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RESEARCH ARTICLE

# BEHAVIOUR OF HIGH PERFORMANCE REINFORCED CONCRETE MODIFIED WITH CARBON NANO TUBES AND SBR LATEX UNDER FLEXURE

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ABSTRACT

Studies on strength and ductility aspects of the concrete are constantly increasing and are one of the most developing areas in the design of concrete structures. High Performance Concrete (HPC) exhibits excellent strength and durability properties. Various factors such as adverse environment, climatic conditions, specific application, etc.demand the use of special type of concretes to meet the durability and performance requirements of infrastructures such as high rise buildings, dams, bridges, transportation terminal facilities like harbours, airports, etc. Detailed experimental investigation on flexural behaviour ofHigh Performance Concrete modified with Carbon Nano Tube (CNT) and Styrene Butadiene Rubber (SBR) latexon four test beam specimens having dimension 150mmx230mm with the effective length of 2000mm to obtain Load-Deflection response were carried out. The results of the study indicate that ductility factor, resistance to energy absorption capabilities and toughness index of CNT and SBR latex modified High Performance Concrete are enhanced significantly as compared to HPC.



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## INTRODUCTION

The use of concrete in the construction industry is widespread all over the world. Although most people prefer reinforced concrete as a choice for general construction, there is a worldwide concern about its strength & durability. As the concrete is a composite material, environment has a profound effect on it. The frequent changes in environmental conditions like changes in temperature, changes in moisture content, and internal drying shrinkage may initiate cracks in the concrete. Such cracks may further propagate due to the brittleness of the concrete. These cracks not only question the safety of the structure but also increase the cost of repair and maintenance of the structures. Though concrete is the most widely used construction material, it suffers from three major weakness- low tensile strength, high porosity and susceptibility to chemical and environmental attack. The key to damage-resistant concrete and long-life concrete structures, which has been known for a long time, lies in enhancing the tensile strength and fracture toughness of concrete material. Therefore, many new macro-to-micro reinforcements have been utilized in order to increase the tensile strength and fracture toughness of concrete but all have led to marginal improvements.Hence, advanced researches have to be conducted to develop an advanced cement - based material. These materials must be able to improve the properties of the concrete like brittleness, vulnerability to chemical attacks etc. Carbon Nano Tubes (CNTs) and Styrene Butadiene Rubber (SBR) latex are some of such materials that are being developed. This can be achieved by integration of CNTs and Polymers in concrete. By using these, ordinary structural concrete can be strengthened and retrofitted (Sy-JyeGuo and Tung-HoTsai, 2012). CNT are expected to have several distinct advantages as a reinforcing material for cements as compared to more traditional fibres (Makar *et al.,* 2005; Al-Rub *et al.,* 2010; Li *et al.,* 2005). First, they have significantly greater strengths than other fibres, which should improve overall mechanical behaviour. Second, CNT have much higher aspect ratios, requiring significantly higher energies for crack propagation around a tube as compared to across it than would

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be the case for a lower aspect ratio fibre. Thirdly, the smaller diameters of CNT means both that they can be more widely distributed in the cement matrix with reduced fibre spacing and that their interaction with the matrix may be different from that of the larger fibres. As with other CNT composites, the major issues to overcome in preparing high quality CNT/cement composites including distributing the CNT within the cement and obtaining suitable bonding between the two materials. One route is to disperse the CNT in a surfactant mixed with water or another solvent, as has commonly been used for polymer composites. While substantial research on Carbon Nano tubes (CNTs) has been focused around their incorporation within polymers (PerumalsamyBalaguru and Ken Chong, 2006) very diminutive attention has been focused on assimilation of CNTs with cement. Therefore, the research on integration of CNTs in cementations materials is at a relatively novel stage; currently, very limited research regarding their effectiveness in enhancing the tensile strength or toughness of concrete has been conducted (Nagaraja and Showkath Ali Khan Zai, 2013). There are different types of polymer and are being used in cement concrete construction. They are aqueous polymer, powder emulsion, water-soluble polymer, liquid polymers etc. Rubber latex comes under aqueous polymer category. Recent studies indicate that both natural and synthetic rubber latex improve the engineering properties of concrete markedly (Arun Kumar Chakraborty, 2008; Sadath Ali Khan Zai and Shashikumar, 2009). SBR Latex is Styrene Butadiene Rubber polymer, designed to use the latex for the modifying the cement composites (HanfengXu and Sidney Mindess, 2006). The adding of SBR Latex in cement improves the mechanical properties of the matrix. Hence an attempt has been made through the present experimental investigation to study the effect of High Performance Concrete modified with CNT and SBR latex on the Flexural behaviour of test beam specimens (Sadath Ali Khan Zai *et al.,* 2013).

**Experimental Program**

The aim of thepresent investigation is to study the flexural behaviour of High performance concrete including CNTs with and without SBR-Latex. The cross section of the test beam specimen 150×230mm (breadth by depth) with a span of 2200mm. The following parameters are considered under this study - load-deflection curves, Toughness Index, ductility factor, energy absorption capacity, cracking moment and crack pattern.

**Materials used in the present study**

In the present work, the concrete used in the experiments consists of 53 grade Ordinary Portland cement, crushed granite with maximum nominal size of 12.5mm down size coarse aggregate, fine aggregate satisfying the requirement of zone II, portable water, Silica fume/micro silica (NUSIL-50,concrete admixture) supplied by M/S NUCHEMS, Ground Granulated Blast furnace Slag (GGBS) supplied by Nandi Cements Pvt. Ltd, Super plasticiser (BASF Gleniam 8233) a high range water reducer, Multi-walled CNT(MWCNTs) having average diameter 25 nm with length of 30 to60µm and Styrene Butadiene Rubber emulsion (SBR)-latex FosrocNitobond SBR latex (Polymer latex bonding aid) with their optimum percentages subject to the required workability. To determine the mix proportions for M60 grade of concrete (HPC), tests on trial mixes were carried out and was finally selected with required workability of 25-50mm, 8% of silica fume is replaced by weight of the cement, 20% of GGBS 0.1% of CNTs, 0.7% of Super Plasticiser and 10% of SBR latex by weight of cementations materials were used in the concrete mix in the present investigation. Final mix proportions for the matrix (1:0.27:0.78) used in the investigation are shown in the Table 1.

**Table 1. Mix Proportioning**

| Mix | Units | HPC | HPC+SBR |
|---|---|---|---|
| Cement | kg/m³ | 513.5 | 513.5 |
| Fine Aggregate | kg/m³ | 375.1 | 375.1 |
| Coarse Aggregate | kg/m³ | 1146 | 1146 |
| Water | kg/m³ | 141.3 | 141.3 |
| SBR | kg/m³ | | 66.68 |
| Silica fume | kg/m³ | 53.3 | 53.3 |
| GGBS | kg/m³ | 133.4 | 133.4 |
| CNTs | Litres | 0.51 | 0.51 |
| Super plasticiser | kg/m³ | 4.0 | 4.0 |
| w/c | | 0.36 | 0.36 |

**Testing Methodology**

**Flexure test on beam specimen:** Four test specimens were made for the investigation and all are having nominal dimension of 150 X 230 mm with an effective span of 2000mm. The test specimens were divided into two categories with two beams in each category according to their material combination listed as below.

**Table 2. Test Beam Specimens**

| | |
|---|---|
| Beam – 1<br>Beam - 2 | High performance concrete (M60 + CNT). |
| Beam – 3<br>Beam - 4 | High performance concrete with Styrene Butadiene Rubber latex (M60 + CNT + SBR-latex). |

The typical details of the pattern of the reinforcement and cross section of the test beam specimens are shown in Fig 1.

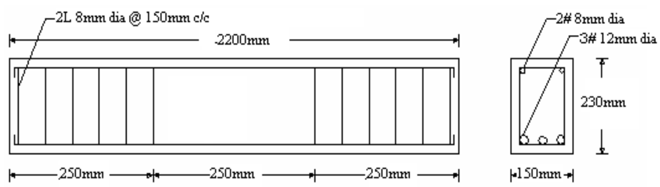


**Figure 1. Reinforcement Details**

## RESULTS AND DISCUSSION

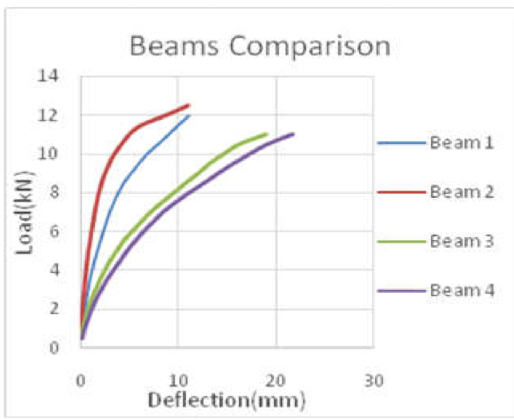


**Figure 2. Load vs. Deflection of HPC+CNT and HPC+CNT+SBR Beams-Comparison**

**Table 3. Ductility factor**

| Beams | Ultimate Load (KN) | Deflection at Ultimate Load (mm) | Yield Load (KN) | Deflection at Yield Load (mm) | Ductility Factor | Average Ductility Factor |
|---|---|---|---|---|---|---|
| Beam-1 | 11.5 | 10.78 | 5.5 | 1.986 | 5.42 | 7.625 |
| Beam-2 | 12.5 | 11.04 | 5.5 | 1.124 | 9.82 | |
| Beam-3 | 9.50 | 119.55 | 6.5 | 6.71 | 12.9 | 12.05 |
| Beam-4 | 10.0 | 121.95 | 6.5 | 10.0 | 12.2 | |

## Ductility factor

The measurement of the elemental capacity to uphold inelastic behaviour and adsorb energy is known as ductility. Many forms of ductility are curvature, rotational, and displacement ductility. In this analysis, displacement ductility is found out. Displacement ductility, $\mu_d$, is the ratio of deflection of ultimate moment to the deflection at first yield. Higher ductility ratios show that a structure member is able to undergo high deflection before failure. Displacement ductility is given by
$\mu_d = \delta_u / \delta_y$

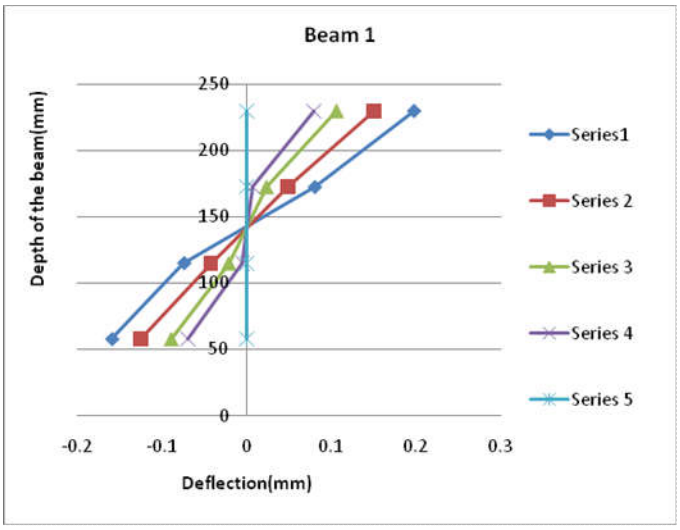


**Figure 3. Strain along Depth of the Beam-1 (HPC+CNT)**

## Energy absorption capacity

The Energy absorption capacity of given material can be obtained from the load v/s deflection curve of the test beam specimen. The value of Energy Absorption Capacity was calculated by finding area under the load-deflection curve for different concrete mix under investigation.

**Table 4. Energy absorption capacity**

| Beam | Energy absorption capacity (KN-mm) |
|---|---|
| Beam -1 | 35.80 |
| Beam-2 | 36.11 |
| Beam-3 | 50.70 |
| Beam-4 | 52.84 |

## Toughness index

The values of toughness index of test beam specimens under investigation are given in table below.

$$\text{Toughness index} = \frac{\text{area under the } P-\delta \text{ curve up to ultimate load}}{\text{area under the } P-\delta \text{ curve up to first crack load}}$$

**Cracking moment:** The observed moments at first crack, $M_{cr(exp)}$, is based on the first visible crack in the pure bending region.

**Table 5. Toughness Index**

| Beam | Toughness Index |
|---|---|
| Beam-1 | 32.83 |
| Beam-2 | 33.54 |
| Beam-3 | 45.5475 |
| Beam-4 | 47.3000 |

The predicted cracking moments, $M_{cr(Theo)}$, were calculated based on the modulus of rupture $f_r$.

$$Mcr = \frac{fr*Ig}{yt} N - mm; fr = 0.7\sqrt{f'c} MPa$$

Where: $I_g$: gross moment of inertia, $y_t$: distance between NA and extreme tension fibre

**Table 6. Cracking Moment**

| Beam | $M_{cr\ (Theo)}$, (Kn-m) | $M_{cr\ (exp)}$, (Kn-m) |
|---|---|---|
| Beam 1&2 | 6.1 | 6.19 |
| Beam 3&4 | 4.99 | 6.00 |

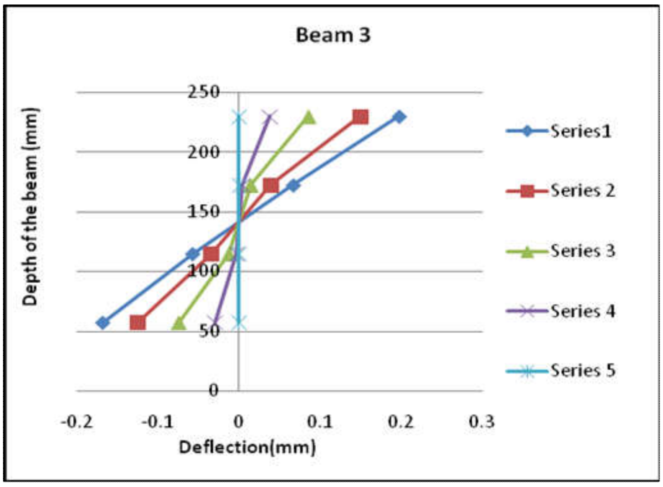


**Figure 4. Strain along Depth of the Beam-3 (HPC+CNT+SBR)**

**Figure 5. Crack pattern of test beam specimens**

**Crack pattern**

Generally, length of the cracks is the main criteria to determine the durability and serviceability of a structural element in actual practice. Observation of the cracks is made using a magnifying glass.

**Summary and Conclusion**

The experimental program deals with the study of behaviour of High Performance Concrete modified with CNT and SBR-Latex under flexure. A concrete mix of grade M60 was designed to which CNTs and SBR latex was added. Three point loading condition was adopted. From the analysis of experimental results obtained, following conclusions are reported.

- A number of variables can cause changes in the flexural behaviour of concrete includes the composition of concrete matrix, type of admixtures and complementary reinforcement.
- Among the both mixes, ductility of beam 3 & beam 4 is increased by 57% as compared to beam 1 & beam 2.
- The energy absorption capacity of beam 3 & beam 4 is greater by 44% as compared to beam 1 and beam 2.
- The toughness index of beam 3 & beam 4 increases by 39% than that of beam 1 & beam 2.
- Cracking moment of test beam specimens made of CNT and SBR latex modified High Performance Concrete is decreased by 6.5% as compared to test beam specimens with CNT modified High Performance Concrete.

From this experimental Investigation, it was observed that High Performance concrete modified with CNT and SBR latex behaved much better with regards to first crack, ductility factor, resistance to energy absorption capabilities and toughness behaviours with respect to High Performance Concrete modified with CNT.

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