An Experimental Investigation on Optimum Percentage of Nano-Silica in Nano-Mortar/Nano-Concrete for Retrofitting of RC Structures

Mr. Vijay Sawant[#1], Dr. Viduala Sohoni*[2]
[1.]Research Scholar, vijaysawantjspm@gmail.com, Department of Civil Engineering, Bharti Vidyapeeth Deemed University, Pune.
[2.]Professor, vssohoni@bvucoep.edu.inDepartment of Civil Engineering, Bharti Vidyapeeth Deemed University, Pune

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Abstract
The purpose of this study was to introduce a proposed method to retrofit RC beams. This paper consists of study of the RC beam behavior after using Nano Silica, Carbon Fibre Reinforced Polymer (CFRP), Glass Fibre Reinforced Polymer (GFRP) and epoxy in order to attain maximum strength, so as to withstand the shear forces, bending moments and other related structural response parameters efficiently. For this purpose, casting of three sets of reinforced concrete (RC) beam. Failure modes of each of the beams were obtained. The change in load carrying capacity and failure mode of the beams were investigated. The laboratory experiment and numerical simulation were used to investigate the behavior of the beams. Three RC beams for three different condition such 10mm U shape Nano silica retrofitting, RC beam with CFRP external wrapping retrofitting and without retrofitting specimens were investigated.

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1. INTRODUCTION

Nanotechnology has changed our vision, expectations and abilities to control the material world. The developments in nano-science can also have a great impact on the field of construction materials. Portland cement, one of the largest commodities consumed by mankind, is obviously the product with great, but not completely explored potential. Better understanding and engineering of complex structure of cement based materials at nano-level will definitely result in a new generation of concrete, stronger and more durable, with desired stress-strain behavior and, possibly, with the whole range of newly introduced “smart” properties.

Nanotechnology is one of the most active research areas that include a number of disciplines including civil engineering and construction materials. Nanotechnology is the understanding, control, and restructuring of matter on the order of nanometers (i.e., less than 100 nm) to create materials with fundamentally new properties and functions. Just how small is Nano? In the serviceability index system of units the Nano means 1- billionths or 10-9. I.e. 1 nanometer is 1 billionth of meter. It is difficult to imagine just how small that is, so here are some examples.

- A sheet of paper is about 100,000 nm thick.
- A strand of human DNA is 2.5 nm in diameter.
- There are 25,400,000 nm in 1 inch.
- A human hair is about 80,000 nm wide.
- On comparative scale, if diameter of marble were 1 nm, then diameter of the Earth would be 1m.

Traditionally nanotechnology has been concerned with developments in the fields of microelectronics, medicine and material sciences. However the potential for applications of many developments in the nanotechnology field in the area of construction engineering is growing. The evolution of technology and instrumentation as well as its related scientific areas such as physics and chemistry is making the nanotechnology aggressive and evolutional. There are many potential areas where nanotechnology can benefit construction engineering like its applications in concrete, structural composites, coating materials and in Nano-sensors, etc.

2. EXPERIMENTAL PROCEDURE:

In the present study fourteen R.C.C. beams are casted and categorized into three groups. The beam has a cross section of (150 ×150) mm with an overall length of700mm.The beams were reinforced with 2 Nos. of 10 mm HYSD Fe500 bars at the top and bottom respectively and stirrups were made up of 8 mm bars and were provided at a distance of 150 mm C/C.

Fig. 2 Reinforcement specimen of beam

2.1 Form Work Details of Beam

The formwork made from plywood was used for the casting of beam. The formwork was made of the dimension 150 mm x150 mm x700 mm.

Fig. 2.1 Form Work details of beam

2.2 Steel Frame and Concrete Cover

The steel frame was made up of 10 mm and 8 mm HYSD bars. The reinforced concrete beam was provided with an effective cover of 25 mm.

Fig. 2.2 Steel Frame Used for Casting of Beam

2.3 Casting Process of M25 Cubes and Beam

In the present study 15 cubes of M25 grade with Nano silica percentage varying from 0.5%-1.5% were casted and being tested for 7 days under the Compression testing machine and 14 beams of M25 grade of cross section 150 mmx150 mm and length 700 mm were casted and tested for 28days under the Universal testing machine. The casting procedure consisted of the following steps given below.

3. EXPERIMENTAL SETUP AND TEST PROCEDURE

A loading frame of capacity 60 tones was used to test the beams. After 28 days of curing, the beams were tested. The beams were tested under three-point loading. Using a hydraulic jack, the cyclic load was applied on a spreader beam, which in turn transfers the load to the beam on three points. Experimental setup the beams were placed on the loading frame. The hydraulic jack was lowered till a point such that there is contact between jack and spreader beam. At increments of 10KN, the load was applied and the corresponding deflections readings were noted. The control beam was tested for ultimate load and the remaining beams were damaged by 60% of the ultimate load. Then the RC beams were retrofitted by nano silica and carbon fiber reinforced polymers are tested up to failure. The load vs deflection was plotted and then the results were compared to identify the effectiveness of rehabilitation.

3.1 Experimental Study of Retrofitting Of Reinforced Concrete Beam By Nano Silica And Glass Fiber Reinforced Polymer:

The experimental study consists of casting of three sets of reinforced concrete (RC) beam. **The Set I** consisted of three beam casted using conventional RCC concrete and tested on Universal Testing Machine for transverse test up to its full failure.

The Set II beams were also casted as above but were tested and failed only up to the appearance of first crack. The first crack beam was retrofitted using Nano silica mortar and tested up to its full failure.

The Set III beams were also casted but were tested and failed only up to the appearance of first crack. The first crack beam set of beams was retrofitted using GFRP sheets and tested up to its full failure. Failure modes of each of the beams were obtained. The change in load carrying capacity and failure mode of the beams were investigated.

3.2 Transverse Testing of Beam SET I:

Before testing the member was checked dimensionally, and a detailed visual inspection made with all information carefully recorded. A 600 tonne capacity reaction frame mounted over strong floor was used to test the beam specimens. The beam was simply supported.

The test span was kept as 600 mm. The used loading arrangement for testing of beams consists of uniformly distributed load. The testing machine used could not apply the load at a specific load speed. Therefore, the load that was applied was manually controlled at an even rate of speed. During the test the load was recorded from the computer program that the hydraulic jack was connected to. The experimental study consists of testing of three sets of reinforced concrete (RC) beams. In set I total three beams were casted for full failure.

For simple reinforced beam:

1. SB1
2. SB2
3. SB3

Fig.3.2.1: Beam specimen for testing

Fig 3.2.1show beam specimens kept ready for testing. The testing of beam consists of three sets of reinforced concrete (RC) beams. In set I total three beams were casted for full failure to observed ultimate load. The test was continued until the load drops about 40-50% of the obtained ultimate loads for concrete beam specimens. All the beams were tested till they reach their full flexural capacity. The behavior of the beam was keenly observed from the beginning to the end till it collapses.

Fig.3.2.2: Beam during loading

The beam failure took place either due to crushing or shears failure up to 83 KN in compression zone and failed with sufficient warning before collapse. The crack patterns were also recorded at every load increment. It has been observed that hairline cracks develop at the lower part of the beam and as loading continues, cracks widen and extend towards the neutral axis. At the time of loading rate was maintained as low as possible and constant.

3.3 Transverse Testing Of Beam SET II and SET III:

In SET II three beams are casted and tested, the three beams were retrofitted by using Nano silica.
In SET III three beams were casted and tested up to first crack, and all three beams were retrofitted using continuous glass fiber reinforced polymer (GFRP) sheets.

For Reinforced Beam Retrofitted Using Nano Silica:

1. SBN1
2. SBN2
3. SBN3

Fig.3.3.1: Simply supported beam testing

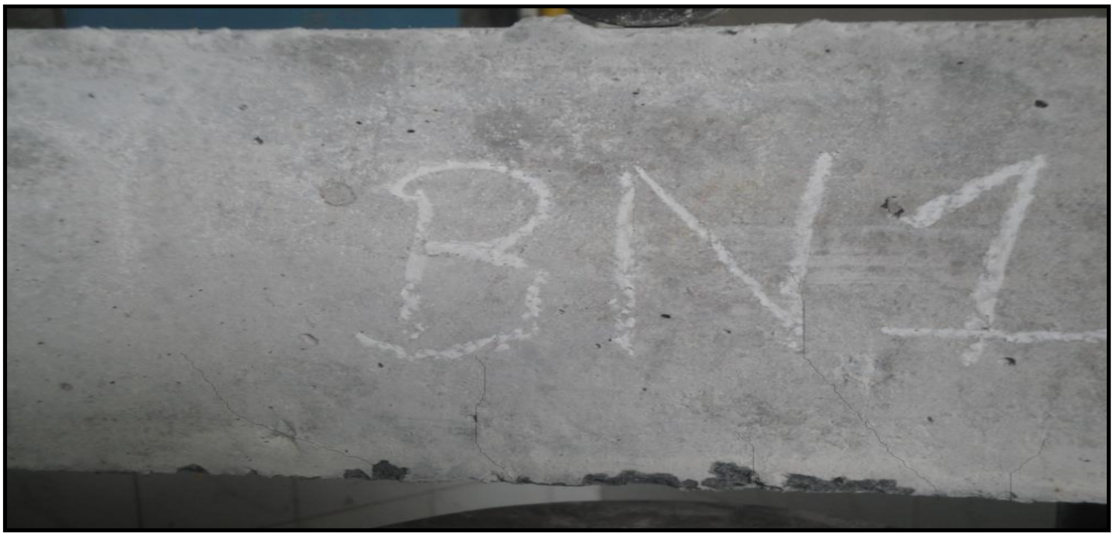

Fig.3.3.2: First crack on beam

The beam failure takes place either due to shear failure up to the first crack. The crack patterns are also recorded at every load increment. It has been observed that hairline cracks develop at the lower part of the beam and as loading continues, cracks widen and extend towards the neutral axis. At the time of loading rate should maintain as low as possible and constant.

3.4Testing of Retrofitted Nano Silica Beam:

While testing the member, all dimensions of element was checked, the centre of beam of beam was also checked and a detailed visual inspection made with all information carefully recorded.

The used loading arrangement for testing of beams consists of uniform distributed loading. The load that was applied was manually controlled at an even rate of speed. During the test the load was recorded from the computer program that the hydraulic jack was connected to.

Fig.3.4.1: Beam specimen for testing

In SET III three beams were tested for full failure. Figure 3.4.1 shows beam specimens kept ready for testing. The testing of beam consists of three sets of retrofitted reinforced concrete beams. We measure the width and thickness of a specimen and mark all the points where the load is to be applied. Under the centre point loading process, place carefully the sample on the stage of UTM such that the loading point is set at the pointed location.

Fig.3.4.2: Failure retrofitted beam using nano silica

The crack patterns are also recorded at every load increment. It has been observed that cracks develop at the lower part of the beam and as loading continues, cracks widen and extend towards the neutral axis. At the time of loading rate should maintain as low as possible and constant.

3.5 Retrofitting of Specimens

3.5.1 Retrofitting of Specimens using Nano Silica: The specimens loaded up to first crack of SET II were retrofitted by replacing 20 mm cover of the specimen by nano silica mortar. By taking all the precautions the cover of beam was removed manually. Figure 3.5.1 to 3.5.4 shows cutting of damaged portion of specimens for retrofitting. Figure 3.5.1: Cutting of Damaged Portion of Simple Beam Specimen for Retrofitting

3.5.1 Retrofitting of Specimens using Nano Silica:

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Figure3.5.1: Cutting of Damaged Portion of Simple Beam Specimen for Retrofitting

Figure3.5.2: Cutting of Damaged Portion of T –Beam Specimen for Retrofitting

Figure3.5.3: Cutting of Damaged Portion of Cross Beam Specimen for Retrofitting

Figure 3.5.4: Cutting of Damaged Portion of Column Specimen for Retrofitting

3.6 Filling of Nano Silica:

As0.5%replacementofcementbynanosilicagavemaximumincrementinstrength as explained in section 3.2, specimens were retrofitted with mortar mix design for the same. After the nano silica mortar has been mixed, and filling of mortar was done by using the same moulds used for concreting. The compaction of the mortar was done manually by using taping rod. After filling of nano silica, the dimensions of beam were checked. Figure 3.6.1 to3.6.5 shows moulding of specimens before filling of nano silicamortarandFigure3.49 shows specimens retrofitted with filling of nano silica mortar.

Figure3.6.1: Moulding of Simple Beam Specimens before Nano Silica Retrofitting

Figure3.6.2: Moulding of T-Beam Specimens before Nano Silica Retrofitting

Figure3.6.3: Moulding of Cross Beam Specimens before Nano Silica Retrofitting

Figure3.6.4: Moulding of column Specimens before Nano Silica Retrofitting

Figure3.6.5: Filling of Nano Silica Mortar

After filling of the mortar, setting of the specimens were done for 24hours and then kept for curing for 28days from date of casting.

3.6 Testing of Retrofitted Specimens

3.6.1 Testing of Retrofitted Specimens using Nano Silica

The SETII specimens retrofitted with Nano Silica were tested as per the procedure explained in section 3.6. Before testing the specimens, all dimensions were checked. The test setup and procedure were the same as for SET I. The specimens retrofitted with nano silica were tested up to the ultimate/failure load. Figure 3.6.1 to 3.6.4 shows sample images of specimens retrofitted with nano silica. The failure loads and the crack patterns were recorded at every load increment.

Figure3.6.1: Testing of Nano Silica Retrofitted Beam Specimen

Figure3.6.2: Testing of Nano Silica Retrofitted T-Beam Specimen

Figure3.6.3: Testing of Nano Silica Retrofitted Cross Beam Specimen

Figure3.6.4: Testing of Nano Silica Retrofitted Column Specimen

3.7 Nano Silica Retrofitted Ultimate Loading Test Results

SetII specimens tested for first crack load were retrofitted using nano silica mortar asexplainedinsection3.8.1wereretesteduptoultimateloadcarryingcapacityandtheresultsof load and respective deflection were withdrawn as given in Table 3.7. Figure 3.7.1, to 3.7.4 shows typical views at complete failure of nano silica retrofitted specimens during tests at ultimate load applied.

Table3.7: Results of Nano Silica Retrofitted SETII Specimens at Ultimate Load

Sr. No.	Element Name	Ultimate Load(kN)	Deflection(mm)	Average Ultimate Load(kN)	Average Deflection (mm)
1.	RSBN1	97.59	0.94	97.76	0.96
2.	RSBN2	99.06	0.99		
3.	RSBN3	96.64	0.95		
4.	RTBN1	126.04	1.15	122.97	1.16
5.	RTBN2	119.05	1.13		
6.	RTBN3	123.83	1.21		
7.	RCBN1	164.68	0.82	164.77	0.81
8.	RCBN2	159.76	0.79		
9.	RCBN3	169.86	0.81		
10.	RCN1	828.64	2.25	816.87	2.19
11.	RCN2	812.91	2.32		
12.	RCN3	809.06	2.01		

Figure3.7.1: Nano Silica Retrofitted Simple Beam Specimen Failure at Ultimate Load

Figure3.7.2: Nano Silica Retrofitted T-Beam Specimen Failure at Ultimate Load

Figure3.7.3: Nano Silica Retrofitted Cross Beam Specimen Failure at Ultimate Load

Figure3.7.4: Nano Silica Retrofitted Column Specimen Failure at Ultimate Load

4. CONCLUSION

For RCC beam, Nano silica retrofitted beam, GFRP

An experimental study was carried out on nine numbers of simply supported beams which are conventional, Nano silica mortar replacement of 10 mm and GFRP sheet and these specimens were tested under centre point loading. From the test results are summarized below:

1) For SET II specimens, retrofitted with Nano silica mortar of 10 mm layer, the load carrying capacity increased by 17.31%.
2) For SET III specimens, retrofitted with GFRP sheet, the load carrying capacity increased by 16.51%.
3) The concrete cube specimen with 0.5% of Nano silica replacement gives the compressive strength greater than normal concrete.
4) Deflection of both SETs retrofitted using GFRP sheet and Nano silica specimens are decreased compared to the conventional element.
5) The initial cracks in the strengthen beams appeared at higher load compared to the simple conventional beams.
6) The bonding between GFRP sheet and the concrete is intact up to the failure of the beam which clearly indicates the composite action due to GFRP sheet.
7) Restoring or upgrading the shear strength of beams using GFRP sheet can result in increased shear strength and stiffness with no visible shear cracks. Restoring the shear strength of beams using GFRP is highly effective technique.

For RCC beam, Nano silica retrofitted beam, CFRP

The addition of the Nano silica particles in the concrete mortar mixes successfully enhanced the properties of concrete. The improvement in strength, durability, impermeability on a higher side by use of Nano material is well established. Considering the obtained results following conclusion can be made.

1. By retrofitting, the concrete integrity is maintained by confinement and has significantly improved the load-carrying capacity of the beam.
2. The analytical results clearly conclude that Nano silica 15mm can enhance the strength of simply supported concrete beam with central point load.
3. The experimental cube test results indicated 31.17% rise in strength with 0.5 % addition of Nano silica.
4. The use of Nano silica as a retrofitting material lead to increase in ultimate capacity compared to those of other strengthens beams.
5. The ultimate capacity of CFRP strengthen beam was increased by 8.23% than RCC unstrengthen beams.
6. The defection at ultimate load of CFRP strengthen beam was decreased by 52.71% than RCC unstrengthen beams.
7. The ultimate capacity of Nano silica strengthen beam was increased by 10.11% than RCC unstrengthen beams.
8. The defection at ultimate load of Nano silica strengthen beam was increased by 30.97% than RCC unstrengthen beams
9. The experimental results indicate the ultimate load of Nano silica strengthen beam was increased by 3.68%, 11.90% and 5.76% respectively than the average of the sum of the ultimate capacity of CFRP strengthen beams and RCC unstrengthen beams.

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