

**EFFECT OF SILICA FUME AND NANO SILICA AS CEMENT
REPLACEMENT MATERIAL ON STRENGTH PROPERTIES OF
PAVEMENT QUALITY CONCRETE (PQC)**

A Dissertation submitted
in partial fulfillment of the requirements for
the award of the degree of

**MASTER OF ENGINEERING
IN
STRUCTURAL ENGINEERING**

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JULY 2015

DECLARATION

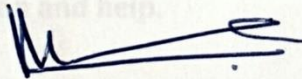
The author hereby declare that this dissertation entitled "*Effect of silica fume and nano silica as cement replacement materials on strength properties of Pavement Quality Concrete (PQC)*", in whole or part has not been used to obtain any degree in this, or any other, institute, except where references have been given in text, it is entirely the author own work. The author conform that the library may lend or copy this upon request for academic purposes.



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CERTIFICATE

This is to certify that the work presented in dissertation entitled "*Effect of silica fume and nano silica as cement replacement materials on strength properties of Pavement Quality Concrete (PQC)*" submitted by **Mr. Sankalp Rana** in partial fulfilment of the requirements for the award of degree of **Master of Engineering** in Structural Engineering at **Thapar University, Patiala**, is a bonafide work carried out by the student under our supervision and guidance. The matter embodied in this report has not been submitted anywhere for award of any other degree.

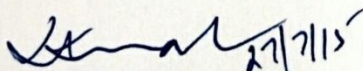


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ACKNOWLEDGEMENT

With my aesthetic attitude of learning management to the best, I am in a state to submit this precipitous report and would like to express my gratitude to all persons and organizations who contributed directly or indirectly to this report with their support, encouragement and advice.

Acknowledgement is due first and foremost to my supervisors, Dr. ManEEK Kumar, Professor and Mr. Tanuj Chopra, Assistant Professor Department of Civil Engineering. I am truly indebted for their advice and guidance. Their abundant knowledge in civil and construction field is a benefit for me.

This report required hard work, sincerity and devotion which I tried my best to put in this project and in turn gained a lot of knowledge and confidence from this report. The cheerful support of my friends Sagar Tandon, Vasu Nanda, Barath Ragesh, Saubhagya Sharma, Abhinav Agrawal, Ajay Pratap, Piyush Kumar are sincerely appreciated for helping me in casting, curing and testing of specimens in the laboratory.

I am also thankful to all the staff members of Civil Engineering Department for their full cooperation and help.

Above all, I thank my parents, whose love and affectionate blessing have been a constant source of inspiration in making this manuscript a reality. I would like to end by saying that the people mentioned above will hold dear in my heart and will never be forgotten. Thank you all.

Sankalp Rana

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ABSTRACT

Civilization also produces waste products. Disposal issue of the waste products is a challenge. Some of these materials are not biodegradable and often leads to waste disposal crisis and environmental pollution. Government policies and public awareness is also contributing to the enhancement of utilization in road pavements. Silica fume and nano silica have been widely used in road pavements. On other hand, silica fume has no use since it is a produced only as a byproduct which causes health hazards. Therefore, it could be possible to consume fewer natural resources as well through its utilization in increasing demand for road construction.

The present study aim at, developing pavement quality concrete mixtures incorporating silica fume and nano silica as partial replacement of cement. The purpose is to design the slab thickness of Pavement Quality Concrete (PQC) pavement using the achieved flexure strength of the concrete for different w/c ratios with replacement of cement by 5% silica fume and nano silica. It is found that the maximum increase in flexure strength and compressive strength is for 5% silica fume and 2% nano silica at w/c of 0.40.

Due to this increase in the flexural strength it is possible to achieve a saving in cost of PQC construction. In this study it has been observed that the replacement of cement with 5% silica fume and 2% nano silica in PQC, the maximum increase in the flexural strength is observed for mixes containing silica fume and nano silica. This satisfy the IRC specifications of PQC and also saves the cement used in concrete leading to economical design of the concrete slab for the pavement.

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CHAPTER 1

INTRODUCTION

1.1 MODERN CONCRETE

Concrete is widely used for constructing structures, foundations, brick/block walls, pavements, bridges/overpasses, highways, runways, parking structures, dams, pools/reservoirs, pipes, footings for gates, fences and poles and even boats. Concrete is used in countless quantity almost everywhere mankind has a necessity for infrastructure. The volume of concrete used worldwide, ton for ton, is double that of steel, wood, plastics, and aluminum combined. Concrete's use in the contemporary world is surpassed only by that of naturally occurring water. Concrete is also the foundation of a large commercial industry. Altogether, the ready-mix concrete industry, the largest division of the concrete market, is projected to surpass \$100 billion in revenue by 2015. In the United States alone, concrete manufacturing is a \$30-billion-per-year, considering only the value of the ready-mixed concrete traded each year. Given the size of the concrete industry, and the essential way concrete is used to figure the infrastructure of the modern world, it is problematic to overstate the role this material plays today. In modern times, researchers have experimented with the addition of other materials, like water-based cross linking polymers, to produce concrete with improved properties, such as higher strength, electrical conductivity, or resistance to damages through spillage.

1.2 RIGID PAVEMENT

Rigid pavement is the practical term for any road surface made of concrete. Concrete roads are called rigid while asphalt-covered roads are flexible. These terminologies refer to the amount of distortion created in the road surface itself when in use or over time. The prime benefits of using concrete pavements are in its durability and ability to grasp a shape.

Design of rigid pavement is very simple. A surface layer, made up of slabs of Portland cement concrete (PCC), sits on top of a handful of sub-layers. The layer directly under the PCC is more flexible than the concrete, but still quite rigid. This layer provides a

stable base for the PCC as well as supports in drainage. Some road have a second sub layer under the first that is even more flexible, while some roads simply have the prevailing material.

There are three main components of a road pavement

1. Foundation
2. Base
3. Surfacing

The foundation includes of sub-grade soil (cut or fill), capping and sub-base. The foundation is designed to offer a certain standard quality of support for the higher layers. The base is the core structural layer of the pavement. In the meantime, an asphalt surfacing includes of a surface course and a binder course. The purpose of the surfacing is to permit good ride quality to be mutual with suitable resistance to skidding and resistance to crack formation.

A concrete pavement, in overall, consists of three layers, comprising of a sub-grade, base layer and the concrete slab. Usually bound base layers are used for concrete pavement construction. As per Indian specification, some case of such base layers are

- Dry Lean Concrete (DLC)
- Roller Compacted Concrete (RCC) (IRC: 15-2011)

The concrete slab is mostly of M40 to M50 grade of concrete as per Indian specifications, and is called as paving quality concrete or pavement quality concrete(PQC).

1.2.1 Components of cement concrete pavement

A typical cross-section showing various component of cement concrete pavement as shown in Fig. 1.1.

Sub-grade

Sub grade is not strictly a pavement layer. In order to design and construct an acceptable pavement over it, its properties and function must be fully understood. Sub-grade is the

regular soil or made-up ground on which the pavement is constructed. The load of the entire pavement finally comes on the sub-grade.

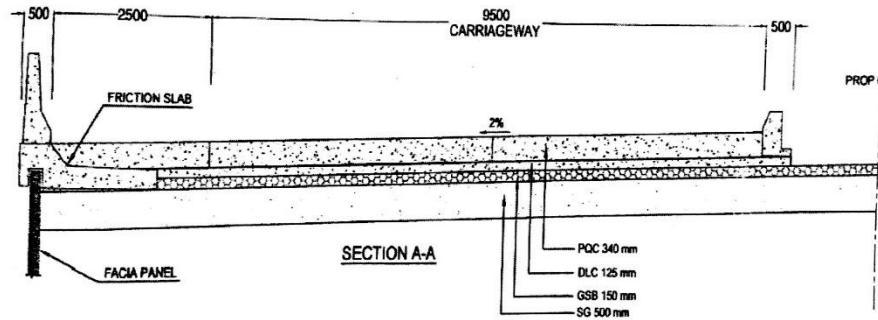


Fig. 1.1: Typical Rigid Pavement Section

The sub-grade and sub-base for laying of pavement concrete slab shall accomplish with the following requirements: (IRC: 15-2011)

- a) No soft spots are present in the sub-grade or sub base.
- b) The uniformly compacted sub-grade or sub-base covers at least 300 mm on either of width to be connected.
- c) It should be properly drained.
- d) The maximum modulus of sub-base reaction obtained with a plate bearing test shall be 5.5 kg/cm^3 .

Drainage layer

Geo-composite drainage layer is set up over a sub grade for enhanced pavement drainage. The geo-composite has benefit over natural drainage in upholding its flow capacity and compressive stiffness under the construction and services besides uneven support. It is a sand/graded gravel layer.

Sub-base course/dry lean concrete (DLC)

It is an important portion of modern rigid pavement. It is a plain concrete with a hefty ratio of aggregate to cement than conventional concrete and usually used as a base/sub-base of rigid pavement (central road research institute, 2010).

1.2.2 Pavement Quality Concrete (PQC)

The IRC specifications of materials used for pavement quality concrete (PQC) are mentioned as below (M.O.R.T&H. section 600).

a) Cement

As per technical specifications M.O.R.T&H cl. 601.2.1, Ordinary Portland Cement of 43 grade obeying to IS: 8112 shall be used.

- 1) Fly ash up to 20 percent by weight of cement may be used in ordinary Portland cement 53 Grade. No fly ash shall be used in any additional grade of cement other than 53 grade. The fly ash shall conform to IS: 3812 (part I).
- 2) Ground Granulated Blast Furnace Slag (GGBFS) obtained by grinding granulated slag following to IS: 12089. GGBFS shall not be used in any other grade of cement except 53 grade. The content of GGBFS shall be up to 50 percent by weight of Ordinary Portland Cement of 53 grade.
- 3) Mix design will be done as per IRC: 44. The OPC content shall not be less than 310 kg/m³ in case of mixing at site. The mutual flakiness and elongation index of aggregate shall not be more than 35 percent.

b) Coarse aggregates

The extreme size of coarse aggregate shall not go above 31.5 mm for pavement concrete. No aggregate which has water absorption more than 2 percent shall be used in concrete mix. The aggregate shall be tested for soundness in accordance with IS: 2386 (Part-5). After 5 cycles of testing, the loss shall not be more than 12 percent if sodium sulphate solution is used or 18 percent if magnesium sulphate solution is used. The joint flakiness and elongation index of aggregate shall not be more than 35 percent.

c) Fine aggregates

The fine aggregates shall involve of clean natural sand or crushed stone sand or a combination of the two and shall conform to IS: 383 (Table 1.1). Fine aggregate shall not contain soft particles, clay, shale, loam cemented particles, mica, organic and other foreign matter.

Table 1.1: Fine aggregates (IS 383-1970)

IS Designation	Percentage passing for			
	Grading zone I	Grading zone II	Grading zone III	Grading zone IV
10mm	100	100	100	100
4.15mm	90-100	90-100	90-100	95-100
2.36mm	60-95	75-10	85-100	90-100
1.18mm	30-70	55-90	75-100	90-100
600 micron	15-34	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	0-10	0-10	0-10	0-15

The fine aggregate shall not contain deleterious substances more than the following:

Clay lumps	1.0 percent
Coal and lignite	1.0 percent

The material passing IS Sieve No.75 micron should not exceed the following:

i) For natural sand (Uncrushed)	3.0 percent
ii) For crushed sand	8.0 percent

The coarse and fine aggregates may be found in either of the following way:

- i) In separate nominal sizes of coarse and fine aggregates and mixed together intimately before use.
- ii) Separately as 31.5 mm nominal, 25 mm nominal single size, 12.5 mm nominal size graded aggregates and fine aggregate of crushed stone dust or sand or a grouping of these three. They shall be mixed together in approved proportion before use.
- iii) Mutual flakiness and elongation index shall not be more than 35 percent. The material after blending shall conform to the grading as shown in Table 1.2.

Table 1.2: Aggregate Gradations for Dry Lean Concrete

Sieve Designation	Percentage by weight passing the Sieve
31.5 mm	100
26.50 mm	90-95
19.0 mm	80-90
9.50 mm	55-75
4.75 mm	35-60
600.00 micron	10-35
75.00 micron	0-8

d) Cement content

When Ordinary Portland Cement (OPC) is used the amount of cement shall not be less than 360 kg/m³. In case fly ash grade I (as per IS: 3812) is blended at site as part replacement of cement, the quantity of fly ash shall be up to 20 percent by weight of cement and the quantity of OPC in such a mixture shall not be less than 310 kg/m³. The minimum of OPC content in case ground granulated Portland blast furnace is used shall also not be less than 310 kg/m³.

e) Concrete strength

The characteristic flexural strength of concrete shall not be less than 4.5 N/mm² (M 40 Grade). In addition, the minimum compressive strength of any individual cube shall not be less than 7.5 N/mm² at 7 day.

f) Separation Membrane

Separation membrane shall be impermeable plastic sheeting of 125 micron thick laid flat without creases. Before putting the separation membrane, the DLC surface shall be swept of all the extraneous materials. Overlap of membrane if any shall be at least 300 mm and any damaged sheet shall be replaced immediately.



Fig. 1.2: Laying of separation membrane

g) Joints

Initial saw cut of 3 mm wide, 100 mm depth in transverse and in longitudinal directions will be provided after initial set (approx. 6-8 hrs.). Final saw cutting 10-12 mm wide, 20-25 mm depth will be provided after 14 days of curing at billeted joint sealant. The staggering of transverse joint with reference to the base will be minimum 0.3 m.

Contraction joints will be provided at every 4.5 m intervals excluding where expansion joints are provided. Transverse construction joints shall be positioned when concreting is done after a day's work. It will be provided at regular location of contraction joints using dowel bars.



Fig. 1.3: Longitudinal and transverse joint in Pavement Quality Concrete (PQC)



Fig. 1.4: Saw cut in transverse direction

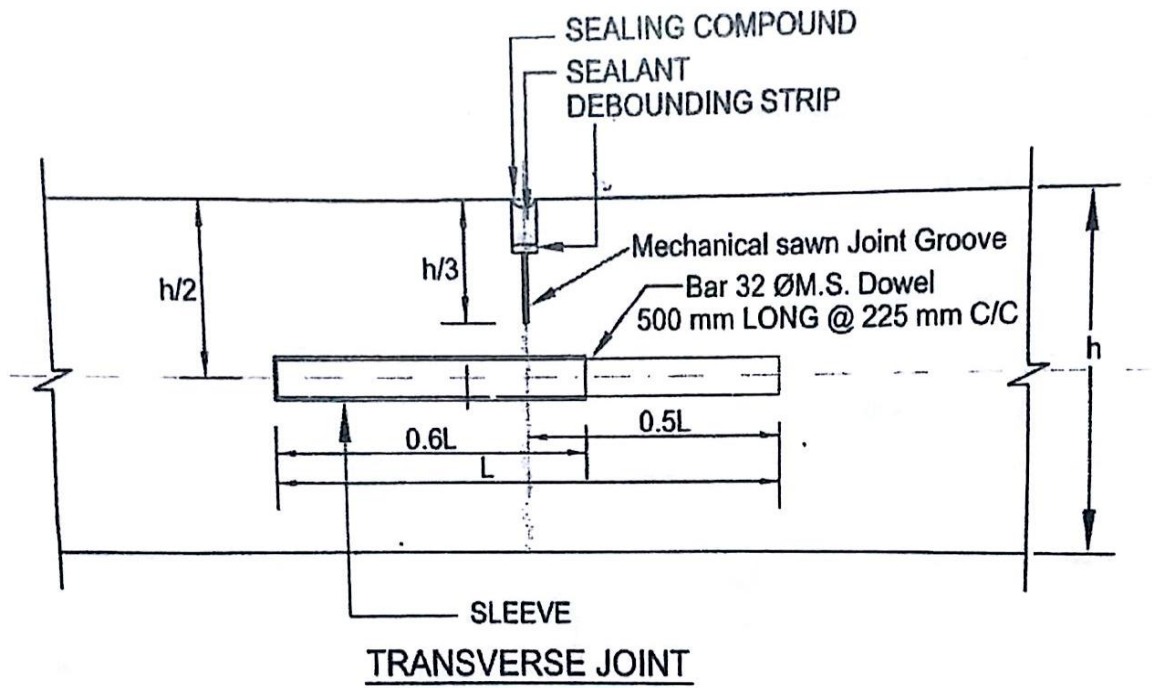


Fig. 1.5: Section of transverse joint in Pavement Quality Concrete (PQC)

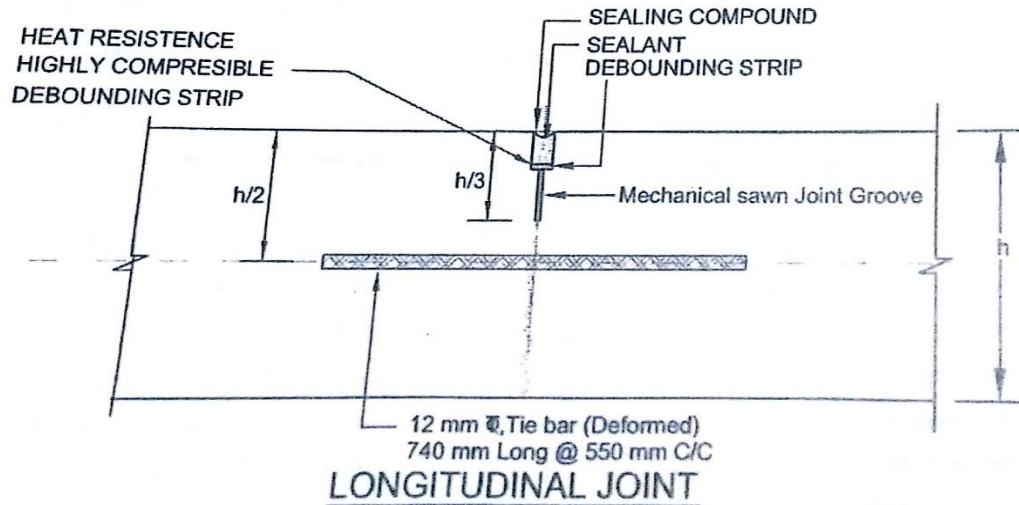


Fig. 1.6: Section of longitudinal joint in Pavement Quality Concrete (PQC)

h) Dowel Bars

Dowel bars shall conform to the necessities of IS: 432, IS: 1139 and IS: 1786. The dowel bars shall sanction to Grade S 240 and tie bars to Grade S 415 of IS. It should be mild steel round, free be placed at the mid depth of the slab with in a tolerance of +/- 20 mm. Dowel bars shall be shielded by thin plastic sheet for at least 2/3 of length from one end for dowel bars in contraction joint or half the length plus 50 mm for expansion joints. The sheet shall be tough, durable and of an average thickness not less than 1.23 mm. for expansion joints, a closely fitting cap 100 mm long cotton waste over sheet end of each dowel bar.



Fig. 1.7: Dowel bars and Tie bars in Pavement Quality Concrete (PQC)

i) Tie Bars

Tie bars should be free from oil, dirt, loose rust and scale. In longitudinal joints shall be deformed steel bars of strength 415 N/mm² complying with IS: 1786. It should protect from corrosion for 75 mm on each side of the joint by applying bituminous paint. The coating shall be dry when Tie bars are used. It should be perpendicular to the line of joint, with the centre of each bar on intended line of the joint with a tolerance of +/- 50 mm and with a minimum cover of 30 mm below joint groove.

j) Surface Tolerance

Surface Tolerance shall be within the limit of +5/-6 mm tolerance limit as per M.O.R.T.H Clause 902.3, surface levels shall be checked on grid of points spaced at 6.25 m along the length and 3.5 m transversely between 0.5 m from the edges and at the centre of the pavement.



Fig. 1.8 Laying of Pavement Quality Concrete (PQC)

1.3 SILICA FUME

A “Very tiny non-crystalline silica formed in electric arc furnaces as a byproduct of the assemblage of elemental silicon or alloys having silicon is known as condensed silica fume or micro-silica”. (ACI 116R-90 cement and concrete technology). Silica fume, also famous as microsilica, is a result of the reduction of high-purity quartz with coal in electric furnaces in the making of silicon and ferro-silicon alloys.

Silica Fume is also composed as a byproduct in the making of other silicon alloys such as ferro-chromium, ferro-manganese, ferro-magnesium, and calcium silicon (ACI Comm. 226 1987b). Before the mid-1970s, nearly all silica fume was discharged into the atmosphere. After environmental anxieties required the collection and filling of silica fume, it befitted economically justified to use silica fume in many applications.

Silica fume include of very well vitrified particles with a surface area on the order of 215,280 ft²/lb. (20,000 m²/kg), when measured by nitrogen absorption techniques, with particles nearly 100 times smaller than the average cement particle. Because of its intense fineness and high silica content, silica fume is a very effective pozzolanic material (ACI Comm. 226 1987b, Luther et al. 1990). Silica fume is used in concrete to enhance its strength as well as durability properties, if used in proper proportions. It has been found that silica fume increases compressive strength, bond strength, and abrasion resistance, reduces permeability, and therefore helps in protecting reinforcing steel from corrosion.

Silica fume has been used as an addition to concrete up to 15 percent by weight of cement, although the ideal proportion is 7 to 10 percent. With an addition of 15 percent, the potential exists for very strong, brittle concrete. It rises the water demand in a concrete mix; however, dosage rates of less than 5 percent will not typically require a water reducer. High replacement rates will require the use of a high range water reducer.

1.3.1 Production of Silica Fume

Electric arc furnaces used in the making of ferrosilicon or silicon metal emit silica fume as a byproduct. The fume, which has a high amount of very fine spherical particles of silicon dioxide, is collected by filtering the gases escaping from the furnaces, as shown in the Fig.1.9.

1.3.2 Desired reaction

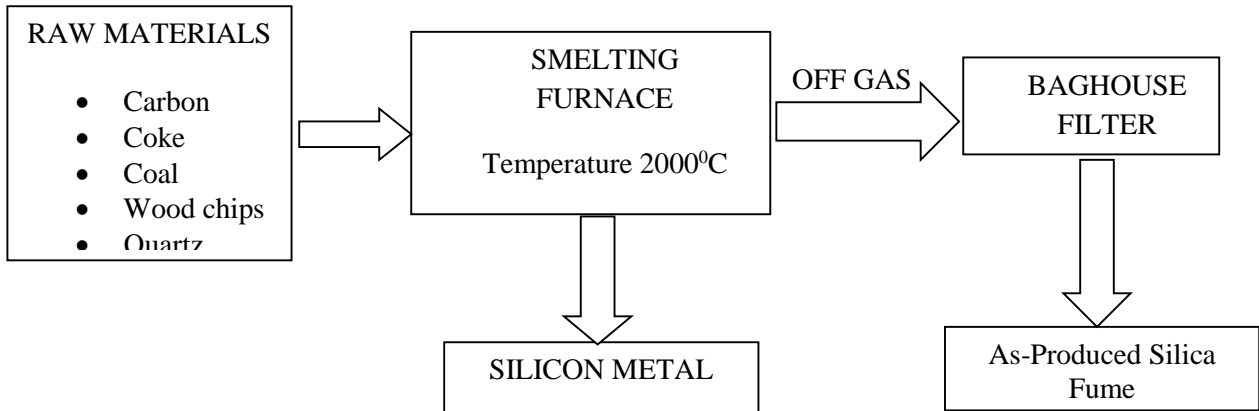
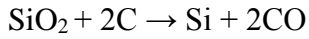


Fig 1.9: Silica fume production

Fig. 1.10, 1.11 and 1.12 show the raw materials going into the smelter viz. metallurgical grade quartz, coal and wood chips. These materials are blended into a charge for the furnace.



Fig 1.10: Coal and Quartz



Fig 1.11: Wood chips



Fig. 1.12: Quartz aggregates used as a source of silicon.



Fig. 1.13: Charging deck of the furnace

The charging deck of the furnace is shown in Fig. 1.13. The tractor is being used to stoke the furnace charge. This is actually the cooler part of the furnace. At the bottom near the electrodes the temperature is 2000°C . The hood over the furnace is part of the collection system that collects the silica fume. The product that results from the smelting operation is simply metal that is sized and sold for further processing.

After being collected over the furnace the silica fume must be transferred, cooled and physically trapped. The large pipe on the left is bringing the silica fume from the furnaces. The vertical cyclones are used to remove oversize and unwanted materials. The large building is a bag house shown in Fig. 1.14 where the fume is captured.



Fig 1.14: Bag house

1.4 NANO SILICA

“Colloidal silica is a nano metric particle size solution of silica particles in water or other mediums”. It finds uses in diverse applications which can be briefed as follows:

- Ceramic slurry binder for making investment casting shells
- Grain binder in refractory (refractory monolithic, gunning and ramming masses, LCC, ULCC , high temperature refractory and ceramic products like vacuum formed fiber shapes, high temperature ceramics , insulation wools , fabrication of artificial dentures etc.).
- As a retention and dewatering aid in paper processing
- For surface sizing and anti-slip treatment of natural fibers, textiles
- Surface anti-static treatment of polyester films
- Packaging (Paper Bags) & Cardboard (Box) Paper Coating for Anti-Skid & Anti-Soiling properties, etc.
- Polyester Films / Fibers for Anti-Block & Anti-Slip & Abrasion Resistance etc.
- Coating material for CRGO Electrical Steel Sheets.
- Textile Auxiliary Formulations for spinning & sizing (dimensional stability and anti-skid properties), finishing etc.
- Additive for Floor Wash, for Anti-skid & Anti-soiling properties
- Silicon Wafers for Polishing purpose.

- Waterborne Inorganic Paints / Coatings. Cement Paints / Sealants.
- Construction additives for water proofing/ improving longevity of concrete structures, nano pore coverage in dams, tunnels, buildings etc.

1.5 SCOPE OF PRESENT WORK

The main objective of the projected work is to study the effect of use of Silica Fume and Nano Silica as partial replacement of cement for the production of Pavement Quality Concrete. The effect of Silica Fume and Nano Silica has been studied on the strength characteristic of Pavement Quality Concrete and reduction in the pavement slab thickness and quantity of materials also studied.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

The relevant literature pertaining to the use of silica fume and nano silica in concrete carried out in India and abroad has been reviewed and presented as follow:

2.2 USE OF SILICA FUME IN CONCRETE

Silica fume is an ultrafine material with spherical particles less than 1 μ m in diameter, the average being about 0.15 μ m. It is a byproduct in the carbothermic reduction of high-purity quartz with carbonaceous materials like coal, coke, wood-chips, in electric-arc furnaces in the production of silicon and ferrosilicon alloys. Because of its extreme fineness and high silica content it improves the concrete proportion i.e. enhance the strength of the concrete due to its fineness and by producing additional calcium silicate hydrates (CSH) by reacting with calcium hydroxide (CH) during the hydration reactions and reduces the permeability of concrete to chloride ions. The first testing of silica fume in Portland cement based concrete was done in 1952. Till then many different percentages of silica fume are replaced with fine aggregates which are discussed as follows:

Abdullah et al. (2004), studied the effect of silica fume and type of coarse aggregates on the split tensile strength, compressive strength and modulus of elasticity of low quality coarse aggregate concrete of both silica fume and plain cement concretes. It was observed that the addition of silica fume enhanced the compressive strength and split tensile strength of all concretes especially of the low quality limestone aggregates. The compressive strength development of the concrete specimens organized with the other coarse aggregates as shown in Fig. 2.1. In these specimens the compressive strength of silica fume cement concrete was also in surplus of that of plain cement concrete specimens. The impact of aggregate quality on the compressive strength of plain and 10% and 15% silica fume cement concretes is summarized in Fig. 2.2. These results specify that the type of aggregate has a vital effect on the compressive strength of concrete. The highest compressive strength was measured in the

concrete specimens prepared with steel-slag aggregates while the lowest compressive strength was noted in the concrete specimens prepared with calcareous limestone aggregates.

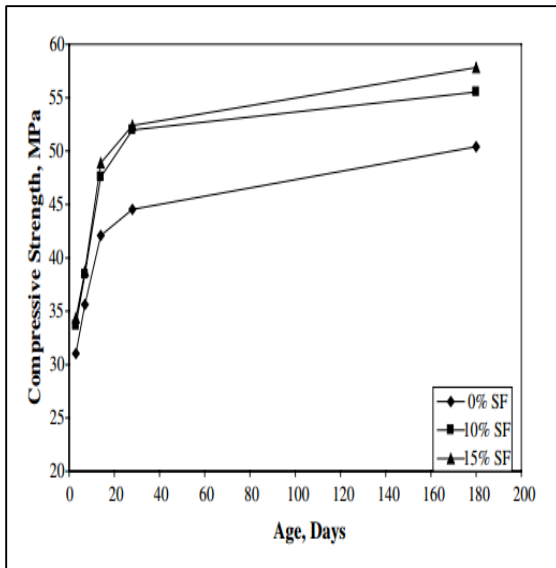


Fig. 2.1: Compressive strength of concrete prepared with dolomitic limestone aggregate (Abdullah et al. (2004))

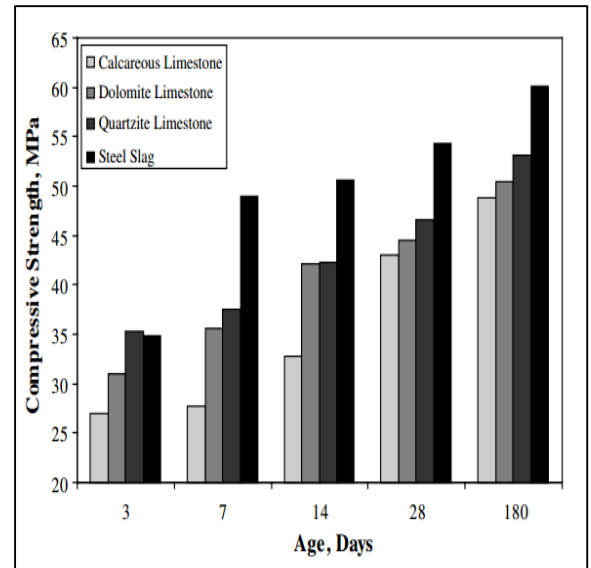


Fig. 2.2: Effect of aggregate type on the compressive strength of plain cement concrete (Abdullah et al. (2004))

Katkhuda et al. (2009), Evaluated the effect of silica fume on tensile, flexure and compressive strengths on high strength lightweight concrete, they replace silica fume by 0%, 5%, 10%, 15%, 20% and 25% for w/c ratios 0.26, 0.3, 0.34, 0.38 and 0.42, the peak silica fume replacement percentages for obtaining maximum 28 day compressive strength and flexure strengths of lightweight high strength concrete ranges from 15% to 25% depending on the w/c ratio of the mix as shown in Fig. 2.3 and Fig. 2.4. The optimum percentage of silica fume replacement increases with the increase of w/c ratio. This percentage is almost a unique for tensile strength where it is noted 15% for w/c 0.26 and 0.30, and 20% for w/c 0.34, 0.38 and 0.42.

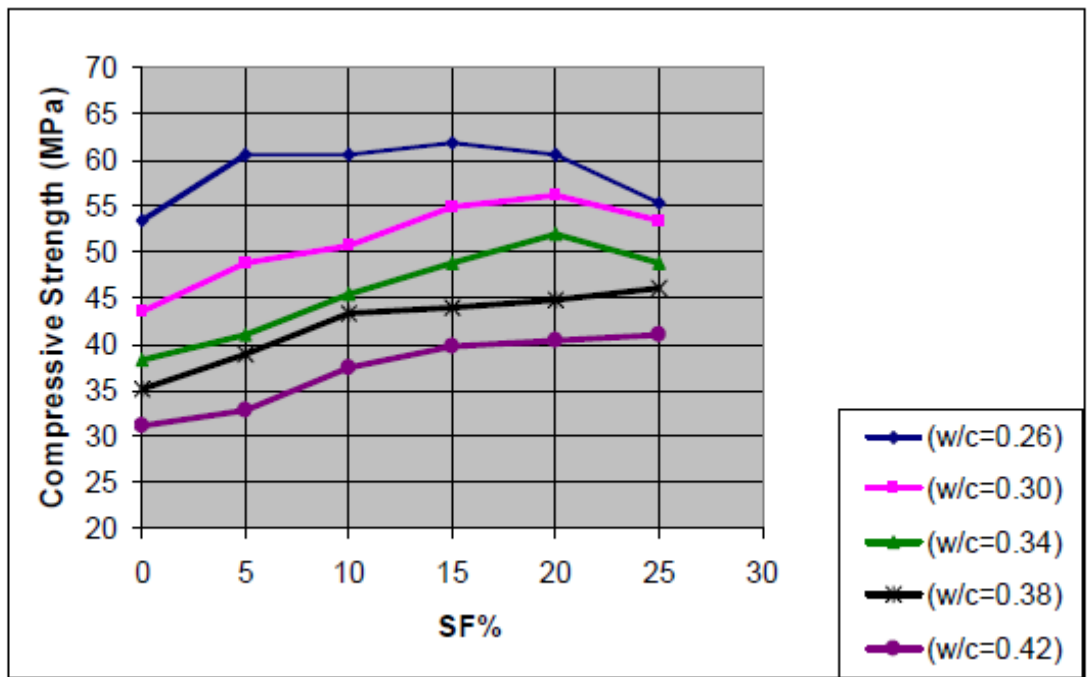


Fig. 2.3: Relationship between 28 day compressive strength and percentage replacement of silica fume (Katkhuda et al. (2009))

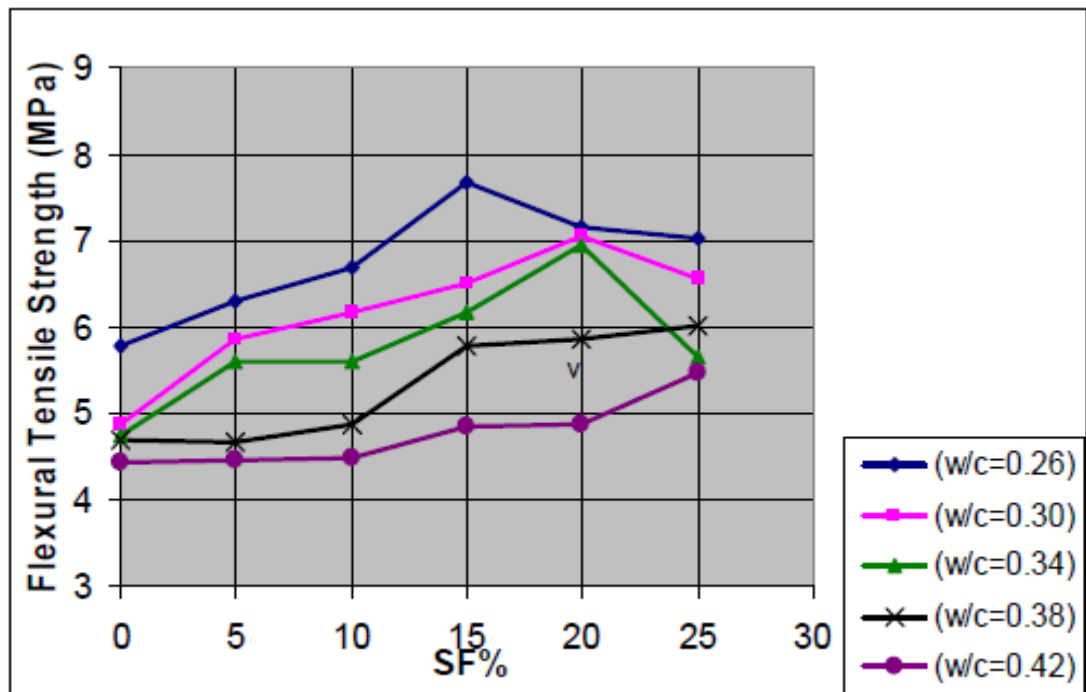


Fig. 2.4: Relationship between 28 day flexure strength and percentage replacement of silica fume (Katkhuda et al. (2009))

Amudhavalli and Mathew (2012), Evaluated that the optimum 7 day and 28 day flexural strength and compressive strength have been obtained in the replacement range of 10-15 % of silica fume. Increase in split tensile strength beyond 10 % silica fume replacement is almost insignificant whereas increase in flexural tensile strength have occurred up to 15 % replacements. Silica fume seems to have a more pronounced effect on the flexural strength than the split tensile strength. When compared to other mix, compressive strength and the loss in weight percentage was found to be reduced by 7.69 and 2.23 when the cement was replaced by 10% of Silica fume. Result of compressive, split tensile and flexural strength at 7 day and 28 day are shown in Table 2.1.

Table 2.1: Results of compressive strength, split tensile strength and flexural strength
(Amudhavalli and Mathew (2012))

Mix	% of silica fume added	Compressive Strength (N/mm ²)		Split Tensile Strength (N/mm ²)		Flexural Strength (N/mm ²)	
		7 day	28 day	7 day	28 day	7 day	28 day
M1	0	25.21	38.30	3.11	4.67	4.89	5.84
M2	5	29.33	41.29	3.65	4.802	6.9	7.07
M3	10	34.12	46.76	4.10	4.95	7.23	9.00
M4	15	38.3	47.3	3.83	4.63	7.75	9.38
M5	20	35.9	44.27	3.65	3.98	6.04	7.09

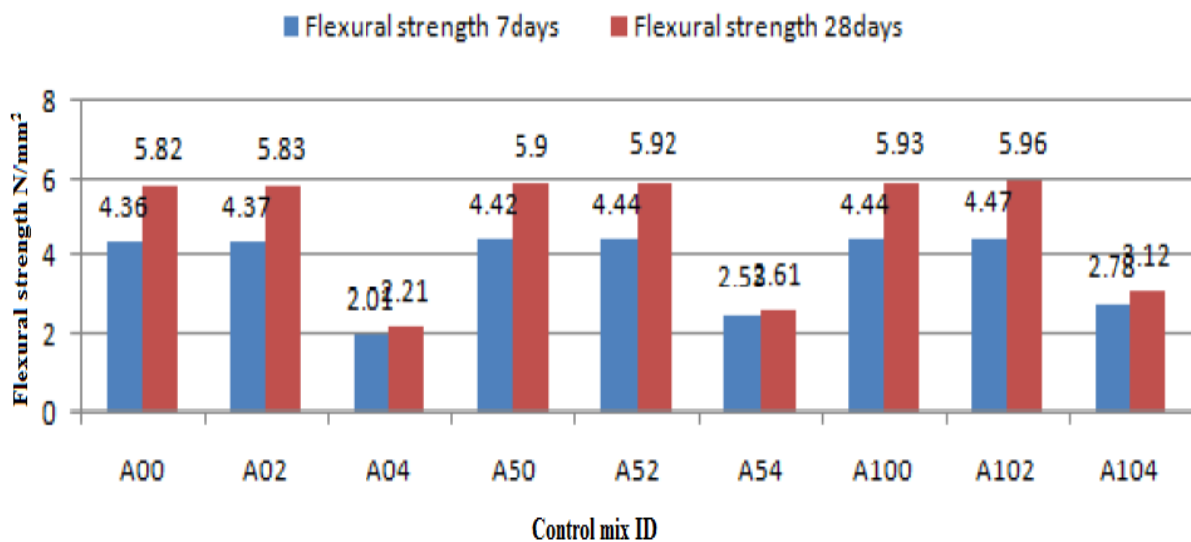


Fig. 2.5: Variation of flexural strength (Sai et al. (2013))

Sai et al. (2013), observed that with addition of silica fume and nano silica the compressive strength and flexural strength of concrete mix at 7 day and 28 day are more than that of controlled specimen Fig. 2.5 and maximum compressive strength and flexural strength was found with 10% of silica fume and 2% of nano silica combination, they also observed that the compressive strength of concrete with 5% silica fume gives same result as 2% nano silica as shown in Fig. 2.6.

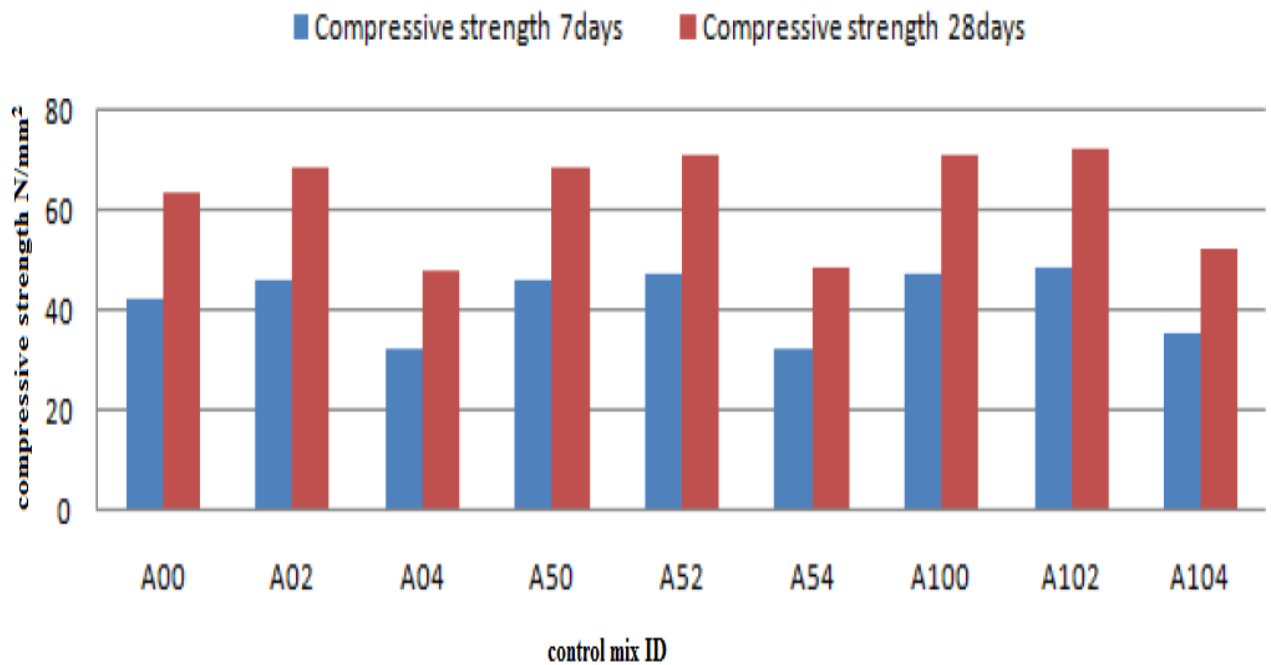


Fig. 2.6: Variation of compressive strength (Sai et al. (2013))

Sridhar and Vanakudre (2014), compared the mechanical properties i.e. compressive strength with M₂₀ and M₄₀ grade of concrete and with different replacement levels of ordinary Portland cement with nano silica (0.25%, 0.5%, 0.75%, 1.0%, 1.25%, 1.5%, 1.75%, 2.0%, 2.25%, 2.5%) used. the optimum replacement of Nano Silica is 2% and 1.5% respectively for M₂₀ & M₄₀ concrete. The percentage increase in M₂₀ concrete is 15.31, 16.3 respectively for 7 day and 28 day, where as in M₄₀ concrete is 11.0, 11.20 respectively for 7 day and 28 day.as shown in Table 2.2.

Table 2.2: Compressive strength of nano silica concrete for 7 days and 28 days
(Sridhar and Vanakudre (2014))

Percentage of Nano Silica	7 Day Compressive Strength (N/mm ²)		28 Day Compressive Strength (N/mm ²)	
	M ₂₀	M ₄₀	M ₂₀	M ₄₀
0.25	24.41	44.90	27.60	49.41
0.50	24.6	45.60	28.15	50.18
0.75	25.00	46.30	28.60	50.95
1.00	25.50	47.00	29.15	51.72
1.25	25.95	48.11	29.67	53.10
1.50	26.41	49.18	30.20	53.80
1.75	26.50	48.57	30.80	53.97
2.00	27.25	48.40	31.40	53.26
2.25	26.66	47.90	30.50	52.91
2.50	26.50	47.50	30.30	52.40

Gupta et al. (2015), estimated the impact resistance of concrete containing waste rubber fibers and silica fume. They use waste rubber fibers for partially replacement of fine aggregate whereas silica fume was used to partially replacement of cement. Three replacement levels of silica fume (0%, 5% and 10%) and six replacement levels of rubber fibers (0%, 5%, 10%, 15%, 20% and 25%) were considered. Compressive test, flexural loading test and rebound test were carried out as per related standards for three different w/c ratios (0.35, 0.45 and 0.55). As shown in Fig. 2.7, Fig. 2.8 and Fig. 2.9 the replacement of cement by silica fume, the compressive strength increases for control concrete as well as for the rubber fiber concrete. Compressive strength of control concrete without rubber fiber and silica fume increases from 58.97 N/mm² to 75.20 N/mm², 50.43 N/mm² to 62.70 N/mm² and 33.70 N/mm² to 39.70 N/mm² for w/c ratios of 0.35, 0.45 and 0.55 respectively, other hand on 10% replacement of cement by silica fume, compressive strength of rubber fiber concrete with 25% rubber fiber and 10% replacement of cement by silica fume, increases from 28.43 N/mm² to 37.90 N/mm², 23.60 N/mm² to 29.90 N/mm² and 15.30 N/mm² to 19.10 N/mm² for w/c ratios of 0.35, 0.45 and 0.55 respectively.

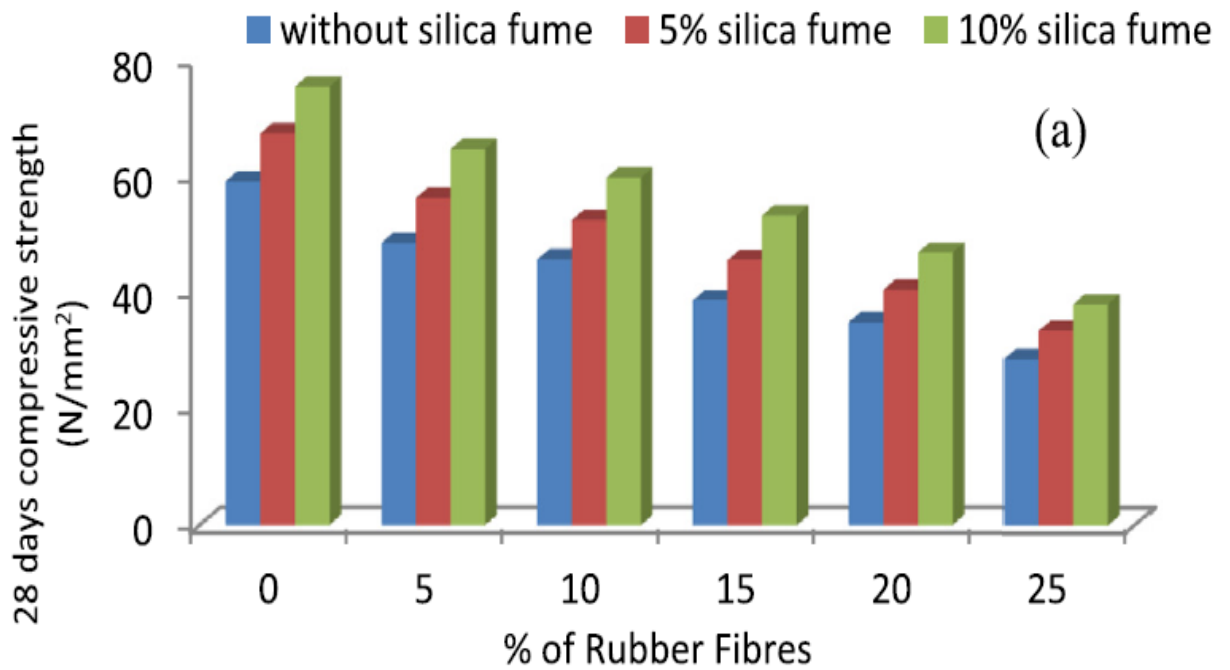


Fig. 2.7: 28 day compressive strength of rubber fiber concrete for 0.35 w/c ratio
(Gupta et al. (2015))

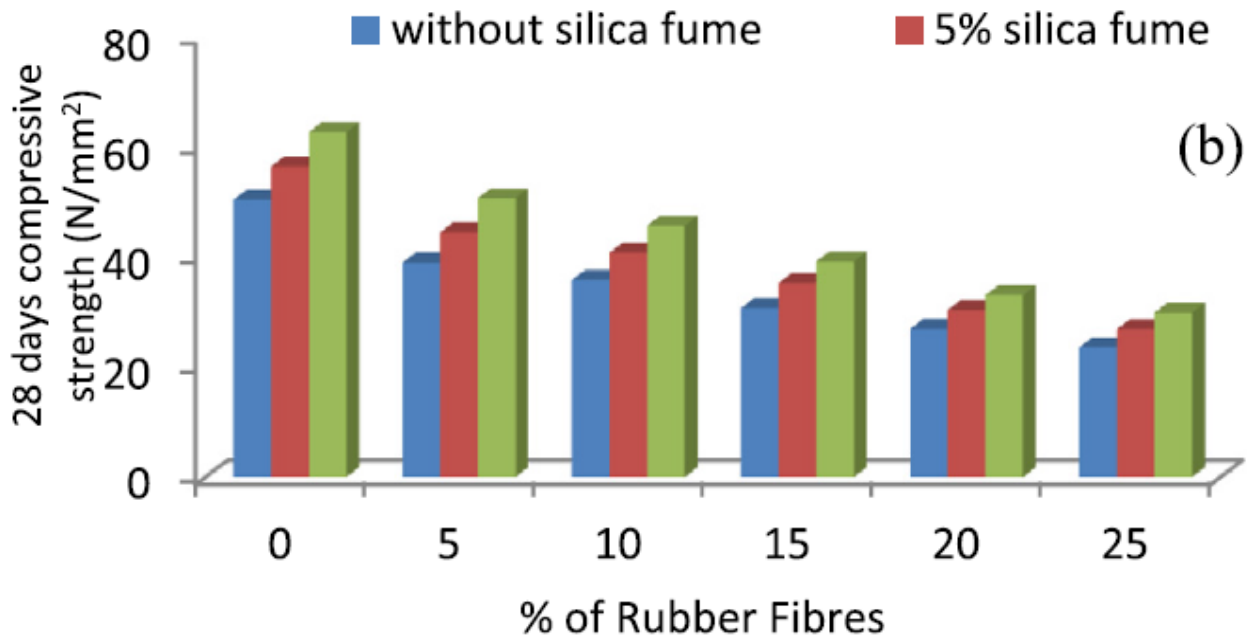


Fig. 2.8: 28 day compressive strength of rubber fiber concrete for 0.45 w/c ratio
(Gupta et al. (2015))

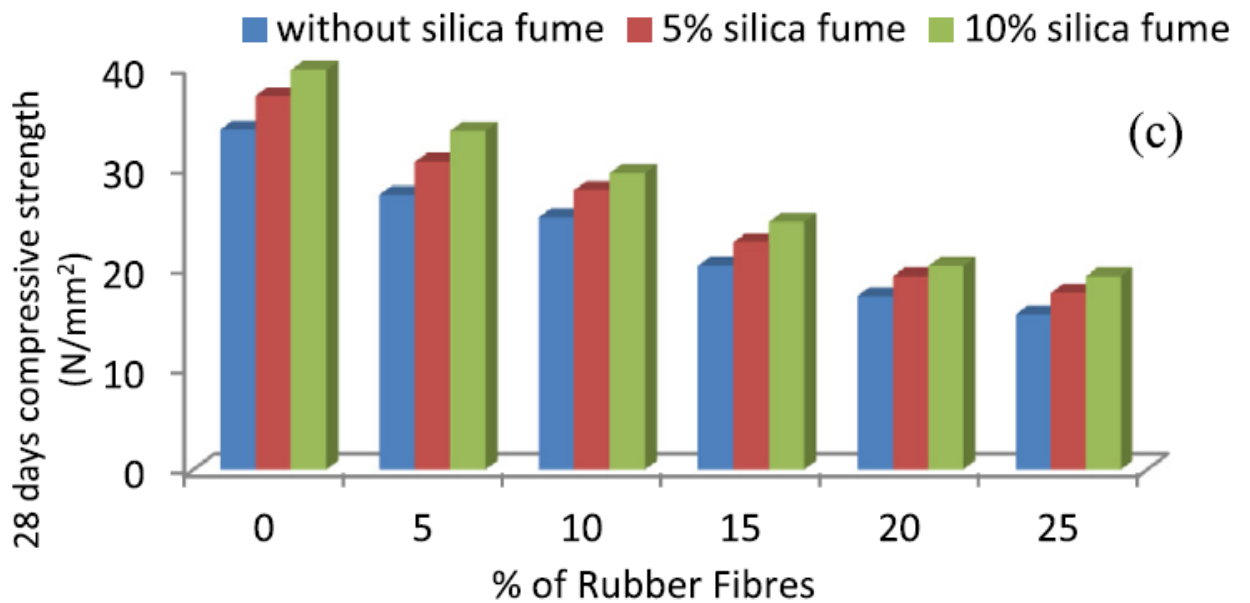


Fig. 2.9: 28 day compressive strength of rubber fiber concrete for 0.55 w/c ratio
(Gupta et al. (2015))

2.3 USE OF NANO SILICA IN CONCRETE

Li et al. (2004), showed that with 5% replacement of cement by nano silica (mean size 15 ± 5 nm), 7 day and 28 day compressive strength of mortars were increased by 20% and 17%, respectively, whereas 15% silica fume replacement increased mortar strengths by 7% and 10% compared with those of control Portland cement mortar. With the experimental analysis, it was proved that the compressive and flexural strengths of the cement mortars with nano-silica and with nano- Fe_2O_3 were both higher than that of the plain cement mortar with the same water to binder ratio.

Zhang and Islam (2012), evaluate the effects of nano silica on rate of setting time, cement hydration and strength growth of concretes with 50% slag or fly ash. The addition of 2% nano silica by mass of cementitious materials reduced initial and final setting times by 90 and 100 min, and improved 3 day and 7 day compressive strengths of high volume fly ash concrete by 30% and 25%, respectively. Compressive strength progress of the high volume fly ash and slag mortars compared to those with silica fume are shown in Table 2.3. The compressive strengths of the fly ash and slag mortars were generally increased with the incorporation of 1% nano silica or silica fume in comparison to the corresponding reference mortars with 50% fly ash or slag. At early ages nano silica gives more effect on the strength enhancement than

the silica fume. Compressive strengths of the fly ash mortars with 1% nano silica were increased by 61% and 25% at 1 day and 3 day, respectively, whereas those with 1% silica fume were increased by 13% and 15% compared to those of the fly ash mortars, nano silica had less effect on the 1 day strength of the slag mortars than at 3 day and 7 day, the nano silica and silica fume seems to have similar effect on the fly ash and slag mortars at 3 day and 7 day, but less effect on fly ash mortars at 28 day and 91 day compared with the slag mortars. Slag can hydrate under the initiation of cement and lime, whereas Class F fly ash is Pozzolanic material and has partial reactivity at early age. Thus, early strength of slag mortar is higher than fly ash mortar.

Table 2.3: Effect of nano silica on the compressive strength of slag and fly ash mortars in comparison to that of silica fume (Zhang and Islam (2012))

Mix ID	Binder type	Compressive strength (N/mm ²)				
		1 day	3 day	7 day	28 day	91 day
FA0	50% Fly ash, 50% cement	7.4	18.1	26.9	40.8	48.3
FA11	1% NS, 49% fly ash, 50% cement	12.0	22.5	31.5	43.6	50.4
FA11 (M)	1% Silica fume, 49% slag, 50% cement	8.4	20.8	29.7	42.3	48.9
SL0	50% Slag, 50% cement	13.8	27.3	40.4	53.8	55.9
SL11	1% NS, 49% slag, 50% cement	16.3	35.8	47.0	60.2	64.3
SL (M)	1% Silica fume, 49% slag, 50% cement	15.2	32.1	46.1	59.8	63.0

Zhang et al. (2014), studied the effect of nano silica particles and steel fibers on the mechanical properties of the concrete composite containing fly ash. Five different nano silica contents (1%, 3%, 5%, 7% and 9%) and five different steel fiber contents (0.5%, 1%, 1.5%, 2% and 2.5%) were used, addition of nano silica decreases the slump and slump flow of the fresh concrete composite containing fly ash, and both the slump and slump flow decrease gradually with the increasing the content of nano silica and steel fibers. There was an increase in the compressive strength and compressive modulus of elasticity with increase of nano silica content when it was below 5%, but beyond 5% it start decreasing, because the Pozzolanic

reaction of nano silica produces additional C–S–H gel, which grows into the capillary spaces that remain after the hydration of the cement in mortar mixes at the early curing stage, all the concrete mixes containing nano silica were found to have higher compressive strengths than the control mix at 3 day, Cube compressive strengths of concrete composites were determined at 3 day, 7 day, 28 day, and 60 day of curing, and axial compressive strengths and compressive modulus of elasticity of concrete composites were determined at 28 day. The test results of the effect of nano silica on the mechanical properties of concrete composites containing fly ash are given in Fig. 2.10. The compressive strength of concrete mix at 3 day with 1%, 3%, 5%, 7% and 9% cement replacement with nano silica, was higher than the control mix, and the mix with 5% nano silica content attained the maximum compressive strength, which increased by 21.6% than the control mix. At 7 day and 28 day, compared to 3 day, the increase in the compressive strength of concrete composites with increase in nano silica content is less when the nano silica content is below 5%. At 60 day, the decreasing trend of the compressive strength is more with the increase of nano silica content than the other curing periods when the nano silica content is beyond 5%.

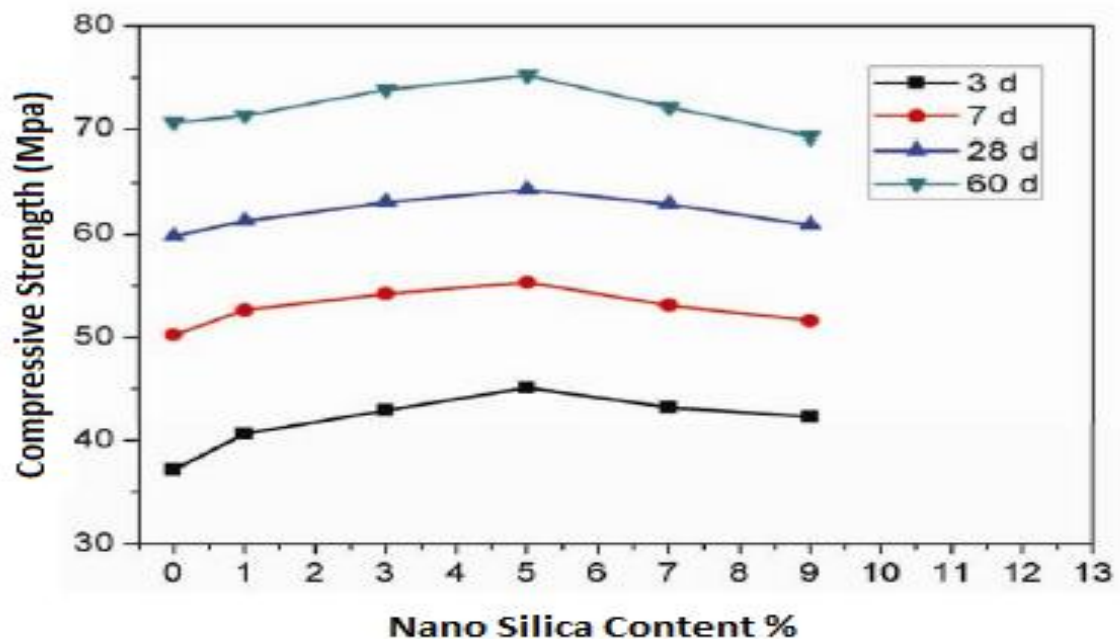


Fig. 2.10: Effect of nano silica content on compressive strength (Zhang et al. (2014))
Bastami et al. (2014), studied the effect of elevated temperature on the compressive and tensile strength of High Strength Concrete (HSC) modified with nano silica. The mechanical properties of the modified HSC were measured by heating 150×300 mm sample cylinders of

concrete to 400, 600 and 800 °C at a rate of 20 °C/min. The obtained results demonstrate that nano silica efficiently used in HSC can improve its mechanical properties at elevated temperature. The results show that the presence of nano silica increased residual compressive and tensile strengths. The mixtures were categorized into two groups, M1-M4 (sum of silica fume and nano silica was 30 kg/m³ and constant) and M5-M8 (sum of silica fume and nano silica was 60 kg/m³ and constant). M1 and M5 were nano silica free. The mixtures containing nano silica had higher normal compressive strength (87.43 N/mm²) than those without nano silica (84.92 N/mm²), indicate that for increasing compressive strength the addition of nano silica was more effective than silica fume. The average compressive strength of the high strength concrete mixtures was 82.47 N/mm² to 91.24 N/mm². M8 had the highest compressive strength and the maximum amount of nano silica. The compressive strength of specimens decreased significantly when the temperature passed 400 °C; residual strength was found about 25%, at 800 °C. It was observed that all heated specimens worsen above 600 °C. The decrease in compressive strength was greater for concrete containing nano silica heated to 600-800 °C. Deterioration occurred for normal high strength concrete at 400-800 °C. The addition of nano silica was more effective than silica fume for increasing residual compressive strength of heated specimens. The presence of nano silica improved the tensile strength of the concrete to prevent crack extension and strength reduction.

Mukharjee and Barai (2014), analyzed the influence of incorporation of colloidal nano silica on compressive strength and Interfacial Transition Zone (ITZ) characteristics of concrete mixes made with fully natural and recycled coarse aggregates. They represents the compressive strength of four different types of concrete mixes at various curing days. The 7 day compressive strength of natural aggregate concrete is 34.15 N/mm² and with the incorporation of 3% nano silica it enhances to 39.12 N/mm². This indicates 15% improvement in 7 day compressive strength with the addition of nano silica, which could be attributed to the higher pozzolanic activity of nano silica during early days of curing. However, in case of recycled aggregate concrete without nano silica, compressive strength is 30.3 N/mm² at 7 day, which indicates 12% reduction in compressive strength with the full replacement of natural aggregates by recycled coarse aggregates. The reduction is because of the inferior qualities of recycled coarse aggregate such as higher water absorption and porosity as compared to natural coarse aggregate. The 7 day compressive strength of nano silica added recycled coarse aggregate is found to be 34.81 N/mm², which is similar to the compressive strength of natural

coarse aggregate without nano silica. This enhancement in compressive strength of recycled coarse aggregates containing nano silica is due to the reduction in porosity. The 28 day compressive strength of natural aggregate concrete increases from 40.67N/mm² to 49.89 N/mm² with the addition of 3% nano silica and reduces to 35.1 N/mm² with the incorporation of 100% recycled aggregates in place of natural coarse aggregates. With the addition of 3% nano silica in recycled aggregate concrete, compressive strength improves from 35.1 N/mm² to 41.32 N/mm². The reduction in 7 day and 28 day compressive strength of fully recycled aggregate concrete is found to around 12-14%. Similarly, 90 day and 365 day compressive strength of natural aggregate concrete improves with the addition of nano silica and decreases with replacement of natural aggregates with recycled aggregates. Fig. 2.11 shows the variation of compressive strength of different mixes with respect to curing time.

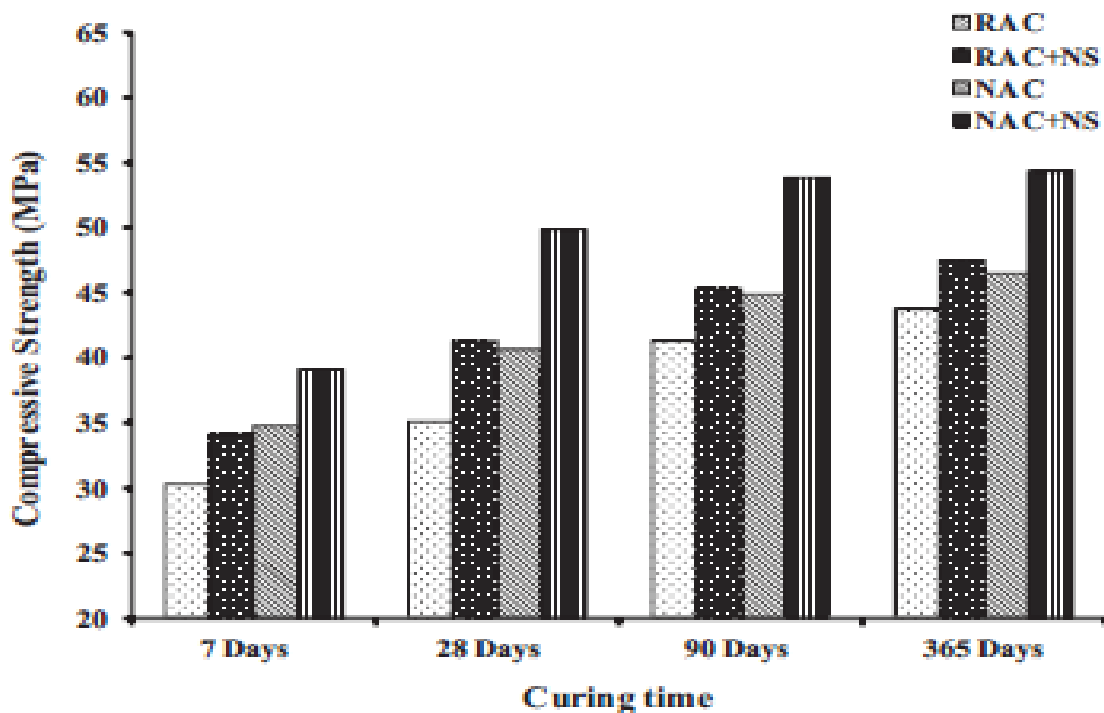


Fig. 2.11: Variation of compressive strength (Mukharjee and Barai (2014))

Du et al. (2014), studied the compressive strengths of concrete with varying amounts of nano-silica at various ages are shown in Fig. 2.12. Concrete strength increased with the increase of nano-silica content, regardless of the testing age. At 28 day, an increase of 9% and 12% in the strength was observed for 0.3% and 0.9% of nano-silica addition respectively. The mechanisms were mainly due to both the nano-filler effect and the Pozzolanic reaction. The ultra-fine size of nano-silica particles can partially fill the large voids and capillary pores to

refine the pore structure of cement paste. Also, the Pozzolanic reaction of nano-silica can consume Portlandite, not only reducing the crystal size but also causing the hydration products to become more homogenous C-S-H gel. The better bond between aggregates and cement paste can contribute to the increased mechanical performances. The compressive strength and resistance against water and chloride ions for concrete added with nano-silica, even at a small amount of 0.3%. At this dosage, the uniform-dispersion of silica nano-particles can be readily achieved.

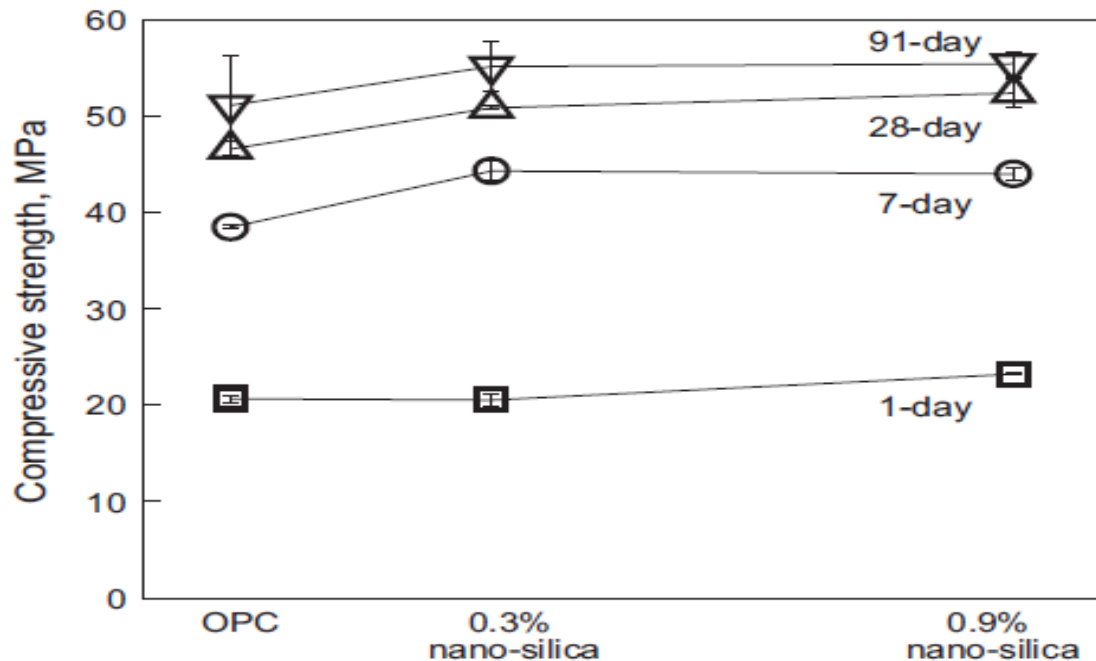


Fig. 2.12: Compressive strength of concrete with nano silica (Du et al. (2014))

Amin and El-hassan (2015), evaluated the effect of addition of nano silica on the compressive strength, flexural strength, splitting tensile strength, and modulus of elasticity of concrete. Nano-silica (NS), was added in five percentages (1%, 2%, 3%, 4% and 5%) of weight of cementitious materials (cement and silica fume). Two types of coarse aggregate (dolomite and granite) were used. It was observed that the optimum dose of nano-silica was 3% by weight. The samples of concrete-containing nano-silica gave better results from samples of control mix. Also, the samples of concrete containing granite gave better results than similar-containing dolomite and the approximate rate of about 10%. The variation of compressive strength with age of the mix for various proportion of nano-silica are shown in Fig. 2.13 and it has been observed that 2% of the nano silica has given optimized results.

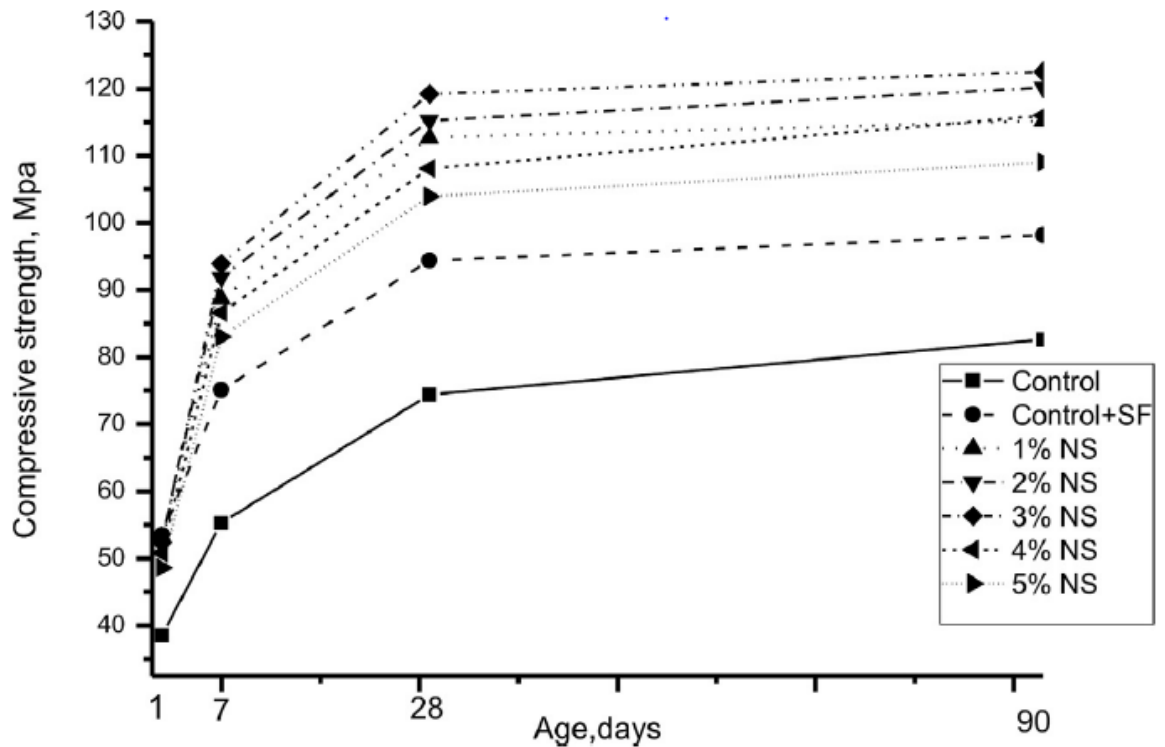


Fig. 2.13: Effect of NS on compressive strength for different mixes

(Amin and El-hassan (2015))

The optimum dose of nano-silica was 3% by weight. The improved percentage of compressive strength and flexural strength of concrete when nano silica was added reaches 21% and 23% respectively, with respect to the control mixes. Increasing the amount of nano silica more than 3% by weight degrades the compressive strength, splitting tensile, flexural strength and modulus of elasticity of concrete. The flexural strength of the specimens increased with nano-silica up to 3.0% replacement and then it decreases, although the results of 4.0% replacement were still higher than those of the control concrete.

CHAPTER 3

MATERIALS AND DESIGN METHODOLOGY

3.1 GENERAL

The current chapter deals with the material properties and the results attained from the various test conducted on the material used for the designing of the Pavement Quality Concrete. In order to achieve the objective of the present study, an experiment was conducted to determine the compressive strength and flexural strength of concrete specimens made by using silica fume and nano silica along with the OPC 43 grade cement and aggregates.

3.2 MATERIAL USED

The properties of material used for designing concrete mix are determined in laboratory as per relevant code of practice. Different materials used in present study were cement (OPC 43 Grade), coarse aggregates (20 mm and 10 mm), fine aggregates, and superplasticizer in addition to silica fume and nano silica. The aim of studying of various properties of materials is to check the appearance with codal requirements and to enable an engineer to design a concrete mix for a particular required strength. The description of various materials which were used in this study is given in following sections:

3.2.1 Portland Cement

All materials that go into concrete mix are essential, but the cement is very often the most important because it is usually the delicate link in the chain. The function of cement is first of all to bind the sand and stone together and second to fill up the voids in between sand and stone particles to form a compact mass. It constitutes only about 20 percent of the volume of concrete mix; it is the active portion of binding medium and is the only scientifically controlled ingredient of concrete. Any variation in its quantity affects the compressive strength of the concrete mix. Portland cement referred as (Ordinary Portland Cement) is the most important type of cement and is a fine powder produced by grinding Portland cement clinker. The OPC is classified into three grades, namely 33 Grade, 43 Grade, 53 Grade depending upon the strength of 28 days. It has been possible to upgrade the qualities of cement by using high quality limestone, modern equipments, maintaining better particle size distribution, finer grinding and better packing. Generally use of high grade cement offers many advantages for making stronger concrete. Although they are little costlier than low grade

cement, they offer 10-20% saving in cement consumption and also they offer many hidden benefits. One of the most important benefits is the faster rate of development of strength.

Ordinary Portland Cement (OPC) of 43 Grade (JK Lakshmi cement) from a single lot was used throughout the course of the investigation. It was fresh and without any lumps. The physical properties of the cement as determined from various tests conforming to Indian Standards IS: 8112-1989 are listed in Table 3.1. Cement was carefully stored to prevent deterioration in its properties due to contact with the moisture.

Table 3.1: Properties of OPC 43 Grade Concrete

Sr. No.	Characteristics	Values Obtained Experimentally	Values specified by IS 8112:1989
1.	Specific Gravity	3.14	-
2.	Standard Consistency, percent	28	-
3.	Initial Setting Time, minutes	152	30 (minimum)
4.	Final Setting Time, minutes	261	600 (maximum)
5.	Compressive Strength		
	7 Days	38.2 N/mm ²	33 N/mm ² (minimum)
	28 Days	47.3 N/mm ²	43 N/mm ² (minimum)

3.2.2 Aggregate

Aggregates occupy a large volume in the concrete mixture and give dimensional stability to concrete. In cement concrete, aggregates are generally used in two size groups: Coarse aggregates particle size more than 4.75 mm and Fine aggregates (sand) particle size less than 4.75 mm. Coarse aggregates make solid and hard mass of concrete with cement and sand and also increase the crushing strength of concrete. It also reduces the cost of concrete, since it occupies major volume. Sand consists of small angular or rounded grains of silica and is commonly used as a fine aggregate in cement concrete. It fills the voids existing in the coarse aggregate and reduces shrinkage and cracking of concrete. It helps in hardening of cement by allowing the water through its voids. The fine aggregate assist the cement paste to hold the coarse particle in suspension, this action promotes plasticity in the mixture and prevent the possible segregation of paste and coarse aggregate. The aggregates provide about 75% volume to concrete so it is extremely important that the aggregates should meet certain requirement if

the concrete is to be workable, strong, durable and economical. The aggregates must be proper shape, clean hard and well graded.

a) Coarse aggregates

The aggregate which is retained over IS sieve 4.75 mm is termed as coarse aggregate. The coarse aggregates may be of following types: - Crushed gravels or stone obtained by crushing of gravel or hard stone or uncrushed gravels or stones resulting from the natural disintegration of rocks. Partially crushed gravel or stone is obtained as a product of blending of above two types. The normal maximum size is 10 mm-20 mm, however particle sizes up to 40 mm or more have been used in Self Compacting Concrete (SCC) and in dry lean concrete. Regarding the characteristics of different type of aggregates, crushed aggregates tend to improve the strength because of interlocking of angular particle. While rounded aggregates improve the workability due to the lower internal friction.

The coarse aggregates used in the present study were a mixture of two locally available crushed stones of 20 mm and 10 mm sizes. The aggregates were washed to remove dirt, dust and then dried to surface dry condition. The specific gravity and other physical properties of coarse aggregates are given in Table 3.2. The sieve analysis of coarse aggregate was done in the laboratory and the values obtained are shown in the Table 3.3 for the 20 mm aggregate and Table 3.4 for the 10 mm aggregate.

Table 3.2: Properties of Coarse Aggregates

Characteristics	Value	
Color	Grey	
Shape	Angular	
Maximum size	20 mm	10 mm
Specific Gravity	2.69	2.657
Water Absorption	0.50%	0.46%

Table 3.3: Sieve Analysis of Coarse Aggregates (20 mm)

Sr. No.	IS-Sieve (mm)	Wt. Retained (g)	%age Retained	%age passing	Cumulative % retained
1	80	0.00	0.00	100	0
2	40	0.00	0.00	100	0
3	20	37	0.37	99.63	0.37
4	10	9601	96.01	3.62	96.38
5	4.75	337	3.37	0.25	99.75
6	2.36	24	0.24	0.01	99.99
7	1.18	0.00	0.00	0.00	100
8	600	0.00	0.00	0.00	100
9	300	0.00	0.00	0.00	100
10	150	0.00	0.00	0.00	100
11	Pan	1	0.01	0.00	
Total		10000		SUM	696.49
FM = 6.97					

Table 3.4: Sieve Analysis of Coarse Aggregate (10 mm)

Sr. No.	IS-Sieve (mm)	Wt. Retained (g)	%age Retained	%age passing	Cumulative % retained
1	80	0.00	0.00	100.00	0.00
2	40	0.00	0.00	100.00	0.00
3	20	0.00	0.00	100.00	0.00
4	10	4373	43.73	56.27	43.73
5	4.75	4355	43.55	12.72	87.28
6	2.36	980	9.8	2.92	97.08
7	1.18	261	2.61	0.31	99.69
8	600	27	.27	0.04	99.96
9	300	0.00	0.00	0.00	100
10	150	0.00	0.00	0.00	100
11	Pan	4	0.04	0.00	
Total		10000		SUM = 627.74	
FM = 6.28					

b) Fine aggregates

The aggregates most of which pass through 4.75 mm IS sieve are termed as fine aggregates. The fine aggregates may be of following types: Natural sand, i.e. the fine aggregate resulting from natural disintegration of rocks; crushed stone sand, i.e. the fine aggregate produced by crushing hard stone; crushed gravel sand, i.e. the fine aggregate produced by crushing natural gravel. Depending upon the particle size distribution IS 383 has divided the fine aggregate into four grading zones (Grade I to IV). The grading zones become progressively finer from grading zone I to IV. In this experimental program fine aggregates were collected from the local supplier and were conforming to grading zone II. It was free from silt and clay particles. Sieve analysis and physical properties of fine aggregates are tested as per IS: 383 and result are shown in Table 3.5.

Specific gravity of fine aggregates was experimentally determined as 2.59 and water absorption of fine aggregates is 1.52%.

Table 3.5 Sieve Analysis of Fine Aggregate

Sr. No.	IS-Sieve (mm)	Wt. Retained (g)	%age Retained	%age passing	Cumulative % retained
1	4.75	26	2.6	97.4	2.6
2	2.36	107	10.7	86.7	13.3
3	1.18	164	16.4	70.3	29.7
4	600 μ	146	14.6	55.7	44.3
5	300 μ	198	19.8	35.9	64.1
6	150 μ	272	27.2	8.7	91.3
7	Pan	87	8.7		
TOTAL		1000		SUM	245.3
Zone II			FM= 2.45		

3.2.3 Silica fume

Silica fume was used in cement concrete as a replacement for cement to study its effectiveness for development of ultra-high performance concrete. Silica fume was obtained from KGR Agro Fusions Pvt. Ltd. Mullapur Road, Humbran, Ludhiana, Punjab, India. Silica fume received was grey in color. Physical and chemical properties of silica fume were provided by KGR Agro Fusions Pvt. Limited.

Physical properties: Physical properties are important in both the micro-filler and pozzolanic roles of silica fume. The very small size of silica fume particles is also one of its key to performance. The various physical properties of silica fume are shown in Table 3.6.

Table 3.6: Physical properties of silica fume

Particle size (typical)	< 4×10^{-6} in (<1 μ m)
Bulk density (as-produced form)	8 to 27 lb./ft ³ (130-430 kg/m ³)
Bulk density (slurry)	11 to 12 lb./gal (1320-1440 kg/m ³)
Bulk density (densified)	30 to 45 lb./ft ³ (480-720 kg/m ³)
Specific gravity	2.20
Specific Surface Area (BET) “nitrogen adsorption method”	60,000 to 150,000 ft ² /lb. (13,000 to 30,000 m ² /kg)

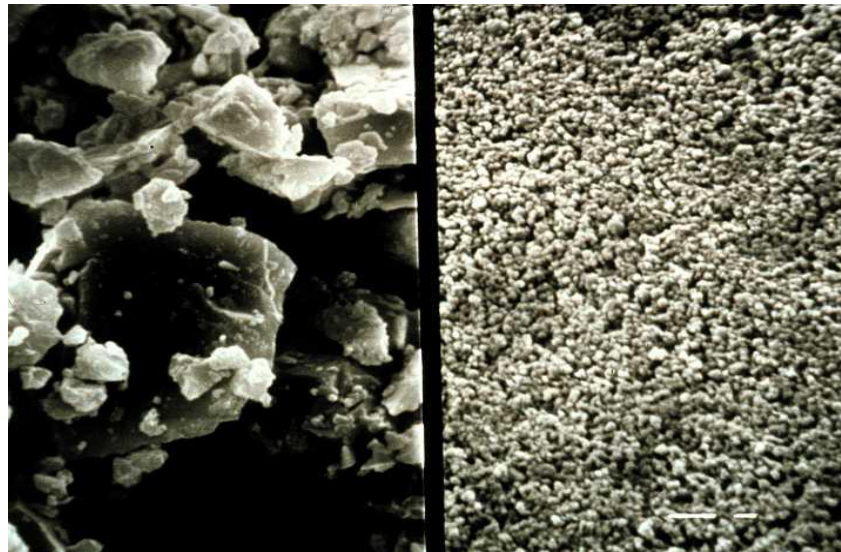


Fig. 3.1: Cement grains and silica fume particles (ACI 234R-96 (2000))

Cement grains and silica fume particles are shown in Fig. 3.1 at same magnification. The ACI 234R-96 report estimates that for 15% silica fume replacement of cement, there are approx. 2,000,000 particles of silica fume for each grain of Portland cement.

a) Chemical properties of silica fume

The primary chemical properties of silica fume are briefed as below:-

- Amorphous: This term simply means that silica is not a crystalline material. A crystalline material will not dissolve in concrete, which must occur before the material

can react. The crystalline material present in concrete is sand and though it is essentially silicon dioxide (SiO₂), it does not react because of its crystalline nature.

- Silicon dioxide (SiO₂): This is the reactive material in silica fume.
- Trace Elements: There may be additional materials in the silica fume based upon the metal being produced in the smelter from which the fume was recovered. Usually, these materials have no impact on the performance of silica fume in concrete.

The benefits seen from adding silica fume are the result of the changes to the microstructure of the concrete. These changes result from two different but equally important processes. The first of these is the physical aspect of the silica fume and second is its chemical contribution (Table 3.7).

Table 3.7: Chemical composition of Silica Fume by *Energy Dispersive X-ray (EDX)*

Component	Percentage
SiO ₂	91.92%
K ₂ O	2.73%
CaO	1.35%
Fe ₂ O ₃	1.11%
Al ₂ O ₃	1.05%
P ₂ O ₅	0.76%
MgO	0.61%
Na ₂ O	0.16%
MnO	0.08%
TiO ₂	0.06%
SO ₃	0.05%
Cl	0.03%
BaO	0.02%
Cr ₂ O ₃	0.01%

3.2.4 Nano silica (colloidal silica)

Colloidal silica is a nano metric particle size solution of silica particles in water or other mediums. It is composed of the same substance (silicon dioxide) as quartz sand but it has an amorphous (random) rather than a crystalline Structure. There is stable dispersion of amorphous spherical particles of silicon dioxide in water. It is in liquid form and its particle size is much smaller than silica fume and alccofine particles.

a) *Physical and Chemical Properties:* It is a white translucent liquid having no odor and has complete solubility. Specific gravity of nano silica is of the range 1.38-1.39 having particle sizes ranging from 1 - 100 nm

3.2.5 Super Plasticizer

Super-plasticizers constitute a relatively new category and improved version of plasticizer. They are chemically different from normal plasticizers. Use of super-plasticizer permits the reduction of water to the extent up to 30 percent without reduction in workability in contrast to possible reduction up to 15 percent in case of plasticizers. The mechanism of action of super-plasticizer is more powerful as dispersing agents and they are high water reducers. It is use of super-plasticizer which has made it possible to use w/c low as 0.25 or even lower and yet to make flowing concrete to obtain compressive strength of the order of 120 N/mm² or more. It is the use of super-plasticizer which has made it possible to use fly ash, slag and particularly silica fume to make high performance concrete.

This method of mix proportioning is especially popular when producing high-strength concrete and fiber reinforced concrete. Adding 1-2% super-plasticizer per unit weight of cement is usually sufficient. However, note that most commercially available super-plasticizer come dissolved in water, so the extra water added has to be accounted for mix proportioning. Adding an excessive amount of super-plasticizer will result in excessive segregation of concrete and is not advisable. Some studies also show that too much super-plasticizer will result in a retarding effect.

Super-plasticizer are chemical admixture that can be added to concrete mixture to improve workability. Unless the mix is “starved” of water, the strength of concrete is inversely proportional to amount of water added or water-cement (w/c) ratio. In order to produce stronger concrete, less water is added which makes the concrete mixture very unworkable and difficult to mix, necessitating the use of plasticizers, water reducers, super-plasticizer or dispersants.

The super-plasticizer “Conplast SP430” procured from FOSROC limited was used present study. The technical data provided by manufacturer is given in Table 3.8.

Table 3.8: Properties of Super-plasticizer

Sr. No.	Characteristics	Values
1.	Appearance	Brown Liquid
2.	Specific Gravity	1.22
3.	Chloride content	Nil to BS 5075
4.	Air entrainment	Typically less than 2% additional air is entrained at normal dosages.
5.	Alkali content	Typically less than 72.0 g. Na ₂ O equivalent / liter of admixture.

3.2.6 Water

The potable water is generally considered satisfactory for mixing and curing of concrete. Accordingly potable water was used for making concrete available in material testing laboratory. It was free from any detrimental contaminants and was good potable quality.

3.3 MIX DESIGN OF PAVEMENT QUALITY CONCRETE (PQC)

Step 1 As per clause 602 of MORTH Specification

- Cement -43 Grade OPC as per **IS 8112** as per **602.2.2**
- Coarse aggregate - 20 mm and 10 mm as per **602.2.4**, Los angles Abrasion value not greater than 35%, Impact value not greater than 30%
- Fine aggregate - Natural sand as per **IS 383**

Step 2 Design Parameters

1. Characteristics flexural strength required at 28 days = 4.69 N/mm²
2. Maximum water cement ratio = 0.36 as per clause **602.3.3.1**
3. Maximum size of coarse aggregate = 25 mm
4. Degree of quality control = Good
5. Minimum cement content = 350 kg/m³ as per clause **602.3.2**
6. Maximum cement content = 425 kg/m³ as per clause **602.3.2**

Step 3 Calculation of fine aggregate content

After determining the weight per cubic meter of cement, water, coarse aggregate and percentage of air content, the fine aggregate is calculated so as to produce one cubic meter of

concrete using absolute volume method. On converting the weight per cubic meter into volume, we have

1. Volume of cement = $\frac{\text{Weight of cement}}{\text{Specific Gravity of cement} \times 1000}$
2. Volume of coarse aggregate = $\frac{\text{Weight of coarse aggregate}}{\text{Specific gravity of coarse aggregate} \times 1000}$
3. Volume of water = $\frac{\text{Weight of water}}{1000}$
4. Volume of fine aggregate = 1 - [Volume of fine aggregate + coarse aggregate + water + Air Content]
5. Weight of fine aggregate = Volume of fine aggregate \times specific gravity \times 1000

Now by following the above steps for mix design, the mix proportion for different compressive strength are given by using following data:

Specific gravity of cement	= 3.14
Specific gravity of fine aggregate	= 2.59
Specific gravity of coarse aggregate, 20 mm	= 2.69
Specific gravity of coarse aggregate, 10 mm	= 2.657
Specific gravity of silica fume	= 2.20
Specific gravity of nano silica	= 1.21

The proportions for pavement quality concrete mixtures are tabulated in Table 3.9

Table 3.9: Mix Design Concrete with 5% Silica fume

	water	Cement	F.A. (Sand)	C.A. (10 mm)	Silica Fume
Quantity (Kg/m³)	150	389	726	1154	18.75
Proportion (wt)	0.4	1	1.86	2.96	0.05

Various concrete mixes are designed with the varying percentage of silica fume and nano silica in the laboratory. Table 3.10 shows the quantity of material in kg/m³ for different mixes which were prepared in the laboratory.

Table 3.10: Quantity of material in (kg/m³) for different mixes and varying w/c ratio

Mix ID	W/C	Water	Super plasticizer	Cement	Sand	SF	Nano Silica (%)	C.A. (10 mm)
MD10	0.40	156	3.75	389	726	18.8	0	1154.2
MD11	0.40	156	3.75	387.5	726	18.7	1	1154.2
MD12	0.40	156	3.75	386	726	18.5	2	1154.2
MD13	0.40	156	3.75	384.5	726	18.4	3	1154.2
MD20	0.43	167	3.75	389	736	18.8	0	1143.4
MD21	0.43	167	3.75	387.5	736	18.7	1	1143.4
MD22	0.43	167	3.75	386	736	18.5	2	1143.4
MD23	0.43	167	3.75	384.5	736	18.4	3	1143.4
MD30	0.46	179	3.75	389	746.5	18.8	0	1132.6
MD31	0.46	179	3.75	387.5	746.5	18.6	1	1132.6
MD32	0.46	179	3.75	386	746.5	18.5	2	1132.6
MD33	0.46	179	3.75	384.5	746.5	18.4	3	1132.6
MD40	0.49	190	3.75	389	757	18.8	0	1121.7
MD41	0.49	190	3.75	387.5	757	18.7	1	1121.7
MD42	0.49	190	3.75	386	757	18.5	2	1121.7
MD43	0.49	190	3.75	384.5	757		3	1121.7

3.4 CASTING AND CURING OF TEST SPECIMENS IN LABORATORY

The mass of cement, each size of aggregate, and water for each were governed by weight and the concrete elements were mixed in a laboratory mixer. When the mixing drum is accused by a power loader, all the mixing water should be put into the drum before the solid material. Subsequently, half the coarse aggregates are loaded in the mixer. If admixture is used, it is diluted with some water and spread at the last in the mix when the total elements are loaded in the mixer. The duration of mixing should not be less than 2 minutes after all the materials are in the drum, and had to continue till the resulting concrete is uniform in appearance. The entire operation as laid down was carefully followed for preparation of all the concrete mixes. Each batch of concrete was cured for consistency immediately after mixing by the slump test as described in IS: 1199:1959. The slump for the mix was not below 50 mm .The mould for test specimen conforming to IS: 10086-1982 were used for casting of cubes and beams, as per

laid down specifications for mould to be used in tests of cement and concrete. Compression test specimens were cubical sized with dimensions of 150×150×150 mm and for flexural test beams specimens should be of size 150×150×700 mm.

The sample was made as soon as practicable after mixing and in such condition to produce full compaction of the concrete with neither segregation nor excessive laitance. Table vibration was used for compaction of concrete in the mould. The test specimens were stored in a place, free from vibration in moist air of at least 90% relative humidity, and at a temperature of $27^0 \pm 2^0$ Celsius for 24 hours. After this period, the specimen were marked and removed from the mould and then stored in a clean water until the time of test. The test samples were cured in the curing tank which is available in laboratory. At the time of test the test samples were tested immediately on removal from water, when they were still in the wet condition. The samples were tested after a curing period of 7 day, 28 day and 56 day for compressive strength and 7 day and 28 day for flexural strength.

CHAPTER 4

RESULT AND DISCUSSION

4.1 GENERAL

This chapter deals with the observation of the results from the various tests conducted on concrete for use as pavement quality concrete. The results are compared with the concrete mixes with fixed 5% replacement of cement with silica fume at different w/c ratios for the various percentage replacement levels of nano silica. The strength characteristics of concrete containing silica fume and nano silica are discussed in this chapter. Tests were performed on hard concrete cured under standard laboratory conditions, and compressive and flexural strengths were observed at 28 day of curing age.

4.2 COMPRESSIVE STRENGTH OF CONCRETE

4.2.1 General

The main function of the concrete in structure is mainly to resist the compressive forces. When a plain concrete member is subjected to compression, the failure of the member takes place, in its vertical plane along the diagonal. The vertical cracks occur due to lateral tensile strain. A flow in the concrete, which is in the form of micro crack along the vertical axis of the member will take place on the application of axial compression load and propagate further due to the lateral tensile strain.

4.2.2 Test procedure and results for compressive strength

Test specimens of size 150×150×150 mm were prepared for testing the compressive strength of concrete with fixed 5% replacement of cement with silica fume at different w/c ratios for the various percentage replacement levels of nano silica. The modified mixture with varying percentage of nano silica as a partial replacement of cement and with varying w/c ratios were prepared and cast into cubes. Compressive strength test results at 28 day curing for different mixes with different w/c ratios are shown in the Table 4.1. For testing in compression, no cushioning material was placed between the specimen and the plates of the machine. The load was applied axially without shock till the specimen was crushed. Fig. 4.1 shows the test setup for the compressive strength.

Three specimens for each mix were tested and the corresponding values were observed and average value were taken for discussion. Fig. 4.2-Fig. 4.5 show the variation of compressive strength with different w/c ratios of 0.40, 0.43, 0.46 and 0.49 respectively with varying percentage replacement of cement with nano silica and fixed replacement with silica fume. Fig. 4.6 shows the combine variation of compressive strength results of different mixes with different w/c ratios.

Table 4.1: Compressive Strength test results at 28 Day

W/C	Mix Designation	Nano Silica	Silica Fume	Compressive Strength			Mean (N/mm ²)
				(N/mm ²)			
0.40	MD10	0%	5%	49.7	50.48	49.28	49.8
	MD11	1%	5%	51.2	52.4	49.8	51.1
	MD12	2%	5%	54.9	53.1	55.73	54.6
	MD13	3%	5%	52.21	49.38	50.7	50.8
0.43	MD20	0%	5%	44.62	45.40	45.23	45.1
	MD21	1%	5%	46.89	47.11	47.61	47.20
	MD22	2%	5%	49.32	49.60	50.13	49.68
	MD23	3%	5%	45.31	45.80	46.83	45.98
0.46	MD30	0%	5%	35.60	34.6	34.45	34.88
	MD31	1%	5%	36.60	36.4	36.12	36.37
	MD32	2%	5%	38.20	38.4	39.26	38.62
	MD33	3%	5%	34.83	35.1	36.41	35.45
0.49	MD40	0%	5%	29.2	29.63	31.20	30.01
	MD41	1%	5%	31.6	31.40	32.20	31.73
	MD42	2%	5%	33.8	32.45	33.45	33.23
	MD43	3%	5%	31.0	30.40	30.14	30.51



Fig. 4.1: Compressive strength test setup

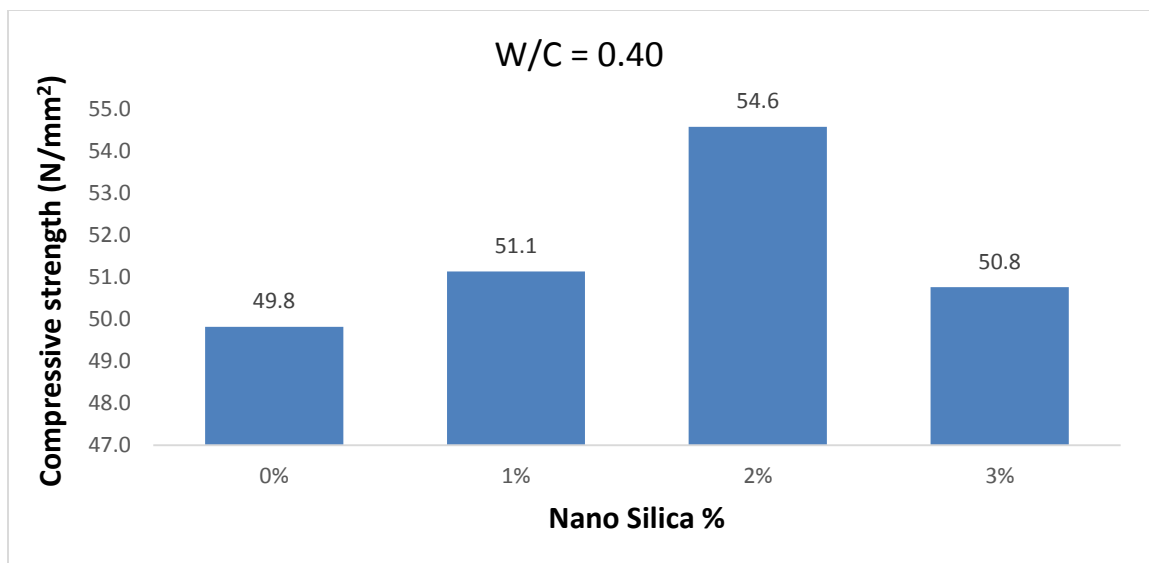


Fig. 4.2: Variation of Compressive strength of concrete with 5% Silica Fume and different replacement level of Nano Silica with cement at w/c of 0.40

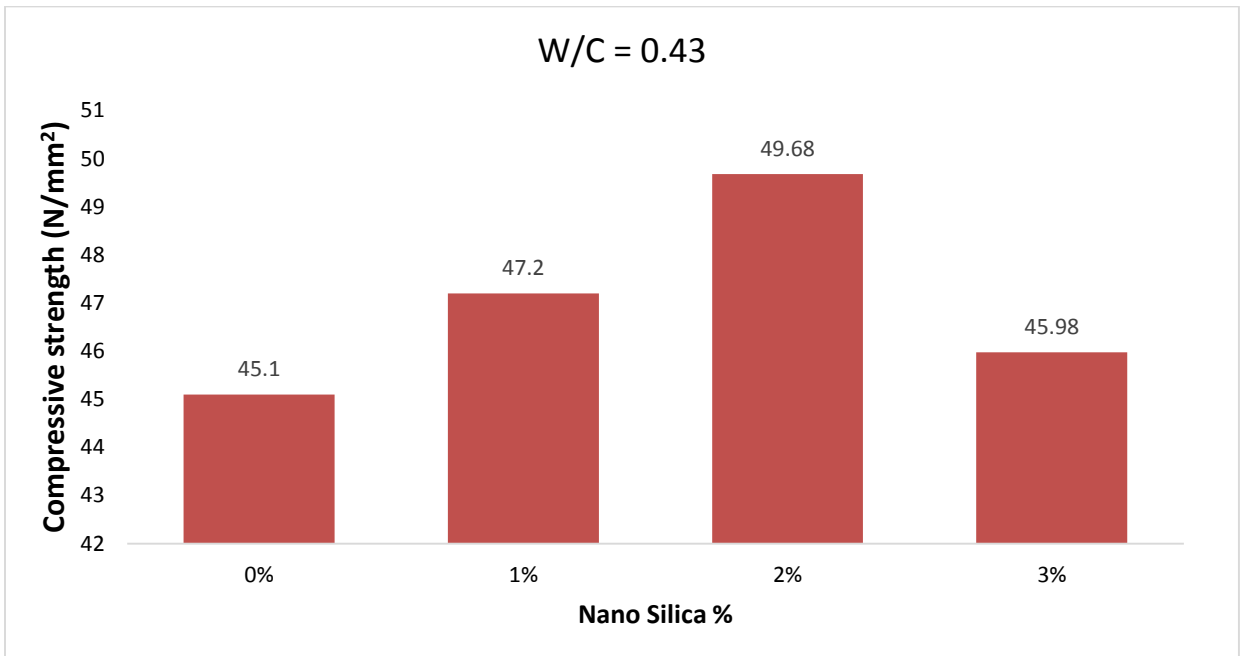


Fig. 4.3: Variation of Compressive strength of concrete with 5% Silica Fume and different replacement level of Nano Silica with cement at w/c of 0.43

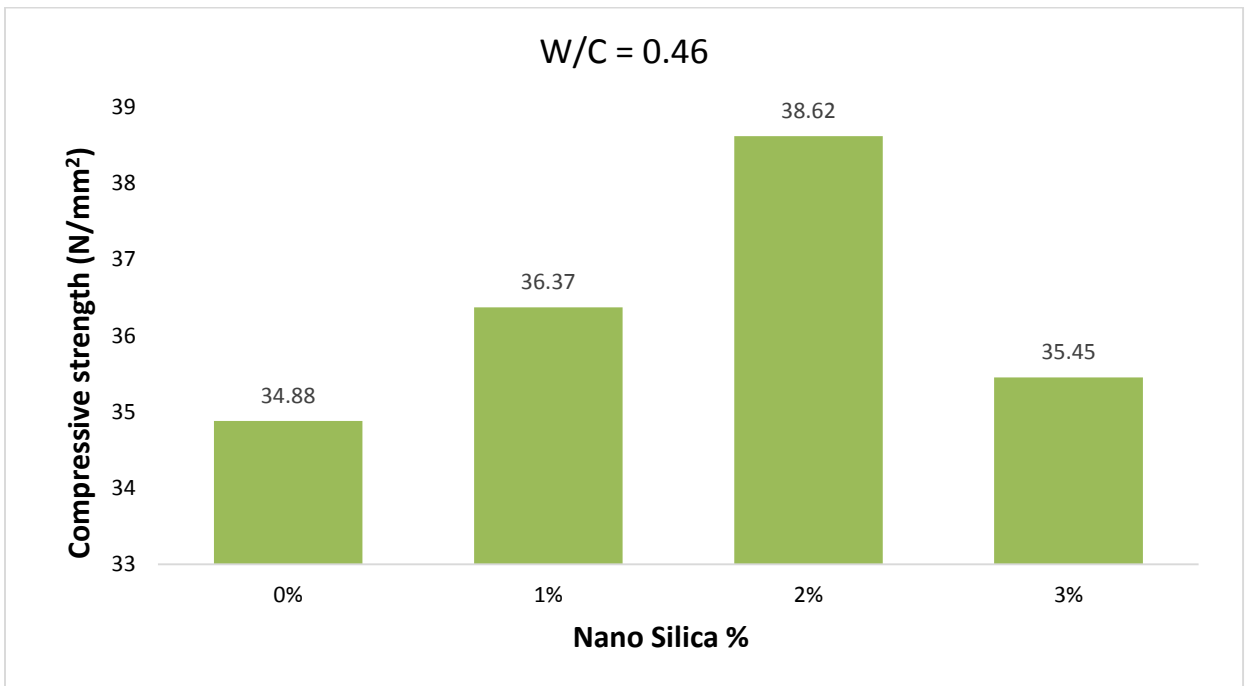


Fig. 4.4: Variation of Compressive strength of concrete with 5% Silica Fume and different replacement level of Nano Silica with cement at w/c of 0.46

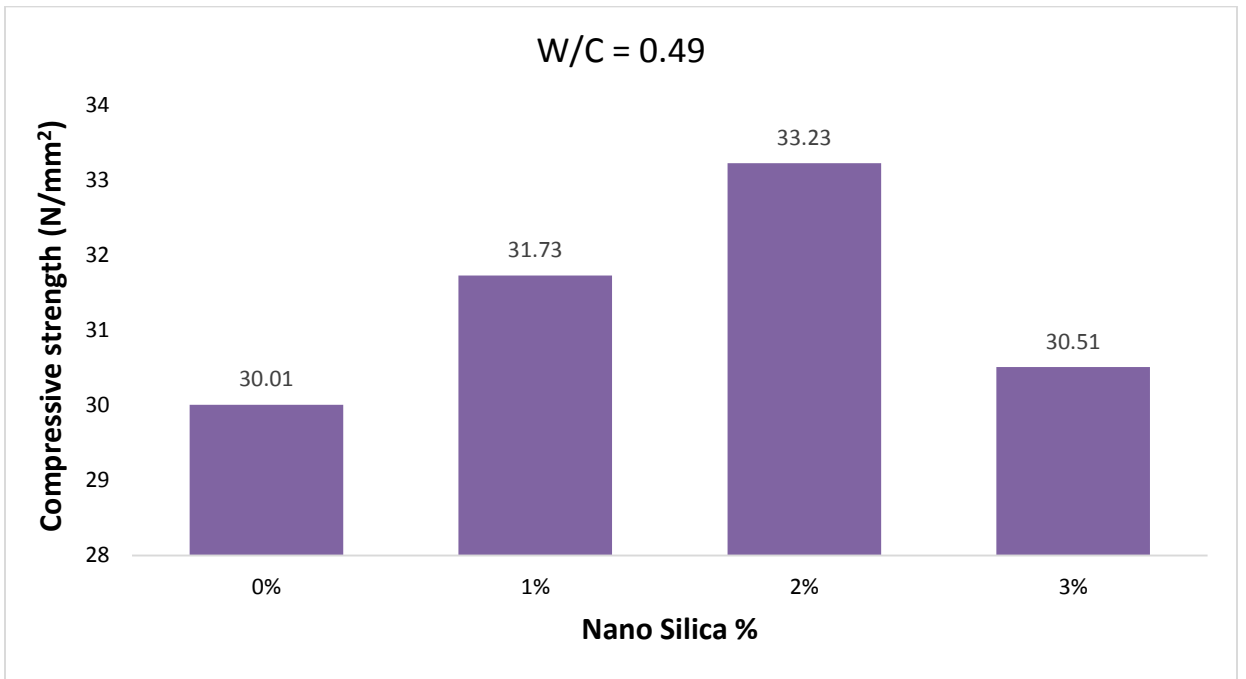


Fig. 4.5: Variation of Compressive strength of concrete with 5% Silica Fume and different replacement level of Nano Silica with cement at w/c of 0.49

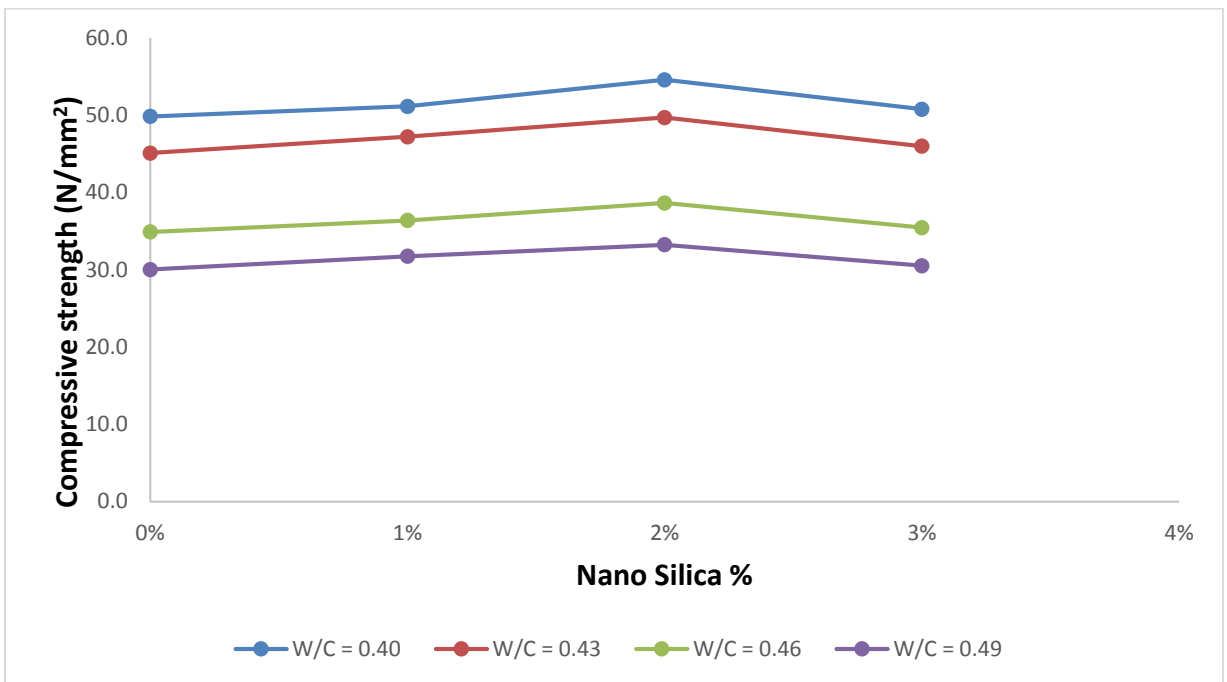


Fig. 4.6: Variation of Compressive strength of concrete with 5% Silica Fume and different replacement level of Nano Silica at different w/c ratios

4.2.3 Discussion of results for compressive strength

From the Table 4.1 and Fig. 4.7, shows the variation of compressive strength at different w/c ratios. It is observed here that with the increase in w/c ratio there is a drastic decrease in the compressive strength of the concrete mixes for the same proportioning of cement replacement of silica fume and nano silica. It is also observed that with increase in replacement level of nano silica there is a massive increase in compressive strength for all w/c ratios (up to 2% replacement of nano silica) of the concrete mixes. The maximum strength was obtained at w/c of 0.40 with 5% silica fume and 2% nano silica in all the replacement mixes with cement.

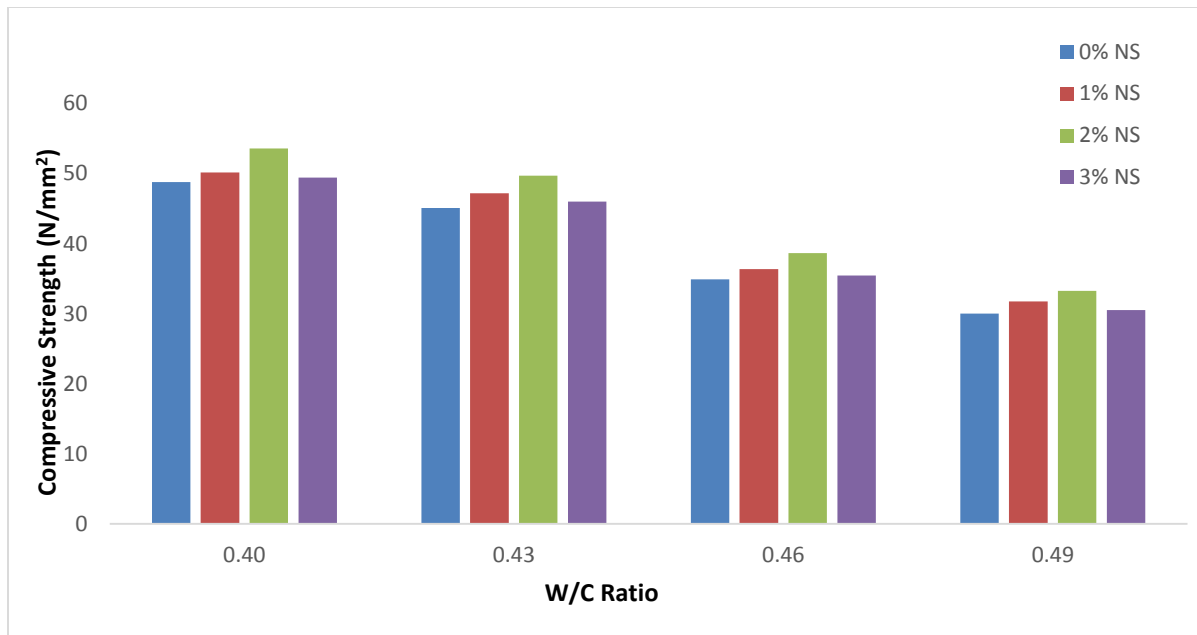


Fig. 4.7: Combined comparison of compressive strengths of concrete with different w/c ratios and replacement of cement with different percentages of nano silica (NS) and 5% Silica fume

From the fig.4.2, observed that there is an increase in compressive strength of the mix with cement replacement with 5% silica fume and varying levels of nano silica. The maximum compressive strength was found in cement replacement with 5% silica fume and 2% nano silica, after further replacement of nano silica there is a fall in compressive strength but greater than 5% silica fume and 0% nano silica replacement. In different water cement ratios i.e. 0.43, 0.46, 0.49 as the water content increases there is a decrease in compressive strength for same replacement level of silica fume and nano silica with cement as shown in Fig. 4.3- Fig. 4.4 and same trend was found in the variation of the development in compressive strength. The

increase in compressive strength of concrete is found because silica fume and nano silica's extreme fineness and high silica content which improves the concrete proportion i.e. enhance the strength of the concrete due to its fineness and by producing additional Calcium Silicate Hydrates (CSH) by reacting with Calcium hydroxide (CH) during the hydration reactions and reduces the permeability of concrete to chloride ions.

4.3 FLEXURAL STRENGTH OF CONCRETE

4.3.1 General

The most common concrete structure subjected to flexure is a highway or airway pavement and strength of concrete for pavements is commonly evaluated by means of bending tests. When concrete is subjected to bending, then tensile and compressive stresses and in many cases direct shear stresses are developed.

When fiber reinforced concrete and composite beams are loaded in pure bending, then the tensile strains develop. The load at first crack would increase with respect to high strength concrete due to crack arresting mechanism of the closely spaced fibers. After the concrete matrix cracks, the fibers continue to take higher load which is provided. Thus the ultimate flexural strength is increased.

4.3.2 Test Procedure and results for flexural strength

The flexural test beam specimens of size of 150×150×700 mm were cast and cured for 7 and 28 days under standard laboratory conditions. For testing the specimens were placed in the machine in such a manner that the load was applied to the uppermost surface as cast in the mould, along two lines spaced 20 cm apart. The axis of the specimen was carefully aligned with the axis of the loading device. No packing material was used between the bearing surface of the specimen and the rollers. The load was applied at a rate of loading of 400kg/min, and was applied until the specimen failed, and the maximum load applied to the specimen during the test was recorded for the further analysis. The flexural strength of the specimen is expressed as the modulus of rupture f_b , if the fracture occurred within the central one-third of the beam; the flexural strength was calculated on the basis of ordinary elastic theory using the following equation:

$$f_b = \frac{p \times l}{b \times d^2}$$

Where,

- f_b is the flexural strength,
- p is the maximum load applied to the specimen,
- b is measured width of the specimen,
- d is the depth of the specimen at the point of failure, and
- l is the length of the span on which the specimen was supported.

Four-point loading condition was used for the test procedure in which the two points loading is applied to the beam 20 cm apart. Fig. 4.8 shows the third point condition and test setup for the flexural strength test.



Fig. 4.8: Test setup for flexural strength

Five specimens for each mix were tested and the corresponding values were observed and average value was taken for further discussion. Table 4.2 shows the values of flexural strength obtained for various mixes at different w/c ratios.

Fig. 4.9-Fig. 4.10 shows the variation of flexural strength with different w/c ratios of 0.40, 0.43, 0.46 and 0.49 respectively with varying percentage replacement of cement with nano

silica and fixed replacement with 5% silica fume. Fig. 4.11 shows the combine variation of flexural strength results of different mixes with different w/c ratios.

Table 4.2: Flexural strength test results

W/C	Mix Designation	Nano Silica	Silica Fume	Flexural Strength (N/mm ²)					Mean(N/mm ²)
0.40	MD10	0%	5%	5.23	5.45	4.72	4.94	4.56	4.98
	MD11	1%	5%	5.72	6.04	6.43	5.83	5.75	5.95
	MD12	2%	5%	6.82	7.21	6.57	6.52	6.41	6.71
	MD13	3%	5%	6.2	6.06	5.65	5.97	6.18	6.01
0.43	MD20	0%	5%	5.38	4.9	4.37	5.11	5.44	5.04
	MD21	1%	5%	5.54	3.891	5.44	5.01	5.78	5.13
	MD22	2%	5%	5.97	5.88	5.83	6.01	5.95	5.93
	MD23	3%	5%	5.48	5.43	5.68	5.57	5.61	5.55
0.46	MD30	0%	5%	4.64	4.23	4.7	4.29	4.35	4.44
	MD31	1%	5%	4.74	4.95	5.02	5.17	4.92	4.96
	MD32	2%	5%	4.64	5.08	4.78	5.69	4.91	5.02
	MD33	3%	5%	4.85	5.87	4.93	3.86	4.87	4.88
0.49	MD40	0%	5%	4.07	4.17	3.99	4.11	4.09	4.09
	MD41	1%	5%	4.4	4.16	4.07	4.28	4.24	4.23
	MD42	2%	5%	4.44	4.57	4.68	4.49	4.37	4.51
	MD43	3%	5%	3.79	4.39	4.05	4.13	4.346	4.14

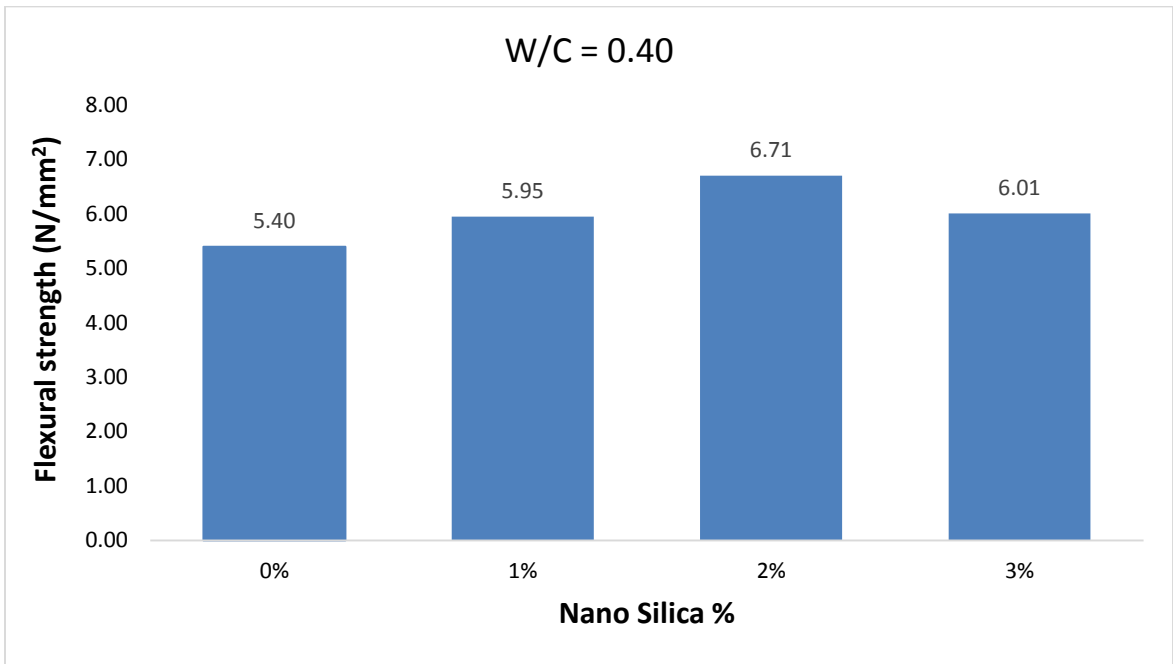


Fig. 4.9: Variation of Flexural strength of concrete with 5% Silica Fume and different replacement level of Nano Silica with cement at w/c of 0.40

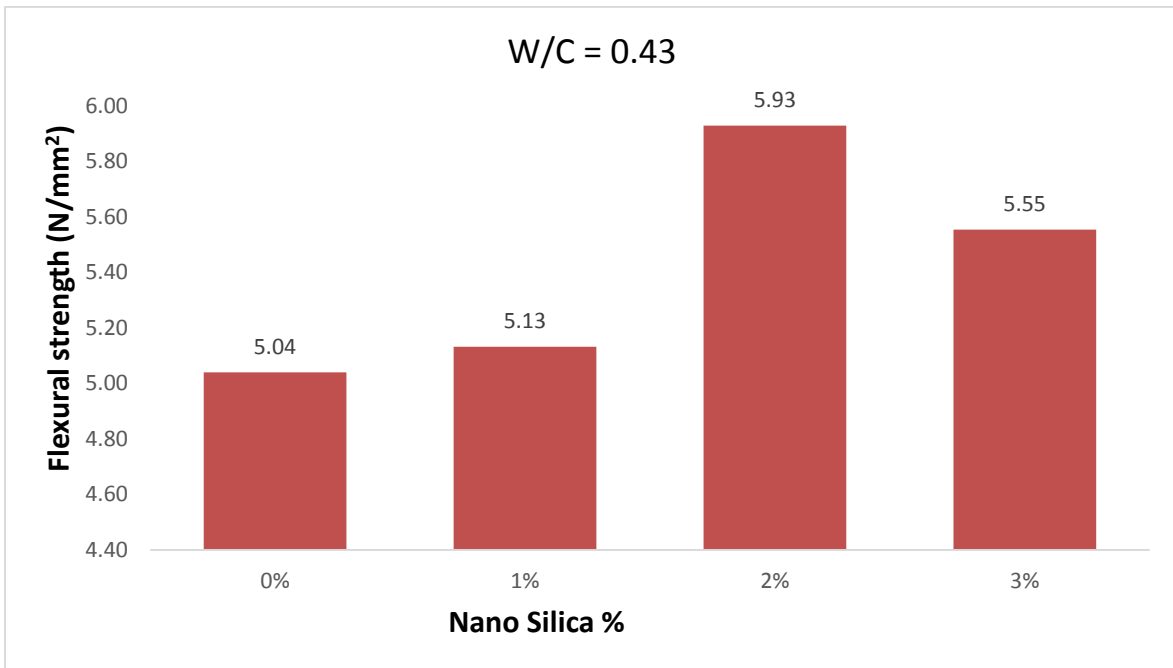


Fig. 4.10: Variation of Flexural strength of concrete with 5% Silica Fume and different replacement level of Nano Silica with cement at w/c of 0.43

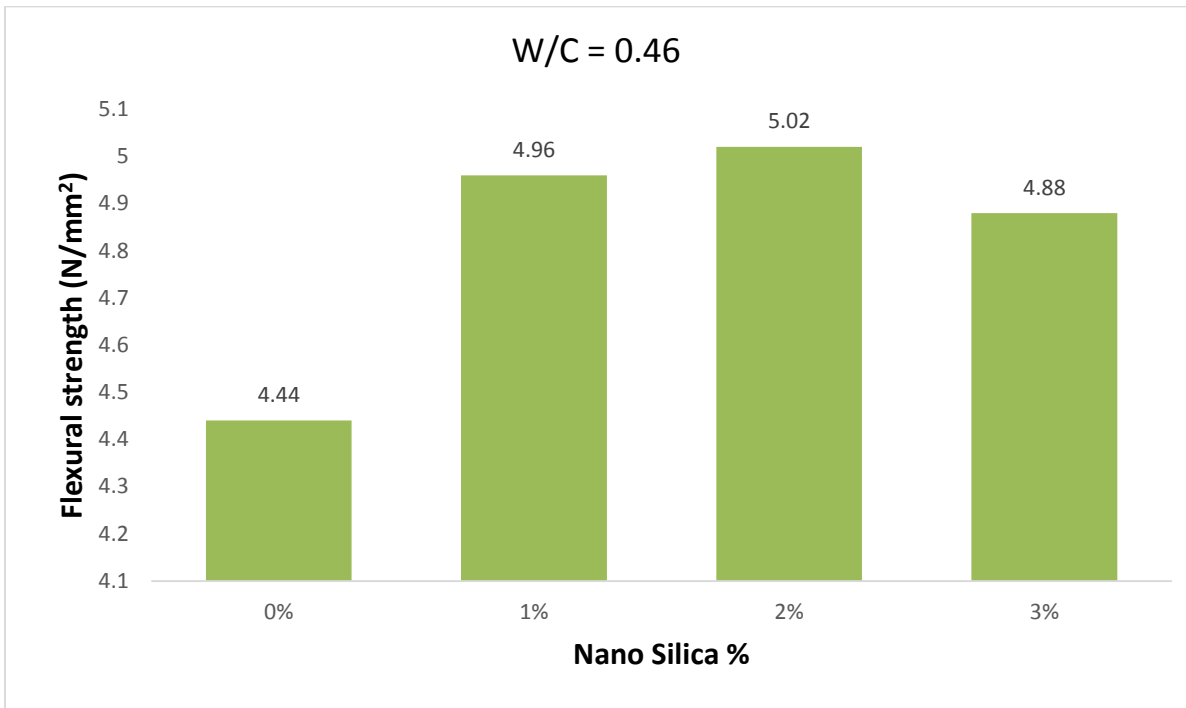


Fig. 4.11: Variation of Flexural strength of concrete with 5% Silica Fume and different replacement level of Nano Silica with cement at w/c of 0.46

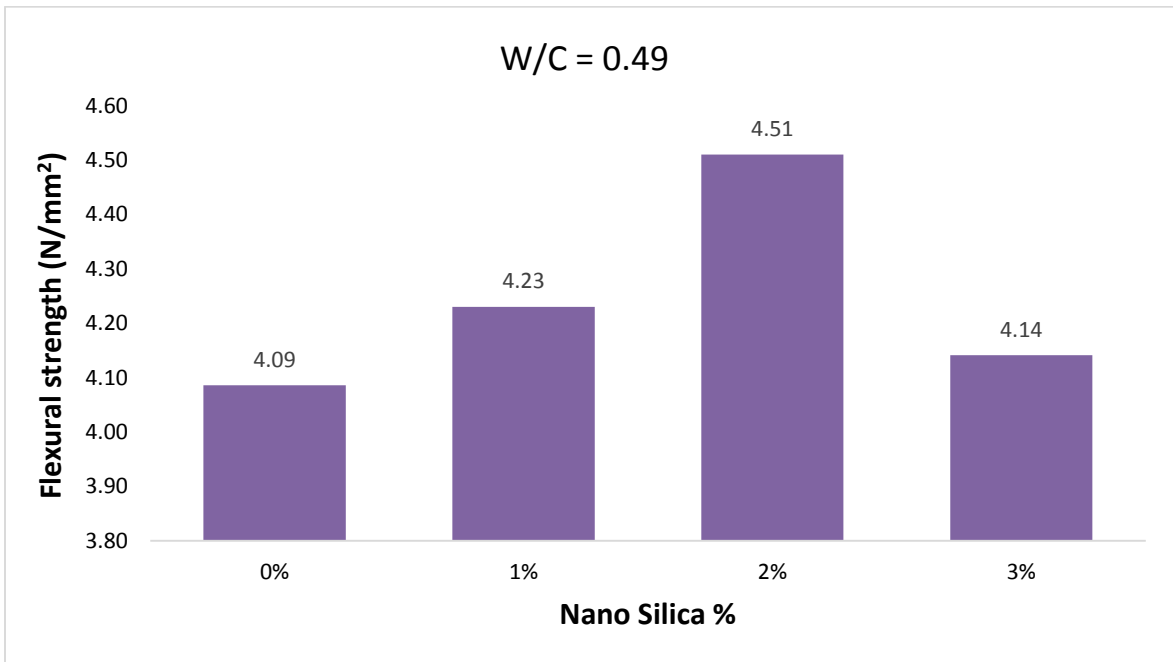


Fig. 4.12: Variation of Flexural strength of concrete with 5% Silica Fume and different replacement level of Nano Silica with cement at w/c of 0.49

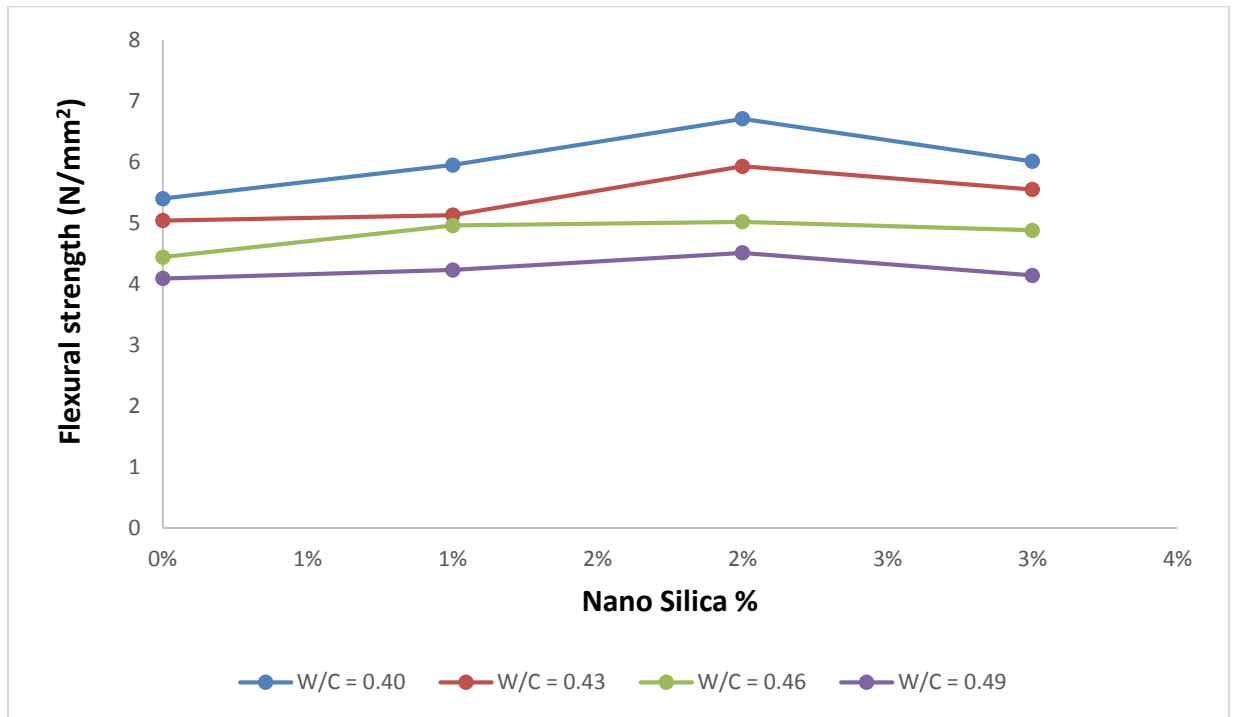


Fig. 4.13: Variation of flexural strength of concrete with 5% Silica Fume and different replacement level of Nano Silica at different w/c ratios

4.3.3 Discussion of results for flexural strength

From the Table 4.2 and Fig. 4.14, shows the variation of flexural strength at different w/c ratios. It is observed here that with the increase in w/c ratio there is a drastic decrease in the flexural strength of the concrete mixes for the same proportioning of cement replacement of silica fume and nano silica. It is also observed that with increase in replacement level of nano silica there is a massive increase in flexural strength for all w/c ratios (up to 2% replacement of nano silica) of the concrete mixes. The maximum strength was obtained at w/c of 0.40 with 5% silica fume and 2% nano silica in all the replacement mixes with cement.

From the Fig.4.9, observed that there is an increase in flexural strength of the mix with cement replacement with 5% silica fume and varying levels of nano silica. The maximum flexural strength was found in cement replacement with 5% silica fume and 2% nano silica, after further replacement of nano silica there is a fall in flexural strength but greater than 5% silica fume and 0% nano silica replacement.

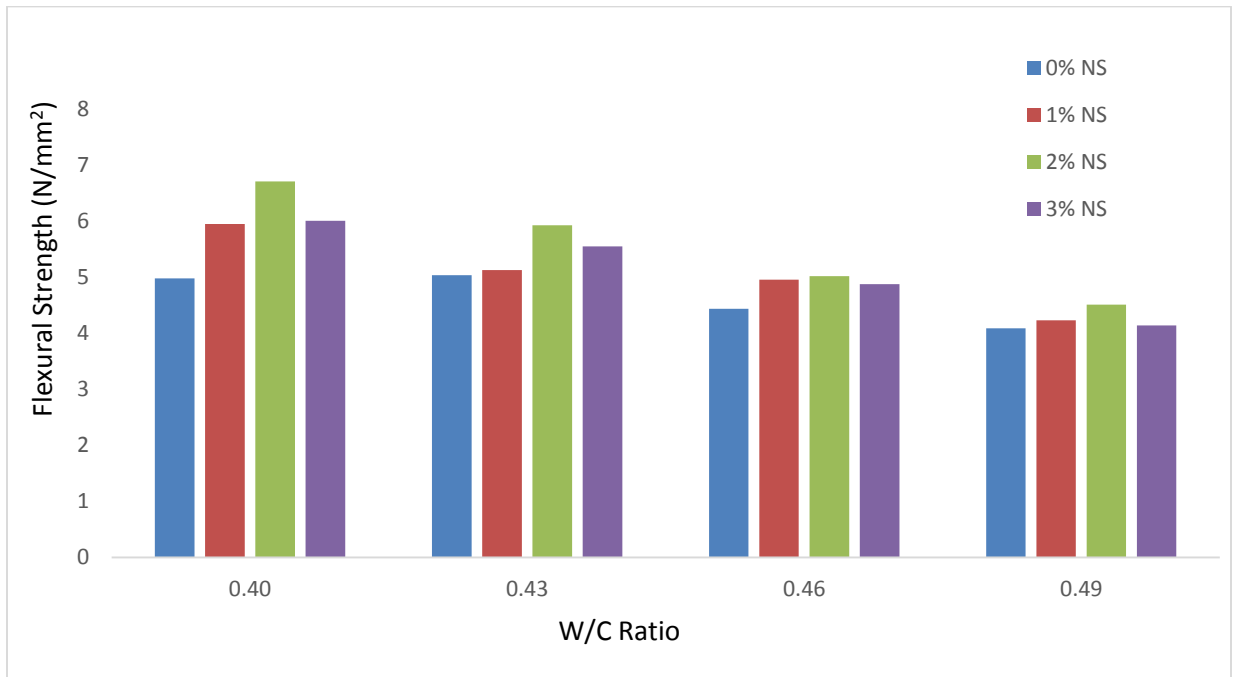


Fig. 4.14: Combined comparison of flexural strengths of concrete with different w/c ratios and replacement of cement with different percentages of nano silica (NS) and 5% Silica fume

In different water cement ratios i.e. 0.43, 0.46, 0.49 as the water content increases there is a decrease in flexural strength for same replacement level of silica fume and nano silica with cement as shown in Fig. 4.10- Fig. 4.12 and same trend was found in the variation of the development in compressive strength. It is observed here that with the increase percentage of nano silica and 5% silica fume the flexural strength follows a pattern similar to compressive strength. This happens because during hydration reactions silica fume and nano silica produce additional calcium silicate hydrates (CSH) by reacting with calcium hydroxide (CH) during the hydration reactions which help to gain strength in early ages.

CHAPTER 5

DESIGN OF PAVEMENT QUALITY CONCRETE

This chapter deals with the design of the Pavement Quality Concrete slab for the various mixes in reference to the guidelines of the IRC: 58-2002.

5.1 PROCEDURE FOR DESIGN OF SLAB THICKNESS AS PER IRC 58-2002

Step1: Stipulate design values for the various parameters.

Step2: Select a trial design thickness of pavement slab.

Step3: From the given data, cumulative repetition in 30 yrs. can be calculated from the formula which is given below:

$$C = A \times 365 \left[\frac{(1+r)^n - 1}{r} \right]$$

Where, C = Cumulative number of axles during the design period.

A = Initial number of axles per day in the year when the road is operational.

r = Annual rate of growth of commercial traffic (expressed in decimals).

n = Design period in years.

Design traffic can be calculated by 25% of cumulative repetition.

Step 4: The Single and Tandem Axle load is multiplied with a factor of 1.2 respectively.

Step 5: Stress (kg/cm²) is calculated from the given graphs as mentioned in IRC 58: 2002 (Graph between slab thickness and flexure strength).

Step 6: The stress ratio is calculated as $\frac{\text{Stress}}{\text{Flexure strength}}$

Step7: Expected Repetition is calculated from the Design Traffic which is multiplied with a percentage of respective Axle loads.

Step8. Allowable Repetition is calculated from the Table 6 of IRC: 58.

Step 9: Fatigue life consumed is calculated which is the ratio of fatigue life (N) and expected repetition (n). The design is unsafe if the cumulative fatigue life consumed is less than 1.0. If unsafe than select a higher thickness and repeat the steps.

Step10: Compute the temperature stress at the edge and if the sum of the temperature stress and the flexural stress due to the highest wheel load is greater than the modulus of rupture, select a higher thickness of slab.

The axle load percentages for calculating design traffic for given design of pavement are given in Table 5.1 and design parameters considered in calculating safe thickness of pavement are shown in Table 5.2.

Table 5.1: Axle Load Spectrum

Single Axle Load		Tandem Axle Load	
Load in Tones	Percentage of axle loads	Load in Tones	Percentage of axle loads
27-29	0		
25-27	0		
23-25	0	42-46	0
23-21	0	38-42	0
19-21	0.6	34-38	0.3
17-19	1.5	30-34	0.3
15-17	4.8	26-30	0.6
13-15	10.8	22-26	1.8
11-13	22	18-22	1.5
09-11	23.3	14-18	0.5
< 09	30	< 14	2
Total	93	Total	7

Table 5.2: Design of Rigid Pavement as Per IRC: 58-2002

Design life	30 years
Design Wheel Load	7000 kg
Present Traffic Intensity	3000 CVPD
28 day Compressive strength of concrete	546 kg/cm ²
Flexural strength of concrete	67.1 kg/cm ²
Sub grade CBR	7.00 %
Thickness of Dry Lean Concrete	15 cm
Modulus of Elasticity of concrete	3×10 ⁵ kg/cm ²
Tyre pressure	8 kg/cm ²
Poisson's Ratio of concrete	0.15
Coefficient of thermal expansion of concrete	10×10 ⁻⁶ °C
Spacing of contraction joints	4.5 m
Width of slab (Lane Width)	3.5 m
Annual traffic growth rate	7.5 %
K value of sub-base	27.7 kg/cm ³
K value of subgrade	4.80 kg/cm ³

- Cumulative repetitions in 30 years = 113222346
- Design Traffic = 28305586
- Radius of relative stiffness (I) = 83.81 cm

Trial fatigue analysis for calculating safe thickness for given flexural strength is shown in Table 5.3.

Table 5.3: Fatigue analysis for the PQC slab trial 1 with slab thickness 20.50 cm

Flexural Strength = 67.1 kg/cm ²				Slab thickness = 20.50 cm		
Axle load (AL), Tonnes	A.L×1.2	Stress kg/cm ² (from chart)	Stress Ratio	Expected repetition, n	Fatigue Life, N	Fatigue life Consumed
1	2	3	4	5	6	5/6
Single Axle						
20	24	35.5	0.53	169833.5	236488.7	0.552372
18	21.6	34	0.51	424583.8	559167	0.235323
16	19.2	31.5	0.47	1358668	5460526	0.248816
14	16.8	29	0.43	3057003	∞	0
12	14.4	26	0.39	6227229	∞	0
Tandem Axle						
36	43.2	26	0.39	84916.76	∞	0.00
32	38.4	24.5	0.37	169833.5	∞	0.00

Cumulative Fatigue Damage / Life Consumes 1.726278

Check for Fatigue Life UNSAFE

The design is unsafe since cumulative fatigue life consumed should be less than 1.0, thickness should be increased and second trial for fatigue analysis is carried over as shown in Table 5.4.

Table 5.4: Fatigue analysis for the PQC slab trial 2 with slab thickness 21.00 cm

Flexural Strength = 67.1 kg/cm ²				Slab thickness = 21.00 cm		
Axle load (AL), Tonnes	A.L×1.2	Stress kg/cm ² (from chart)	Stress Ratio	Expected repetition, n	Fatigue Life, N	Fatigue life Consumed
1	2	3	4	5	6	5/6
Single Axle						
20	24	35	0.52	169833.52	307462.3	0.552372
18	21.6	32.5	0.48	424583.80	1804256	0.235323
16	19.2	30	0.45	1358668.15	∞	0
14	16.8	27.5	0.41	3057003.34	∞	0
12	14.4	25	0.37	6227229.02	∞	0
Tandem Axle						
36	43.2	25	0.37	84916.76	∞	0.00
32	38.4	23	0.34	169833.52	∞	0.00

Cumulative Fatigue Damage / Life Consumes 0.787695

Check for Fatigue Life SAFE

Therefore, the assumed slab thickness of 21.00 cm is safe for the defined traffic and concrete mix characteristics.

Similarly for all the mixes the PQC slab is designed for the various mixes and required thickness are compared.

5.2 REDUCTION OF MATERIAL IN DESIGN OF SLAB THICKNESS PAVEMENT

According to the result, if the flexural strength increases there is a decrease in slab thickness which directly decreases the volume of concrete and thus a considerable saving in ingredient materials. For the mix MD12 (w/c of 0.40, 5% silica fume and 2% nano silica) there is a decrease of 40 mm in the thickness of slab. Similarly for the other mixes the variation in thickness as shown in the Table 5.5. Reduction in PQC slab thickness and saving of cubic meter content of PQC as shown in Fig. 5.1 and Fig. 5.2.

Table 5.5: Reduction in concrete pavement thickness (mm) in different water-cement ratios

Mix identity	PQC slab thickness (cm)	Reduction in concrete pavement thickness
MD10 (w/c=0.40, 5% silica fume and 0% nano silica)	25.00	-
MD11 (w/c=0.40, 5% silica fume and 1% nano silica)	23.00	20 mm
MD12 (w/c=0.40, 5% silica fume and 2% nano silica)	21.00	40 mm
MD13 (w/c=0.40, 5% silica fume and 3% nano silica)	23.00	20 mm
MD20 (w/c=0.43, 5% silica fume and 0% nano silica)	26.00	-
MD21 (w/c=0.43, 5% silica fume and 1% nano silica)	25.50	5 mm
MD22 (w/c=0.43, 5% silica fume and 2% nano silica)	23.00	30 mm
MD23 (w/c=0.43, 5% silica fume and 3% nano silica)	24.00	20 mm
MD30 (w/c=0.46, 5% silica fume and 0% nano silica)	28.00	-
MD31 (w/c=0.46, 5% silica fume and 1% nano silica)	27.75	2.5 mm
MD32 (w/c=0.46, 5% silica fume and 2% nano silica)	25.75	22.5 mm
MD33 (w/c=0.46, 5% silica fume and 3% nano silica)	26.50	15 mm
MD40 (w/c=0.49, 5% silica fume and 0% nano silica)	30.00	-
MD41 (w/c=0.49, 5% silica fume and 1% nano silica)	29.75	2.5 mm
MD42 (w/c=0.49, 5% silica fume and 2% nano silica)	27.75	22.5 mm
MD43 (w/c=0.49, 5% silica fume and 3% nano silica)	29.00	10 mm

Reduction in the concrete slab thickness indicates that the volume required also decreases. Therefore there is a saving in the materials for the concrete which gives an economical support to the pavement. As the silica fume is a byproduct in making silicon alloys and its utilization not only gives satisfactory results but also increase the concrete strength which leads to economy. On the other hand nano silica is very small, much smaller than the size of silica fume, hence it gives better rise in strength of concrete mix with silica fume. The total saving in concrete ingredients in mixes with different water-cement ratios are shown in the Table 5.6.

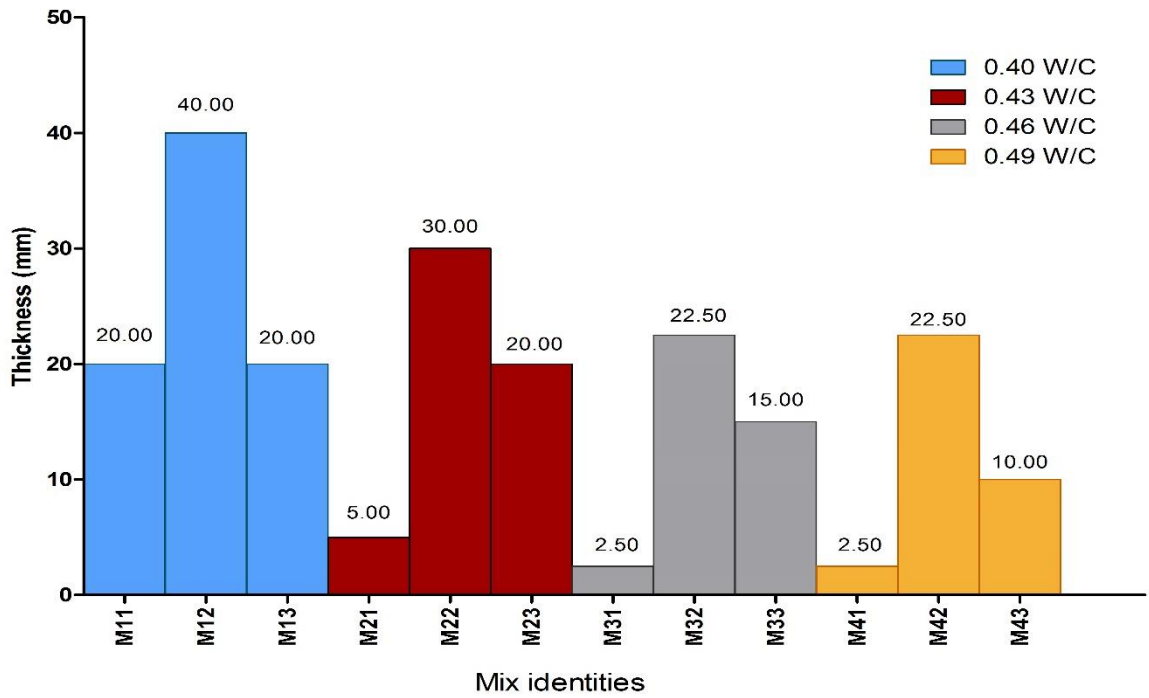


Fig. 5.1: Reduction in thickness (mm) of PQC slab with respect of 0% nano silica

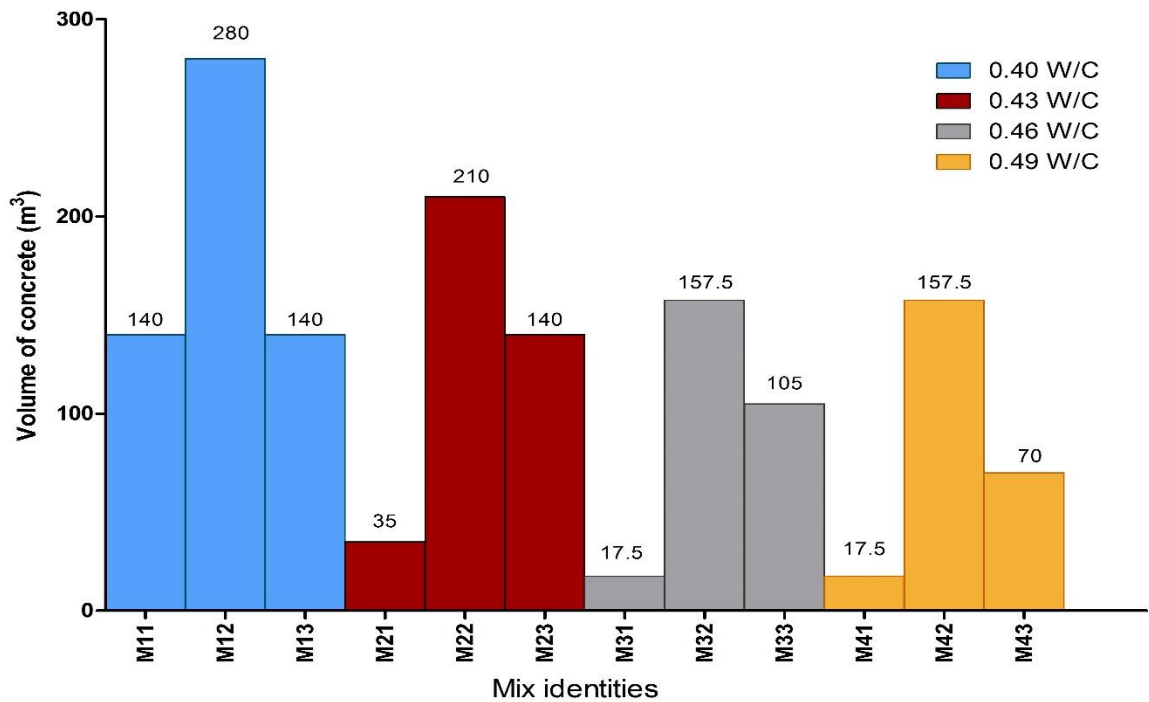


Fig. 5.2: Saving in cubic meter of PQC with respect of 0% nano silica

Table 5.6: Saving in concrete ingredients in mixes with different water-cement ratios

Mix ID	W/C ratio	Slab Pavement Thickness (mm)	Saving in PQC slab thickness (mm)	Saving in m³ of concrete for 1 km two lane highway	Saving in cement content (kg)	Saving in fine aggregate (kg)	Saving in coarse aggregate (kg)
MD10	0.40	250	-	-	-	-	-
MD11		230	20.00	140	56873.39	101640	161587.7
MD12		210	40.00	280	113327.1	203280	323175.4
MD13		230	20.00	140	61700.17	101640	161587.7
MD20	0.43	260	-	-	-	-	-
MD21		255	5.00	35	16290.72	25760	40018.23
MD22		230	30.00	210	86516.78	154560	240109.4
MD23		240	20.00	140	62014.96	103040	160072.9
MD30	0.46	280	-	-	-	-	-
MD31		280	2.50	17.5	9719.308	13063.49	19819.75
MD32		260	22.50	157.5	66671.4	117571.4	178377.7
MD33		265	15.00	105	49186.94	78380.93	118918.5
MD40	0.49	300	-	-	-	-	-
MD41		290	2.50	17.5	9929.168	13247.5	19630.38
MD42		280	22.50	157.5	67091.12	119227.5	176673.4
MD43		290	10.00	70	36358.91	52990	78521.52

CHAPTER 6

CONCLUSIONS

6.1 GENERAL

The present study was undertaken to investigate the compressive strength and flexural strength of concrete with different level of replacement of cement with nano silica and fixed replacement of 5% silica fume at different w/c ratios i.e. 0.40, 0.43, 0.46 and 0.49. Cement was partially replaced by 5% silica fume and with different percentages i.e. 0%, 1%, 2% and 3% of nano silica for calculating compressive and flexural strength of the mixes after curing period of 28 days. 48 samples of cube size 150×150×150 mm were casted for compressive strength and 80 samples of beam size 150×150×700 mm were casted for flexural strength of concrete with different water-cement ratios. Super plasticizer was used in all the mixes at 1% level by weight of cementitious material.

6.2 CONCLUSION

From the experimental results, the following conclusion can be drawn:

- Concrete mix at water-cement ratio 0.40 with 5% silica fume and 2% nano silica as replacement of cement is the optimum level and it has been observed a significant increase in flexural strength at 28 day when compared with other mixes.
- The compressive strength also tends to increase with increase percentage replacement of cement with nano silica, similar to results of flexural strength.
- On increasing the percentage replacement of cement with 5% silica fume and nano silica beyond 2%, there was decrease in flexural and compressive strength of the concrete.
- Significant decrease in the thickness of slab as with increasing percentage of nano silica (up to 2%) was observed, the maximum thickness decrease in slab is 40 mm. From all the mixes, 280 cubic meter of PQC is saved on water-cement ratio 0.40 with 5% silica fume and 2% nano silica replacement.

6.3 SCOPE FOR FUTURE WORK

- In the present study experimental programs was devised to study the strength characteristics of mixes containing silica fume and nano silica. The work can be extended to study the durability characteristics as well.
- The performance of the pavement quality concrete slabs containing silica fume and nano silica can be evaluated by constructing the trial stretches. The behaviour of these Pavement Quality Concrete (PQC) slabs can be analyzed under repetition loading for the fatigue life consumed.

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