Influence of nano-silica in beam-column joint flexural properties

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Abstract. The performance of reinforced concrete moment resisting frame structures in present-day earthquakes across world has highlighted the outcome of poor performance of beam-column junction, usually important in the reinforced concrete frame design. In reinforced concrete moment resisting frame the beam column joints are crucial zones for load transfer productively between the linking elements (i.e. beams & columns) in the structural design. So this is especially necessary to reduce the vulnerability of Beam-Column joint in connection with the Seismic loading. In this investigational examination, Fly ash, a throw away product, generated in thermal power stations is roughly around 105 million tons every year (in India) whose percentage usage is less than 13%, was added. This reduction in strength was tried to compensate by adding 0 to 2.5% of Nano Silica (nS) as it reacts with calcium hydroxide (Ca(OH)2) mini crystals, and are array in the Interfacial Transition Zone (ITZ) linking hardened cement paste and aggregates, evenly produce C–S–H gel. Nano-SiO2 can also behave as nucleus to tightly bonded elements with cement hydrates. Fly ash concrete with respect to nano-SiO2 maintains higher density and strength. High-strength concrete with respect to nS owns higher flexural strength. On an average 7 exterior Reinforced Concrete beam-column joint specimens (control) were casted, cured for complete 28 days and tested to failure. Only three contained Fly ash (20%, 40% and 60%) and the other three specimens with nS (2.5%) and Fly ash (20%, 40% and 60%). Evenly, on the column an axial load was applied. Then seismic load (i.e. Push and pull load) was applied at the free end of the cantilever beam till failure occurs. The reinforced Nano concrete Beam-Column joints and the Fly ash mixed RC Beam-Column joints were compared each other and the test results are obtained.

Keywords: Nano Silica (nS), Fly ash, Calcium Hydrate, Calcium Silica Hydrate.

1. INTRODUCTION

Upgradation to higher seismic zones of several cities and towns all over the country has become mandatory in evolving new strengthening technologies[1]. Modern earthquakes established severe damage in almost all of the concrete Structures and Earthquakes are showing the unprotectedness of existing reinforced concrete Beam-Column joints to seismic loading. So they need to be strengthened adequately[2]. Internal confinement by using nano silica is one of the techniques of strengthening the reinforced concrete structural members. In Reinforced concrete buildings, beam-column joints are defined as the portions of columns that are common to beams at their
The joints have limited force resisting capacity since their materials have very limited capacity. When heavy force is applied during the time of earthquakes, the damage is severe. Repairing a damaged joint is very difficult; in that case damage should be mostly avoided. Therefore, beam-column joints should be designed in order to resist the earthquake effects. Concrete is mostly used in infrastructure, buildings[4,5]. It is mixture of granular materials of various sizes and composed solid mix size range covers wide intervals. Particles from 300 nm to 32 mm stimulates the mix properties of the concrete[6]. The properties in the form of fresh state (flow properties and workability) are for instance and also governed by the particle size distribution (PSD), also the properties of hardened state concrete, i.e. durability and strength are affected by the mix grading and resulting particle packing[7,8]. At present nanotechnology research in construction is mainly focusing on the structure of cement-based materials and also their fracture mechanisms[9,10]. Advanced equipment makes it feasible to observe a structure at its basic level. So in order to improvise the packing we need to raise the solid size range, e.g. by counting particles with sizes under 300 nm[11]. Materials which are available at present are limestone and silica fines i.e. silica flavor (SF), silica fume (SF) and nano silica [12,13].

2. MATERIALS AND METHODS

The scope of this investigation includes Studies on Reinforced Concrete beam-column joints which were made by partially replacing the cement with fly ash. Different percentages of replacing the cement with fly ash are 0%, 20%, 40% and 60%. Similar proportions of replacing the cement with fly ash in addition with Nano silica were observed and their results were studied. The cost of cement is considerably reduced as fly ash is used and economical too. Nano silica also increased the durability of concrete. Compressive strength and workability of concrete are increased in addition with nano silica. In concrete, the nano silica (Sf and SF) works based on two levels. The very first one is chemical effect: i.e. the reaction of silica in addition with calcium hydroxide forms C-S-H gels at final stages. The second function is completely physical one, because micro-silica is almost all 100 times smaller than that of cement [14]. Micro-silica fills the leftover voids in partially hydrated cement paste, consequently increasing its final density. Some researchers observed that addition of 1 kg of micro-silica allows a reduction of 4 kg of cement, and this can be estimated higher if nS is being used [15]. The key mechanism of this working principle is related with the high surface area of nS, only because it acts as nucleation site for precipitation of CSH gel. However, according to Bjornstrom et al. [16] it has not yet been determined whether the more rapid hydration of cement in the presence of nS is due to its chemical reactivity upon dissolution (pozzolanic activity) or to their considerable surface activity. Also the accelerating effect of nS addition was established indirectly by measuring the viscosity change (rheology) of cement paste and mortars. Nano silica concrete has better strength and durability[17]. Concrete with better performance and low cost can be produced using nano silica. Concrete with improved ecological footprint can be designed with high workability. Initial and final setting time is reduced when nS is used. Thus increases the early strength. It promotes pozzolanic reaction and it increases the compression, tensile, and flexural strength. It also provides better permeability resistance. Ennur sand with high percentage of silica is grinded in ball mill to nano size. The maximum size range of nano silica is 152.32 nm and the minimum size range nano silica is 68.64 nm, so the average size of nano silica found 106.59 nm. The silica thus obtained is stored and used for project. It was found that it has about 98.5% of silica which is highly prone to form the C-S-H compound. The various size ranges of nS are shown in figure 1.
3. EXPERIMENTAL INVESTIGATION.

Flexure.
Flexural strength, popularly known as modulus of rupture, bond strength or fractural strength, a mechanical parameter for brittle material, is defined as the material’s ability to resist deformation under given load. The transverse bending test is frequently employed, wherein a rod specimen having either a circular or rectangular cross-section is bent until fracture using a three point flexural test technique. The flexural strength represents the high stress experienced in contact with the material at its moment of rupture. Measured in terms of stress, denoted by the symbol $\sigma$.

For determining the flexure strength of concrete the beam specimen casted is 15cm x 15cm x 75cm. UTM is used for implementing the test and permissible errors are arranged within ± 0.5% as per the standard test procedures. The bed of machine should be provided with two steel rollers of 38mm diameter on which the specimen is supported. Rollers are placed at centre to centre distance of 60cm.

The test specimen is casted, cured for 28 days and then tested for maximum load. The Flexural strength or Modulus of rupture ($f_b$) is calculated according to the formula,

$$f_b = \frac{3Pa}{bd^2}$$

Where, $P$ - maximum load,
- $a$ - distance of loading from support,
- $b$ - Breadth of specimen,
- $d$ – Depth of specimen.

Details of specimen. It was observed that the test specimen has been reduced to 1/5 th scale to match the loading arrangement and test facilities. The columns have a cross section of 150 mm x 150 mm with an overall length of 1650 mm and the beams have a cross section of 150 mm x 200 mm with an overall length of 750 mm cantilevered. The column head dimensions of 100 X 200 mm.
Formwork and Reinforcement:

The reinforcement details of beam column joint are as shown in fig 2. To be clear, the column portion was reinforced with 4 numbers of 12mm diameter rods and the beam portion was reinforced with 2 numbers of 10 mm diameter rods at tension and 2 numbers of 12 mm diameter rods at compression zones. Casted specimen is shown in fig 3. The lateral ties in the columns of the specimens were 6 mm diameter bars with the spacing of 150 mm c/c. Beam had vertical stirrups of 6 mm diameter bar at 150 mm c/c. The load carrying capacity of the column was estimated to be 440 kN. The load reversal (push and pull) tests were conducted on the control, Fly ash and Nano reinforced concrete beam column joint specimens.

Generally, the effect of axial load will be more predominant on the joint, when the axial load on the column exceeds 50 to 60% of its capacity. In case of seismic forces, the effect of lateral load will be more predominant than expected. Hence, in order to reflect the behavior of the joint under seismic load conditions, it was decided to restrict the axial loads of column to a maximum of 200 kN which is less than 50 % of load carrying capacity of the column. A point load was applied at the free end of the cantilever beam portion till the failure is occurred in the specimen. The loading was continued till the joint failed by crushing of concrete in the case of control specimens and by the rupture.

Test setup and instrumentation. The experimental setup is as shown in fig 4. The column was completely fixed at the ends on a loading frame. It was subjected to the constant axial loading of 100KN which is 50% of ultimate load carrying capacity of the column. This is considered because column is expected to carry under the normal loading conditions. Cyclic load was applied with the
help of a hydraulic actuator. The displacement has been started from the neutral position and then oscillated harmonically about that particular position. It increased at a uniform rate 0.25mm/cycle. It is observed that Each cycle comprises of three full waves of similar amplitude in 10s (0.3Hz. frequency). The deflection of final tip was 22.5mm. The other end of the beam was free. Vertical deflection of the tip of the beam was recorded directly by the linear variable displacement transducer (LVDT) which is built in the actuator. It was compared with another external LVDT. The data was collected with the help of computerized data acquisition system.

![Figure 4. Test Setup of Beam Column Joint](image)

4. RESULT AND DISCUSSION

**Flexural strength.** Flexural strength, also known as modulus of rupture, bend strength, or fracture strength, a mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load. The flexural strength (Table 1) represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress, denoted by the symbol $\sigma$.

At the edge of the object, inside the bend (concave face) the stress shows maximum compressive stress value. At the outside of the bend (convex face) the stress shows maximum tensile value. These inner and outer edges of the beam or rod are known as the 'extreme fibers'. It is well known that most materials fail under tensile stress before they fail under compressive stress, so the maximum tensile stress value that can be sustained before the beam or rod fails is its flexural strength. Failure of beam column joint is shown in fig 5. Flexural strength is given by

$$\sigma = \frac{3FL}{2bd^2}$$

- $L$ is the length of the support span
- $b$ is width
- $d$ is thickness
- $F$ is the load (force) at the fracture point

| Specimen | Average load in (kN) | Flexural Strength $\sigma = \frac{3FL}{BD^2}$ (kN/m2) |
|----------|----------------------|-----------------------------------------------------|
| CS       | 17.74                | 3.94                                                |
| F20      | 18.09                | 4.02                                                |
| F40      | 15.48                | 3.44                                                |
| F60      | 11.48                | 2.55                                                |
| NC       | 33.81                | 7.5                                                 |
Table 2. Maximum End Deflection:

| Specimen description | Max Lateral Sustained load in (kN) | Column Axial load in (kN) | Number of Cycles | Max. tip deflection of beam in (mm) |
|----------------------|-----------------------------------|---------------------------|-----------------|-----------------------------------|
| CS                   | 15                                | 60                        | 15              | 4.51                              |
| FN20                 | 18                                | 60                        | 18              | 14.62                             |
| FN40                 | 12                                | 60                        | 12              | 10.18                             |
| FN60                 | 8                                 | 60                        | 8               | 8.99                              |
| NC                   | 35                                | 60                        | 35              | 43.85                             |
| FN20                 | 27                                | 60                        | 27              | 37.54                             |
| FN40                 | 21                                | 60                        | 21              | 18.81                             |
| FN60                 | 19                                | 60                        | 19              | 10.44                             |
Figure 6. Load deflection curve for control specimen

Figure 7. Load deflection curve for F20 specimen

Figure 8. Load deflection curve for F40 specimen

Figure 9. Load deflection curve for F60 specimen
Figure 10. Load deflection curve for FN20 specimen

Figure 11. Load deflection curve for FN40 specimen

Figure 12. Load deflection curve for FN60 specimen

5. CONCLUSION

Partial replacement of cement with fly ash in concrete proves to give the desired strengths in concrete. The emission of carbon dioxide which is the main cause if global warming is controlled by avoiding high volume cement while concreting. Workability of concrete gets increased with the addition if Nano silica. Effective waste management has been done since the use of fly ash is a recent finding which was before a waste from thermal stations dumped into land or water resources. Durability of structures which are built using addition of nano silica in concrete is higher than the ordinary buildings. Permeability of concrete is reduced since nano silica fills even the small voids in concrete. We can recommend this type of concrete for special conditions such
as bunkers, silos, petrol tank, some monumental structures and heavy industrial structures since it has low wear and tear. As the percentage of fly ash added increases in the concrete the flexural strength increases to a certain range of (20% to 40%) and then it get decreases. It can be compensated by the addition of Nano silica. From the graph, it is obvious that within FN20 and FN40, the efficiency of concrete is maximum.

The failure observed in the column portion of the joint for the control specimen which is to be avoided. For the same type of seismic load, the tensile force in steel is lower in the nano silica specimen than in the fly ash specimens. Considerable increase in yield load can be achieved by use of these materials. Ability of the structure to resist an earthquake depends to a large extent on its ability to dissipate the input energy. Forms of energy dissipation include kinetic energy, hysteretic damping and viscous damping.

REFERENCE

[1] Abdelsamie Elmenshawi, Tom Brown, Hysteretic energy and damping capacity of flexural elements constructed with different concrete strengths, Engineering Structures 32 (2010) 297_305, from the journal Elsevier.

[2] Bhijit Mukherjee, Mangesh Joshi, FRPC reinforced concrete beam-column joints under cyclic excitation, Department of Civil Engineering, Indian Institute of Technology Bombay, Mumbai.

[3] Benavent-Climent, Cahile X, Zahran R, Exterior wide beam-column connections in existing RC frames subjected to lateral earthquake loads Engineering Structures, 31 (2009) 1414_1424 from the journal Elsevier.

[4] Bjornstrom J, Martinelli A, Matić A, Borjesson L, and Panas I, Accelerating effects of colloidal nano-silica for beneficial calcium–silicate–hydrate formation in cement, Chemical Physics Letters 392 (2004), pp 242–248.

[5] Anandaraj.S, Jessy Rooby, Awoyera P.O, Gobinath.R, Structural distress in glass fiber reinforced concrete under loading and exposure to aggressive environments, Construction and building materials, doi: 10.1016/j.conbuildmat.2018.06.090.

[6] Ravi kumar T, Siva Krishna A, Design and Testing of Fly-Ash Based Geo Polymer Concrete, International Journal of Civil Engineering and Technology, Issue 5, Vol. 8, May 2017, pp. 480-491.

[7] Thahira Banu, Chitra. G, Gobinath.R, P.O.Awoyera, Ashokumar.E, Sustainable structural retrofitting of corroded concrete using basalt fiber composite Ecology, Environment and Conservation, 24(3), pp 353-357.

[8] Dunster A, Silica fume in concrete, Information paper N° IP 5/09, IHS BRE Press, Garston, U.K. (2009).

[9] Ravi kumar T, Siva Krishna A, Design and Testing of Fly-Ash Based Geo Polymer Concrete, International Journal of Civil Engineering and Technology, Issue 5, Vol. 8, May 2017, pp. 480-491.

[10] Gaitero J, Campillo I, Guerrero A, Reduction of the calcium leaching rate of cement paste by addition of silica nanoparticles, Cement and Concrete Research 38 (2008), pp 1112–1118.

[11] Gengying Li, Properties of high-volume fly ash concrete incorporating nano-SiO2.

[12] Green B H, Development of a high-density cementitious rock-maching grout using nanoparticles, Proceedings of ACI Session on “Nanotechnology of Concrete, Recent Developments and Future Perspectives, November 7, Denver, USA (2006), pp 119-130.
[13] Rajesh Kumar, K., Karthik, S., Ramamohan, R., Awoyera, P.O., Gobinath, R., Shivakrishna, A, Murthi, P, Shear resistance of portal frame reinforced with Bamboo and steel rebar: Experimental and numerical evaluation, *International Journal of Recent Technology and Engineering*, vol. 8, no. 1, pp. 445-452.

[14] Hüskens G, Brouwers H.J.H., A new mix design concept for earth-moist concrete: A theoretical and experimental study, *Cement and Concrete Research* 38 (2008), pp 1246–1259.

[15] Kien Le-Trung, Kihak Lee, Jaehong Lee, Do Hyung Lee, Sungwoo Wooc, Experimental study of RC beam–column joints strengthened using CFRP composites

[16] Li G, Properties of high-volume fly ash concrete incorporating nano-SiO2, *Cement and Concrete Research* 34 (2004), pp 1043–1049.

[17] Lin K L, Chang W C, Lin D F, Luo H L, Tsai M C, Effects of nano-SiO2 and Different ash particle sizes on sludge ash–cement mortar, *Journal of Environmental Management* 88 (2008), pp 708–714.