (RHS), Mine waste (MW), Silica-fume (SF), Red mud (RM) etc., had shown efficient results than the conventional concrete in terms of fresh, mechanical and durability properties [5-10]. Recently some of the researchers have reported that the micro fine material namely Alccofine (AL), 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 [11]. By using AL as an admixture a significant improvement in workability and mechanical properties of concrete was observed [12-14]. Due to the ultrafine particle size, AL improves the micro pore filling ability and resistance to segregation which helps in enhancing fresh, mechanical and durability properties of concrete significantly. It is much economical than all other micro pozzolanic materials like SF, MK [15,16]. However, very little work has been reported on the use of AL in concrete and mortars.

Recently nanotechnology has attracted researcher's interest due to the novel potential application of particle size in nano scales [17]. Due to the higher specific surface in area, nano particles have gained more attention in construction field [18, 19]. The nano materials like nano silica (NS) possess high pozzolanic nature and can significantly improve the physical and mechanical properties of concrete [20]. 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

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concrete [6,16]. 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 [3].

In the present paper an investigation was carried out to develop a Blended Concrete (BC) by replacing cement with a combination of FA at 25%, AL at 10% and various percentages (0%, 0.5%, 1%, 2% and 3%) of Colloidal Nano Silica (CNS). The current study highlights the result outcomes of the mechanical and water absorption tests performed on BC mixes. The paper moreover looks at the effects of using the combination of FA, ALC, and CNS on initial stage and Hardened properties of BC. Hence the efforts are to address the improvement in BC 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 play a significantly important role in attaining the strength properties. But now-a-days cement had become a major source for pollution which propels 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 menance. Previous researchers focused on the use of combination of FA and CNS 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 FA, AL and CNS as partial replacement of cement on mechanical and water absorption properties of concrete so that their scope to address environmental pollution can be explored.

3. Materials

3.1 Cement

Ordinary Portland cement (OPC) conforming to the BIS 12269-2013 [21], 53 Grade Cement is used in concrete in the entire investigation. The specific gravity of cement is 3.12, normal consistency is 32%, initial setting time is 50 minutes and final setting time is 450 minutes respectively.

3.2 Fly Ash (FA)

Low calcium FA (Class F type) having specific gravity of 2.3, specific surface area of 4750 m^2/kg and fines modulus of 1.19% had obtained from NTTPS Ibrahimpatnam, Vijayawada confirming to BIS 3812-2013 [22] was used in entire investigation. The oxide composition of FA is given in Table 1 and EDAX result was given by Table 2.

Table 1

Oxide composition of FA

Characteristics	% of Composition
Sio_2	59.14
Al_2O_3	24.08
Fe_2O_3	12.02
Cao	2.22
SO_3	0.15
MgO	0.43
Na_2O	0.57
K_2O	0.76
LOI	0.63

Table 2

Properties of FA form EDAX

Characteristics of Element	Results for EDAX	
	Weight %	Atomic %
C K	59.19	68.02
O K	31.99	27.60
Al K	2.75	1.41
Si K	6.07	2.98

The Examination of FA by using SEM and EDAX analysis was carried out at 20 keV of accelerated voltage. The result shows that the FA sample was composed of spherical particles. Figure 1 shows SEM and EDAX analysis graph of the FA particle and the Table 2 shows the composition result of FA from EDAX analysis. It can be noticed that the fly ash sample consists of almost regular spherical particles ranging 2 µm to 70 µm and it contains C K ($CaCO_3$), O K (SiO_2), Al K (Al_2O_3), Si K (SiO_2) elements with weight % of 59.19, 31.99, 2.75, 6.07 and atomic % of 68.02, 27.60, 1.41, 2.98 respectively.

3.3 Alccofine (AL)

AL-1203 was obtained from Ambuja Cement Ltd, Goa having the specific gravity of 2.9 and specific surface area of 12000 cm^2/grm confirming

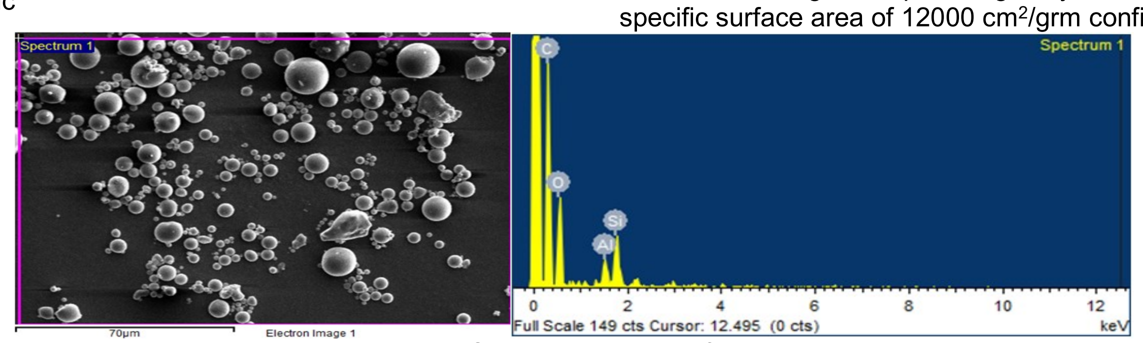

Fig. 1 - SEM and EDAX image of FA.

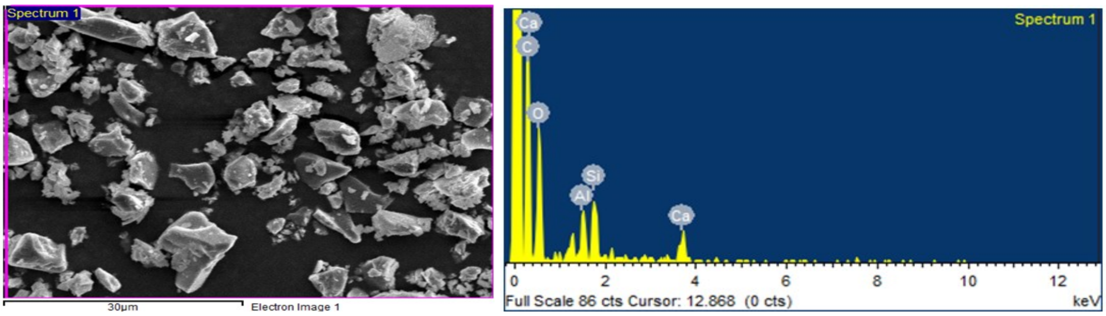

Fig. 2 - SEM and EDAX image of AL

to ASTM C989-1999 [23] was used in entire investigation. The oxide composition of AL is given in Table 3 and EDAX result was given by Table 4.

Table 3

Oxide composition of AL

Characteristics	% of Composition
CaO	33.91%
SO_3	0.10%
SiO_2	34.83%
Al_2O_3	21.44%
Fe_2O_3	1.39%
MgO	6.81%
Loss on ignition	1.42
Sulpuric anhydride	0.68

Table 4

Chemical Properties of AL form EDAX

Characteristics of Element	Results for EDAX	
	Weight %	Atomic %
C K	45.69	57.64
O K	35.26	33.39
Al K	4.01	2.25
Si K	6.38	3.44
Ca K	8.66	3.27

The Examination of AL by using SEM and EDAX analysis was carried out at 20 keV of accelerated voltage. The result shows that the AL sample was composed of irregular shaped particles. Figure 2 shows SEM and EDAX analysis graph of the AL particle and table 4 shows the composition result of AL from EDAX analysis. It can be noticed that the AL sample consists of almost irregular shaped particles ranging 2 µm to 30 µm and it contains C K ($CaCO_3$), O K (SiO_2), Al K (Al_2O_3), Si K (SiO_2), Ca K (Wollastonite) elements with weight % of 45.69, 35.26, 4.01, 6.38, 8.66 and atomic % of 57.64, 33.39, 2.25, 3.44, 3.27 respectively.

3.4 Colloidal Nano Silica (CNS)

CNS used in our investigation is a nanometric particle size solution having a particle size of 10-20 nm and specific gravity of 1.21 and specific surface area of 150-180 m^2/gm.

3.5 Coarse aggregate

Locally available crushed stone passing through 20 mm sieve having specific gravity of 2.7, water absorption of 0.83% and fines modulus o 7.2% confirming to BIS 383-2016 [24] was used as course aggregates.

3.6 Fine aggregate

River sand passing through 4.75 mm sieve having specific gravity of 2.6, water absorption of 1.02% and fines modulus of 2.71% confirming to BIS 383-2016 [24] was used as fine aggregates.

3.7 Water

Potable tap water at room temperature is used for preparation of concrete according to BIS 456-2000 [25] recommendations.

3.8 Superplasticizer

High-performance superplasticizer based on poly-carboxylic ether confirming to ASTM C 494-2017 [26] was used superplasticizer.

4. Research Methodology

4.1 Mix proportions

In the present investigation, M30 grade concrete mix design was carried out according to BIS 10262-2009 (reaffirmed in 2014) [27]. The details of the mix design are as shown in Table 6.The cement content was partially replaced with a combination of FA, AL and CNS. FA and AL that

Table 5

Mix proportions of controlled conventional concrete mixture

Materials	Cement	Fine Aggregate	Coarse Aggregate	Water
Quantity (kg/m^3)	350.22	721.51	1273.86	150.59

Mix Proportion = 1: 2.06: 3.63: 0.43

Table 6

Mix proportions of concrete with FA, AL and CNS

Mix ID	Cement (kg/m^3)	FA (kg/m^3)	AL (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	236041	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
N4	229.31	87.55	26.26	7.10	721.51	1273.86	150.59

CM: Conventional Concrete Mix; N0 - N4: Blended Concrete (BC) Mix

Table 7

Compressive strength values of CM and BC mixes

Mix ID	7 Days	28 Days	56 Days	90 Days
CM	24.3	43.2	44.7	45.6
N0	26.7	46.3	47.9	48.8
N1	29.3	47.5	49.1	50.1
N2	30.8	49.3	51	52.1
N3	30.1	48.5	50.1	51.2
N4	27.7	47.06	48.6	49.6

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 BC 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 6 and table 7, respectively.

4.2 Casting and curing

All the concrete mixes were prepared at room temperature i.e 27^0 C ± 10. Dry mixing of cement, FA, AL, 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 100mm×100mm×100mm, cylindrical samples of size 200mm×100mm diameter and beam samples of size 500mm×100mm×100mm were cast and de-molded after 24 hours. The concrete specimens so prepared were cured under water at room temperature.

5. Results and Discussions

The test results of CST, STST, FST and WAT of Blended Concrete with varying percentage of CNS are explained in the subsequent sub-sections. As per BIS 456-2000 [25] the concrete will attain the maximum strength at 28 Days curing but here we are using pozzolanic materials like FA, AL and CNS and the reactivity of concrete will continue for longer period (I,e for more than 28 days curing period). Hence the compressive strength was done for 7, 28, 56 and 90 days curing period. The split tensile and flexural strength was performed for 7 and 28 days only. The water absorption test was done for 28, 56 and 90 days period.

5.1 Compressive strength test

The CST was performed on cube samples of size 100mm×100mm×100mm according to BIS 516-1959 (reaffirmed in 2013) [28]. Table 7 and Figure 3 compares the compressive strength of CM mix and BC mixes.

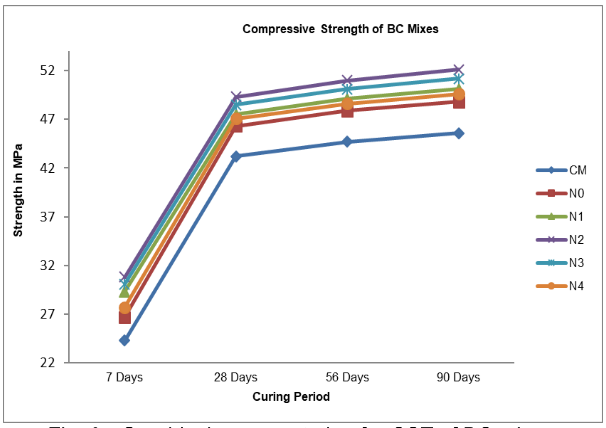

Fig. 3 - Graphical representation for CST of BC mixes.

From the Figure 3, it is clearly observed that the BC mixes made with CNS showed higher compressive strength than CM. 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 CM. It was also noticed that the compressive strength of BC samples was enhanced when cement content was replaced up to 1% CNS and declined slightly on increasing the CNS material. The improvement in early age CST of BC mixes might be due to the accelerated hydration reaction on addition of AL and CNS

[6,12-14,20]. Similar types of results were observed at the age of 28,56 and 90 days curing period also. The mixes with combination of CNS, FA and AL (i.e N0, N1, N2 and N3 mixes) showed an improvement in CST of 7.08%, 9.78%, 14.10%, 12.17% and 8.78% for 28 days, 7.07%, 9.76%, 14.08%, 12.14%, 8.64% for 56 days, 7.01%, 9.78%, 14.08%, 12.18%, 8.61% for 90 days respectively with respect to the CM. 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 CST of BC mixes at early age shows that the AL and CNS 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 CNS beyond 1% is attributed to the reason that the quantity of CNS 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 [6,29,33-37]. Thus, at this stage the combination of CNS acts only as cement replacement material used for filling the pores but does not involve in the hydration process [6,29]. From the CST result it is clearly seen that inclusion of FA, AL and CNS enhanced the CST for all the employed cases, in comparison with the CM. From Figure 3 it is clearly seen that the increase in strength percentage patron was almost same for 28, 56 and 90 days, so the further strength properties were tested for only 7 days and 28 days curing period.

5.2 Split tensile strength test

The STST was performed on cylinder samples of size 200mm×100mm according to BIS 516-1959 (reaffirmed in 2013). The variation in STST for CM and BC mixes are shown in Table 8 and Figure 4.

Table 8

Split tensile strength values of CM and BC mixes

Mix ID	7 Days	28 Days
CM	3.4	4.5
N0	3.5	4.7
N1	3.77	4.75
N2	3.8	4.8
N3	3.78	4.76
N4	3.6	4.73

From the results, it is clearly observed that the BC mixes made with CNS showed higher tensile strength value than CM. The early age (7 days) 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 CM. Similar types of results were observed at the age of

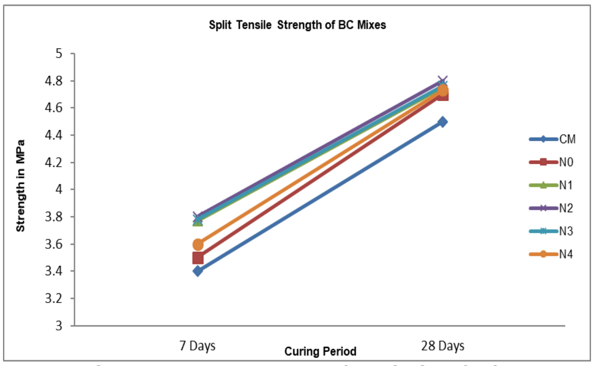

Fig. 4. Graphical representation of the STST of BC mixes.

28 days also. The mixes with combination of CNS, FA and AL (i.e N0, N1, N2 and N3 mixes) showed an improvement in tensile strength of 3.73%, 4.62%, 7.24%, 4.90% and 4.20% respectively compared to CM for 28 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, FA, AL and CNS) and the aggregates used [29]. By utilizing FA, AL and CNS, the Interfacial Transition Zone (ITZ) becomes denser resulting in improvement of tensile strength [29-31]. From the results, it was also noticed that the tensile strength of BC mix samples was enhanced when cement content was replaced with CNS upto 1% and declined slightly on increasing the CNS content further.

5.3 Flexural strength test

The FST was performed on beam samples of size 500mm×100mm×100mm according to BIS 516-1959 (reaffirmed in 2013). The variation in FST for CM and BC mixes are shown in Table 9 and Figure 5.

Table 9

Flexural strength values of CM and BC mixes

Mix ID	7 Days	28 Days
CM	3.5	4.9
N0	3.7	5.1
N1	4.1	5.25
N2	4.3	5.5
N3	4.2	5.35
N4	3.9	5.2

From the results, it is clearly observed that the BC mixes made with CNS showed higher flexural strength than CM. 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 CM. Similar types of results were observed at the age of 28 days also. The mixes with combination of CNS, FA and AL (i.e N0, N1, N2 and N3 mixes) showed an improvement in flexural strength of 4.08%, 7.14%, 12.14%, 8.41% and 5.06% respectively with respect to the CM for 28 days

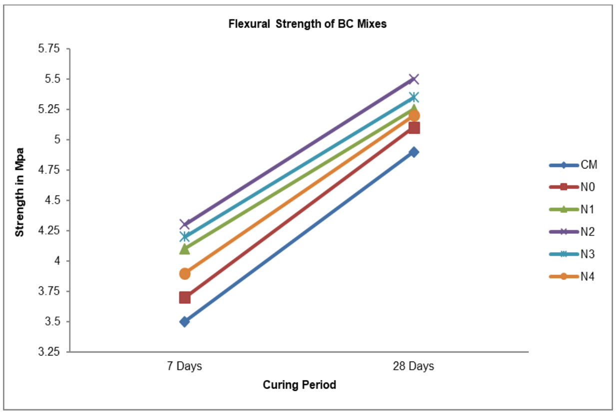

Fig. 5 - Graphical representation of the FST of BC mixes.

curing period. From the result it is also noticed that the flexural strength of BC samples was enhanced when cement content was replaced up to 1% CNS and declined slightly on increasing the CNS content. From the above results, the inclusion of FA, AL and CNS enhanced the strength for all the employed cases, in comparison with the CM.

5.4 Water absorption test

The WAT was performed according to ASTM C642-2013. The impact of combination of FA, AL and CNS on the WAT of BC mixes at the age of 28, 56 and 90 days are shown in Table 10 Figure 6.

Table 10

Compressive strength values of CM and BC mixes

Mix ID	28 Days	56 Days	90 Days
CM	3.7	3.4	3.2
N0	3.6	2.99	2.9
N1	3.2	2.7	2.5
N2	2.8	2.5	2.3
N3	3.1	2.6	2.4
N4	3.3	2.8	2.7

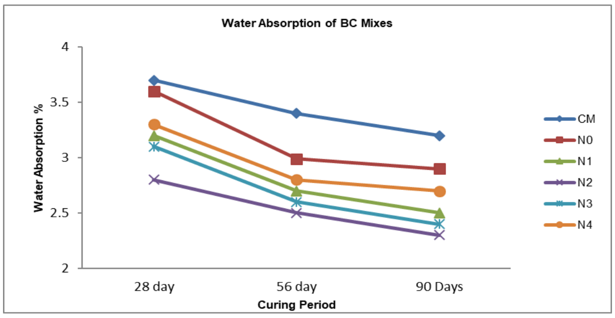

Fig. 6 - Graphical representation of the WAT of BC mixes

From the results, it is clearly observed that the BC mixes made with CNS showed lower water absorption percentage than the CM. On 28th day the water absorption percentage was decreased by 3.6%, 3.2%, 2.8%, 3.1% and 3.3% respectively N0, N1, N2, N3 and N4 mixes, where as for CM it was 3.7%. Similar types of results were observed at the age of 56th and 90th days. The mixes with CNS, FA and AL (i.e N0, N1, N2 and N3 mixes) showed decrease in water absorption percentage of 2.99%, 2.7%, 2.5%, 2.6% and 2.8% respectively for 56th day and on 90th day the water absorption showed a decrease in percentage of 2.9%, 2.5%, 2.3%, 2.4% and 2.7% respectively for N0, N1, N2, N3 and N4 mixes, where as for CM mix the water absorption for 56th and 90th days is about 3.4% and 3.2%. The low water absorption percentage results in BC mixes is may be due to occurrence of higher pozzolanic effect by FA, AL and CNS 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 [6,29].

5.5 Regression analysis

In the present study, the correlation between CST and STST as well as between CST and WAT was also developed for BC.

5.5.1 Relationship between CST and STST

Figure 7 illustrates the relationship between CST and TSTS for BC which can be represented by equation below.

$$TS = 0.691 \times (CST)^{0.5}$$

It can be noted that the relationship between CST and STST of BC is very similar to that recommended by BIS 456-2000 for CM. It is clearly seen that the regression line for BC 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.

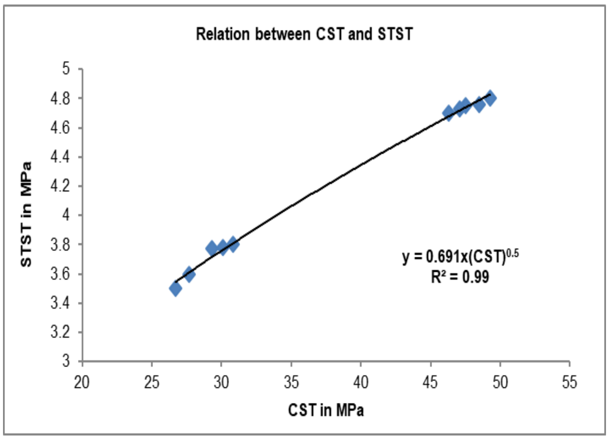

Fig. 7 - Graphical representation of the relationship between CST and TSTS of BC mixes

5.5.2 Relation between CST and WAT(%)

The relationship between WAT and CST is shown in Figure 8. The correlation coefficient R^2 = 98.7% indicates the strong relation between the WAT and CST of BC. By this relation it is possible to predict the WAT behavior by knowing the trend

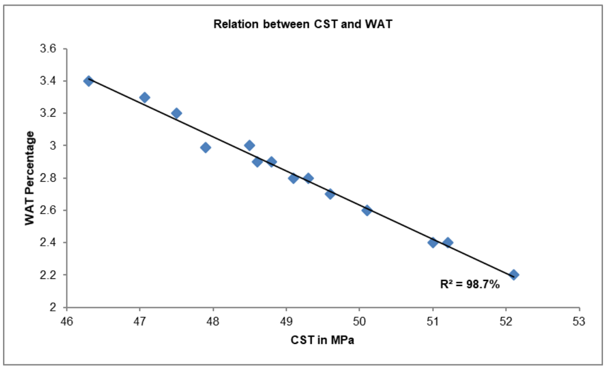

Fig. 8 - Graphical representation of the relationship between CST and WAT of BC mixes

of CST for BC. Therefore it can be concluded that as the CS increases, the WAT will decreases.

6. Conclusions

Based on the experimental investigation carried out on BC mixes, the following conclusions are drawn

- By utilizing the combination of FA, AL and CNS had improved the particle packing and pore structure which results in enhancement of mechanical and water absorption properties of the concrete.
- The incorporation of CNS in BC increased the mechanical strength and decreased the water absorption properties when compared with conventional concrete mix at all ages. The strength was increased up to 1% CNS replacement and then reduced but showed the higher results than the conventional concrete mix. This may be due to the hydrated products formation in the presence of CNS in concrete.
- CNS content increased the early-age strength but was adversely affected by >1% with a combination of 25% FA and 10% AL. It can be concluded that the optimal amount of CNS is 1%, which enhances the pozzolanic reactivity of BC mix.
- The maximum compressive, splitting tensile and flexural strength of BC was obtained by the sample containing 25% FA, 10% AL and 1% of CNS, totally 36% replacement for cement. Due to the higher specific surface area and high pozzolanic activity of AL and CNS results in high production of C-S-H gel and helps in formation of compact structure to the concrete which helps in improving the early strength gaining capacity of concrete.
- Water absorption percentage of BC reduces due to the combined action of pore filling effect and acceleration of hydration of AL and CNS particles making the concrete denser and compacted. The maximum reduction in water absorption percentage was observed for BC mix containing 25% FA, 10% AL and 1% CNS, greater than 1% CNS replacement is attributed to the reason that the quantity of CNS 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 leads to increase in water absorption slightly.
- Utilizing the combination of FA, AL and CNS as a replacement for cement leads to eco-friendly and sustainable concrete.

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