STUDY ON EFFECT OF NANO SILICA ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF HIGH STRENGTH SELF COMPACTING CONCRETE

Gunti Venkata Sowmya[1] , Dr. I. Chandra Sekhar Reddy[2]

[1]M.Tech Student, Dept. of Civil Engineering, Sree Dattha Institute of Engineering & Science, Sheriguda, Ibrahimpatnam, Hyderabad, Telangana

[2]Assistant Professor, Dept. of Civil Engineering, Sree Dattha Institute of Engineering & Science, Sheriguda, Ibrahimpatnam, Hyderabad, Telangana

ABSTRACT

This paper aims to make high-strength self-compacting concrete by utilizing supplementary cementitious materials (SCMs) in cement partially. The SCMs used in the present work are fly ash, Ground granulated blast furnace slag (GGBS), and Nano silica (NS). In the present work, six mixes were prepared. Mix NS0SCC is cement replaced with fly ash by 10% and 15% GGBS in all mixes. 1%, 2%, 3%, 4%, and 5% of Nano silica were added to the mixes, NS1SCC, NS2SCC, NS3SCC, NS4SCC, and NS5SCC respectively. The tests performed are fresh, mechanical, and durable. To find the fresh properties slump flow test, V-funnel test, and L-Box test are performed. To find mechanical properties compressive strength tests at 28 and 56 days, flexural tests at 28 and 56 days, and split tensile tests at 28 and 56 days of curing are performed. And durability tests performed are ultrasonic pulse velocity and dynamic modulus tests. Further scanning electron microscopy analysis was done to study the microstructure of the concrete. From the results, it was observed adding the fly ash and GGBS improves the fresh properties whereas adding silica decreases the fresh properties of self-compacting concrete that the combination of slag-based admixtures and nano-silica mixes showed good performance in terms of strength, durability, and micro-structural improvement.

Keywords: Fly ash, Ground granulated blast furnace slag (GGBS), Nano silica (NS), slump flow test, V-funnel test, and L-Box test.

I INTRODUCTION

The factors concerned with the cement production are environmental sustainability issues and intense energy needs, due to the calcinations of limestone and combustion of fuel, cement production produces an equal amount of CO_2 into the atmosphere. It is evaluated with the industry of construction on fast track and rapid industrialization, the pollution produced by the production of cement could reach an alarming 17% of global CO_2 emissions that is presently about 7%. The construction activities of infrastructure in the future construction industry is under stress to go in for eco-friendly green practices. The 7% of world's Carbon Dioxide (CO_2) emissions from Portland cement add to the global warming considerably. Additionally, out of 450 million tons of fly ash considered as the waste from thermal power plants, only 8% is used in the production of cement.

Furthermore, a small portion of the100 billion tons of slag, a waste, by-product of steel industry worldwide utilized as a partial cement substitute in every year. Generally, 90% of coal ash and metallurgical slag produced today end up as low value applications or simply undergo disposal by ponding and streak pilling. The Supplementary Cementitious Materials (SCM) partially replacing OPC and introduced as blended cements with a genuine concern to minimize the overall CO2 emissions with the composites of OPC to economically incredible and focus on sustainability in concrete construction. In the function of SCM many industrial by products play a vital role like fly ash, micro silica, nano silica, metakaolin, rice husk ash etc., to improve the rate of cement hydration and altering the characteristics of the concrete.

In the current project, the mineral admixtures in the form of nano silica used as partial replacement of cement by weight to improve the micro structural characteristics of concrete.

Self compacting concrete (SCC) is a special type of concrete that was invented in Japan by H.Okamura in the 1990s. Nowadays because of so many advantages, the SCC is preferred over normal concrete in all major construction. The advantages of self compacting concrete are it is self compactable without any external force/vibration, construction time will be less, easy transportation, required less labor force etc,. instead of so many advantages it has some disadvantages which are required skill labor, the initial cost of SCC will more.

A concrete is said to be self compacting concrete when it satisfies the guidelines given by the EFNARC. According to the guidelines of EFNARC, the concrete should be self compactable, if it possesses filling ability, flowing ability, and passing ability. The flowing ability of SCC can be found out by slump flow test. Filling ability can be found out by V-funnel test and passing ability by L-Box test.

Nano-Silica is a white powder that constitutes a high purity of amorphous silica (99%). It provides better results than micro silica. Nano-Silica incorporation in concrete modifies the properties of concrete from the nanoscale level. It constitutes a high percentage of silica that generates a pozzolanic reaction and increases the CSH gel formation by consuming $Ca(OH)_2$ which makes dense and high strength concrete. The size of the nanomaterials also plays effect role in modifying the properties of concrete. In the present study medium-range Nano-Silica used of size 30 nm, it replaces the cement partially along with fly ash and GGBS from 1.5% to 9% in 1.5% increment and was tested for fresh, mechanical, and durability properties.

II SURVEY OF RESEARCH

Du et al. (2014) have investigated the durability properties of concrete with nano silica at dosages of 0.3% and 0.9%. The microstructure became more homogeneous due to pozzolanic reaction and nano filler effect. There are less pores at interfacial transition zone. Compressive strength, water sorptivity, rapid chloride migration tests were conducted. Even at 0.3% addition of nano silica, compressive strength and resistance against water will increase. The pozzolanic reaction due to nano silica densified the paste microstructure and the paste is more homogeneous for concrete containing nano silica.

Chithra et al. (2016) have discussed that this experimentation has led to research the impact of colloidal nano silica on the characterization of High Performance Concrete. Bond mortars and cement blends were included by replacing portland concrete by Nano silica at 0.1%, 0.2%, 0.3%, 0.4% and 0.5%. Tests on workability, rapid chloride penetration, elasticity, compressive strength, water absorption, flexural strength were conducted. The addition of nano silica enhances the strength characteristics upto 2% replacement level.

Zhidan Rong et al. (2014) investigated on the behaviour of nano silica particles on the process of hydration, hardened and pores structures of the ultra high performance cementitious composites. The authors have studied the behavior using various percentages of nano silica (0%, 1%, 3% and 5%) and they revealed that the strength properties were enhanced for the composites upto 3% of nano silica. In addition, they pointed that increasing the percentage of nano silica beyond 3% results in agglomeration of the particles and the non –uniformity in the pore structures.

Tang et al. (2021) have selected four replacements like 0%, 2%, 4% and 6% of nano silica in the concrete. From the research they concluded that 2% of nano silica was added into the concrete and it improved the mechanical and durability properties of the concrete.

Mahmoud Nili & Ahmad Ehsani(2015) investigated on the effect of interfacial transition zone and the cement paste on the hardened property of concrete containing the various percentage of nano silica and micro silica. They observed that the transition zone is not upto the limit in terms of microstructural arrangements for the concrete with the conventional ingredients especially with the powder materials. Blended powder components such as nano silica (0%, 1.5%, 3%, 5% and 7.5%) and micro silica (0%, 5% and 7.5%) were added with respect to the weight of cement. They proved that the concrete contains 3% or 5% nano silica, free of micro silica will show better effect in compressive strength for both cement paste and concrete.

Zhang et al. (2016) have investigated the reinforcement mechanism of nano silica to cement based materials with the theoretical calculation and experimental evidence. The content of nano silica will increase by the use of calcium hydroxide. Nano silica has a high level in fineness, specific surface area and pozzolanic activity than micro silica. Nano silica increases the hydration of cement because of the nucleus effect which improves the strength. Nano silica resorts to form the tensile cement matrix. Thus, the nano silica enhanced the flexural strength, electrical resistivity and compressive strength.

Hussain & Sastry (2021) have investigated the effect of micro silica and nano silica on the mechanical properties of the fibre reinforced concrete. Compressive strength, tensile strength, modulus of elasticity and water absorption were found out. The introduction of silica fume and nano silica in the fibre reinforce concrete improves the elastic modulus due to increase in compactness of cement paste bond with aggregates and also tensile strength.

Mohammed H. Hameed et al.(2020) This research paper studies the influence of micro silica (MS) and colloidal Nano silica (CNS) on SCC.

The addition of micro silica in SCC at 10% (this used as a reference) and addition of colloidal Nano silica in SCC at a percentage of (2.5%, 5%, 7.5%, 10%) then conducted the fresh and hardened test. All these mixes were tested for slump flow, V funnel, and L-box tests to determine consistency (workability). and compressive strength modulus of elasticity and tensile strength were conducted to determine hardened properties then compared results with reference mix of micro silica. Concluded that the slump flow L-box test values decreases and V-funnel time increases for CNS compared to MS. And increment in hardened properties for CNS in SCC than that of MS in SCC.

Some of the practical problems for the infusion of nanomaterials in cement composites are

- Presently, Production of Nanomaterials in huge quantities is not possible.
- Production and processing techniques of nanomaterials should be improved to make them commercially viable.
- Due to small size and high specific surface area this nanoparticle accelerates the hydration reaction thereby a large amount of heat generated, therefore to counteract this problem suitable additives need to be added.
- Nano materials reduce the workability of cement composites as the percentage of inclusion increases.
- Balancing both flowability and strength parameters are difficult thereby care need to be taken properly while adding filler materials.

III OBJECTIVES

The objectives of this paper are:

- Study on strength characteristics of M50 grade self compacting concrete with addition of 1%, 2%, 3%, 4% and 5% nano silica in the weight of cement.
- To determine the fresh properties of self compacting concrete by slump flow, v funnel and l-box test.
- To determine the Harden concrete by compressive, split tensile and flexural strength for 28 and 56days curing.
- To determine the durability properties of self compacting concrete with Ultrasonic pulse velocity test.

IV METHODOLOGY

- Collect the materials (cement, water, nano silica, ggbs, fly ash, coarse and fine aggregate).

- Choose the mix design and literature survey (for mix proportions and pending works from past researches).
- Design mix design of M50 grade self compacting concrete.
- Find out the mix proportions for different mix grades.
- Mixing of all dry materials for 2mintues and required quantity of water to add the dry mixed materials and mix it for 3-5mints.
- Freshly prepared concrete test with slump flow, l-box, v funnel test
- Cast the cubes, beams & cylinders moulds based on the requirement.
- Cure the sample in water for 28 and 56 days for cubes, cylinders and beams.
- After curing ages, the samples tested. Compressive strength test for cubes, flexural strength for beams and split tensile strength test for cylinders.
- Durability tests such as Ultrasonic pulse velocity test for 28 and 56days.
- Results & discussions
- Conclusions

V EXPERIMENTAL WORK

Concrete in general is made up of cement, aggregates and water. In current research, nano-silica added to the self compacting concrete to get better durability and strength properties. The material properties mentioned below.

Table.1 Properties of cement

S.No	Properties		Values
1	Specific gravity		3.15
2	Initial setting time		38 mins
3	Final setting time		3 hours
4	Compressive strength	3 days	28 N/mm^2
		7 days	39 N/mm^2
		28 days	53 N/mm^2

The natural river sand is used as fine aggregate. Locally available sand confirming to Zone II with specific gravity 2.81 and fineness modulus 2.89 is used for casting the concrete.

The work 20mm and 12.5mm size in the combination of 60% and 40% were selected. From the 20mm aggregate having specific gravity 2.74 and fineness modulus 5.94 and 12.5mm size having specific gravity of 2.74 is used for casting the structure.

To impart additional workability a super plasticizer (Conplast SP430) 20% by weight of cement is used.

Nano Silica is a fine non – crystalline by – product of Nano – silicon industry. It is approximately made at 20000C temperature. It is considered as an excellent pore filling material. It can be used as replacement of 2 – 10 % of cement content in a mixture.

Figure.1 Nano silica

Table.2 Properties of Nano silica

S.No.	Properties of Nano-silica	Values
1	Specific gravity of Nano silica	1.06
2	Particle size	49 nm

Concrete M50 mix design is the process of finding right proportions of the cement, sand and aggregates for concrete to achieve target strength in structures.

Table.3 Mix proportion of SCC

SCC BF %	Cement (Kg/m^3)	Fly ash (Kg/m^3)	GGBS (Kg/m^3)	Water (Kg/m^3)	Coarse aggregate (Kg/m^3)	Fine aggregate (Kg/m^3)	SP (Kg/m^3)	Nano silica (Kg/m^3)
0	525	70	105	196	695	753	7	0
1								5.25
2								10.5
3								15.75
4								21
5								26.25

In the present project the test performed are fresh, mechanical and durability then further micro structural studies was done to study the microstructure of concrete. The fresh properties testing are very important to check the concrete behaviour during fresh state especially for self compacting concrete. In the present project the fresh properties of self compacting were performed by following the guidelines of EFNARC 2002. The test performed are slump flow diameter test to find the spreading or flowing ability of the fresh concrete measure in mm. V-Funnel test to find the filling ability of the SCC measured in seconds. L-Box test performed to the passing ability of the SCC measured in the ratio of heights.

The mechanical tests performed were compressive test, flexural test and split tensile tension test. The moulds sizes used for compressive test are 150x150x150 mm, flexural test the size used are 100mmx100mmx500mm prism and for split tensile test the mould size used are 100mmx200mm height cylinder. This mechanical test performed for 28, 56 days. All the mechanical tests conducted following the guidelines of IS 516-1959. Further the Ultra sonic pulse velocity test performed to find the dynamic modulus of concrete following the guidelines of IS 1331:1992.

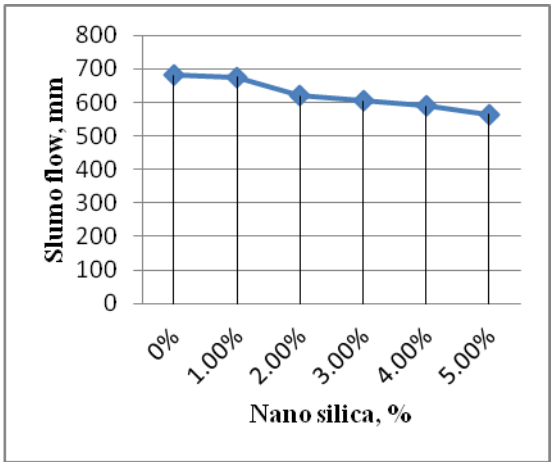
VI RESULTS AND DISCUSSIONS

A. Fresh properties of self compacting concrete

The fresh properties of concrete are very important especially for self compacting concrete.

a. Slump flow

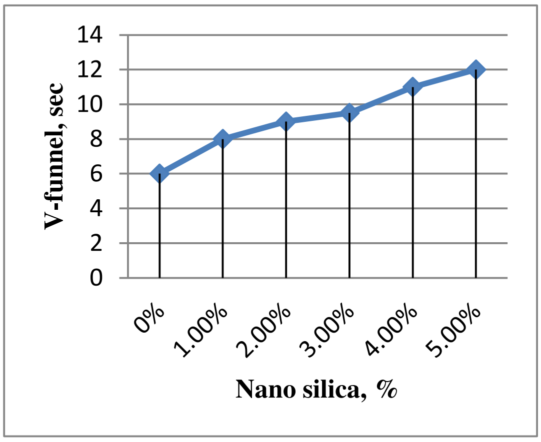
The slump flow tests results are tabulated in below graph.1 from mix NS to NS5 the flow properties shows decrement. Mix NS1 and NS2 shows higher flow ability compared to other mixes because of fly ash which is a sphere size of particle that induce ball bearing effect between the particles. From mix NS3 onwards drastic decrement in slump flow was observed because of presence of silica. Mix NS5 shows the lowest slump flow value. According to EFNARC guidelines the limits for slump flow diameter given is 650 to 800mm.



Graph.1 Slump flow test results graph

b. V-funnel test

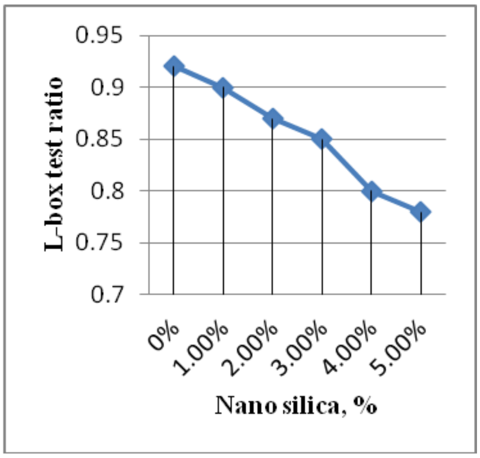
V-Funnel test performed to determine the segregation resistance of the concrete and also filling ability of the concrete. The V-Funnel test results are interpreted as in seconds. The test results are indicated in below graph2 shows the conducting V-Funnel experiment test in lab represents the graphical representation of the test results. From the graphs we observed that after addition of silica that is from mix NS5 the v-funnel time increases that indicate the less flow and mix NS 0 and NS 5 shows good flow property.



Graph.2 V-Funnel test results graph

c. L-box test

L-box test is very important in indicates the passing ability of the self compacting concrete. It has three steel rods which implicates the practical congested reinforcement situations. The values of the L-box test represents as the ratio of heights near to the test bars and the height at the ends.

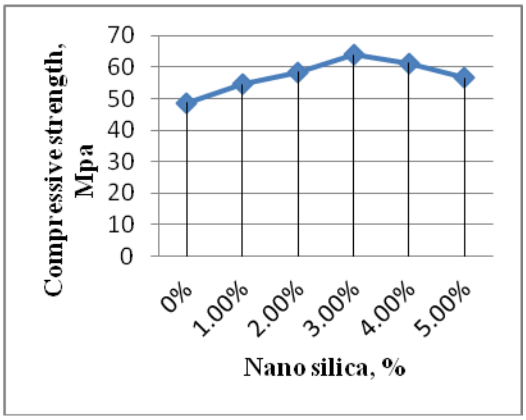


Graph.3 L-box test results graph

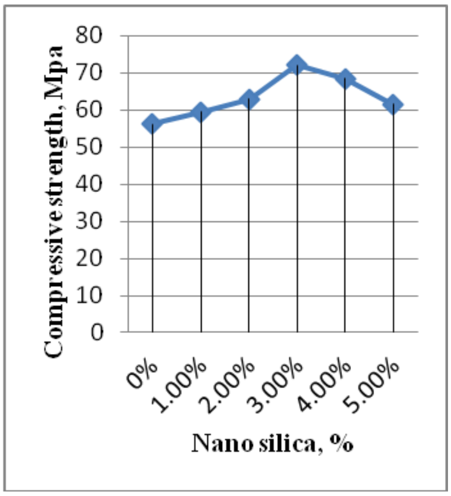
The L-Box test conducting in the lab shows the l-box test results in a graphical form the L-box test results followed a similar trend as of slump flow and v-funnel test that mix NS 1 and NS2 shows the good fresh properties and mix NS5 showed the least value.

B. Harden properties of self compacting concrete

a. Compressive strength



Graph.4 28days compressive strength test results graph

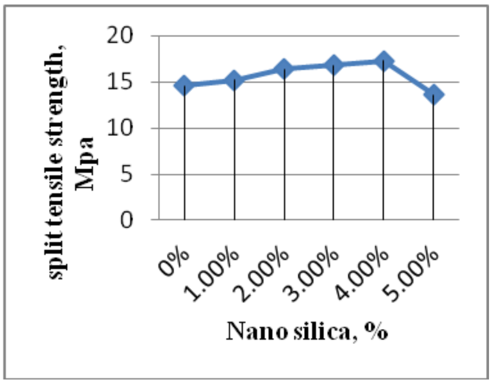


Graph.5 56days compressive strength test results graph

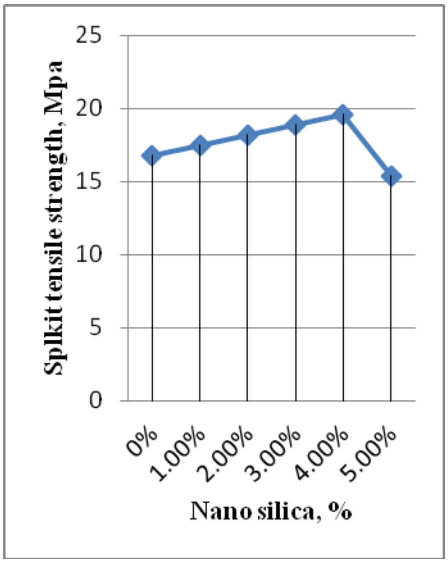
Compressive strength is a very important mechanical test. Above graph shows the digital compressive machine in which concrete specimen is kept and load will be applied load on the specimen will be act till it crushes. The size of the specimen used was 150x150x150mm. the test was conducted for 28, 56 days. can observe that among all the mixes mix NS5 shows the least strength after addition of silica from mix NS3 onwards Compressive strength test results shows drastic increment in strength because this micro and nano-silica undergoes a pozzolanic reaction with calcium hydroxide present in the concrete and produces secondary CSH gels. Mix NS3 which is a combination of micro and nano silica shows the highest compressive strength among all the mixes. The highest strength observed is 63.8 MPa.

b. Split tensile strength

To measure the direct tension of the concrete is practically impossible. The specimen used for the test is 100mm in diameter and 200 mm in height. Below graph shows the graphical representation of the split tensile values the mixes NS0 and NS5 show the least strength and mix NS3 shows the highest strength among all the mixes.



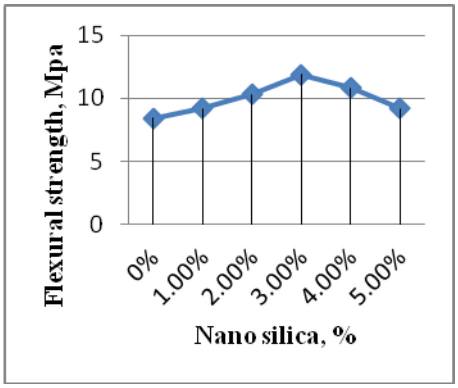
Graph.6 28days Split tensile strength test results graph



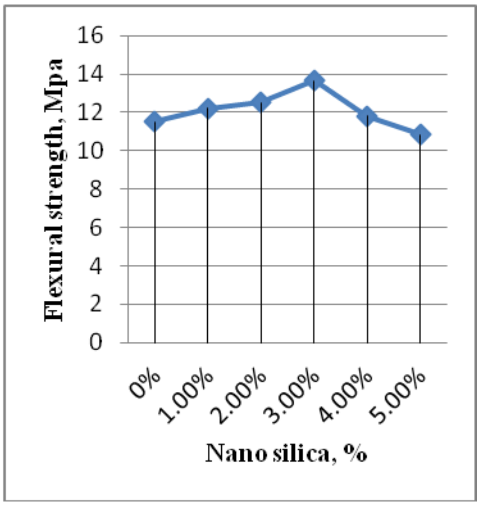
Graph.7 56days Split tensile strength test results graph

c. Flexural strength

Flexural test values represent the bending strength of the concrete. The specimen size used for the flexural test is 100x100x500mm size. Graph 5.8 shows the flexural test results represented in a graphical form. From figure we can observed that mix NS0, NS1 and NS5 shows the least flexural values. From mix NS3 shows drastic increases in flexural strength. The mix NS3 shows the highest strength about 11.9 MPa among all the mixes. we can also observed that the increment in the strength for flexural are more compared to compressive.



Graph.8 28days Flexural strength test results graph

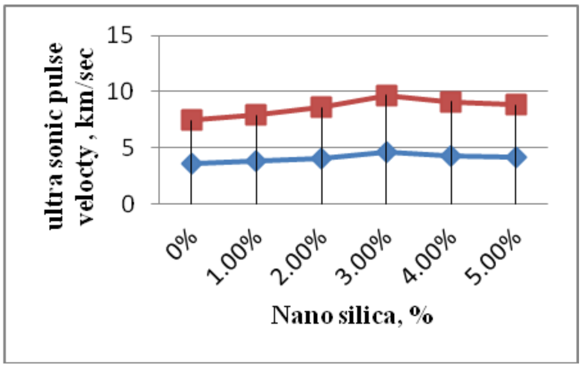


Graph.9 56days Flexural strength test results graph

C. Durability properties of self compacting concrete

a. Ultra sonic pulse velocity

The mix with only Nano silica 3% dosage (SCC NS 3) shows the excellent quality of concrete due to microstructure densified by micropores filled by Nano silica and cement hydrate forming strong chemical bonds with nano silica. All the upv values above 4km/sec represent the good quality of concrete. The Dynamic youngs modulus of concrete was determined by empirical formula from IS 13311(Part 1):1992 codal provision. The mix SCC NS3 given the highest dynamic modulus of concrete. Deflections are inversely proportional to youngs modulus so there are no cracks during the service life of the structure. Graph 10 shows the variation of Upv and Dynamic youngs modulus of the concrete prism at only 56 days after curing.



Graph.10 Ultra sonic pulse velocity test results

D. SEM Analysis

Scanning electron microscopy (SEM) uses a beam of electrons to scan the surface of a specimen. SEM imaging was carried out on the mixes NS0SCC, NS1SCC, NS2SCC, NS3SCC, NS4SCC, and NS5SCC. NS0SCC depicts the porous microstructure (10 percent fly ash & GGBS), with black marks indicating the pores. Figure 3 shows how adding 4% nano silica enhanced the microstructure compared to the prior one NS0SCC mix. Because of the pozzolanic reaction, which produces more CSH gels, silica in the concrete enhances the microstructure, and because of the lower particle size, it exhibits a packing effect, resulting in a denser crystal structure which is 5 percent MS pulse 4 percent NS, exhibits a more homogeneous and dense microstructure.

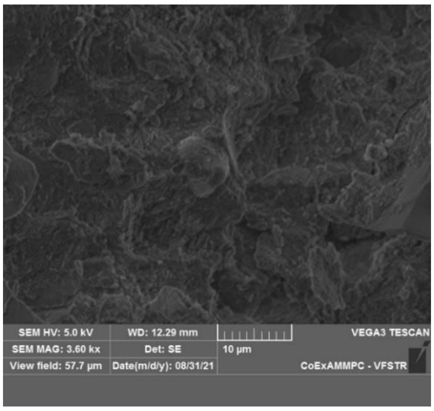


Figure.3 SEM Analysis

CONCLUSIONS

In the previous chapter, the results obtained were listed and discussed. In the present chapter, the conclusions are drawn based on the results obtained as detailed in the previous chapter.

- The workability of all Self-compacting concrete mixes was reduced when Nano silica was added, due to the large surface area it will absorb more water so it will reducing the flow of concrete.
- Nano-silica has a broad filling impact because of its nuclear layer resolution, prompting an expansion in unambiguous surface region contrasted with concrete. This diminishes workability since fine particles require more water. And yet start and speed up the pozzolanic movement in the mortar, framing a lot of C-S-H gel. The addition of nano-silica up to a limit of 4% does not affect the fresh properties of SCC.
- From the perspective of new properties NS0SCC is a good workable mix, followed by NS1SCC. The addition of Nano Silica resulted in a significant reduction in fresh characteristics. NS5SCC was the least workable due to the addition of NS, which made the mixture extremely sticky.
- All the fresh properties of all mixes of slump flow are within the limits of EFNARC guidelines.
- The addition of nano-silica improved the stability and reduced the separation and bleeding effect of SCC.
- As the percentage of nano silica gets on increasing (up to 4%) the formation of hydrated products also increases as well as the filling ability of the voids increases the compressive characteristics as well as the durability properties of SCC.
- At 28 and 56 days of curing, the compressive strength of the Control Mix NS0SCC grade obtained 48.61 MPa and 56.2 MPa respectively.
- At 28 and 56 days of curing, the compressive strength of the Mix NS3SCC grade obtained 63.8 MPa

and 72.1 MPa respectively. NS3SCC mix has 28.2% more strength compared with the control mix.

- At 28 and 56 days of curing, the split tensile strength of the Control Mix NS0SCC grade was 14.56 MPa and 16.8 MPa respectively.
- At 28 and 56 days of curing, the split tensile strength of the Mix NS4SCC grade obtained 17.3 MPa and 19.6 MPa respectively. NS4SCC mix has 16.8% more strength compared with the control mix.
- At 28 and 56 days of curing, the Flexural strength of the Control Mix NS0SCC grade obtained 8.3 MPa and 11.5 MPa respectively.
- At 28 and 56 days of curing, the Flexural strength of the Mix NS3SCC grade obtained 11.9 MPa and 13.64 MPa respectively. NS3SCC mix has 18.6% more strength compared with the control mix.
- The ultrasonic pulse velocity of all mixes indicates a similar trend, with NS0SCC showing the least velocity and NS4SCC showing the highest velocity due to pore filling in concrete and secondary C-S-H gel formation.
- The Dynamic modulus of all mixes indicates a similar trend, with NS0SCC showing the least modulus and NS4SCC showing the highest dynamic modulus due to pore filling in concrete and secondary C-S-H gel formation.
- The higher the silica measurements, the more noteworthy the obstruction to infiltration.

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