

NANO-SILICA FOR REPAIR AND REHABILITATION OF REINFORCED CONCRETE STRUCTURES : A REVIEW

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ABSTRACT

Reinforced concrete structures can get worse over time because of things like cracks, rust in the steel water coming in salt getting in the concrete getting other things in the environment. These issues make the structures weaker, not as strong. They don't last as long. That means repair and fixing them is important to get them working again and make them last longer.. The success of the repair depends not just on how strong the material is but also on how long it lasts and how well it sticks to the old concrete. In years special tiny materials called nanomaterials have become popular in concrete work because they help make the cement better. One of these materials called nano-silica has shown results in making concrete stronger and more lasting. This paper looks at how nano-silica's used in concrete especially when it comes to fixing and making old reinforced concrete better. Nano-silica has small particles that can fill tiny spaces and make the cement part of the concrete tighter. When it reacts with a part of cement called calcium hydroxide it makes more of a material called C-S-H, which helps make the inside of the concrete solid. These changes can make the concrete stronger stop water from getting in and stop things from moving through the concrete. The studies also show that nano-silica can help with how strong the concrete's when pulled, bent how much water it takes in how well it handles salt and how well the parts of the concrete stick together. These are all important for concrete that has to deal with weather. The paper pays attention to using nano-silica in the materials used to fix old concrete and in treatments for the surface. It is very important that the new repair material sticks to the old concrete because if it doesn't the repair might not work and could fail early. Some studies have found that when nano-silica is added to the repair material or used on the surface the bond gets better. Using nano-silica might also make the parts of the repair area better and stop water and bad things from getting in. But how well it works depends on things like how much's used how it is spread out how much water is in the mix how it is mixed how it is kept while it hardens and how it is put on. Even though many studies say things about nano-silica the results are not always the same for every mix or every part. If too much is. If it is not spread out well it can use more water make the mix harder to work with and cause the particles to clump together. Also many studies look at how strong and lasting new concrete's but not many look at how well the repair works on old damaged concrete. How the bond holds up over a time and how well it lasts in different weather also needs more research. Overall nano-silica has a lot of promise, for making repair materials and helping fix old reinforced concrete.. Using it in real life needs the right amount, good spreading and the right way to fix things. More studies are needed to see how it works over time and to make the way s to fix damaged concrete.

Keywords : Nano-Silica, Reinforced Concrete Structures, Repair, Rehabilitation, Bond Strength, Mechanical Properties, Durability, Corrosion Resistance.

1. INTRODUCTION

Reinforced concrete is used a lot in buildings, bridges and other structures because it is strong and versatile. Yet cracks and other damage can appear while the structure is in use. Steel reinforcement can rust. Water can seep in. Chlorides can enter. The environment can attack the concrete. If these problems are not solved the structure will not last long. Repair and rehabilitation are therefore vital to

bring damaged concrete back to life and keep the structure working. The success of a repair depends not on the strength of the repair material but also on how well it bonds to the existing concrete. A weak interface between new material can pull apart and make the repair fail. Surface damage and tiny cracks in the concrete can hurt this bond. Ordinary repair materials sometimes do not give the needed performance under exposure conditions. Because of this researchers have looked into materials that can improve concrete and the bond between new parts. Nano-silica is one of those materials. Its small particles can fill pores. Its reaction with calcium hydroxide creates C–S–H gel. These effects can strengthen the microstructure. Change its strength and resistance to water. Previous studies have found compressive strength and better durability when the right amount of nano-silica is used. Its performance relies on factors like dosage how well it spreads, the mix proportions and the application method. Much or poorly dispersed nano-silica can make the mix hard to work with and may limit some benefits. Nano-silica is also used as a surface treatment for damaged concrete. This is especially useful for repair and rehabilitation because the condition of the existing surface matters for bonding with the repair material. Studies show that nano-silica treatment can improve the bond between damaged concrete and repair mortar. Some research also looks at its effect on the bond between steel reinforcement and concrete when corrosion is present. However stronger new concrete does not automatically mean repair of damaged structures. These uses must be considered separately when looking at the research. This review examines published studies on nano-silica in concrete. It focuses on its effects on properties, microstructure, durability, corrosion resistance and bond performance. Special attention is given to its use in repairing and rehabilitating reinforced structures. The review also compares the reported benefits and limits of nano-silica dosages and application methods. By spotting what the literature says and what is missing this study aims to give a picture of how useful nano-silica's, for concrete repair and where more work is needed.

2.LITERATURE REVIEW

Norhasri et al. (2017) Carried out a review that looked at how many different nanomaterials were mixed into concrete focusing on how nanomaterials make the concrete stronger and last longer. In technology particles that're larger than 500 nanometers are called nanomaterials. The main way that nanomaterials work is by filling spaces and making the concrete matrix denser. The review explains two ways to make nanomaterials: a down method that uses high-energy ball milling to grind larger particles and a bottom-up method that creates particles through chemical reactions. Top-down methods can produce amounts of material at lower cost but the particles may not be evenly sized. Bottom-up techniques produce particles though they cost more and require laboratory equipment. When it comes to materials nano-silica works as a replacement for silica fume. Nano-silica speeds up the strength of concrete makes the mix easier to work with because of a ball-bearing effect. Allows the cement content to be lowered by 20% to 30%. Nano-alumina reduces the set time helps spread out cement particles and strengthens the network of hydrogel. Carbon nanotubes or CNTs have shapes that greatly improve the pull-out, crush and bending strengths of concrete. Carbon nanotubes might be used in place of steel reinforcement in concrete designs. Carbon nanotubes can make the concrete stronger and more durable. Polycarboxylates, also called PCE are added to concrete to reduce the amount of water needed. This helps create Self Compacting Concrete, which flows easily and fills forms without vibration. In places near the coast polycarboxylates are especially helpful. Polycarboxylates reduce the number of pores in the concrete, which makes it harder for salt and sulfate to damage it. Titanium dioxide or TiO₂ has a surface that lets it clean itself when exposed to sunlight. This self-cleaning feature is useful for structures. Also titanium dioxide improves the strength of concrete making it more resistant to wear and tear over time. Additionally pozzolanic activity is demonstrated by nano-metakaolin and nanoclays such as montmorillonite. Nano-metakaolin and nano-clays add 8% to 10% to strength 10% to 15% to tensile or flexural strength and make the material more thermally stable. The authors end by saying that nano-additives do a job of improving the microstructure. However more study is needed to explore how nano-metakaolin and nano-clay work, inside Ultra-High Performance Concrete or UHPC.

Barbhuiya et al. (2020) Carried out a review on adding nanosilica or NS as a replacement for cement in concrete. They highlighted how NS can improve strength and reduce the use of Ordinary Portland Cement or OPC and the related carbon dioxide emissions. Because NS particles are under 100 nanometers and have a high surface area NS particles speed up the hydration of cement. React with calcium hydroxide, Ca(OH)₂ to produce more calcium-silicate-hydrate or C-S-H gel. The reaction makes the Interfacial Transition Zone or ITZ denser. Reduces the pores inside the concrete. When the concrete is fresh NS speeds up setting. This makes the mix less workable. Slump fell by 40% when 2% NS was used. By 60% when 4% NS was added. To keep the mix flowing polycarboxylate-based superplasticizers were needed. Strengths—compressive, flexural and split tensile— well as elasticity all improved when NS was added at about 1.0% to 1.5%. The best amount depends on the mix and the materials. Using, than 4% NS can cause particles to clump together and lower the strength. NS also makes concrete more durable. NS lowers water penetration stops chloride ions from getting in and gives resistance to acid attack, sulfate damage, carbonation and freeze-thaw cycles. Using NS widely is still limited because NS is expensive not always available, hard to disperse evenly and there are no standard mix-design rules.

Ji (2005) did experiments to see how concrete with nano-silica can stop water from moving and to look at the inner structure. The author added 13.9 kg per meter of nano-silica as a cement replacement together with Class 1 fly ash. Water permeability tests showed that concrete with nano-silica had resistance to water penetration than normal concrete of the same 28-day strength, reaching a permeability grade above S12. Environmental Scanning Electron Microscopy (ESEM) revealed that nano-silica reacts quickly with $\text{Ca}(\text{OH})_2$ crystals in the Interfacial Transition Zone (ITZ) to form C-S-H gel, acting as a nano-nucleus that creates a matrix. However the study has limits, such as testing one fixed dose of nano-silica (13.9 kg/m^3) reduced slump flow because the fresh mix is sticky and a small drop in 28-day strength compared with normal concrete (44.0 MPa vs. 47.5 MPa). Moreover the investigation covered water permeability and microstructure. Did not evaluate other durability aspects such, as chloride ion penetration or freeze-thaw resistance. I was intrigued by how the addition of nano-silica changes the behavior of concrete.

Jo et al. (2007) Studied the properties of cement mortars that were modified with nano-silica particles in comparison with Ordinary Portland Cement (OPC) and silica fume (SF). In that study nano-silica particles with a size of 40 nm and a Blaine fineness of $60 \text{ m}^2/\text{g}$ were added at replacement levels of 3 %, 6 %, 10 % and 12 % by weight of cement. The results showed that nano-silica improved strength at both 7 days and 28 days compared with OPC and silica-fume mixes. At 28 days the mortar with 10 % nano-silica reached a strength of 68.2 MPa surpassing the 10 % silica-fume mix (37.4 MPa) and the control OPC mortar (25.6 MPa). Scanning Electron Microscopy (SEM) analysis revealed a denser and compact hydrated microstructure with fewer calcium hydroxide [$\text{Ca}(\text{OH})_2$] crystals. Additionally residual $\text{Ca}(\text{OH})_2$ testing showed content in the 10 % nano-silica mix (4.06 %) than in the OPC mix (8.89 %) at 7 days. Further analysis of the heat of hydration revealed that nano-silica accelerates the reaction and physically fills holes to aid in cement hydration. However there are drawbacks to employing nano-silica, including dispersion issues within the cement matrix and particle agglomeration brought on by high surface energy. Higher replacement levels may also reduce workability. If water and superplasticizer dosages are not optimized the chance of self-desiccation increases and cracking becomes more likely. Also a higher need, for superplasticizer may delay cement hydration. This shows that careful mix design and efficient dispersion methods are essential.

Du et al. (2014) Looked at how amounts of nano-silica 0.3% and 0.9% by weight of cement affected the structure and how concrete lets things pass through. Strong pozzolanic activity was found using analysis (TGA). This showed that adding 0.9% nano-silica made the hydration process faster. It also kept the Portlandite (CH) level around 15% compared to 22% in concrete. Scanning electron microscopy (SEM) showed that the CH was used up more and a new C-S-H gel formed. This made the structure much denser at the area where the cement and aggregate meet. Pore size was checked with MIP analysis. It showed that the pores changed from capillary to medium capillary. The size of the pore went down from 74 nm to 47.8 nm. Because of this the compressive strength after 28 days went up by 9% for 0.3% nano-silica and by 12% for 0.9% nano-silica. In terms of how well the concrete lasts the 0.3% nano-silica mix had performance. It cut down how deep water went in by 45%. It also reduced the chloride migration coefficient by 28.7% and the apparent chloride diffusivity by 31%. The authors noted that higher doses (0.9 %) suffered from particle agglomeration, which limited gains in chloride resistance emphasizing the importance of dispersion techniques such, as ultrasonic mixing with surfactants.

Gopinath and colleagues in 2012 studied how colloidal nano-silica changes the microstructure, strength and durability of M30-grade concrete that was made using the particle packing method. They used three colloidal nano-silica suspensions – XLP, XTX and XFX. XLP had 14.0% to 16.0% silica XTX had 30.0% to 32.0% silica and XFX had 40.0% to 41.5% silica. These suspensions had particle sizes between 5 nanometers and 40 nanometers. They added these suspensions to the concrete at replacement levels of 1.5% and 3.0%. X-ray diffraction data showed a calcium hydroxide peak and changes in the tricalcium silicate phases. These changes suggest hydration and more calcium silicate-hydrate (C-S-H) gel. The results showed that nano-silica increased strength by 6% to 13% after 28 days compared with the control concrete. The XFX-3 mix reached a strength of 55.14 MPa, versus 49.00 MPa for the control mix. However split tensile strength fell by 3.3 %–9.8 % in all mixes and flexural strength dropped 5 % for the XFX-3 mix. These drops were blamed on poor nano-particle dispersion, which created spots in the matrix. Rapid chloride permeability tests (RCPT) also showed electrical charge passing through concrete with added nano-silica while treating the surface with a nano-silica solution lowered chloride permeability. The study had limits; the particle packing method did not fully capture the filling effect of nanoscale particles and a few trial mixes were made so a general mix design for nano-modified concrete could not be produced. Additionally the modified mixes' increased chloride permeability and decreased tensile and flexural strength underscored the need for nanoparticle dispersion, optimum mix proportions and more research, on long-term durability.

Vandhiyan et al. (2024) Looked at how nano-silica (NS) changes the performance, corrosion resistance and bond strength of reinforced concrete. NS was added as an additive at 0.5 percent, 1.0 percent, 1.5 percent and 2.0 percent of binder weight while keeping a ratio of 0.5 and using a melamine-formaldehyde superplasticizer to keep concrete workable. Their tests showed that 1.5 percent NS – the C3 mix – was the dose that boosted 28-day strength, flexural strength and split tensile strength. It increased strength by 37.85 percent. Going from 31.70 MPa to 43.70 MPa. Flexural strength went up by 45.13 percent from 6.22 MPa to 9.03 MPa. Split tensile strength rose by 23.48 percent from 2.64 MPa to 3.26 MPa compared to concrete. To check how bonds behave in environments the authors used a corrosion test. They applied a current of 12 V DC in a 5 percent NaCl solution. This was done on both pull-out and flexural bond samples. They reported that NS refinement lowered permeability, which cut electrical current flow and greatly reduced steel mass loss during accelerated corrosion. The uncorroded bond strength of the NS mix improved by 34.37 percent in pull-out tests (13.69 MPa vs. 10.19 MPa). By 43.75 percent in flexural bond tests (5.35 MPa vs. 3.57 MPa) over the control concrete. When corroded NS-modified concrete showed resistance, to expansion and shear stresses keeping up to 67.85 percent higher bond strength, than ordinary concrete.

Yazdi et al. (2021) Studied how bio-based and nano-material surface treatments can restore bond strength between damaged substrates and repair mortars. The study focused on microcracks made by jackhammering (JH). These micro-damage cracks surface tensile strength and weaken the bond with repair materials. The researchers tested colloidal nano-silica (CNS) calcium carbonate that the bacteria *Bacillus sphaericus* had produced and a mix of these treatments on crushed limestone and gravel substrates. They applied the treatments by pouring and by spraying then applied a repair mortar. Bond performance was measured with direct tensile pull-off tests and by checking surface tensile strength, surface roughness, porosity and microstructural characteristics. The results showed that making the surface rougher does not automatically give a bond because the microcracks under the surface are the main cause of bond failure. Pouring the solution made a calcium carbonate layer that acted as a weak barrier while spraying avoided this problem. Of all treatments tested, pouring colloidal nano-silica that had 12-nm amorphous SiO_2 particles gave the improvement in bond performance. The nano-silica entered the microcracks of the damaged substrate reacted with calcium hydroxide $[\text{Ca}(\text{OH})_2]$ to form calcium-silicate-hydrate (C–S–H) gel and its micro-filler effect helped refine pores. Strengthen the damaged surface area. The treatment increased pull-off bond strength by 53 % in crushed limestone concrete and by 45 % in gravel concrete when compared with jackhammered substrates that meet NBN EN 1504-3 requirements. The study had limitations. The separate spraying of colloidal nano-silica was not tested. The long-term durability of the treatments needs testing. Three specimens were used for each measurement on gravel concrete, which gave standard deviations and statistically insignificant differences between treated and untreated specimens. Spraying both CNS and the bacterial solution together caused gel formation, which stopped the nano-silica from entering the substrate microcracks. Bond performance was mainly measured by tensile pull-off tests so the behaviour of the treated interface under shear loading is not well known. These limitations show that more research is needed on application methods, long-term durability and bond performance, under loading conditions.

SUMMARY OF LITERATURE

Notice that nano-silica can make cement-based materials stronger by tightening the structure and helping more calcium-silicate-hydrate (C–S–H) gel form. Ji (2005). Jo et al. (2007) Observed changes in the higher compressive strength. Du et al. (2014) Found that small amounts of nano-silica lowered water penetration and chloride transport. Barbhuiya et al. (2020) Also saw concrete strength and durability but the results depended on how much nano-silica was used and on the mix proportions. Nano-silica did not improve every property in all studies. Gopinath et al. (2012) Did not see increased strength but reported lower tensile and flexural strength in some mixes. That study also showed that the effect on chloride permeability depended on how nano-silica was applied. Vandhiyan et al. (2024) Reported properties, bond strength and resistance to reinforcement corrosion when 1.5 % nano-silica was used which was the best among the dosages tested. Yazdi et al. (2021) Found that colloidal nano-silica applied to damaged surfaces improved the bond between the existing repair mortar. In general the results suggest that nano-silica can improve performance and help with repair work. However how well nano-silica works depends on the amount used how well the particles spread, the mix proportions and the way it is applied. The studies used settings so comparing the results directly is hard. More research is needed to understand how durable nano-silica is and how effective it is, for repairing and rehabilitating reinforced structures.

FUTURE SCOPE

Future studies should compare the amounts of nano-silica in the experimental setup so that we can find the best amounts for concrete repair. More focus should be on the bond between the concrete and the repair materials

especially when nano-silica is used as a surface treatment. We also need to test the long-term durability of concrete in environments, such as exposure to chloride and moisture penetration. Further experimental work should look at how nano-silica dispersion and workability influence the performance of repair materials. Repaired reinforced concrete members can be tested under loading conditions to examine their bond behaviour and structural performance. These studies may help us set up application methods for using nano-silica in the repair and rehabilitation of reinforced structures.

CONCLUSION

This review looked at the use of nano-silica in concrete focusing on its properties, durability, corrosion resistance and how it is used in concrete repair. The studies reviewed show that nano-silica can boost strength refine the structure and cut down the penetration of water and chloride ions but only when conditions are right. Using nano-silica as a surface treatment also shows promise for improving the bond between damaged repair mortar. However the benefits of nano-silica depend on how much used how well it is dispersed the mix proportions and the method of application. Some studies reported drops in tensile or flexural strength and poor dispersion and lower workability stay as challenges. The materials and testing conditions in the studies also make it hard to compare results directly. Based on what we have seen nano-silica looks like a material for boosting the performance of concrete repair systems. However using nano-silica in practice, for repairing and rehabilitating reinforced structures still needs study, especially for long-term durability, bond performance and finding the best application methods.

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