Indian Journal of Engineering & Materials Sciences
Vol. 27, April 2020, pp. 452-457

Effect of Nano-Silica on the Physical, Mechanical and Thermal Properties of the Natural Rubber Latex Modified Concrete

Marina LeyanVarghese[a], Richu John Babu[b], Suraj Menon R[a], Reny Rajan[a], Vinayak Venu Gopal[a], Ancheli Siby Jacob[a], Vinny Ann Titus[a], MiniMathew[a] & Soney Chathukulam. George[c*]

[a]Department of Civil Engineering, AmalJyothi College of Engineering, Koovapally P.O, Kanjirapally686518, India

[b]Department of Mechanical Engineering, AmalJyothi College of Engineering, Koovapally P.O, Kanjirapally 686518, India

[c]Department of Basic Sciences, AmalJyothi College of Engineering, Koovapally P.O, Kanjirapally 686518, India

Received: 28 September 2017 ; Accepted: 16 January 2019

The preparation and properties of latex modified concrete (LMC), nano silica modified concrete (nSMC) and silica-latex modified concrete (SLMC) have been investigated in this study. Properties like compressive strength, tensile strength, flexural strength, thermal characteristics and water absorption have been evaluated. The 7-day compressive strength has increased 37% (30.15 N/mm^2) after the inclusion of nano silica and latex. The composite has showed considerable improvements in splitting tensile strength (3.24 N/mm^2), flexural strength (6.05 N/mm^2) and thermal conductivity, while it lowered the water absorption rate. The property increase has been attributed to the pore filling and pozzolanic activity of nano silica and densification of matrix by natural rubber latex and nano silica. The results of this study have suggested that the addition of nano silica and latex could be a relevant technique toward conventional concrete as a key material along with energy efficient construction and building technology.

Keywords: Concrete, Polymer, Nano-silica, Latex, Composite

1 Introduction

Polymer modified concrete is exhaustively used in various applications in the construction industry. However, with the increasing demand being made on concrete technology to accommodate the needs of society, experts are responding positively by proposing incipient formulations utilizing other materials[1,3]. Concrete is a heterogeneous material consisting of finely powdered cements, aggregates (both fine and coarse), water and admixtures mixed in correct proportions. Many vibrant effects are produced after the addition of Nanosilica (nS) or silica fume (SF) into the concrete. The amount of cement required can be reduced by the addition of micro silica. This effect is more pronounced for micro silica than nS[4,5].Bastami*et al.*[6] asserted that the addition of nS was more effective than SF for improving residual compressive strength of the heated samples. The crack extension and strength reduction can be controlled after the addition of nS since it improves the tensile strength. Yu *et al.*[7] averred that after the addition of nS the viscosity of the Ultra-High Performance Concrete (UHPC) increases significantly because of the entrapment of air voids within the fresh mixture and thereby increases the porosity. But due to the nucleation effect of nS the cement hydration can be promoted and more C-S-H gel can be formed. Another work by Yu *et al*[8] showed that after the addition of waste bottom ash (WBA), the water permeable porosity of the ultra-high performance fibre reinforced concrete (UHPFRC) increases but after the addition of nS, the porosity of the concrete can be reduced to some extent. The addition of WBA also decreases the compressive strength of the concrete but the nS addition increases the overall mechanical properties especially flexural strength. The study by Maheswaran *et al.*[9] highlighted the influence of nS in concrete and he concluded that the addition of nS improves the properties like permeability, pore filling effects, reduction in CH leaching, rheological behavior of cement pastes, heat of hydration, micro structure analysis, the pozzolanic activity or reactions and workability, strength and durability. Similarly, according to Palla *et al.*[10] shortened duration of dormant period, increased rate of hydration, reduction in initial setting time, final setting time, flow and flow retention and densification of matrix were observed in a nano silica incorporated

*Corresponding author (E-mail: soneygeo@gmail.com)

specimens. Also, the CH content did not follow a regular pattern with increasing nS content which is due to the combined pozzolanic and nucleation effect of nano silica.

The usage of polymers as a modifier in recent concrete structures is a strategy in improving micro structure and enhancing the durability of concrete and cement mortars. Recently, latex modified concrete has been widely used in construction industry due to its superior performance and suitability for various special applications like bridge overlays[11]. Studies indicate that the incorporation of natural rubber latex into concrete increases compressive strength and durability. Also, Sudarshana *et al.*[12] averred that the chloride permeability value increases with the increase of Water-Binder ratio (W/B) of natural rubber latex and decreases with increase in the percentage of steel fibres.

At this juncture, the researchers are more focused on nanotechnology, to innovate a new generation of concrete materials that overcome the drawbacks of conventional concrete structures. There is a need for materials which possess improved or enhanced properties for special engineering applications and for modifying the material in terms of composition or microstructure or nanostructure. The extraordinary physical and chemical properties of the materials at the nanometer scale enable novel applications ranging from structural strength enhancement to self-cleansing properties. In this work, we are focused to investigate the effect of both latex and nanosilica as the additive on the mechanical properties, especially the compressive strength of the concrete structure.

2 Materials and Experimental Methods

2.1 Materials used

The materials used are Portland Pozzolana Cement, manufactured as fine aggregate, crushed stone of size 20mm as coarse aggregate, water as per IS 456, 2000, natural Rubber latex and Nano silica in concrete. The properties of cement used are shown in Table 1 and are within limits as per IS 269, 1989.

Table 1 — Properties of cement.

Properties	Value Obtained	Limits as per IS 269, 1989
Initial Setting Time	70 minutes	>30
Soundness (expansion)	1mm	<10mm
Density	3.17 g/ml	3.15
Fineness	5%	<10%

The bulk density, specific gravity and fineness modulus of the fine aggregate used are 1.70 gm/cc, 2.65 and 3.21. The properties of the coarse aggregates are: bulk density – 1.62 gm/cc and specific gravity – 2.66.

2.1.1 Natural rubber latex (NRL)

Natural rubber is a high molecular weight polymeric substance with viscoelastic properties. Structurally it is cis 1, 4- polyisoprene. Isoprene is a diene and 1, 4 integration leaves a double bond in each of the isoprene unit in the polymer. The natural rubber latex is collected from SMR Ltd, Kottayam, India. The various properties of natural rubber are shown in Table 2.

2.1.2 Nanosilica

A cement paste is compound of minuscule grains of hydrated calcium silicate gels nanosized particular pores, capillary pores, and astronomically immense crystals of hydrated products. Thus, there should be room for nanophase materials to fill the pores of the cement paste. Amorphous nanoscale silica, which is the main component of a pozzolan, reacts with calcium hydroxides composed by the hydration of calcium silicates. Silica fume is a by-product of the reduction of quartz for the engenderment of silicon and ferrosilicon. It is a very fine powder consisting of non-crystalline silica spheres with an average diameter of 0.1 μm and is engendered at temperatures of about 2050 K. Silica fume is mainly utilized as an admixture in cement and concrete to amend strength and durability. Due to the minuscule particle size and the considerable surface area (up to 30 m^2/g), it acts both as a micro filler that reduces the porosity and as a pozzolan which reacts with the calcium hydroxide from the cement. The various properties of nanosilica are shown in Table 1.

Table 2 — Characteristics of NRL and nS.

Sl. No.	Parameters	Values
	Natural Rubber Latex	
1	Total Solid Content (TSC)	33.65 %
2	Dry Rubber Content (DRC)	32.5 %
3	Non Rubber Content(NRC)	2.8 %
4	Ammonium Content (NH_3 %)	0.65 %
5	Volatile Fatty Acid No (VFA No.)	0.060
6	Mg Content	170 ppm
	Nano Silica	
1	Molecular weight	60.08 g/mol
2	Melting point/range	>1600 ^oC
3	Relative density	2.2-2.6 mg/l at 25 ^0C
4	Surface Area	200 ± 30 m^2/g
5	Particles size	0.1 μm

2.2 Preparation of the Composite

A Mix design was conducted as per IS 10262-2009 for m 30 mix concrete with a mix proportion of 1:1.59:2.68 and a water cement ratio of 0.45. Conventional concrete, natural rubber latex modified concrete and nano silica modified concrete were mixed and tested for its compressive, flexural and tensile strength. Compressive strength of concrete is done as per IS 516-1959. The standard size of the cube is 150 × 150 × 150 mm^3. Dimensions of the specimens were measured and its weights were noted. A compressive strength testing machine of 3000 kN capacity was used for loading. Four number of specimens were casted and tested for each batch of concrete mixes. The mean strength was calculated as per IS 456, 2000. The load was applied without shock at a rate of approximately 14 N/mm^2 per minute. Tensile and Flexural test is done according to IS 516-1959. The standard size of the specimen used for tensile test is cylinder of size 150 mm x 300 mm and beam of size 150 × 150 × 700 mm^3. The calculated amount of cement and fine aggregate are mixed together till a uniform mix is obtained. Coarse aggregates are then added to the same and mixed to uniform colour, water is added carefully making sure no water is loosed during mixing. Workability of the concrete mix also was tested using Vee Bee Consistometer. Cubes, beams and cylinders were casted, cured and is tested.

Natural Rubber Latex modified concrete was also casted with the same water cement ratio. In this, calculated amount of cement and fine aggregate are mixed together till a uniform mix is obtained. Coarse aggregates are then added to the same and mixed. The amounts of latex adopted are 0.25%, 0.5%, 0.75%, 1.0%, 1.25%, 1.5% and 2% of cement. Latex mixed with water and is added to the dry mix to make a uniform mix. Cubes, beams and cylinders were casted and is tested. The optimum latex content corresponds to maximum compressive strength was determined. The admixture content was incremented from 0.4% to 1.5% depending upon the workability. Care was taken to keep the workability constant as 5 seconds for all the mixes. Cubes, beams and cylinders were casted, cured and is tested. The optimum latex content found out based on maximum compressive strength.

In silica modified concrete the silica powder and cement are mixed thoroughly. Silica powder is added 0.25 %, 0.5 % and 0.75 % of cement and are mixed together to form a uniform mixture. Then the remaining procedure is same as discussed above for conventional concrete. The optimum latex content found out based on maximum compressive strength. Silica latex modified concrete also casted and tested with optimum percentage of latex (1.25%) and silica (0.5%) based compressive strength.

3 Results and Discussion

The schematic representation of the various mixes is shown in Fig. 1. It represents the partial replacement of Nano silica and Natural Rubber Latex in M30 mix concrete. Fig 1 (a) is a schematic representation of ordinary concrete mix and is the dispersing medium. Fig 1 (b) is a representation of Natural rubber latex as dispersant in the concrete mix. Fig 1 (c) shows Nano silica compound which acts as a dispersant. Fig 1 (d) is the schematic representation of the mix concrete obtained after adding Nano silica particles and Natural rubber latex as dispersants.

3.1 Conventional concrete cubes

Workability of the concrete mix was obtained as 5 seconds. The results of compressive strength, tensile strength, flexural strength are shown in Table 3. As per IS 456:2000, for M30 concrete, compressive strength is 30 N/mm^2, flexural strength is 3.83 N/mm^2 and tensile strength varies between 2.5 to 3.75 N/mm^2.

3.2 Natural rubber latex modified concrete cubes (LMC)

Workability of the mix was obtained as 15 seconds which implicatively insinuates that the mix has very

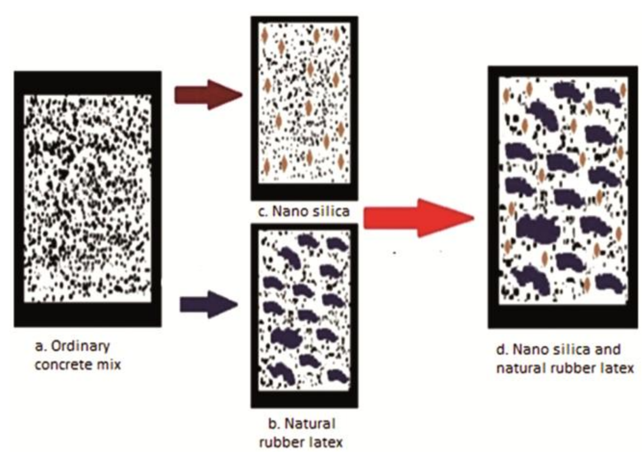

Fig. 1 — Schematic representation of various mixes.

Table 3 — Mechanical properties of conventional concrete cube.

Compressive Strength		Splitting Tensile Strength	Flexural Strength
7 Day strength	28 Day strength	28 Day strength	28 Day strength
22 N/mm^2	33.65 N/mm^2	2.91 N/mm^2	5.16 N/mm^2

low workability. Hence admixtures were added to obtain desired workability. The result of 7-day compressive strength of natural modified rubber latex concrete for varying latex content is shown in Fig 2. From the graph, it can be inferred that the maximum value for 7-day compressive strength increases till 1.25% replacement by rubber latex. This improvement can be attributed to the pore filling and densification of matrix by natural rubber latex.

3.3 Nano-silica modified concrete cubes

Workability of the mix was obtained as 15 S which implicatively insinuates that the mix is very dry. Hence admixtures were added to obtain desired workability. The result of compressive strength of nanosilica modified concrete is shown in Fig 3. An increase in 3-day compressive strength was observed till 0.5% replacement by nanosilica and the strength decreased with further increase in percentage of silica. When a small amount of the nS is uniformly dispersed in the cement paste, the nanoparticles will act as a nucleus to firmly bond with cement hydrate and further enhances cement hydration due to their higher activity, which is favorable for the strength of cement mortar[9,13,14]. Due to this phenomenon the compressive strength first increases and reaches a maximum till its optimum concentration. The increase of compressive strength and splitting tensile strength in the nS modified concrete tubes is due to the rapid consumption of $Ca(OH)_2$ which was formed during the hydration of Portland cement especially at early ages related to the high reactivity of nS particles. As a result, the hydration of cement is accelerated and larger volumes of reaction products are formed.

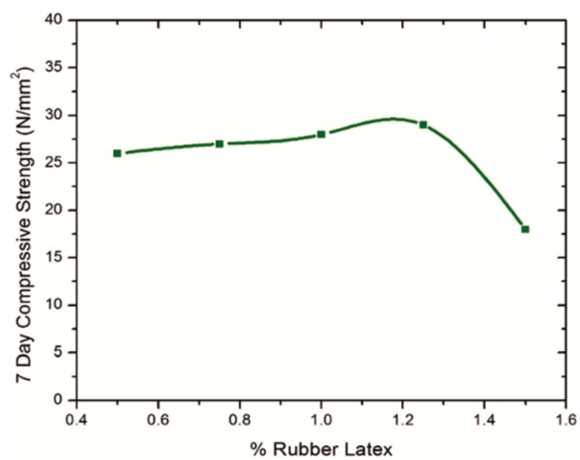

Fig. 2 — Compressive strength variation with concentration of rubber latex (wt %).

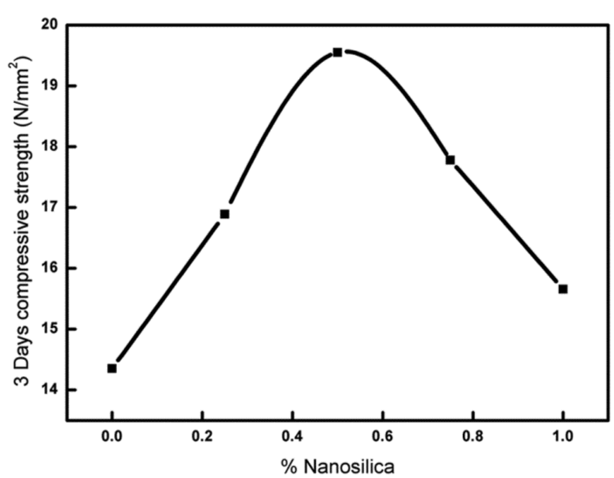

Fig. 3 — The variation of 3 day compressive strength with filler concentration (wt %.)

3.4 Silica- latex modified concrete cubes

Results of compressive, flexural and splitting tensile strength tests are shown in Table 4. The increase in the flexural strength is due to the rapid consuming of $Ca(OH)_2$ which was formed during hydration of Portland cement specially at early ages related to the high reactivity of nanoparticles[15]. The nanoparticles among the hydrate products will prevent growing of crystals which has got a profound impact on the strength of cement paste[16-18].

3.5 Comparative study on thermal property

Thermal properties of both conventional and silica latex modified concrete was determined. Temperature was quantified utilizing an Infrared Gun (IR Gun). Temperature of the cube was checked before heating, and after heating for 45 minutes. After heating the cube, an average of temperature obtained on the top surface was taken as final reading. Heat transfer through the edges would have been more facile, due to which a higher temperature is obtained at edges. 3 cubes were utilized for the test of each supersession ratio. Results of thermal conductivity test conducted on conventional and modified cubes are given in Table 5.

Usually thermal conductivity varies with the density of concrete and with heavier aggregates thermal conductivity will be high. The nanosilica

Table 4 — Mechanical properties of natural rubber latex and nanosilica modified concrete.

Compressive Strength		Splitting Tensile Strength	Flexural Strength
7 Day strength	28 Day strength	28 Day strength	
30.15 N/mm^2	39.48N/mm^2	3.235 N/mm^2	6.04 N/mm^2

Table 5 — Thermal property of concrete cubes.

Before heating (W/m. K)	After heating (W/m. K)	Increase (W/m. K)	% Increase
Conventional Concrete Cubes (mean values)			
29.5	35.5	6	21%
Modified Concrete Cubes (mean values)			
39.5	62.5	23	58.23%

Table 6 — Percentage water absorption.

Test Specimen	Saturated Weights	Oven Dry Weights	Difference	% Water Absorption
Conventional cube	8.474	8.128	0.346	4.08
Silica Latex Modified Cube	8.323	8.247	0.076	0.91

reinforcement along with NRL will improve the density of the concrete and hence the conductivity of concrete improves as we have obtained

3.6 Water absorption

The absorption capacity is resolute by finding the weight of surface-dry sample after it has been marinated for circadian and again finding the weight after the sample has been dried in an oven. The difference in weight, expressed as a percentage of the dry sample weight, is the absorption capacity. The cubes were then placed in oven at 100 degrees for 24 hours. Weight of the oven dry cubes was later taken.

Water absorption is found to be reduced by 3% in silica latex modified concrete cubes on comparison with conventional concrete cubes. The latex-film is a fine-grain textured membrane. In its liquid state, natural rubber latex mainly consists of a dispersion of poly 1–4 isoprene particles. However, as the dispersed medium (water), drains away, inter-particle spacing reduces until coalescences is achieved and thus a continuous film is formed. However, when latex is added into concrete in small quantities a continuous film is not formed, instead a cluster of the isoprene particles is present in the capillary pores and voids. Thus, the latex performs its action by blocking the access of the moisture which normally transports the chemical agents into the concrete matrix[15,19]. Table 6 shows the percentage water absorption of conventional and silica latex concrete. From the saturated and oven dry weights, the percentage of water absorption was determined.

4 Conclusions

There is an impressive amelioration in the compressive strength of silica latex modified concrete cubes on comparison with conventional concrete cubes. This improvement can be attributed to the pore filling and pozzolanic activity of nanosilica and densification of matrix by natural rubber latex. The addition of natural rubber latex also has an impact on the incremented rate of early strength development, 7-day strength is over 37%, while the 28 day strength escalated by 17% compared to conventional concrete cubes.

(i) There is appreciable increase in flexural and tensile strength of silica latex modified concrete cubes on comparison with conventional concrete cubes. The increase in flexural strength is over 17% and the splitting tensile strength augmented by 11%. This increase is due to the rapid consumption of $Ca(OH)_2$, which was formed during the hydration of Portland cement by the highly interactive nanosilica particles due to its high specific surface area

(ii) Water absorption is reduced in silica latex modified concrete cubes on comparison with conventional concrete cubes by 3%. This decrease is because of the water exclusion capacity due to reduction in interparticle gaps by filling of pores and voids by isoprene and nanoslica particles. This will reduce the leakage issues of the concrete specially in places having more rainfall.

(iii) The modified concrete cubes also showed some notable increase in their thermal conductivity by over 37%.

Acknowledgement

We express our gratitude to Sr. Prof. Claramma Rosary for the help and guidance for the smooth conduct of the project. We additionally thank Ms. Grace Mary Abraham, Asst. Professor and Ms. Jessymol George for their suggestions.

References

1 Kong X M, Wu C C, Zhang Y R &Li J, *Constr Build Mater,* 38 (2013) 195

2 Cresson L. *Improved manufacture of rubber road-acing, rubber-flooring, rubber-tiling or other rubber lining,* British Patent 19, 474, United Kingdom, January 1923.

3 Lefebure V. *Improvements in or relating to concrete, cements, plasters and the like*. British Patent 217, 279, United Kingdom, June51924.

4 Bastami M, Chaboki-Khiabani A, Baghbadrani M & Kordi M, *Sci Iran,*18 (2011) 1026.

5 Ḧusken G & Brouwers H J H, *Cem Concr Res,* 38 (2008) 1246.

6 Bastami M, Baghbadrani M & Aslani F, *Constr Build Mater* 68 (2014) 402.

7 Yu R, Spiesz P & Brouwers H J H,*Constr Build Mater* 65 (2014) 140.

8 Yu R, Spiesz P & Brouwers H J H, *Constr Build Mater* 60 (2014) 98.

9 Maheswaran S, Bhuvaneshwari B, Palani G S, Nagesh R I & Kalaiselvan S, *Resear J Rec Sci,* 2 (2013) 17.

10 Palla R, Karade S R, Mishra G, Sharma U, Singh L. P, *Constr Build Mater138* (2017) 285.

11 Okba S H, Eidie A S & Reda E M, C*em Concr Res,* 278(1997) 861.

12 Sudarshana R. K, Munirathnam V, Ghorpade G & Sashidhar C, *Int J Innov Res Sci Eng Tech* 2 (2013) 7.

13 Amin M & El-hassan K A *Constr Build Mater,* 80 (2015) 116.

14 Jalal M, Pouladkhan A, Harandi O F & Jafar, D. *Constr Build Mater,* 94 (2015) 90.

15 Garboczi E J & Bentz D P, *Constr Build Mater,* 10 (1996) 293l.

16 Fernandez E, Gil F J, Ginebra M P, Driessens F C M, Planell J A & Best SM , *J Mater Sci Med,* 10 (1999) 223.

17 Ollitrault-Fichet R, Gauthier C, Clamen G & Boch P, *Cem Concr Res*, 28 (1998) 687.

18 Qing Y. Zenan Z, Li S & Rongshen C, *J Wuhan Univ Technol Mater Sci Edu,* 21 (2008) 153.

19 Muhammad B & Ismail M, *Constr Build Mater,* 31 (2012) 129.