Comparative Study of Nano-Silica Induced Mortar, Concrete and Self-Compacting Concrete – A Review

Sabir Shafi Lone, Megha Gupta and Geeta Mehta

Department of Civil Engineering, Lovely Professional University, G.T. Road, Phagwara, Jalandhar-Delhi, Punjab –144411, India; sabir.19613@lpu.co.in, megha.16756@lpu.co.in, geeta.18262@lpu.co.in

Abstract

Objective: Nanotechnology is the most emerging business in modern age. Concrete, mortar matrix shows demandable change with inclusion of nano-silica. This review has generalised the effect of nano-silica on good scale. Method: Demandable analyses of different researches related to Nano-silica were thoroughly observed and persistent results were accepted in this paper. Finding: Use of nano materials has given new and developed path for improvement towards construction. Among that great stock of nano materials, our preferred choice is nano-silica. This is a review paper which is generalised from number of researches done by great intellectuals. In this paper, the use of nano-silica in mortar, concrete and self compacting concrete has been profoundly analysed. On the basis of minute study, it was deduced that nano-silica can prove a worthy material towards renovation of modern market strength demand. In case of mortar, concrete it showed positive impact towards mechanical properties. Study about filler tendencies of nano-silica further proved its greater concern towards pozzolanic activities which in-turn carved a thought that C-S-H gel is produced in acceptable amount. Throughout this paper, impact of nano-silica towards fresh and hardened properties of concrete, mortar and Self compacting concrete are reviewed and on the basis of practical approach its optimal usage is analysed in all the cases. Applications: Nano-silica can be effectively replaced with cement as its pozzolanic nature is somehow similar to that of binding agent. Introduction of nano-silica in concrete or mortar is narrowly economical as compared to cement. Construction with demand of high compressive, flexural and split-tensile strength in effective and economical sense can vouch for nano-silica replacement.

Keywords: Concrete, Mortar, Nano-Silica, Self Compacting Concrete

1. Introduction

Backbone of construction is defined in terms of concrete. Concrete is highly disparate material with possibility of positive variation at every nano step. Concrete is blend of finely graded cement, aggregate of numerous sizes and water. Concrete production contributes nearly around 5% – 8% of annual anthropogenic global CO₂ production primarily because of its vast use. Main contribution in this regard is provided by cement. So primarily for environmental effect there is need of an alternative material for concrete. Huge amount of research has already been done which finally lead to use of nano materials viz Carbon Nanotubes, Nanoclays, Nanosilica, Nanofibres, Nanometals, and Titanium Dioxide etc. Out of which most positive effect is shown by Nano-silica. This review paper adds up results of various research studies on use of Nanosilica as replacement of cement in concrete, mortar and self compacting concrete.

Nanotechnology of concrete is the study of concrete at utter most atomic level. By changing molecular distribution of concrete or mortar particles, high strength can be achieved up to demandable percentage replacement of cement with concrete. Cement acts as binding agent in concrete and in addition to that it provides its share of strength by genesis of C-S-H gel. This amount of strength can also be achieved

*Author for correspondence
by percentage replacement of cement with nano-silica. Main motive behind utilization of nano-silica is the molecular variation in matrix of concrete. Nano-silica acts as filler in concrete which intensifies density of concrete matrix which in-turn lowers water demand and even contributes positive half towards strength also. Over the period of time various researchers have studied the impact of nano silica in mortar, concrete and self compacting concrete. Summary of some the research work is illustrated.

1.1 Mortar with Nano-silica

1.1.1 Fresh Properties

In have studied impact of nano-silica on fresh and hardened properties of mortar. It was concluded that workability of concrete was showing negative effect with increase in percentage replacement of nano-silica. As long as the nano-silica is reacting with calcium hydroxide which in turn is result of hydration process of cement with water? Further illustration is given in Table 1. In studied workability of mortar on the basis of different percentage replacements being 1%, 3%, 5% and 10%. It was observed that with increment in percentage of nano-silica, demand of water also increases. The reason as per analysis is the particle size distribution and high specific surface area of the material. It was analysed by them that at 10% replacement of cement, demand of water is 33% more in comparison to control mix. In studied nano-silica and concluded that cement hydration process accelerates with increase in percentage of nano-silica in mortar. Setting time is accelerated and variation between early (initial) and final setting time is decreased. In used pyrogenic nano-silica in their research. It was observed that rate of pozzolanic reaction of nano-silica in lime paste or mortar is very high as compared to silica fume. The reason being increasing surface areas. Increment in initial setting time and decrease in difference of initial and final setting time was completely analysed. In came forward with the observation that with increase in percentage of nano-silica (24.8 nm) varying from 0.5% to 4% by weight of cement in cement paste can reduce water demand. Thus lowering workability of paste. In researched that mortar flowability (Marsh cone flow times) is being negatively affected with increment in percentage of nano-silica. It was also observed that more amount of super plasticizer is demanded by mortar. In addition to that, observation was made that cohesion of the mortar was highly affected with use of nano-silica. In observed that mortar workability decreased at good rate for the adopted water/binder ratio. The reason being formation of gels characterised by a significant water retention capacity. In studied impact of nano-silica on cement paste. In this research, nano-silica was varied from 0 to 2.5% and it was observed that positive percentage of nano-silica, accelerate hydration process and reduce setting time. Best value of setting time over observed at 2.5% replacement. In analysed that workability of mortar is adversely affected by use of colloidal nano-silica. The reason being increasing specific surface area. Morphology of CNS is given in Figure 1. In studied combined effect of colloidal nano silica (10mm) and fly ash (class F). It was observed that colloidal nano-silica is accelerating setting time in terms of accelerating cement hydration. In observed that nano-silica hydrosols reduced initial setting time and accelerated pozzolanic activities. Thus lead to the development of C-S-H gel at good scale.

Figure 1. Morphology of (a) CNS-10 nm (b) CNS-50 nm.

1.1.2 Hardened Properties

In studied that flexural strength and compressive strength of cement paste. It was concluded that with increase in percentage of nano-silica up to 7%, positive affect was...
observed on these strengths. It was analysed that with replacement starting from 0 % to 7 %, a numerical increase in flexural and compressive strength was observed and then it started to decrease as amount of calcium hydroxide started exhausting. Further illustration is given in Table 1. Studied variation in compressive strength with different percentage replacements of cement with nano-silica. It was concluded that optimum result is attained at 10% replacement with around 80% improvement in strength as compared to control mix. In observed that with positive variation in percentage of nano-silica, increment of around 3% to 10% is observed in compressive strength as compared to control mix. The reason being high specific surface area or high reactivity of siliceous material. According to research it was made sure that results can be attained with proper variation in w/b ratio. In observed that compressive strength of mortar shows positive impact with increment in colloidal nano-silica percentage. It was analysed that with involvement of 5% colloidal nano-silica, compressive strength of mortar has improved by more than 60% in comparison to control mix. The reason being formation of C-S-H gel, density and high pozzolanic reaction. Morphology of CNS is given in Figure 1. In varied colloidal nano-silica percentage 0%, 2.25% and 5% by mass of binder and fly ash mortar. It noticed that increment in colloidal nano-silica percentage boosted strength at early stage for fly ash mortar as compared to later ages. Analyses were made that with 5% colloidal nano-silica and 20% fly ash in mortar, the strength development was more as compared to control mix. In studied compressive strength of mortar by replacement of cement with different particle size of nano-silica at water/binder ratio 0.65. It was investigated that with variation in particle size of nano-silica, strength of mortar varies comparatively. It was observed that mortar containing 40nm particle size nano-silica is having greater strength then mortar containing nano-silica with particle size 12 nm and 20 nm. Optimum result of compressive strength for particle size 12 nm, 20 nm and 40 nm were observed at 9% replacement by weight of cement with value 1.32, 1.67 and 1.74 times that of OPC respectively. In studied influence of nano-silica in mortar. In this research, high strength cement with nano-SiO$_2$ of 14 nm size and 200 m$^2$/g specific areas was used. In this work, mortar was prepared with different percentage replacement being 0%, 0.5%, 1%, 2%, 5% w/w of cement. Optimum flexural strength limit was observed around 8 Mpa in case of 1% and 2% replacement In addition to that compressive strength reached 50 Mpa, when percentage replacement was 0.5% that meant around 25% increase in strength as compared to control mix. In observed positive effect on compressive strength of cement paste. At 100% substitution of cement with nano-silica, intensification of around 30% to 37% was observed in compressive strength than normal cement specimens. In observed that nano particles with superior fines exhibit improvisation towards performance of mortar. It was concluded that good amount of nano-silica will produce good amount of C-S-H gel that will in-turn show positive affect towards strength performance of mortar. In analysed that nano-silica accelerates the pozzolanic activities at good scale that in-turn improves early strength of mortar. It was observed that creation of micro cracks due to pressure variation effects later age strength. But, at later stage combined effect for compressive strength is more as compared to control mix. In analysed fly ash cement paste with 5% and 7.5% involvement of nano-silica in the place of cement. Remarkable change in compressive strength was noticed at early age being 76% for 5% nano-silica and 94% for 7.5% nano-silica as compared to control mix. In addition to that it was noticed that later age variation does not show much impact towards positive change.

Table 1. Mix proportion, flow and strength properties of concrete

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mix Proportion</th>
<th>Flow (mm)</th>
<th>Compressive Strength (kg/cm$^2$)</th>
<th>Flexural Strength (kg/cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C %</td>
<td>NS %</td>
<td>W %</td>
<td>Sand %</td>
</tr>
<tr>
<td>NS1</td>
<td>100</td>
<td>0</td>
<td>48.5</td>
<td>275</td>
</tr>
<tr>
<td>NS2</td>
<td>99</td>
<td>1</td>
<td>48.5</td>
<td>275</td>
</tr>
<tr>
<td>NS3</td>
<td>97</td>
<td>3</td>
<td>48.5</td>
<td>275</td>
</tr>
<tr>
<td>NS4</td>
<td>95</td>
<td>5</td>
<td>48.5</td>
<td>275</td>
</tr>
<tr>
<td>NS5</td>
<td>93</td>
<td>7</td>
<td>48.5</td>
<td>275</td>
</tr>
<tr>
<td>NS6</td>
<td>90</td>
<td>10</td>
<td>48.5</td>
<td>275</td>
</tr>
</tbody>
</table>
1.2 Concrete with Nano-silica

In modern era with growing demand of strength and threat to environment, nano-silica proves to be the best ray of hope. On the basis of analysis by variety of researchers it was analysed that demandable replacement of cement with nano-silica in concrete can lead to positive change in terms of mechanical properties.

1.2.1 Fresh and Hardened Properties

In studied compressive and flexural strength of concrete. In this research M40 and M50 grade of concrete is studied. In this research, nano-silica (15nm) in combination with silica fume was used It was observed that when 2.5% of nano-silica was used with 7.5% of silica fume then optimum values were attained. Optimum value of flexural strength, split tensile strength and compressive strength was observed to be 18.9%, 25.766% and 25.807% times greater than control mix in case of M40 and 16.087%, 25.035% and 25.357% times greater than control mix in case of M50 grade concrete respectively. In used nano-silica of size 10 to 150nm in this research. An elevation was observed in numerical value of compressive strength. Maximum value being 129.48 MPa. This rapid development shows that nano-silica acts as filler which in-turn increases density of matrix and initiates as well as accelerates hydration reaction. In studied effect of nano-silica on abrasion and compressive strength of concrete. Increase in compressive strength with 1% to 2% usage of nano-silica by weight of cement was observed. It was depicted that reason behind this could be high rate of pozzolanic reaction. In studied nano-silica of size 10 to 100nm in their research and specific surface area of same was 60 to 500m²/g. It was observed that nano-silica activates the hydration of calcium silicates and leads to formation of C-S-H on good amount. Compressive strength was increased at good rate due to this reason. In performed research with nano-silica particles and observed increase in compressive strength. It was noticed that nano-silica not only acts as filler material but also initiates pozzolanic activities at good rate that leads to formation of C-S-H gel. In analysed that with use of nano-silica (0.75%) and silica fume (3%), compressive strength of concrete is increased and chloride ion penetration is reduced. In studied effect of nano-silica with fly ash concrete and slag concrete. In this research, tests were performed with variety of variations. Conclusion was made that with inclusion of 2% nano-silica by mass of cement, there is reduction in initial and final setting time by 90 min and 100 min respectively. Improvement in compressive strength was observed after 3 days and 7 days by 30% and 25% respectively in comparison to control mix with 50% fly ash. It was depicted that speed of hydration process is more with nano-silica (12nm size) in contrast to silica fume. Further illustration is given in Table 2. In studied concrete at atomic level and observed that with introduction of around 6% of nano-silica in fly ash (class F) concrete, there was improvement in compressive strength as nano-silica has good filler properties. In studied usage of nano-silica in high volume slag concrete. Observation was made that nano-silica dosage from 0.5% to 2% by mass of cement, increased compressive strength of concrete. The reason being smaller particle size. At this amount, reduction in initial and final setting time by 95 min and 105 min was observed respectively. It was concluded that early strength results with nano-silica are better than late strength results. In studied effect of different sized nano-silica particles namely 15nm and 80nm. It was observed that compressive, tensile and flexural strength showed positive impact with percentage replacement of cement by nano-silica. 15nm nano-silica particles overpowered particles of size 80nm in terms of strength. Best results in case of 15nm and 80nm particles were attained at 1% and 1.5% respectively. Reason behind this was formation and effect of C-S-H gel. In studied participation of nano-silica in strength of powdered concrete. Different percentage of nano-silica was used in their work being 3%, 6%, 9% and 12% by weight of cement. Effect of nano-silica was observed at different water cement ratio and finally an explanation was made that compressive strength of concrete increases due to uniform dispersion of nano-silica particles in concrete. In have studied influence of nano-silica in concrete. It was observed that introduction of nano-silica in concrete improved compressive strength of concrete. In studied high volume fly ash concrete (HVFA) with nano-silica. In this study, cement was replaced 2% and 4% by nano-silica and mechanical properties were analysed which showed positive change in early stage as compared to later age. It was also noticed that concrete with 2% nano-silica showed elevated values of compressive strength.

1.3 Self Compacting concrete with Nano-silica

1.3.1 Fresh Properties

In studied the effects of fibres and nano-silica in self compacting concrete. It was observed that due to high effective surface area, workability of self compacting concrete decreases. In derived number of observations on
the basis of V-funnel, slump flow and L box test, with values 4 to 125, 640 to 840mm, 0.73 to 0.98 respectively. In observations were made related to negative variation in workability. In studied effects of nano-silica in high strength compacting concrete. It was observed that particles of nano silica act as nano filler and lead to increment for demand of water. It was noticed that 4% weight percentage of nano-silica lead towards negative numerical value of workability.

### 1.3.2 Hardened Properties

In emphasized on the point that atomic effect of nano particles lead to formation of C-S-H gel. It was observed that cement replacement with nano-silica up to 4%, shows positive impact on compressive, flexural and tensile strength. Thus it was pinned out that 4% is the optimal value for replacement. In analysed effect of micro silica and nano-silica in self compacting concrete with different binder content. It was noticed that with 2% nano-silica, compressive and split tensile strength was increased due to enhanced formation of crystalline Ca (OH)₂ in early days of curing. In addition to that formation of C-S-H gel shows same positive impact towards strength. In studied minute dispersion of nano-silica particles in self compacting cement, a reasonable change was observed towards formation of hydrated products which in-turn lead towards conclusion that compressive, split tensile strength and flexure strength of self compacting concrete is increased at 4% replacement of cement by nano-silica. In evaluated performance of nano-silica in high strength self compacting concrete. In this research, cement was replaced with nano-silica at different percentages being 0%, 2%, 4% and 6%. Throughout this work, percentage increase in flexure strength, compressive strength and split tensile strength at 4% usage of nano-silica was observed as 16.01%, 18.88% and 23% respectively as compared to control mix. Conclusion was made that nano-silica showed positive impact towards strength.

### 2. Conclusion

Based on the thorough reviewing on nano technology, certain observations were common over and over again. Positive effect of nano-silica on such an atomic level is worth bringing a change in mortar, concrete and self compacting concrete. The detailed study of nano-silica induced mortar and concrete matrix on nano level has finally leaded us towards number of believable conclusions that are discussed.

i. Nano-silica has extensive filler effect due to its atomic level fineness. In addition to this pour filling effect of nano-silica, it has more specific surface area as compared to cement which leads to decrease in workability as fine particles demand more water. It was observed that nano-silica initiate as well as accelerate pozzolanic activity in mortar which results in formation of C-S-H gel in good amount that steer towards increase in compressive strength.

### Table 2. Setting time and compressive strength for different mix proportions of concrete with ultrasonic premixing of nano-silica or silica fume with water

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Mixing and dispersing procedure</th>
<th>Binder type</th>
<th>Setting Time (h:min)</th>
<th>Compressive Strength (MPa)</th>
<th>Charge Passed (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Initial</td>
<td>Final</td>
<td>3-day</td>
</tr>
<tr>
<td>CFA0</td>
<td>Mechanical</td>
<td>50% Fly ash, 50% cement</td>
<td>06:05</td>
<td>08:15</td>
<td>19.5</td>
</tr>
<tr>
<td>CFA21</td>
<td>a</td>
<td>2% NS, 48% fly ash, 50% cement</td>
<td>04:35</td>
<td>06:35</td>
<td>25.3</td>
</tr>
<tr>
<td>CFA2SF</td>
<td>a</td>
<td>2% Silica fume, 48% fly ash, 50% cement</td>
<td>05:45</td>
<td>08:05</td>
<td>20.4</td>
</tr>
<tr>
<td>CSL0</td>
<td>Mechanical</td>
<td>50% Slag, 50% cement</td>
<td>06:05</td>
<td>08:10</td>
<td>35.4</td>
</tr>
<tr>
<td>CSL21</td>
<td>a</td>
<td>2% NS, 48% slag, 50% cement</td>
<td>04:30</td>
<td>06:25</td>
<td>43.1</td>
</tr>
<tr>
<td>CSL2SF</td>
<td>a</td>
<td>2% Silica fume, 48% slag, 50% cement</td>
<td>05:50</td>
<td>08:05</td>
<td>36.7</td>
</tr>
</tbody>
</table>
of concrete. So, use of super plasticizer in this situation is of key demand. Throughout the study, it was observed that impact of nano-silica towards hydration activities is noticeable. Nano-silica initiates formation of hydrated products at good rate which leads to high early strength as compared to later strength. But it should be keenly noted down that overall effect of nano-silica on compressive, flexural and split tensile strength is more as compared to control mix.

iii. Impact of nano-silica on self compacting concrete is not different than normal concrete at all. It was observed that workability of self compacting concrete shows negative curve towards increase in percentage of nano-silica. The reason being that much water is exhausted as hydration process is in command. In addition to that increasing specific surface area has same negative effect on workability. On the other hand, mechanical properties show remarkable improvement as compared to control mix. The reason behind their inclination is the formation of C-S-H gel at huge amount due of high pozzolanic activities in SCC. It should be kept in mind that the positive impact on mechanical properties is demandable.

3. References


