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Strength and Durability Studies on Steel Fiber Reinforced Ternary Blended Concrete Containing Nano Silica and Zeolite

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Abstract An experimental study conducted to evaluate the hardened and durability characteristics of ternary blended concrete containing Nano-Silica and Zeolite along with steel fibers to act as micro- reinforcement has been presented in this paper. Nano-Silica and Zeolite were included in different dosages and the optimum combination of the above two materials (Nano-Silica -1% and Zeolite- 10%) has been obtained through trails from the viewpoint of workability and strength. Steel fibers have been added in varying volume fractions of 0.5%, 1.0% & 1.5%. Tests have been performed on cubes, cylinders, and prism specimens to evaluate the impact of steel fibers on various hardened and durability parameters of the ternary blended concrete. The test results clearly exhibit that inclusion of steel fibers significantly influences the material characteristics of the ternary blended concrete which includes compressive strength, indirect tensile strength, flexural strength, elasticity modulus, water absorption, Sorptivity and porosity. Nano silica and zeolite supplied the voids in the micron size of cement particle and formed a denser concrete which enhanced the improvement of the concrete. Based on the results obtained, the optimum compressive, splitting tensile, flexural strengths and modulus of elasticity of ternary blended concrete with micro reinforcement were obtained by 24.95%, 21.16%, 23.56% and 13.72%, respectively. The results suggested that cementitious materials, including ternary blended concrete with micro reinforcement, were the most influential factors on the mechanical properties.

Keywords Deformation, Modulus of Elasticity and Rupture, Nano Silica, Steel Fibers, Zeolite

1. Introduction

In recent years, research efforts are being made to tailor the properties of concrete to make it fit for use under a variety of environmental conditions. In this context, micro fillers and nano fillers stand as prospective players in enhancing the overall performance of the concrete. Moreover, apart from durability aspect, ductility plays a key role. This demand can be met with through various internal and external drive mechanisms. Use of NS and natural zeolite has a positive influence on compressive and flexural strength, water absorption, electrical resistivity, and rapid chloride permeability resistance [1]. Use of micro-reinforcement stands out as a better choice. The choice of the micro-reinforcement depends upon the target performance expected out of concrete [2]. Blending of NS and SF enhanced the flexural strength and the fracture performance of concrete specimens, which can be attributed to the crack bridging ability of steel fibers and better adhesion and bond strength of the nano-silica incorporation [3]. Use of NS as a binder replacement

enriched the compressive & flexural strength, and flexural fatigue performance of HPC [4]. Inclusion of nano silica enhanced the hardened properties, strain hardening behavior, and flexural toughness index of GECC containing high volume natural zeolite [5]. With the inclusion of steel fibers, the energy absorption and ductility of the concrete were enhanced. Inclusion of 1% nano silica exhibited the lowest porosity of matrix associated with denser and more homogeneous microstructure [6].

An attempt was made in this work to evaluate the hardened and durability parameters of ternary blended concrete consisting of Nano Silica, Zeolite, and steel fibers through standard experimental protocol.

2. Experimental Program

2.1. Materials and Properties

2.1.1. Binding Material

OPC 53 grade Dalmia cement meeting the requirements of IS 12269 (2013) was used for all the mixes of concrete used in this research investigation. Parameters of cement used are provided in Table 1.

Table 1. Parameters of Cement

Parameters	Observations
Specific Gravity	3.14
Initial setting time	50 minutes
Final setting time	380 minutes
Specific surface area	300

2.1.2. Coarse Aggregate

Crushed granite of maximum nominal size of 20mm & 12mm angular in shape meeting the requirements of IS 383:2016 has been used whose specific gravity is 2.80.

2.1.3. Fine Aggregate

Natural river sand of Zone – III whose specific gravity of 2.61 used as fine aggregate meets the requirements of IS 383:2016.

2.1.4. Super plasticizer

Water reducing admixture FOSROC CONPLAST SP430 procured from Astra Chemicals, Chennai. has been used in the experimental program for attaining the desirable workability. The parameters of SP used are presented in Table 2 and shown in Fig.1.

Table 2. Parameters of Super plasticizer

Properties	Value observed in Investigation
Colour	Dark brown
Form	Liquid
Specific gravity	1.26 at 25^0C

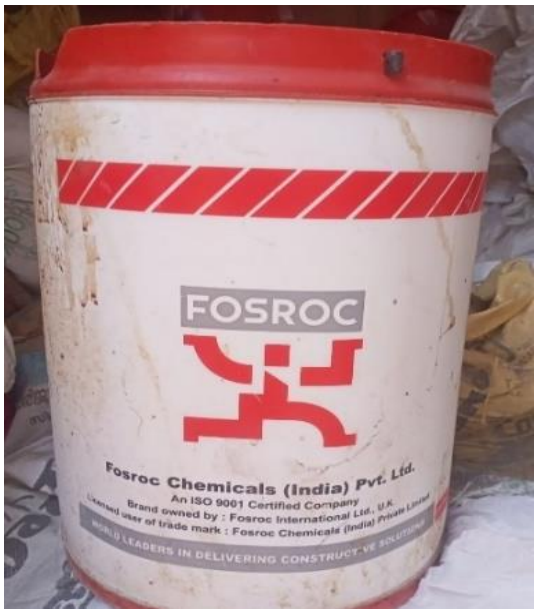

Figure 1. SP used

2.1.5. Zeolite and Nano-Silica

Zeolite and Nano-Silica used in the present work are obtained from Astra Chemicals, and Chennai are presented in Fig.2 & 3 and Table 3.

Figure 2. Zeolite

Figure 3. Nano-Silica

Figure 4. Steel fibers

Table 3. Physical Properties

Materials	Specific Surface Area (m^2/g)	Specific Gravity
Zeolite (Z)	20	2.6
Nano-Silica (NS)	202	1.2

2.1.6. Steel Fibers

In the experimental work, Steel Fibers Procured from STEWOLS INDIA Pvt. Ltd., Nagpur shown in Fig.4 has been used as a micro-reinforcement and its properties are mentioned in Table 4.

Table 4. Properties of Steel Fiber

Properties of Steel Fibers	Specifications
Shape	Hooked End
Length	60mm
Diameter	0.8mm
Aspect Ratio	75
Density	7850 kg/m^3
Tensile Strength	1225Mpa
Specific Gravity	7.85
Elasticity of Modulus	200Gpa

2.2. Mix Proportions

The controlled concrete had a compressive strength of 39. 83MPa. W/C of 0.48 maintained as constant for all mixes. The desired slump in each case has been achieved using SP in appropriate dosages. Data of Mix Proportion are furnished in Table 5.

Table 5. Mix Proportion of Concrete with and without Fibers

Cement(Kg/m^3)	Fine Aggregate(Kg/m^3)	Coarse Aggregate(Kg/m^3) 20mm	12mm	Zeolite(Kg/m^3)	Nano Silica(Kg/m^3)	Steel fiber (%)
387	654	731.4	487.6	-	-	-
348.3	654	731.4	487.6	38.7	-	-
344.43	654	731.4	487.6	38.7	3.87	-
344.43	654	731.4	487.6	38.7	3.87	0.5%
344.43	654	731.4	487.6	38.7	3.87	1.0%
344.43	654	731.4	487.6	38.7	3.87	1.5%

2.2. Preparation of Control Specimens

Figure 5. Casting of Cube and Cylinder Specimens

The various constituents of the design concrete mix were dry mixed. As per the mix design, the water and the super plasticizer are added at the stage of dry mixing and the mixing process is continued until homogeneity is attained. This concrete mix was then charged into a hand operated drum mixture and mixed once again. The leftover water and super plasticizer were added and mixed. To this wet mix, steel fibers were added slowly, and the entire charge was thoroughly mixed. The control specimens comprising of cubes, cylinders and prism were cast in moulds made of steel and were vibrated with the help of the vibrating table. Casted specimens were then removed from the mould after 24hrs of casting followed by curing for 28 days duration. Control specimens were casted and tested for both hardened and durability properties. The control specimens are shown in Fig.5 & 6.

Figure 6. Casting of Prism Specimens

2.3. Test Specimens

The investigation including laboratory and details of specimens is presented in Table 6. The nomenclature of all concrete specimens is presented in Table 7.

Table 6. Test Specimens

Experiment	Specimen	Size(mm)	No. of specimens
Compressive Strength Test (IS1959-2004 Reaffirmed)	Cubes	150X150	18
Flexural Strength Test (IS 1959-2004 Reaffirmed)	Prism	100X100X500	18
Elasticity of Modulus Test (IS 1959-2004 Reaffirmed)	Cylinder	150X300	18
Split Tensile Strength Test (IS 1959-2004 Reaffirmed)	Cylinder	150X300	18
Water Absorption Test (As per ASTM C642-97)	Cubes	150X150	18
Porosity (As per ASTM C642-97)	Cubes	100X50	18
Sorptivity Test (As per ASTM C1585-04)	Cylinder	100X50	18

Table 7. Nomenclature of Test Specimens

Test Specimen	Description
CC	Control Specimen
ZS	Specimen with 10% Zeolite (Z)
ZNS	Specimen with 10% Zeolite (Z),1% Nano-Silica (NS)
ZNSF-1	Specimen with 10% Zeolite (Z), 1% Nano-Silica (NS) and 0.5% Steel fiber
ZNSF-2	Specimen with 10% Zeolite (Z), 1% Nano-Silica (NS) and 1.0% Steel fiber
ZNSF-3	Specimen with 10% Zeolite (Z), 1% Nano-Silica (NS) and 1.5% Steel fiber

2.4. Test Methods

The experimental research was split up into two stages. In the earlier stage, binder material was partially replaced by different proportions of zeolite and nano silica to find the optimum combination. In the later stage, hooked end steel fibers with an aspect ratio of 75 in different volume fractions (0.5,1.0 & 1.5%) were added to the concrete with optimum dosage of zeolite and nano-silica. For ternary blended concrete, mechanical and durability test were carried out to find the compressive strength for cubes and cylinders, flexural strength for prism, Elasticity of modulus for cylinder, percentage of water absorption, porosity, Sorptivity and percentage of voids.

2.4.1. Compressive Strength Test

Cubes and cylinders are casted and tested for compressive strength as per IS1959-2004.

2.4.2. Compressive Strength Test for Cube

Cubes are casted and cured in a water tank and tested for evaluating its compressive strength. The test setup is shown in Fig.7. The test results are presented in Table 8.

Figure 7. Cube Compressive Strength Test Setup

Table 8. Cube Compressive Strength Test Results

Test Specimen	Compressive Strength of Cubes (MPa)
CC	39.83
ZS	41.86
ZNS	42.89
ZNSF-1	45.20
ZNSF-2	47.40
ZNSF-3	46.89

2.4.3. Compressive Strength Test for Cylinder

Cylinder of size 150X300mm was casted and tested for compressive strength as per ASTM C39. The test setup is shown in Fig.8. The test results are provided in Table 9.

Figure 8. Cylinder Compressive Strength Test Setup

Table 9. Cylinder Compressive Strength Test Results

Test Specimen	Compressive Strength of Cylinder (MPa)
CC	23.91
ZS	25.83
ZNS	26.50
ZNSF-1	28.50
ZNSF-2	29.89
ZNSF-3	29.02

2.4.4. Modulus of Rupture Test

100 X 100 X 500mm prisms were made and tested for flexural strength as per IS 516:1959 (2004 Reaffirmed). The test setup is shown in Fig.9 and test results are furnished in Table 10.

Figure 9. Modulus of Rupture Test Setup

Table 10. Modulus of Rupture Test Results

Test Specimen	Modulus of Rupture (MPa)
CC	6.47
ZS	7.07
ZNS	7.33
ZNSF-1	7.93
ZNSF-2	8.33
ZNSF-3	8.56

2.4.5. Elasticity Modulus Test

Cylinder Specimens of size 150 X 300mm with control concrete, ternary blended concrete and fiber reinforced ternary blended concrete were tested for modulus of elasticity as per IS 516:1959(2004 Reaffirmed). The test setup is shown in Fig.10. The test outcomes are mentioned in Table 11.

Figure 10. Modulus of Elasticity Test Setup

Table 11. Modulus of Elasticity Test Results

Test Specimen	Elasticity of Modulus (GPa)
CC	31.56
ZS	33.34
ZNS	33.86
ZNSF-1	34.06
ZNSF-2	35.24
ZNSF-3	35.89

2.4.6. Split Tensile Strength

Cylinder Specimens of size 150 X 300mm with control concrete, ternary blended concrete and fiber reinforced ternary blended concrete were tested for split tensile strength as per IS 516:1959(2004 Reaffirmed). The test setup is shown in Fig.11. The test outcomes are mentioned in Table 12.

Figure 11. Split Tensile Strength Test Setup

Table 12. Split Tensile Strength Test Results

Test Specimen	Split Tensile Strength (MPa)
CC	4.82
ZS	4.98
ZNS	5.22
ZNSF-1	5.48
ZNSF-2	5.62
ZNSF-3	5.84

2.4.7. Water Absorption and Porosity

Cube specimens of size 150X150X150mm with control concrete, ternary blended concrete and fiber reinforced ternary blended concrete were casted and evaluated for water absorption and porosity as per ASTM C642-97. The test setup is shown in Fig.12 & 13 and test outcomes are mentioned in Table 13.

Figure 12. Water Absorption

Figure 13. porosity test set up

Table 13. Water Absorption Test Results

Test Specimen	Water Absorption
CC	1.334
ZS	1.006
ZNS	0.983
ZNSF-1	0.920
ZNSF-2	0.822
ZNSF-3	0.905

2.4.8. Sorptivity

Figure 14. Sorptivity Test Setup

Specimens of 100mm diameter and 50mm thickness of control concrete, ternary blended concrete and fiber reinforced ternary blended concrete were tested for capillary rise of water as per ASTMC1585-04. The test setup is shown in Fig.14.

3. Results and Discussion

3.1. Compressive Strength Results

3.1.1. Compressive Strength Test for Cube

The effect of steel fibers on cube compressive strength and cylinder compressive strength is shown through Fig.15. The results have been averaged for three specimens. An increase of 19.01% and 24.95% has been observed for the ternary concrete mix with 1.0% volume fraction of steel fibres [ZNSF-2]. The ternary concrete mix with 0.5% volume fraction of steel fibres showed an increase of 13.48% and 19.14% compared to control specimen, 7.97% and 10.33% compared to concrete with zeolite [Z], 5.38% and 7.54% compared to concrete with zeolite and nano silica [ZNS] in respect of cube compressive strength and cylinder compressive strength respectively. The ternary concrete containing nano silica and zeolite exhibited an increase of 7.68% and 10.79% when compared to the control concrete specimen and the specimen containing only zeolite in respect of cube strength. An increase of 2.46% and 2.60% has been shown by the ternary concrete containing nano silica and zeolite in comparison with the control concrete specimen and the specimen containing only zeolite in respect of cylinder strength. The concrete specimen containing only zeolite showed an increase of 5.10% and 7.98% when compared to control concrete specimen. The increase in compressive strength for concrete specimen containing fibers may be due to the stitching action of steel fibers as well as the improved bond between the matrix and fibers. The ternary concrete containing nano silica and zeolite showed enhanced compressive strength due to the improved bond at the interface between the matrix and the aggregates as well as the pore refinement caused by the nano silica along the interfacial transition zone. The concrete containing zeolite showed an increase in compressive strength due to the fact that addition of zeolite caused densification of matrix and reduction in porosity. It has been noted that with the ternary concrete having 1.5% volume fraction of steel fibers, a reduction in compressive strength occurred. This may be because of improper dispersion of steel fibers resulting in void formation.

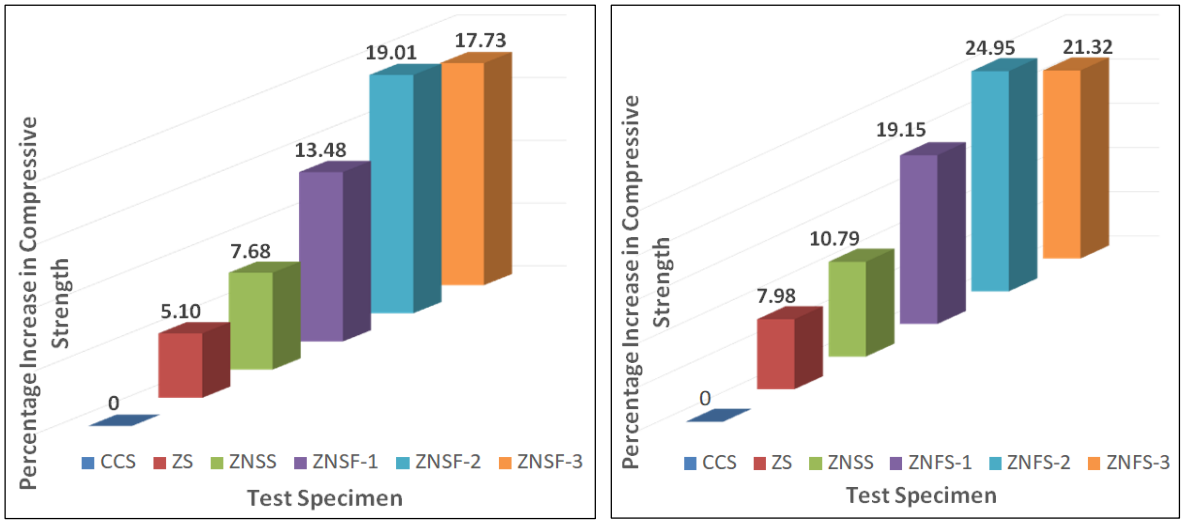

Figure 15. Effect of Steel Fibers on Cube and Cylinder Compressive Strength

(a)Specimen-CC

(b)Specimen-Z

(c)Specimen-ZNS

(d)Specimen- ZNSP-1

(e)Specimen- Z**NSP-2**

(f)Specimen- ZNSP-3

(a)Specimen-CC (b)Specimen-Z (c)Specimen-ZNS

(d) Specimen- ZNSP-1 (e)Specimen- ZNSP-2 (f) Specimen- ZNSP-3

Figure 16. Failure Mode of Cubes and Cylinders Specimens

Failure Modes

The failure modes of ternary blended fibers reinforced concrete specimens under axial compression are shown through Fig.16. Under initial stages of loading, cracks appeared on the surface of the specimens. With increase in loading, the cracks propagated towards the interior of the specimens with considerable increase in their size. In case of ternary blended concrete specimens, the cracking process was slowed down because of the enhancement in the bond between the aggregates and matrix as a result of the incorporation of nano silica and zeolite. With fibers reinforced ternary blended concrete specimens, the initiation and propagation of cracks were retarded because of the stitching action of the steel fibers used.

3.1.2. Split Tensile Strength

The influence of steel fibers on cylinder split tensile strength is shown through Fig.17. The results have been

averaged for three specimens. An increase of 21.16% has been observed for the ternary concrete mix with 1.5% volume fraction of steel fibers [ZNSF-3]. The ternary concrete mix with 0.5% volume fraction of steel fibers showed an increase of 13.69% compared to control specimen, 10.34% compared to concrete with zeolite [Z], 7.54% compared to concrete with zeolite and nano silica [ZNS] in respect of tensile strength. The ternary concrete containing nano silica and zeolite exhibited an increase of 10.78% when compared to the control concrete specimen and the specimen containing only zeolite. An increase of 2.59% has been shown by the ternary concrete containing nano silica and zeolite in comparison with the control concrete specimen and the specimen containing only zeolite. The concrete specimen containing only zeolite showed an increase of 3.32% when compared to control concrete specimen. The increase in tensile strength for concrete specimen containing fibers may be due to bridging action of steel fibers as well as the improved bond between the matrix and the fibers. the ternary concrete containing nano silica and zeolite showed enhanced split tensile strength due to the improved bond at the interface between the matrix and the aggregates as well as the pore refinement caused by the nano silica along the interfacial transition zone. The concrete containing zeolite showed a n increase in split tensile strength due to fact that the addition of zeolite caused densification of the matrix and reductionin porosity.

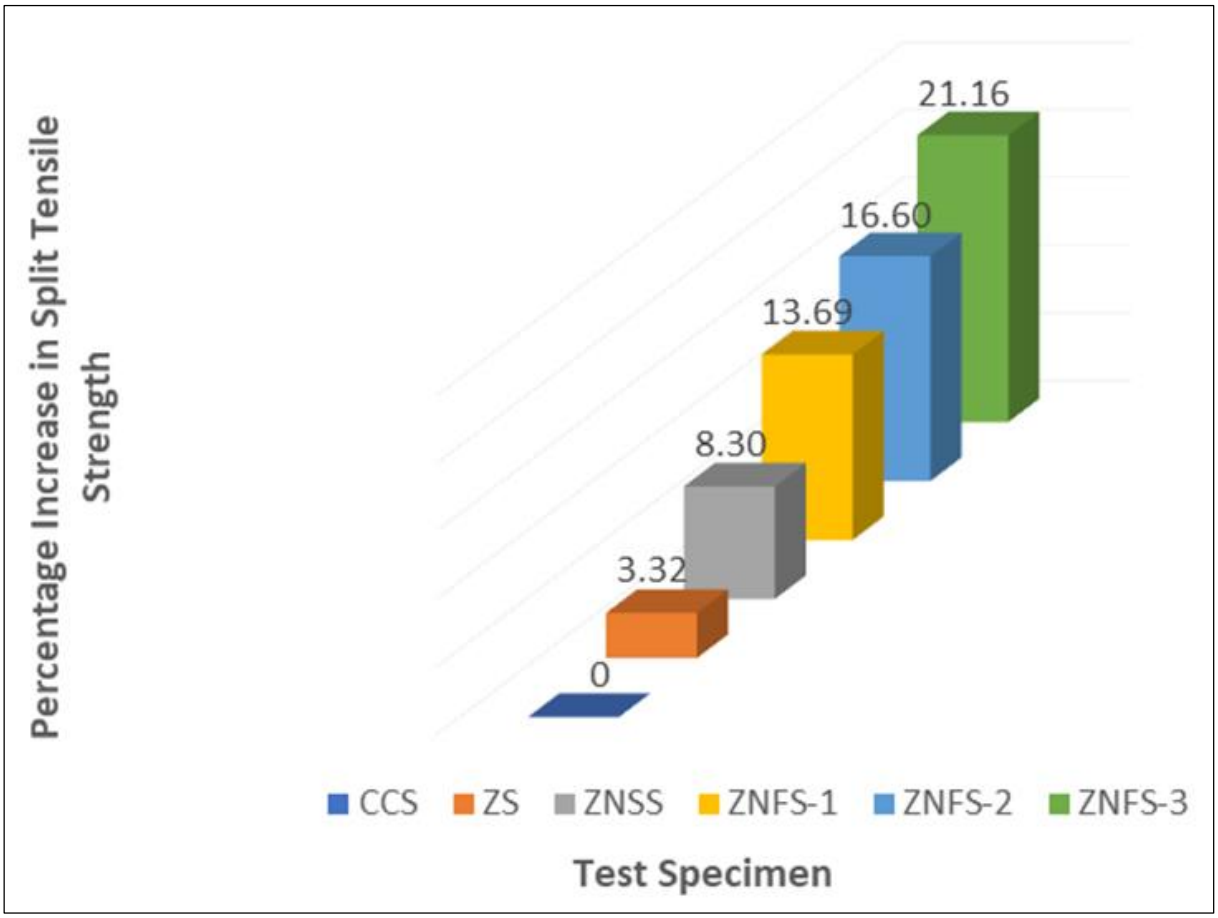

Figure 17. Effect of Steel fibers on Split Tensile Strength

Failure Modes

The failure modes of ternary blended concrete specimens with and without fibers under indirect tension are shown through Fig.18. Longitudinal splitting failure was observed in the control specimen. The ternary blended concrete specimens with and without fibers also showed the same mode of failure as the control specimen except that the failure occurrence time was more. This may be attributed to the improved bond at the interfacial transition zone as well as the bridging action of the steel fibers used. It has also been observed that the size of crack was less with increase in volume fraction of steel fibers.

Figure 18. Failure Mode of Cylinder Specimens Under Indirect Tension

3.1.3. Modulus of Elasticity

The influence of steel fibers on cylinder elasticity of modulus is shown through Fig.19. The results have been averaged for three specimens. An increase of 13.71% has been observed for the ternary concrete mix with 1.5% volume fraction of steel fibers [ZNSF-3]. The ternary concrete mix with 0.5% volume fraction of steel fibers showed an increase of 11.66% compared to control specimen, 6.02% compared to concrete with zeolite [Z], and 4.08% compared to concrete with zeolite and nano silica [ZNS]. The ternary concrete containing nano silica and zeolite exhibited an increase of 7.92% and 2.35% when compared to the control concrete specimen and the specimen containing only zeolite. The concrete specimen containing only zeolite showed an increase of 5.64% when compared to control concrete specimen. The increase in elasticity modulus for concrete specimens containing fibers may be due to the bridging effect of steel fibers as well as the improved bond between the matrix and the fibers. The ternary concrete containing nano silica and zeolite showed an enhanced modulus of elasticity due to improved bond at the interface between the matrix and the aggregates as well as the pore refinement caused by nano silica along the interfacial transition zone. The concrete containing zeolite showed an increase in modulus of elasticity owing to fact that the addition of zeolite caused densification of the matrix and reduction in porosity.

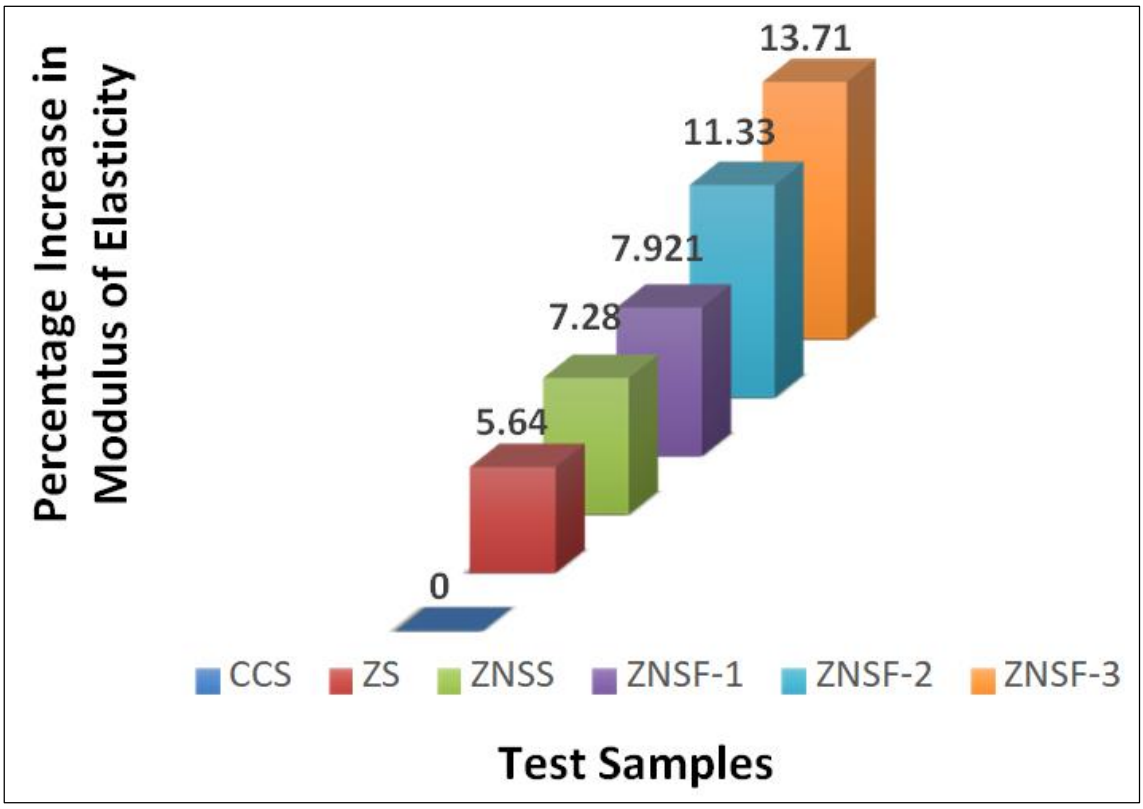

Figure 19. Effect of Steel fibers on Modulus of Elasticity

Failure Modes

The failure modes of ternary blended concrete with and without steel fibers are shown in Fig.20. Longitudinal crack extending from top to bottom of the specimen was observed in the initial stages of loading. With increase in loading, new cracks formed parallel to the earlier formed longitudinal cracks because of lateral dilation experienced by the specimens. The same trend was observed in specimens made with ternary blended concrete containing fibers. It has been noted that the specimens made of concrete involving only zeolite and nano silica plus zeolite experienced higher strain levels compared to the control specimen. The specimens made with fiber reinforced ternary blended concrete exhibited still higher strain levels because of an internal confinement mechanism caused by the micro fibers.

Figure 20. Effect of Steel fibers on Modulus of Elasticity

3.1.4. Modulus of Rupture

The influence of steel fibers on prism flexure strength shown through Fig.21. The results have been averaged for three specimens. An increase of 23.56% has been observed for the ternary concrete mix with 1.5% volume fraction of steel fibers [ZNSF-3]. The ternary concrete mix with 0.5% volume fraction of steel fibers showed an increase of 17.24% compared to control specimen, 14.60% compared to concrete with zeolite [Z], 3.90% compared to concrete with zeolite and nano silica [ZNS]. The ternary concrete containing nano silica and zeolite exhibited an increase of 12.83% when compared to the control concrete specimen and the specimen containing only zeolite. An increase of 10.29% has been shown by the ternary concrete containing nano silica and zeolite in comparison with the control concrete specimen and the specimen containing only zeolite. The concrete specimen containing only zeolite showed an increase of 12.83% when compared to control concrete specimen. The increase in flexural strength for concrete specimen containing fibers may be due to the stitching action of steel fibers as well as the improved bond between the matrix and the fibers. The ternary concrete containing nano silica and zeolite showed an increase in flexural strength due to the improved bond at the interface between the matrix and the aggregates as well as the pore refinement caused by nano silica along the interfacial transition zone. The concrete containing zeolite also showed an increase in flexural strength because of the fact that the addition of zeolite caused densification of matrix as well as reduction in porosity.

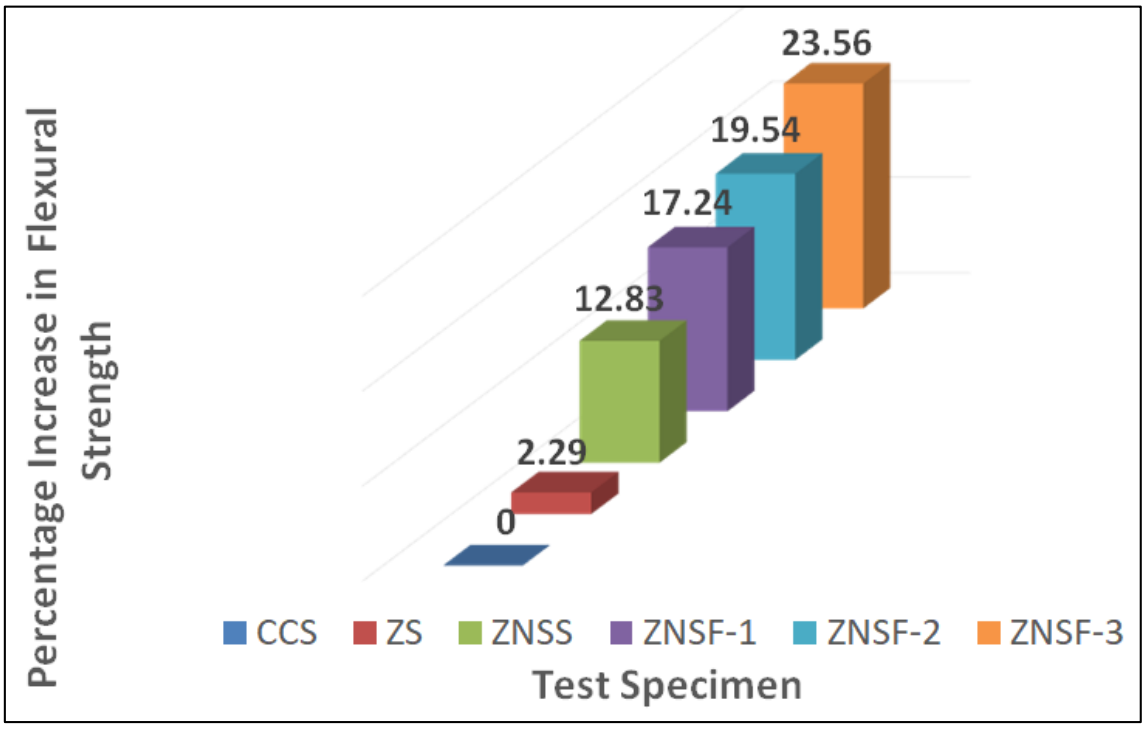

Figure 21. Effects of Steel Fibers on Modulus of Rupture

(a) Specimen-CC (b) Specimen-Z

(c) Specimen-ZNS (d) Specimen-ZNSF-1

(e) Specimen-ZNSF-2 (f) Specimen-ZNSF-3

Figure 22. Failure Mode of Prism Specimens

Failure Modes

The prism specimens were tested under four-point bending over a span of 400mm. In the case of control specimen, a single crack was formed at mid - span in the early stages of loading. The crack size increased with an increase in loading and the failure took place suddenly at ultimate level. The same pattern of failure has been observed in specimens made with ternary blended concrete with and without fibers. It has been noted that the failure was delayed and the crack growth was retarded due to the presence of micro-reinforcement and the densification of the matrix because of the inclusion of nano silica.

3.1.5. Water Absorption

The percentage water absorption of control concrete, zeolite-based concrete, concrete containing nano silica - zeolite combine and fiber reinforced ternary concrete has been summarized in Table 14. It can be seen from the results that introduction of zeolite in isolation as well as zeolite combined with nano silica cause an apparent reduction in water absorption in concrete compared to the control mix. It can also be seen that introduction of steel fibers also caused a positive impact in decreasing the water absorption of concrete. With control concrete as reference, the percentage reduction in water absorption shown by other concrete mixers is illustrated in Fig.23. Concrete containing 10% zeolite,1% nano silica and 1.0% volume fraction of steel fibers [ZNSF-2]. Showed the maximum reduction in water absorption of 38.38%. The reduction in water absorption may be due to the densification of the transition zone caused by the inclusion of zeolite, nano silica and steel fibers in isolation or in combination.

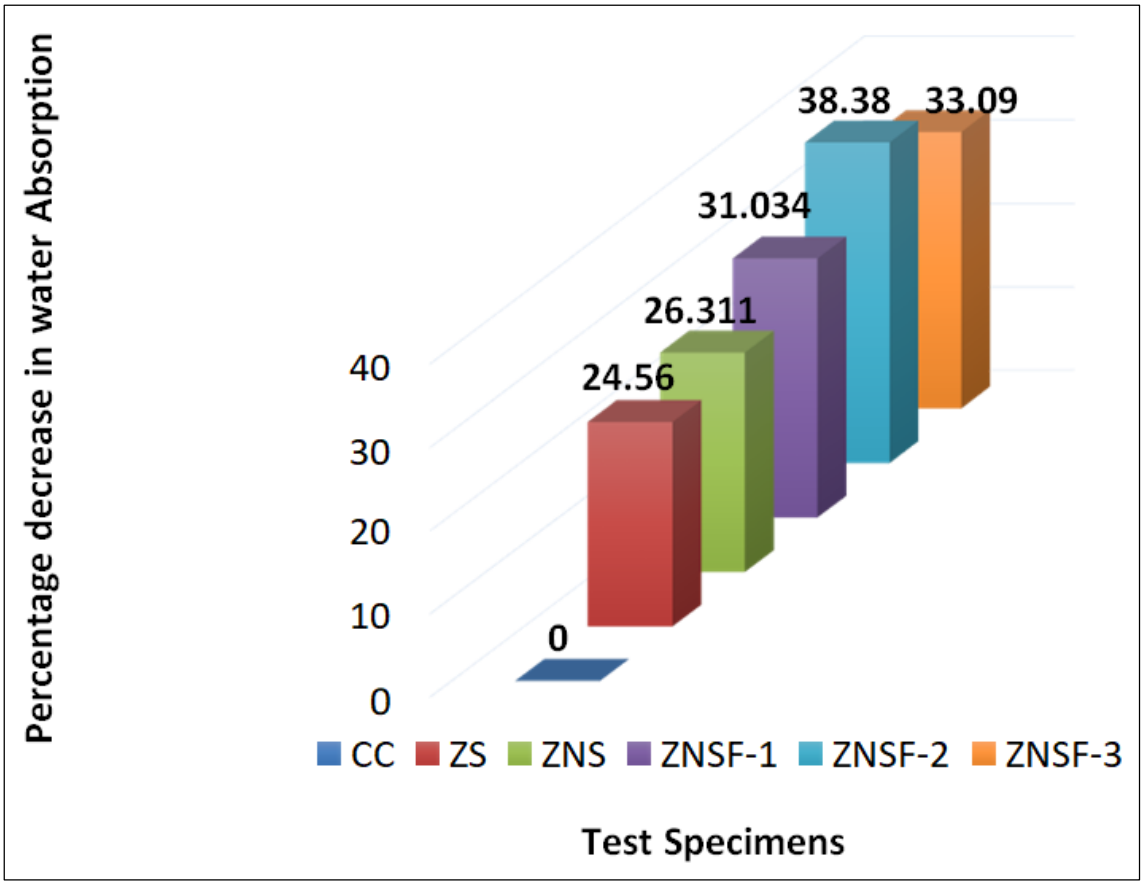

Figure 23. Effects of Steel Fibers on water Absorption

3.1.6. Porosity

The reduction in percentage of voids relating to the control concrete, zeolite-based concrete, concrete with nano silica - zeolite combine and the fiber reinforced ternary blended concrete are furnished in Table 14 and Fig.24. It is evident from the results presented that the addition of zeolite, inclusion of nano silica and zeolite and incorporation of steel fibers have appreciable effect on the porosity of concrete mixes. The reduction in porosity has been caused by the densification of the matrix due to the addition of zeolite and nano silica. The percentage of voids got reduced with increase in the volume fraction of steel fibers. The refinement of the pore structure caused by the fiber addition would have resulted in the decrease of porosity. The maximum reduction in 42.78% of voids has been experienced with concrete containing 1% nano silica ,10% zeolite and 1.0%volume fraction of steel fibers [ZNSF-2].

Table 14. Porosity Test Results

Test Specimen	Volume of permeable pore space (voids)%
CC	2.40
ZS	1.775
ZNS	1.747
ZNSF-1	1.575
ZNSF-2	1.373
ZNSF-3	1.482

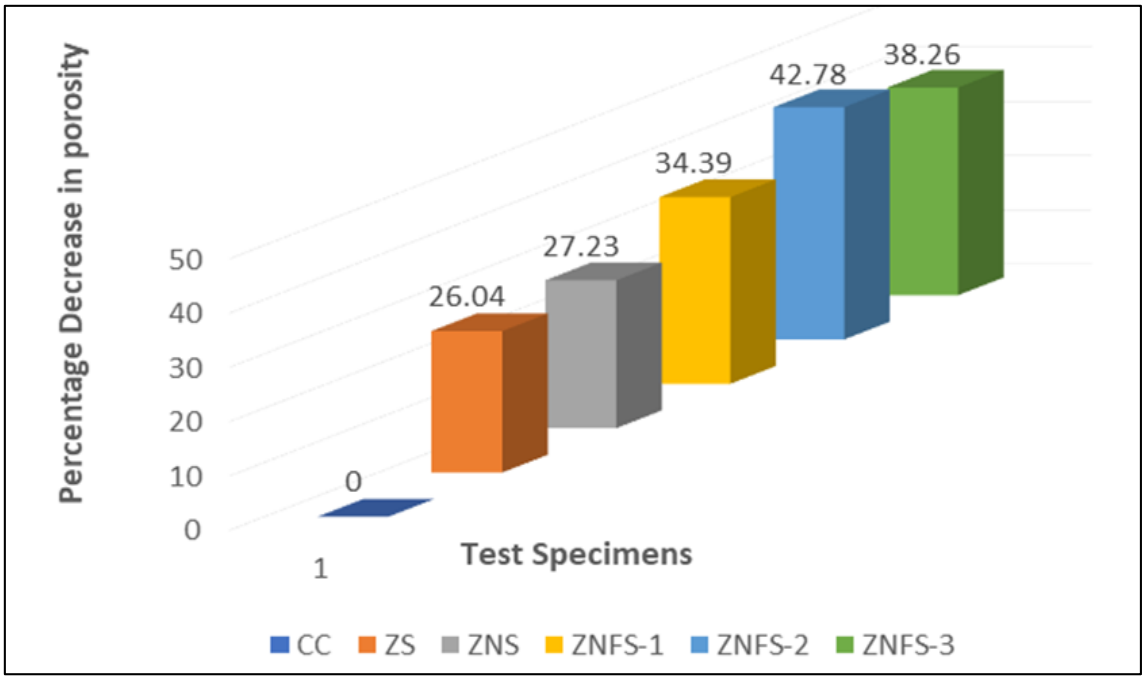

Figure 24. Effects of Steel Fibers on porosity

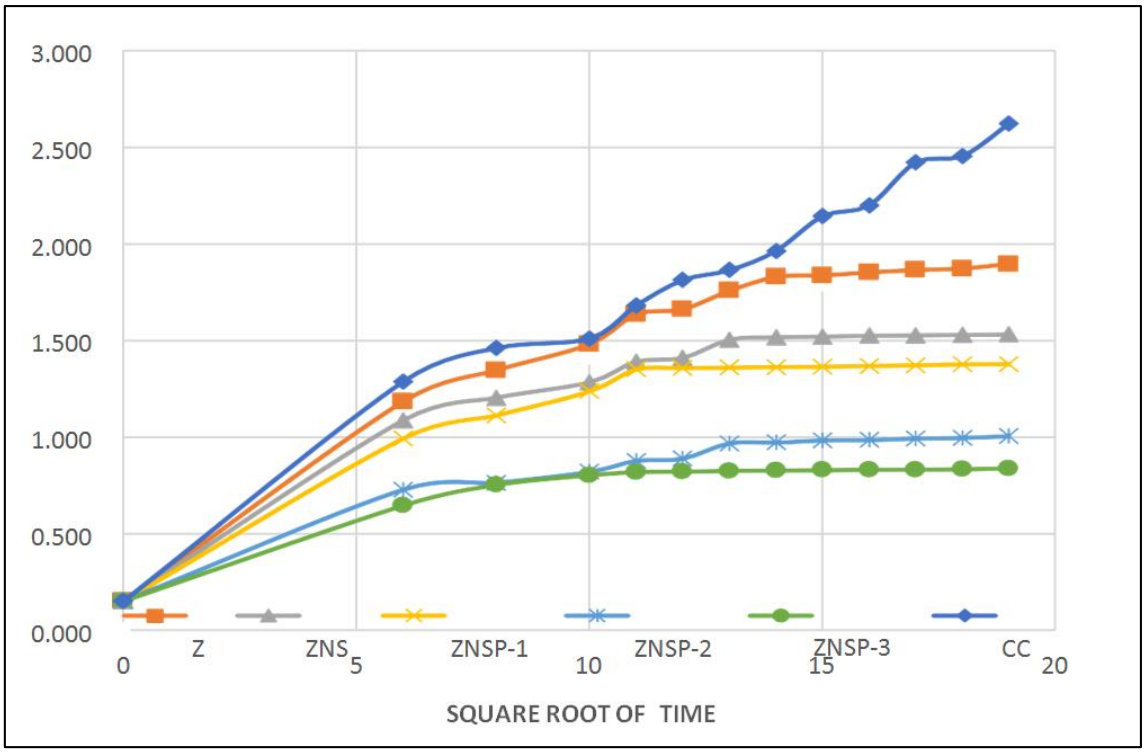

Figure 25. Effects of Steel Fibers on Sorptivity

3.1.7. Sorptivity

The effect of steel fiber addition on the sorptivity of ternary blended concrete is shown through Fig.25 & Table 15. The reduction in sorptivity has been observed for fibrous as well as non- fibrous concrete. the maximum reduction has been noted with concrete containing 10% zeolite,1% nano silica and 1.0% volume fraction of steel fibers. The percentage reduction increased with the increase in the volume fraction of steel fibers. The prime reason for reduction in Sorptivity may be due to the reduced porosity of concrete as well as the refined pore structure of concrete. Addition of micro filler, nano filler

and steel fibers would have resulted in improved bond between the matrix and the fibers as well as the matrix and aggregates. This probably would have led to noticeable reduction in porosity.

Table 15. Sorptivity Test Results

Test Specimen	Sorptivity[mm/min]
CC	0.138
ZS	0.097
ZNS	0.077
ZNFS-1	0.068
ZNFS-2	0.048
ZNFS-3	0.061

4. Conclusions

1. Incorporation of zeolite enhanced the compressive strength by 7.98%, split tensile strength by 3.32%, flexural strength by 2.29% and modulus of elasticity by 5.64% compared to the control concrete.
2. Inclusion of nano silica - zeolite combine resulted in an increase of 10.79% in compressive strength, 10.78% in split tensile strength, 12.83% in flexural strength and 7.29% in modulus of elasticity in comparison with the control concrete
3. Incorporation of steel fibers improved the compressive strength by 25.95%, split tensile strength by 21.60%, flexural strength by 23.56% and modulus of elasticity by 13.72%.
4. Inclusion of steel fibers has significant impact on the durability properties of ternary blended concrete. A reduction of 38.38% in water absorption and 42.78% in porosity have been obtained.
5. In general, inclusion of micro filler, nano filler and micro-reinforcement noticeably improved the overall performance of concrete.

REFERENCES

[1] Nasr, Danial, Behforouz, Babak, Borujeni, Pouria Rezaei, Borujeni, Sajjad Afzali, Zehtab, Behnam, "Effect of Nano-Silica on Mechanical Properties and Durability of Self-Compacting Mortar Containing Natural Zeolite", Construction and Building Materials, 229,116888, 2019. DOI: 10.1016/j.conbuildmat.2019.116888

[2] Yining Ding, Wolfgang Kusterle, "Compressive Stress–Strain Relationship of Steel Fibre Reinforced Concrete at Early Age", Cement and Concrete Research 30, 1573-1579, 2000. DOI: 10.1016/S0008-8846(00)00348-3

[3] Gülşan, Mehmet Eren, Alzeebaree, Radhwan, Rasheed, Ayad Ali, Anıl, Kurtoğlu, Ahmet Emin, "Development of Fly Ash/Slag Based Self-Compacting Geopolymer Concrete Using Nano-Silica and Steel Fiber'. Construction and Building Materials, 211, 271-83, 2019. DOI: 10.1016/j.conbuildmat.2019.03.228

[4] Peng Zhang, Jinyi Wan. "Influence of Nano-Silica on Properties of Fresh and Hardened High-Performance Concrete", Construction and Building Materials, Vol. 148, 2019. DOI: 10.1016/j.conbuildmat.2017.05.059.

[5] Seyed Mohammadhossein Razavi, Hadi Nazarpour, Morteza Hosseinali Beygi. "Investigation of the Efficacy of Nano-Silica on Mechanical Properties of Green-Engineered Cementitious Composite Containing High Volume Natural Zeolite". Construction and Building materials, Vol.291, 2021, DOI:10.1016/j.conbuildmat.2021.123246

[6] Zemei Wu, Kamal Heni Khayat, Caijun Shi, "Effect of Nano-Silica Particles and Curing Time on Development of Fiber Matrix Bond Properties and Microstructure of Ultra-High Strength Concrete," Cement and Concrete Research, Vol. 95, pp. 247-256, 2017, DOI: 10.1016/j.cemconres.2017.02.031.