Effect of GGBS and Nano Silica on the Mechanical Properties of Ternary Concrete

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Abstract. This paper presents the effect of mechanical behavior of high strength concrete, prepared using Ground Granulated Blast Furnace Slag (GGBS) and Nano Silica (Average particle size-15nm). Ground Granulated Blast Furnace Slag (GGBS) was replaced up to 50% and Nano silica was replaced 1%, 2%, 3%, 4% and 5% by weight of cement. Compression Testing, Pull Out Testing, Split Tensile Testing and Flexural Testing were carried out to characterize the mechanical behavior of high strength concretes at 7, 28, 56 and 90 days and results obtained were compared with the corresponding values obtained for controlled concrete (100% OPC). The entire specimen were prepared, cured and tested as per the Indian standard code of practice. The results showed that compressive strength significantly improved at early age with the increasing content of Nano silica. Compressive, tensile and flexure strength of the concrete with GGBS and NS was found better than that of the controlled concrete. Utilization of this type of material into the public sphere through civil infrastructure can be done by its usage in Dams and High rise buildings where dense concrete is required.

1. Introduction
Nanotechnology has been regarded as an emerging technology, introducing new dimensions to science and technology with the possibility of manipulating atoms and molecules at the nanometer level (‘nano’ means one-billionth of a meter) [1]. Nano technology can be considered as most advanced field of science and technology and has great market potential and economic impacts [2]. The aim of this research work is to understand the behavior of materials at nano level and how to improve microstructure of the cementitious materials and to achieve cohesiveness in concrete structures. Concrete is most used man made material on this earth and worldwide production of concrete has exceeded over 2600 million tones [3]. It is responsible for about 5% of the global man made CO2 emission. For each tonne of cement being produced, an average of 0.87 tons of CO2 is being emitted [4, 5]. Extensive research has been directed to reduce the effect of cement industry on green house gases [6].

GGBS, a by- product of Iron industry is considered as one of the most used SCM in the industry. The use of supplementary cementitious materials as partial replacement to Portland cement in concrete is a better step towards sustainable development because of their technological, economic, and environmental benefits

2. Materials and methods
Materials used in this research work are: OPC (53 grade) conforming to IS: 8112-1989 and Ground Granulated Blast furnace Slag (GGBS) whose chemical and mineralogical properties are shown in
Table 1. Nano Silica (Hydrophilic Nano powder, Reinste Nano Ventures) of average particle diameter 10 nm has been substituted 1%, 2%, 3%, 4% and 5% by weight of cementitious material. In the present study, Super Plasticizer (SP) of Carboxylic Ether (CONFLOW SNS 2, Essence Construction) with specific gravity 1.21 was used. Table 2 demonstrates the mix design of M 60 grade of concrete used during the study.

The gravel used was crushed gravel with size less than 12.5 mm in accordance to ASTM standard grading curve. The fine aggregate used was river sand conforming to IS: 383 and passing from sieve size of 4.75 mm. The of river sand of specific gravity 2.67, Bulk Density 1585 Kg/m$^3$ and fineness modulus of 2.62 was used in the research work.

Compressive strength was measured as per I.S. 516-1959 using 200 T capacity universal testing machine using standard 150×150×150 mm cubes. Concrete cylinders of size 150 mm diameters and 300 mm height were casted. After the specified curing period was over, the concrete cylinders were subjected to split tensile test by using universal testing machine. Tests were carried out on triplicate specimens and the average split tensile strength values were recorded. Flexure strength was measured using standard 100×100×500 mm beam specimens, simply supported on an effective span of 400 mm and loaded at the third points after 28 days of curing. The test was carried out as per IS: 516-1959 (Reaffirmed 2004). The Bond strength of the concrete was measured using 16 mm TMT bar as per Indian standard (IS:2770-1) code of practice and results obtained for M60 grade concrete for different binders at 28, 56, 90 days of curing The pull out specimens were then tested in the hollow mechanical machine of 2000 KN capacity

Table 1. Chemical and mineralogical properties of OPC, GGBS and NS

| Description                | Water | OPC   | GGBS | Nano Silica |
|----------------------------|-------|-------|------|-------------|
| **Physical Characteristics**|       |       |      |             |
| Specific Gravity           | 1     | 3.15  | 3.14 | 2.4-2.6     |
| Blaine’s Fineness, cm$^2$/gm| -     | 2285  | 3250 | 10,00,000   |
| **Chemical Characteristics**|       |       |      |             |
| Calcium oxide, CaO, %      | -     | 66.73 | 35.9 | -           |
| Silicon dioxide, SiO2, %   | -     | 17.54 | 40.65| 99.9        |
| Aluminum oxide, Al2O3, %   | -     | 9.82  | 17.07| -           |
| Ferric oxide, Fe2O3, %     | -     | 2.19  | 0.68 | -           |
| Manganese oxide, MnO, %    | -     | 0.02  | 0.03 | -           |
| Magnesium oxide, MgO, %    | -     | 1.24  | 3.75 | -           |
| Potassium oxide, K2O, %    | -     | 0.48  | 0.56 | -           |
| Sodium oxide, Na2O, %      | -     | 0.22  | 0.19 | -           |
| Loss of ignition, %        | -     | 0.9   | 0.08 | -           |

Table 2. The mix design concrete samples used in study

| Mix No. | Mix                  | Cement | GGBS | Nano Silica | Coarse Aggregate | Fine Aggregate | Water | SP |
|---------|----------------------|--------|------|-------------|------------------|----------------|-------|----|
| 1       | 100% OPC             | 594    | 0    | 0           | 755.5            | 807.5          | 208   | 8.07 |
| 2       | 50% OPC+50% GGBS     | 297    | 297  | 0           | 755.5            | 807.5          | 208   | 8.07 |
| 3       | 49% OPC+50% GGBS+1% NS| 291.06 | 297  | 5.94        | 755.5            | 807.5          | 208   | 8.07 |
| 4       | 48% OPC+50% GGBS+2% NS| 285.12 | 297  | 11.88       | 755.5            | 807.5          | 208   | 8.07 |
| 5       | 47% OPC+50% GGBS+3% NS| 279.18 | 297  | 17.82       | 755.5            | 807.5          | 208   | 8.57 |
| 6       | 46% OPC+50% GGBS+4% NS| 273.24 | 297  | 23.76       | 755.5            | 807.5          | 208   | 8.57 |
| 7       | 45% OPC+50%          | 267.3  | 297  | 29.7        | 755.5            | 807.5          | 208   | 8.98 |
3. Results and Discussion:

3.1. Study of Workability.

Table 3 indicates the values of slump in mm of the concrete mix used in this study. It can be noted from Table 3 that the range of the slump varies from 120-166 mm. During the test, it was noted that further addition of Nano Silica makes concrete sticky and also decreases its workability. It can be observed that mix 6 has highest slump value as compared to others.

| MIX COMBINATIONS          | MIX NO. | SLUMP (MM) |
|---------------------------|---------|------------|
| 100% Control              | Mix1    | 120        |
| 50% OPC+50% GGBS          | Mix2    | 127        |
| 49% OPC+50% GGBS+1% NS    | Mix3    | 138        |
| 48% OPC+50% GGBS+2% NS    | Mix4    | 146        |
| 47% OPC+50% GGBS+3% NS    | Mix5    | 154        |
| 46% OPC+50% GGBS+4% NS    | Mix6    | 166        |
| 45% OPC+50% GGBS+5% NS    | Mix7    | 157        |

3.2. Compressive Strength Test.

The averaged compressive strength results of cube specimens of each batch of different concrete cubes were measured at 7, 28, 56 and 90 days of curing are presented in Fig.1. It can be observed that compressive strength of all mix combinations increases over time. Mix 6 and 7 have shown better performance among others at higher ages. In all mixes samples, when Nano silica content increased to an optimum value of 4% in the sample, compressive strength of the sample was significantly improved. This is due to the Pozzolanic reaction of Nano silica, its high surface area reactive with C3S and C2S and produces C-S-H condensed gel as a result of reaction with Ca(OH)2. Nano particle, having filling ability property, fills the porosity in C-S-H gel and makes a denser adhesive cement paste. This reduction is because the Nano particles have high surface area and are likely to stick together through a physical reaction, and form unstable balls. The sticky mix which reduces the workability of concrete and hampers mixing and compaction process. It leads to the reduction in the compressive strength. Thus 4% is the optimum percentage. This trend is observed at all ages and the strength for different percentages of Nano silica at different ages is higher than that of the reference.

3.3. Tensile Strength Test.
It was also observed that the tensile strength of all mix combinations increases over time as evident in Fig. 2. The increase in the split tensile strength as compared control mix can be attributed to continuation pozzolanic reactions with time. Moreover, high surface area of the Nano silica decreases the air void and evidently cause increase in the Tensile strength. It can be observed from Fig.2 that for Mix 6, increase of 46.7%, 49.31%, 54.63% of tensile strength of OPC could be seen, which is maximum among all other mixes. 4% Nano Silica yields optimum Tensile Strength for all ages. Also, it was concluded that split tensile strength of concrete does not increase significantly with replacement of very high percentage of Nano Silica.

3.4. Flexural Strength Test.
Fig.3 summarizes the flexural strength of unitary, binary, and ternary concretes at 7, 28, 56 and 90 age days of curing. It can be observed from Fig.3 that for Mix 6, increase of 21.28%, 35.10%, 36.94%, 48.24% of flexural strength of OPC could be seen, which is maximum among all other mixes. It was observed from the test results that flexural strength increases till 4% replacement of Nano silica and thereafter there is no significant increase in the flexural strength. Flexural strength assessments demonstrated that having filler and pozzolanic effects, Nano silica can improve the structural properties of the concrete.

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3.5. Pull Out Strength (Bond Strength)
The pullout test specimens failed by the following three modes of failures, pullout failure (P), splitting failure of the tested specimen (S) and steel rupture failure (CS). The pullout failure mode occurred when the concrete cover provided adequate confinement, thus preventing a splitting failure of the test specimen. Splitting failure mode was the predominant type of failure of the tested specimen. It was characterized by splitting of the concrete specimen in a brittle mode of failure. Both transverse and longitudinal cracks were observed at failure. It can be observed from fig. 4 result of bond strength test that the mix which had maximum cohesiveness between the concrete and steel bars due to minimum air voids has maximum bond strength.

4. Conclusions
This study, experimentally evaluated the combined effects of GGBS and Nano silica on the mechanical properties of high strength concrete. The following conclusions can be drawn from this study:

Workability of the concrete mix is observed to increase till maximum of 4% replacement of Nano silica and thereafter workability was reduced. Reduction in workability can be attributed to high surface area of nano silica and formation of sticky concrete paste.

Bond Strength was found maximum for ternary mix (50% GGBS, 46% OPC and 4% Nano Silica). The increase in bond strength of the mix as compared to control can be attributed to increased cohesiveness as compared to control.
Mechanical properties such as compressive, flexural and tensile strength are initially increased by the increase of Nano silica content up to 4% and then decreased. The increase in strength is because of Nano silica pozzolanic reactions while its decrease is because of high surface area of Nano particles. When the content of Nano particles increases beyond a certain value (optimal percentage), they will stick to each other through a physical reaction leading unstable balls. An increase of 4% of Nano silica is considered as optimal value in this experimental study.

References
[1] Kumiko Miyazaki, Nazrul Islam “Nanotechnology systems of innovation—An analysis of industry and academia research.” Technovation(Elsevier) 27 (2007) 661–675.
[2] A.M. Said, M.S. Zeidan, M.T. Bassuoni, Y. Tian “Properties of concrete incorporating nano-silica A.M. Said.” Construction and Building Materials(Elsevier).
[3] USGS.org [Internet]. Reston, VA: United States Geological Survey; c2010 [cited 2011 May 9]. <http://minerals.usgs.gov/minerals/pubs/commodity/cement/mcs-2010-cemen.pdf>.
[4] J.S. Damtoft, J. Lukasik, D. Herfort, E.M. Gartner “Sustainable development and climate change initiatives.” Cement and Concrete Research(Elsevier) 38 (2008) 115–127.
[5] D.J. Barker, S.A. Turnera, P.A. Napier-Moore, M. Clark and J.E. Davison.“CO2 Capture in the Cement Industry.” Energy Procedia(Elsevier) 1 (2009) 87-94.
[6] Niragi Dave, Anil Kumar Misra, Amit Srivastava, Anil Kumar Sharma, Surendra Kumar Kaushik “Study on quaternary concrete micro-structure, strength, durability considering the influence of multi-factors.”Construction and Building Materials(Elsevier) 139 (2017) 447-457.