Amalgamation of nano carbon for the advancement of the performance in mechanical properties of the concrete: A cementitious material

Hitesh R. Ashani[1], Sachin P. Parikh[2], Jaysukh H. Markna[3]

[1]*Department of Civil Engineering, Shri Jagdishprashad Jhabarmal Tibrewala University, Jhunjhunu, 333001, India*
[2]*Department of Chemical Engineering, V.V.P. Engineering College, Gujarat Technological University, Gandhinagar, 382028, India*
[3]*Department of Nano Technology, V.V.P. Engineering College, Gujarat Technological University, Gandhinagar, 382028, India*

[*]Corresponding author, Hitesh R. Ashani, Tel: (+91) 9624097755; E-Mail: hiteshashani@yahoo.com, technofabrics@gmail.com

Received: 31 March 2016, Revised: 30 September 2016 and Accepted: 01 November 2016

DOI: 10.5185/amp.2017/732
www.vbripress.com/amp

Abstract

Nanotechnology is considered as one of the active research area of 21st century due to its increasing economic importance and ability to study the material at nano scale to improve its behavior in construction industry. Concrete the second highest consume commodity on the planet after water is highly heterogeneous material with thumping performance challenges on it. Demand of concrete is increasing due to increasing demand for infrastructure development, rapid urbanization, rapid industrial development, population growth, economic development of the nation etc. A little diminution in the number of problems related with concrete would add up to noteworthy recital enhancement and economic benefits to society and nation. In the present communication, the cement one of the main ingredient of concrete was replaced with a range of 5%, 10%, 15% and 20 % of the weight of cement by nano carbon material to study the effect on the mechanical properties like – compressive strength, surface hardness, water absorption, consistency, morphology on nano carbon concrete specimen. A rapport was made between standard and nano carbon black concrete specimen to arrive at a legitimate conclusion that improvement in the mechanical properties like strength, hardness, compactness etc. and C-S-H gel structure is obtained.

Keywords: Carbon black, nano technology, concrete, mechanical properties, C-S-H gel structure.

Introduction

Concrete is a unique the widely used building material in modern epoch at global level [**1**]. Concrete is the second highest consumable man made construction material used on the planet after water. Its demand is increasing day by day due to increasing population growth, rapid urbanization, rapid industrial development, need in infrastructure development sector etc. [**2**]. One cannot avoid importance of concrete for the economic development of the nation but at the same time one had to take care of problems related with concrete science its discovery [**1**]. Concrete is a mixture of cement, sand, aggregate and water in required proportion. Reaction between cement and water known as hydration process creates, calcium-silicate-hydrate gel which is considered as a strength phase of the concrete with 28% of voids comparison to total volume of Calcium-Silicate-Hydrate gel [**3**]. Concrete composed of a phase without clear defined shape or form, nanometer to micrometer size crystals and bound water [**4**]. In this phase, calcium-silicate-hydrate gel holds concrete together. Being a flexible material, existence of pores in concrete proves to be a major problem since ever it was discovered [**3**]. Pores consecutively create a center of attention to water that escort to numerous ill effects. The cracks and pores in concrete structures and premature erosion are mainly due to alkali silica reaction, which is a chemical reaction that causes fissures in the concrete. Apart from the above, permeability of gases through pores and micro-cracks in the concrete, which leads to corrosion problem in the reinforcement of concrete causes further deterioration. Moreover, the expansion and shrinkage in concrete, which are also cause for crack in concrete at later ages, are mainly due to the sulphate attack, which causes disintegration in concrete, chemical leaching and both the events are mainly due to the excess calcium hydroxide [CH], the by-product during cement hydration as per the following chemical equations.

This situation triggers to adverse effect on strength, workability, uniformity, and other mechanical properties

of the concrete [**5**]. By means of deliberate this issue a study is carried out to diminish pores in the concrete with carbon black, a powder obtained from rubber industries. the addition of carbon black enhances the possibility for the reaction with calcium hydroxide (CH) to develop more strength carrying structure of cement: calcium silica hydrate (C-S-H) and also pore filling effect of carbon black in the concrete, improve the mechanical properties of concrete, its workability, alteration in setting times and durability.

Carbon black

Carbon black is nearly pure rudimentary carbon in the form of colloidal atom that are produced by imperfect incineration or thermal breakdown of liquid or gaseous hydrocarbons beneath controlled environment. Its substantial manifestation is that of a black, thinly separated pellet or powder. It is a waste from rubber industry, finds difficulty in disposal. Usually these rubber wastes are discarded into soil give rise to soil pollution and contamination of water table [**6**]. By using carbon black as space filler in concrete we can trim down this problem to a great magnitude. Thereby reusing the waste usefully and making it eco-friendly to environment. The specific gravity of carbon black was determined by density bottle method and it was found to be 1.33. The pH value was found to be 6. This indicates that carbon black is almost an inert material.

The objective of current study is -

1. To study the property of carbon black as nano material.
2. To study calcium – silicate-hydrate (C-S-H) structure at nano level and its modification due to use of nano material.
3. To analyze the effect of carbon black material on the performance of concrete in terms of compressive strength, flexure strength, tensile strength, durability, stress - strain behavior etc. in comparison with conventional and other nano material used for preparation of concrete.

Nanotechnology and concrete

Nanotechnology and Nanomaterial is the active research area of 21st century. It deals with the study and use of structures between 1 nano meter (nm) and 100 nano meters in size. Nanotechnology means science which deals with nanoscale to understand, control and restructuring of matter to create materials with new properties and functions [**7**]. Nanotechnology is the study to control matter at molecular and atomic scale in which size of the particle is the critical factor [**8**] which affect the property of the materials [**9**]. As the particle become nano sized the ratio of atoms on the exterior raise virtual to those in the interior and this being charge to novel property of materials [**2**]. With nanotechnology knowledge crucial happening in cement at the nano degree like, origins of cement cohesion ,structure and mechanical properties of the main hydrate phases, cement hydration, interfaces in concrete, and mechanisms of degradation is increasing can be scrutinize and look at carefully in skilful way. Thus, Improved perceptive and engineering of intricate arrangement of cement-based materials at nanolevel with insertion of nano material will without doubt result in a new age group of concrete more durable and stronger, with desired stress strain behaviour and, possibly, with the whole range of newly introduced "smart" properties.

Experimental

For the research work the casting of 18 numbers of concrete cubes of 150x150x150 mm size and 12 numbers of concrete cylinders of 150x300 mm size was done. From this time a total of 30 concrete samples were casted with an assortment of percentage of carbon black to carry out various tests. Concrete cubes were cast with the carbon black as filler of 0%, 5%, 10%, 15%, and 20% in the amount of cement; Concrete cylinders were cast with the carbon black of 0%, 5%, 10%, 15% and 20% in the amount of cement for concrete grade M25. Hand mixing method was used for preparation of mix. During mixing carbon black was come across difficulty in amalgamation with the element of concrete, to obtain a consistent mix sundry mixing course of action was adopted.

Details of Material with their manufacturer names, purity and place of manufacturing:

1. Cement :
   (a) Type of Cement : Ordinary Portland Cement
   (b) Manufacturer : Ultratech
   (c) Grade : 53 grade
   (d) Place of Manufacturing : village : Jafrabad, district : Amrili, State : Gujarat
2. Aggregate :
   (a) Type : course Aggregate
   (b) Size : 10 mm and 20 mm
   (c) Manufacturer : Local
   (d) Type : fine Aggregate
   (e) Zone : 1as per I.S.383(1970)
   (f) Source : Local
3. Water :
   (a) Type/purity : Potable
   (b) Source : bore well
4. Carbon Black :
   (a) Type : N110
   (b) Source : rubber industry

Experimental procedure

The fine aggregates, coarse aggregates, and water were taken by weight basis and blended manually on a water tight platform. Water was added gradually until all the materials were mixed to get uniform mix. After 10 minutes the cement and the remaining of water were added. Later than 2 minutes of mixing, carbon black was introduced and mixed for 3 additional minutes. Cubes as per I.S. size – 150 mm x 150 mm x 150 mm were casted in three layers, each compacted with compaction rod 60 cm length. After 24 hours cubes were opened and put in water tank for curing. Before used for experiment cubes were surface dried and weighted.

To study the recital of carbon black concrete the following tests were carry out on carbon black concrete specimens: 1. Compressive strength test on concrete cubes using compression testing machine, 2. Non-destructive Compressive strength test on concrete cubes using Rebound Hammer, 3. Ultrasonic Pulse Velocity test to find the Uniformity of concrete, 4. Water absorption test to study the permeability of concrete, 5. Morphology of concrete specimens is studied using Scanning Electron Microscope (SEM).

Results and discussion

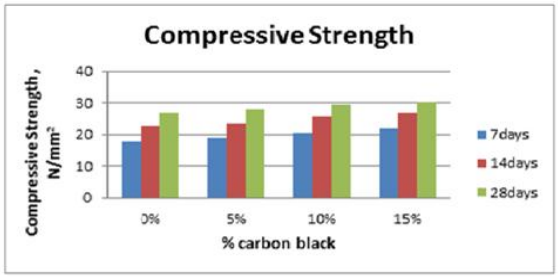
Compressive strength test

To accomplish the compressive strength of concrete cubes, the samples was set in the compression testing machine after curing for 7 days, 14 days and 28days. The load was applied steadily exclusive of tremble and constantly at the rate of 140kg/cm^2/minute till the specimen failed. The utmost load at which the specimen failed was witness.Fig. shows the Experimental Setup of Compressive Strength Testing. Results are tabulated in **Fig. 1**.

(a)

% carbon black	Compressive Strength N/mm^2			% increase in Compressive Strength
	7 days	14 days	28 days	
0%	17.74	22.79	26.64	
5%	18.73	23.46	27.96	4.95%
10%	20.22	25.67	29.44	10.51%
15%	21.76	26.86	30.38	14.03%

(b)



(c)

Fig. 1. (a) Experimental Set Up for Compressive Strength Testing. (b) Compressive Strength Results of Concrete Specimen. (c) Schematic Result Analysis of Concrete specimen for Compressive Strength Test.

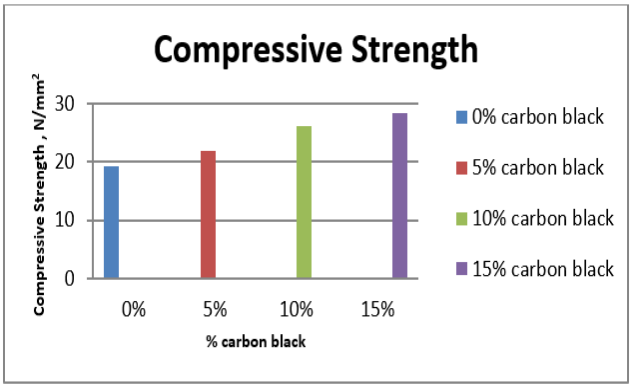
From the Tabulated result and Graph it is clear that concrete specimen with 5%, 10% and 15% has given better results compared to control specimen. Result indicates that carbon black filler enhance the strength of concrete. Among all concrete cubes, 15% carbon black concrete shows the best result. This is due to densification of transition zone.

Rebound hammer test

This test is established on the standard that the rebound of elastic mass depends on the resistance of surface alongside which the mass strikes. The surface rigidity and consequently the rebound is taken to be coupled to the compressive strength of concrete cubes. The results of rebound hammer test is shown in the **Fig. 2.**

% of Carbon Black	Rebound No.	Compressive Strength N/mm^2
0%	24	19.22
5%	25.50	21.85
10%	28.30	26.21
15%	30.24	28.48

(a)



(b)

Fig. 2. (a) Rebound Hammer Test Results of Concrete Specimen. (b) Schematic Result Analysis of Concrete specimen for Rebound Hammer Test.

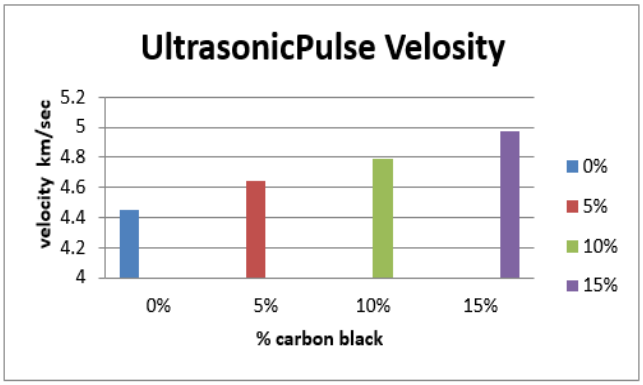
It is clear from the test that 15% carbon black concrete specimen gives improve compressive strength compare to standard concrete specimen, 5%, 10% concrete specimen with carbon black.

Ultrasonic pulse velocity test

The ultrasonic pulse velocity (UPV) test is employ to ascertain the homogeneity of the concrete and to discover the existence of voids , cracks, and other shortcoming. The test is based on the ideology that the velocity of an ultrasonic pulse by means of any material depends upon the density, modulus of elasticity and Poisson's ratio of the material. Comparatively higher velocity is obtained when concrete quality is good.UPV test was conducted on concrete cubes to analyze the density, uniformity, homogeneity of carbon black concrete. The results of ultrasonic pulse velocity test are shown in the **Fig. 3**.

% of Carbon Black	Time , Micro Second	Distance Travelled , m	Velocity , km/s	% increase in velocity
05	33.55	0.15	4.45	----
5%	31.65	0.15	4.64	+4.26
10%	30.65	0.15	4.79	+7.64
15%	29.87	0.15	4.97	+11.68

(a)



(b)

Fig. 3. (a) Ultrasonic Pulse Velocity Test Results of Concrete specimen. (b) Schematic Result Analysis of Concrete specimen for Ultrasonic Pulse Velocity.

Water absorption test for concrete cubes

For the durability of concrete permeability of concrete is a vital criterion. Permeability directly relates with the pore size available in concrete. Three cubes of concrete for each 0%, 5%. 10% &15% was immersed in clean water at room temperature for one day .The cubes were removed from water & allowed to dry for one minute and weighted. After that, cubes were dried in oven at 100 to 115 °C and weighted. The weight loss was measured and shown in **Table 1**.

Table 1. Weight measurement.

% of Carbon Black	Dry weight (kg)	Wet weight (kg)	% increase in weight	% Increases in Water absorption
0%	8.98	9.15	1.89	----
5%	8.44	8.54	1.18	-41.2
10%	8.32	8.40	0.962	-52.9
15%	8.64	8.70	0.694	-64.7

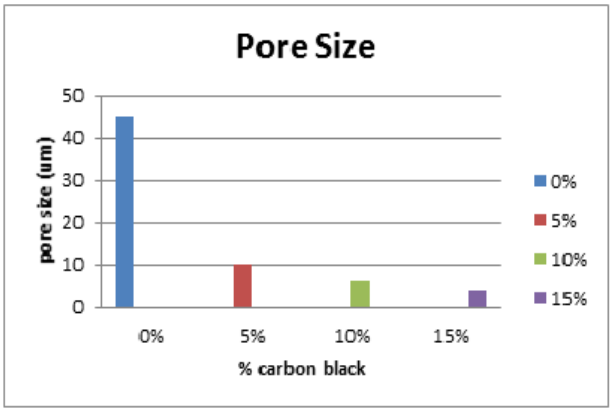
From the water absorption test it is clear that concrete specimen with 5%, 10%, 15% has better results narrate to control specimen. This proves that carbon black when used as filler in concrete diminish the porosity of concrete. Among concrete with carbon black specimens 15% shows the best result.

SEM analysis

The scanning electron microscope uses signals that derive from electron sample interactions reveal information like external morphology (texture), chemical composition and crystalline structure and orientation of materials making the sample. In SEM pore size of concrete specimen has been measured and results are presented in **Fig. 4**.

% carbon black	Proe Size (um)	% increase in pore size with respect to control sample
0%	45	----
5%	10	-77.77
10%	6	-86.67
15%	4	-91.11

(a)



(b)

Fig. 4. (a) Scanning electron microscope Test Results of Pore Size of Concrete Specimen. (b) Schematic Result Analysis of Pore Size of Concrete specimen.

From the SEM images and Table V it is clear that the pore size has been decreased in case of carbon black concrete when related to control specimen.15% carbon black concrete specimen has the minimum pore size compare to all other specimens. This be a sign of that carbon black is effective in filling the pores also in mortar specimens.

Conclusion

Therefore from the above experiments and result it can be make your mind up that the toting up of carbon black up to 15% as a filler will be very effectual in concrete to improve its mechanical properties, enhance calcium-silicate-hydrate gel structure, reduce porosity, increase homogeneity.

Acknowledgements

This work was supported by Funding Program for Next-Generation World-Leading Researches (NEXT Program) and KAKENHI from JSPS. A.A. and T.S. thank the Japan Society for the Promotion of Science for a Young Scientist Fellowship.

Author's contributions

Conceived the plan; Performed the expeirments: HRA,JHM; Data analysis: JHM; Wrote the paper: HRA , SPP. Authors have no competing financial interests.

References

1. Taylor, P.; Rajan, K.; Birgisson, B.; Cackler, T; Nanotechnology for cement and concrete, National Nanotechnology Coordination Office **2007,** *pp. 1-69*.
2. Pacheco-Torgal, F.; Diamanti, M. Nazari, A.; Granqvist, C-G.; 2013, Nanotechnology in eco-efficient construction, Woodhead Publication in Materials, **2013,** *pp. 1-428*.
3. Birgisson, B.; Mukhopadhyay, A.; Geary, G.; Khan, M.; Sobolev, K.; 2012, Nanotechnology in Concrete Materials, Transportation Research Circular E-C170, Task Force on Nanotechnology-Based Concrete Materials Transportation Research Board, **2012,** *pp. 1-2.*
4. Sanchez, F.; Sobolev, K. Nanotechnology in concrete – a review, Construction and Building Materials, Science direct, **2010,** *pp. 2060-2071*.
5. Khan, M.; Nanostructure and Microstructure of Cement Concrete Incorporating Multicementitious Composites, Journal of the Transportation Research Board, **2010,** *pp. 21-27*.
6. International Carbon black Association
7. Saurav; Application of Nanotechnology in Building Materials, International Journal of Engineering Research and Applications, Vol. 2, Issue5, **2012,** *pp. 1077-1082*.
8. Mann, S.; Nanotechnology and Construction, European Nanotechnology Gateway, **2006,** *pp. 1-55*
9. Sobolev, K.; Flores, L.; Hermosillo, R.; Torres-Martínez, L-M.; Nanomaterials and Nanotechnology for High-Performance Cement Composites, American Concrete Institute, **2008,** *pp. 93 120.*

