EFFECT OF ADDITION OF NANO-SILICA ON MICRO STRUCTURAL, MECHANICAL AND DURABILITY PROPERTIES OF CEMENT MORTAR AND CONCRETE – A REVIEW

Vinay Mohan Agrawal[1], Purnanand Savoikar[2]

1. Research Scholar, Department of Civil Engineering, Goa Engineering College, Farmagudi-Goa, India
2. Professor, Department of Civil Engineering, Goa Engineering College, Farmagudi-Goa, India

ABSTRACT. The application of nano materials in concrete is being researched tremendously with an objective to enhance properties of concrete at micro structural level. The addition of nano materials in concrete improves its microstructure due to its smaller particle size and high reactive surface areas. One such nano material which is used for cement replacement or as cement additive is silica fines. Nano-silica is a commercially produced silica fine which is used in concrete and its addition significantly improves mechanical and durability properties of concrete. This paper reviews the use of nano silica and its effect on compressive and flexural strength. The micro structural changes due to addition of nano-silica and the effect of nano-sized particle on the hydration mechanism are discussed in this paper. Durability properties such as chloride penetrations, water absorption and sorptivity are seen to improve with addition of nano-silica. This paper reviews the published literatures to analyze the feasibility of nano-silica as pozzolanic material/cement replacement and/or filler material / cement additives. This paper also discusses effect due to incorporation of nano silica with supplementary cementitious materials like fly ash; blast furnace slag and silica fume in isolation or in combination.

Keywords: Concrete, Nano material, Nano silica, Durability, Microstructure

Vinay Mohan Agrawal is a Ph.D. research scholar in civil engineering department of Goa Engineering College, Goa. His research interest includes study of supplementary cementitious materials and use of nano material in concrete construction.

Dr Purnanand Savoikar is a Professor in Civil Engineering Department of Goa Engineering College, Goa. His research interest includes use of recycled plastic waste in concrete, use of supplementary cementitious materials in concrete and nano materials in concrete construction, steel structures and Geotechnical Earthquake Engineering. His joint research work on plastic waste in concrete with Bath University, UK has been awarded prestigious Atlas Award (April 2018) by Elsevier Science Direct Publishers.

INTRODUCTION

Structures built using cement concrete are expected to be strong and durable. Many researchers have studied ways to improve the mechanical strength of concrete but along with mechanical strength, durability of concrete is equally important. New improved materials can replace conventional material used in construction. The improved material is expected to impart good mechanical, durability and fresh properties in concrete. Many researchers have tried to introduce the finer material in concrete like fine slag, silica fume, metakaolin, etc. which is capable of improving the microstructure of concrete thereby increasing the mechanical and durability parameters.

Nano material which is about 10^{-9} m in size is used along with discussed micro fine materials which further enhance the micro structure of paste or mortar or concrete. Nano materials can fill the pores or voids created by micro fine materials, this will confirm durable concrete. The particle size and specific surface area of nano material are much smaller compared to conventional material and hence they react faster in the system and provide dense and continuously packed structure.

Nano silica is one such nano material which is discussed in this paper for its effect on mechanical and durability properties as replacement of Portland cement. This paper reviews some of the specific research works which focuses on use and effect of nano silica. This paper discusses significant parameters such as effect of nano silica fineness, nano silica replacement ratio, and fiber usage and carbonation resistance.

REVIEW OF LITERATURE

The effect of nano silica has been experimentally investigated by [1] on strength development of high volume slag mortar. The properties investigated were setting time and early strength. They have studied the behaviour of mortar due to presence of different nano silica dosage, various sizes of nano silica and different dispersion methods. Throughout the experiment a constant w/c ratio of 0.45 was maintained. Reduction in setting time and increment in compressive strength is observed with increased nano silica content up to 2 percent. They identified increments compressive strength with reduction in size of silica. The addition of 2 percent nano silica resulted in 18-22 percent incretement in compressive strength at 3 and 7 days. The capillary pore reduction was observed with addition of nano silica and dense microstructure is seen. Nano silica with mean particle size of 7 to 12 nano meter was reported to be more effective in increasing the rate of cement hydration as compared to that of silica fume.

Performance of ultra high performance concrete is studied by [2] in the presence of nano silica. Consumption of $CaOH_2$ in the presence of nano silica and micro silica is compared ad was noted that the nano silica better consumes $CaOH_2$ as compared to micro silica, this was confirmed by TGA analysis, this is attributable to higher rate of pozzolanic reactivity in nano silica at early age. If the nano silica is dispersed in paste properly it can provide better early strength, this can be made possible by uniform mixing of nano silica. 3 percent of nano silica is found to be optimum dosage which achieved highest compressive strength. It was noted by MIP results that the presence of nano silica imparts denser and more homogenous mixture. SEM images confirm the extreme fine particles of nano silica as filler and effective pozzolanic material available in micro pores. The improvement in ITZ is also observed due to

nano silica. Lower water absorption and sorptivity resulted in lower capillary pores due to pozzolanic reactivity of nano silica.

Quantities of different mineralogical phased during the hydration process is studied by [3] with mortar made with Portland cement and nano silica blend. High resolution TGA and XRD analysis is performed to study the behaviour of paste. Compressive strength is also studied with varying percent of nano silica in mortar. Development of compressive strength was correlated with calcium hydroxide quantities to understand the pozzolanic activity of nano silica. Large quantities of C-S-H and C-A-H are seen during early age as a result of increasing substitution of cement by nano silica. It is concluded that in early hours the specific surface area and in early days chemical reactivity is responsible for hydration in nano silica incorporated mortar. Distribution of C-S-H in paste matrix is reported to be good in early age despite small in quantity; this imparts noticeable improvement in compressive strength.

Colloidal nano silica is studied for cement hydration and gel properties in early and later age [4]. Cement paste is mixed with 5 percent of colloidal nano silica and studies were done on this sample after 1 day with curing in saturated lime solution. Similar samples were prepared with silica fume as well and the results were compared. Pozzolanic activity and hydration acceleration effect is reported to be more with nano silica in early age as compared to with micro silica, but in later age the difference is negligible. Colloidal nano silica is considered to be an accelerating agent at early ages but its presence hinders the later age hydration of cement.

Effect of nano silica with difference concrete fibers are studied by [5] for mechanical, rheological and durability properties. The fibres which were studied include steel, polypropylene and glass fibers. Nano silica content was varied in 0, 2, 4 and 6 percent by weight of cement. Balling effect due to different fibres was observed which deteriorates the microstructure by creating holes and pores. This issue was resolved by addition of nano silica which optimal value of 4 percent nano silica was suggested beyond which the compressive strength reduces dramatically. Increase in the steel fibre content and addition of nano silica increasers the tensile and flexural strength of concrete which is attributable to refinement in pore structure. It is concluded that 4 percent nano silica imparts impressive filling and pozzolanic effects in contact area between fibres and cement matrix. Toughness was also observed to increase with a maximum value at 2 percent replacement by nano silica. Modulus of elasticity does not show any significant variation due to presence of nano silica in all combinations. Nano silica is reported to be responsible for reduction in water absorption and chloride ion penetration significantly. Reduction in chloride ion penetration is due to high reactivity of nano silica, and reduced water absorption is due to pore reduction due to formation of calcium hydrate jelly.

Durability performance of concrete incorporation 0.3 and 0.9 percent of nano silica is presented by [6]. The study was focused on permeability, pore size distribution and ITZ characteristics with nano silica. They observed the reduction in portlandite content and increment in 1 day compressive strength. The pozzolanic effect and nano filler effect imparts denseness to material especially in interfacial transition zone ITZ. MIP results confirmed the refined pore size distribution which reduces the water permeability and improvement in chloride attack resistance. This study reveals that even at low dosage of 0.3 percent of nano silica, marginal increment in compressive strength and better resistance against chloride migration and water penetration can be achieved.

Durability properties such as porosity, capillary suction and sulphate resistance were evaluated by [7] made mortars containing 0, 1, 3, 5 and 10 percent replacement of Portland cement by nano silica. Significant refinement of pores was observed which resulted in lower absorption rate and a smaller total absorption of fluids by mortar. Due to nano silica the capillary pores diminishes, and gel pores are formed. This results in increase in compressive strength and durability as a result of sulphate resistance improvement. Compressive strength in initial day was observed high at 10 percent replacement level. Sulphate resistance assessment was observed for 2 years, and is reported that use of nano silica in 5 and 10 percent replacement level is sufficient to control magnesium sulphate attack which can make an ordinary Portland cement sulphate resistance cement.

Effect of different particle size of nano silica is studied by [8] with cement mortar with and without nano silica and also with silica fume. Three different particle size of 12, 20 and 40 nm is used in this study to investigate the durability and repair work properties of cement mortar. Water permeability, abrasion resistance, drying shrinkage and repair work properties are studied. Study concluded that with the increase in nano particle size the water permeability and abrasion resistance increases as compared to one with silica fume. Cement mortar containing small particle size of range 12 and 20 nm experience higher drying shrinkage. Repair work properties such as crack and adhesive strength have reduced with finer nano sizes.

Carbonation of cement paste is studied by [9] on cement paste incorporating nano silica. An accelerated carbonation test was conducted with nano and micro silica. TGA, SEM and BSE image analysis is used to characterize the cement paste at various degrees of carbonation. The study reveals the fundamental effect of nano silica on main hydration products CH and CSH. They concluded that in the initial 7-17 days, the rate of CH carbonation is faster. Carbonation could be reduced by nano silica or micro silica as they reduce the pH and alkali content. Also they concluded the initial CH reduction is also due to pozzolanic reactivity of nano silica which reduces the carbonation of CH. Reduction is pH of pore solution and chemical stability increment in hydrated products causes reduction in carbonation of CSH. It was concluded that both nano silica and micro silica can be used to effectively reduce the carbonation depth.

CONCLUDING REMARKS

This review paper studies the fresh, mechanical, and durability properties of concrete modified by nano silica. The current research proves that nano silica has huge potential to be used in cement concrete for enhancing its engineering properties. It is been observed that different researchers have different opinion about optimum dosage of nano silica and this needs to be further investigated and generalised.

Addition of nano silica improves the pore structure of paste, mortar or concrete from the very initial stage of hydration. Reduction in capillary pores and formation of gel pores are major factor responsible for early age strength improvement and resistance against acid attacks. The pozzolanic reactivity of nano silica also adds to the refinement of matrix. Nano silica reduces the water absorption and chloride ion penetration drastically in system. The high reactivity of nano silica is attributable to its large specific surface area. Nano silica effectively reduces the carbonation depth by reducing the pH of pore solution and increasing the chemical stability between hydrated products.

Uniform distribution of nano silica in matrix is still the biggest challenge and researchers propose sonication process for uniform dispersal of nano silica. Most of the research work is limited to cement paste and mortars; there are very few literatures available on use of nano silica with cement concrete. The chemical compatibility study of nano silica with various supplementary cementitious materials is very limited. Optimization and mathematical correlations in fresh, mechanical and durability properties under the influence of nano silica parameters can be researched upon in future.

REFERENCES

1. ZHANG M H, ISLAM J, PEETHAMPARAN S. Use of nano-silica to increase early strength and reduce setting time of concretes with high volumes of slag. Cement and Concrete Composites, Vol 34, No 5, 2012, pp 650 – 662.

2. GHAFARI E, COSTA H, JULIO E, PORTUGAL A, DURAES L. The effect of nanosilica addition on flowability, strength and transport properties of ultra high performance concrete. Materials & Design, Vol 59, No 1, 2014, pp 1 – 9.

3. TOBON J I, PAYA J J, BORRACHERO M V, RESTREPO O J. Mineralogical evolution of Portland cement blended with silica nanoparticles and its effect on mechanical strength. Construction and Building Materials, Vol 36, No 1, 2012, pp 736 – 742.

4. HOU P, KAWASHIMA S, KONG D, CORR D J, QIAN J, SHAH S P. Modification effects of colloidal nanoSiO2 on cement hydration and its gel property. Composites Part B: Engineering, Vol 45, No 1, 2013, pp 440 – 448.

5. BEIGI M H, BERENJIAN J, OMRAN O L, NIK A S, NIKBIN I M. An experimental survey on combined effects of fibers and nanosilica on the mechanical, rheological, and durability properties of self-compacting concrete. Materials & Design, Vol 50, No 1, 2013, pp 1019 – 1029.

6. DU H, DU S, LIU X. Durability performances of concrete with nano-silica. Construction and Building Materials, Vol 73, No 1, 2014, pp 705 – 712.

7. TOBON J I, PAYA J, RESTREPO O J. Study of durability of Portland cement mortars blended with silica nanoparticles. Construction and Building Materials, Vol 80, No 1, 2015, pp 92 – 97.

8. HARUEHANSAPONG S, PULNGERN T, CHUCHEEPSAKUL S. Effect of Nanosilica Particle Size on the Water Permeability, Abrasion Resistance, Drying Shrinkage, and Repair Work Properties of Cement Mortar Containing Nano-SiO2. Advances in Materials Science and Engineering, Vol 1, No 1, 2017, pp 1 – 11.

9. LIM S, MONDAL P. Effects of incorporating nanosilica on carbonation of cement paste. Journal of Materials Science, Vol 50, No 10, 2015, pp 3531 – 3540.