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Structural Performance of Ternary Blended Concrete Beams Involving Nano-Silica and Zeolite & Micro-reinforcement

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Beam deflection; first crack load; Ultimate load; Ductility; Energy capacity; Yield load.

Abstract

The finding of a research investigation on the structural behavior of ternary blended concrete beams involving Nano-Silica, Zeolite, and micro reinforcement has been presented in this paper. The optimum combination of nano-silica and zeolite has been obtained through preliminary studies. Dramix steel fibers have been added in varying volume fractions of 0.5%, 1.0%, and 1.5%. Six beams' specimens of overall dimensions 150X250X3000mm were evaluated for their flexural capacity in a standard testing frame. One beam was made out of control concrete. The remaining five beams were fabricated with ternary blended concrete beams involving micro-reinforcement. The beam specimens were examined under static loading conditions. The study parameters comprise load and deflection at various loading stages. The beams were also examined for their ductility and energy capacity. It is evident from the observations made that the addition of steel fibers caused a significant positive impact on the overall performance of the ternary blended concrete beams.

Disciplinary: Civil Engineering and Technology.

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1 Introduction

In recent years, ultra-fine materials are introduced into concrete to achieve particle packing thereby resulting in improved performance for use under varying environmental conditions. Some ultrafine materials include nano silica, nano alumina, nano clay, Zeolite, Alccofine (Ponraj et al., 2021) and Silica fume. Fibres, steel as well as synthetic, find a place in concrete to impart ductility characteristics for its use where energy absorption capacity is a mandatory demand.

A significant improvement has been caused in the physical properties and the static behaviour of RC beams by replacing cement with 10%MS and 1%NS in presence of a 2% volume fraction of steel fibres (Eisa et al., 2020). The utilization of hybrid fibres enhanced the flexural strength and fracture energy of UHPC beams (Wei et al., 2021). RC beams reinforced with crimped and hooked steel fibres exhibited higher flexural toughness, improved ductility, and reduced crack width and spacing when compared to non-fibrous beams (Sakthivel et al. 2020). The UHPFRC beams cured at room temperature showed good performance and flexural behaviour as those cured at high temperatures (Huang et al. 2021). The inclusion of 1% volume fraction of hybrid fibres enhanced the mechanical properties, the failure load, the flexural toughness and the ductility of bagasse ash blended HPC beams (Kumar et al.2019). The use of GFRP rebars in UHPFRC beams resulted in enhanced load carrying capacity, post-cracking stiffness and deformability (Yoo et al 2016).

2 Test Materials

2.1 Materials

Ordinary Portland Cement (OPC) 53-grade (IS: 12269-2013) was used throughout the experimental study. Natural river sand was used as fine aggregate. Crushed granite was used as coarse aggregate. Nano silica and Zeolite were used as cement replacement materials. The characteristics of all the materials used are provided in Table 1 and Table 2. A Superplasticizer Conplast SP 430 was used for the preparation of the control specimens as well as the beam specimens. High Yielding Strength Deformed (HYSD) bars were used for the main reinforcement and shear reinforcement.

Table 1: Properties of Aggregate

Material	SpecificGravity	Gradingzone
Coarse aggregate	2.80	Angularshape
Fine aggregate	2.67	Zone III

Table 2: Properties of Materials

Material	SpecificGravity	Specific SurfaceArea
Cement	3.14	300
Nano-Silica	1.2	202
Zeolite	1.89	20

2.2 Mix Proportions

The control concrete mix used in the present investigation was designed to have a target strength of 39 MPa the mix contains. The concrete consisted of 387 kg/m^{3}of cement,654 kg/m^3 of fine aggregate and 1219 kg/m^3 of coarse aggregate. A w/cm ratio of 0.48 was adopted for the control concrete and ternary blended concrete with and without fibres. The desired slump in each case has been achieved through the use of SP in appropriate dosages.

Table 3: 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%

2.3 Control Specimen

The absolute volume method recommended by ACI 318-18 was used to compute the quantities of materials. Cubes of size 150X150X150mm have been used for estimating the compressive strength, Prism's specimens of size 100X100X500 mm were cast and tested for determining the modulus of rupture and Cylinder specimens of size 150X300mm were cast and tested for finding the modulus of elasticity and for evaluating the split tensile strength. The nomenclature of beam specimens is presented in Table 4.

Table 4: Designation of Test Beams

Designation	Description
CCS	Control Specimen
ZS	Specimen with 10% Zeolite (Z)
ZNSS	Specimen with 10% Zeolite (Z),1% Nano-Silica (NS)
ZNFS-1	Specimen with 10% Zeolite (Z), 1% Nano-Silica (NS) and 0.5%Steel fiber
ZNFS-2	Specimen with 10% Zeolite (Z), 1% Nano-Silica (NS) and 1.0%Steel fiber
ZNFS-3	Specimen with 10% Zeolite (Z), 1% Nano-Silica (NS) and 1.5%Steel fiber

2.4 Beam Specimens

A total of six beams were used in the present investigation. One beam was made with control concrete. One beam was made with Zeolite based concrete. One beam was made with ternary blended concrete containing nano-silica and Zeolite. Three beams were fabricated with ternary blended concrete containing steel fibres in varying volume fractions. The beam specimens were of size 150X250X3000mm. A reinforced index of 0.603% was adopted for the beam specimens. The transfers steel consisted of 8 mm-diameter 2-legged links at 125 mm c/c. The details of beams specimens are presented in Figure 1.

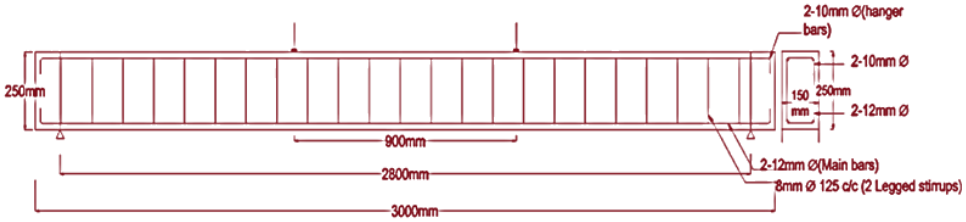


Figure 1: Reinforcement Details of Test Beam

Table 5: Details ofBeam Specimens

Beam Designation	Steel ratio	Steel volume fraction (%)	Zeolite (%)	Nano-Silica (%)
CCS	0.603	0	0	0
ZS	0.603	0	10	0
ZNSS	0.603	0	10	1
ZNFS-1	0.603	0.5	10	1
ZNFS-2	0.603	1.0	10	1
ZNFS-3	0.603	1.5	10	1

2.5 Test Setup

The RC beam specimens were subjected to static loading in a loading frame of capacity 1000 kN until failure. Four-point bending test was conducted over a span of 2800 mm. The beam specimen was mounted on the roller at one end and a hinge at another end. A stiff distribution girder was used to facilitate the application of two-point loading. The displacements were measured at desired locations using dial gauges having 0.01 mm precision. The crack width was measured using a crack detection microscope of 0.02 mm accuracy. The crack growth and propagation were monitored throughout the loading. The test setup for static loading of the beam is shown in Figure 2.

Figure 2: Static Loading Arrangement and Instrumentation

3 Result and Discussion

3.1 Control Specimens

The results of all the control specimens pertinent to physical properties such as compressive strength, modulus of rupture, split tensile strength, modulus of elasticity are presented in Table 6.

Table 6: Test Results of Control Specimens

Specimens	Compressivee Strength (MPa)	Modulus of Elasticity (GPa)	Modulusof Rupture (MPa)	Split Tensile Strength (MPa)
CCS	39.83	31.56	5.22	4.82
ZS	41.86	33.34	5.34	4.98
ZNSS	42.89	33.86	5.89	5.22
ZNFS-1	45.20	34.06	6.12	5.48
ZNFS-2	47.40	35.24	6.24	5.62
ZNFS-3	42.49	35.89	6.45	5.84

3.2 Beam Specimens

In this research study, six full-scale RC beams specimens of overall size 150X250X3000mm were cast and tested. The longitudinal reinforcement consisted of two numbers of 12 mm diameter bars. Two numbers of 10 mm diameter were used as hangar bars. Each beam was provided with 8mm diameter two-legged stirrups at 125 mm c/c spacing as transferee steel. The beams were made with M30 grade concrete using OPC 53-grade cement. The reinforcement details of the test beam are shown in Figures 3 & 4. The experimental results are furnished in Table 7.

Figure 3: Steel Cages.

Figure 4: Beam Specimen

3.3 Load-Defection Relationship

The load-deflection responses of the tested beams are shown in Figure 5. The load-deflection curves were linear up to the occurrence of the first cracking. The gradient of the load-deflection plots was also quite high. With increased loading, the gradient of the load-deflection plots decreased as a result of the formation of cracks. On further loading, the longitudinal reinforcement started to yield. The number of cracks developed also showed an uptrend. Beyond the yield stage, the slope of the response curves decreased significantly. The beams also showed higher deformations. This trend continued until the peak load was reached. After this stage, the applied load started to decrease.

Table 7: Principal Experimental Results

Beam Designation	First Crack Load (kN)	Deflectionat First Crack Load (mm)	Yield Load (kN)	Deflection at Yield Load (mm)	UltimateLoad (kN)	Deflectionat Ultimate Load (mm)
CCS	15.5	2.42	33	7.91	50	13.37
ZS	17.5	2.80	34	8.61	52.5	15.77
ZNSS	20	3.20	35.8	8.9	55	16.48
ZNFS-1	22.5	3.44	38.8	9.97	60	19.33
ZNFS-2	22.5	3.58	41.5	10.95	65	21.71
ZNFS-3	25.5	3.76	42.6	11	70	24.98

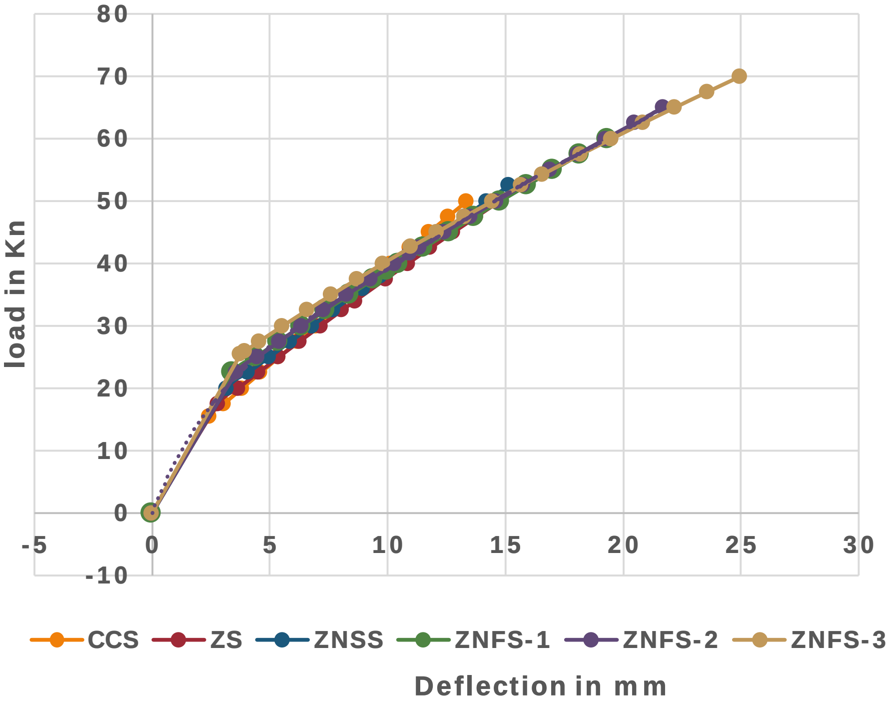


Figure 5: Load Deflection plots of Beams

A maximum increase of 64.51% in the first crack load was shown by the ternary blended concrete beam having 1.5% volume fraction of steel fibres (ZNFS-3) over the control beam CC. An increase of 16.8% was exhibited by the beam specimen ZS over the CC beam. The beam specimen ZNSS showed an increase of 14.28% and 32.78% in comparison with the beam specimens ZS and CC. The beam specimen ZNFS - 2 showed an increase of 4.65%,12.50%, 28.57% and 45.16% when compared to the beam specimens ZNFS - 1, ZNSS, ZS and CC. The percentage gain in the first crack load is shown in Figure 6.

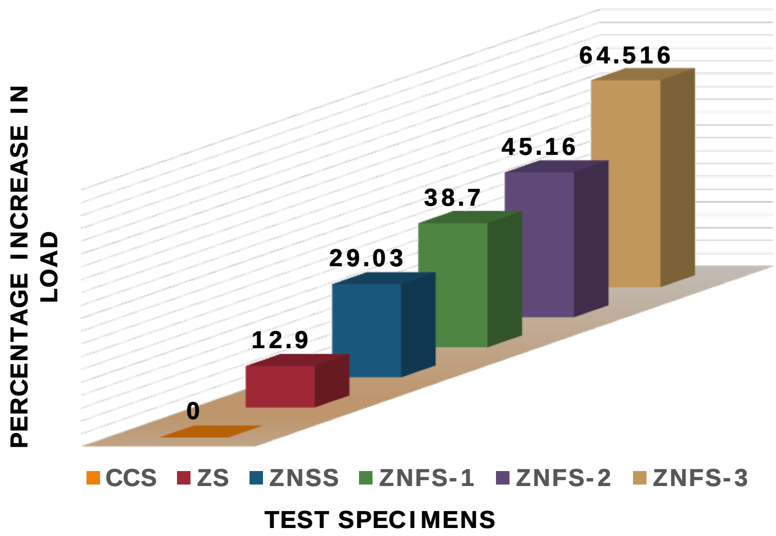


Figure 6: Effect of Steel Fibers on First Crack Load

3.4 Deflection at First Crack Load

A maximum increase of 55.37% in the first crack load was shown by the ternary blended concrete beam having a 1.5% volume fraction of steel fibres (ZNFS-3) over the control beam CC. An increase of 15.7% was exhibited by the beam specimen ZS over the CC beam. The beam specimen ZNSS showed an increase of 14.28% and 32.23 % in comparison with the beam specimens ZS and CC. The beam specimen ZNFS - 2 showed an increase of 4.06%,11.87%, 28.57% and 47.89% when compared to the beam specimens ZNFS - 1, ZNSS, ZS and CC. The percentage increase in deflection is provided in Figure 7.

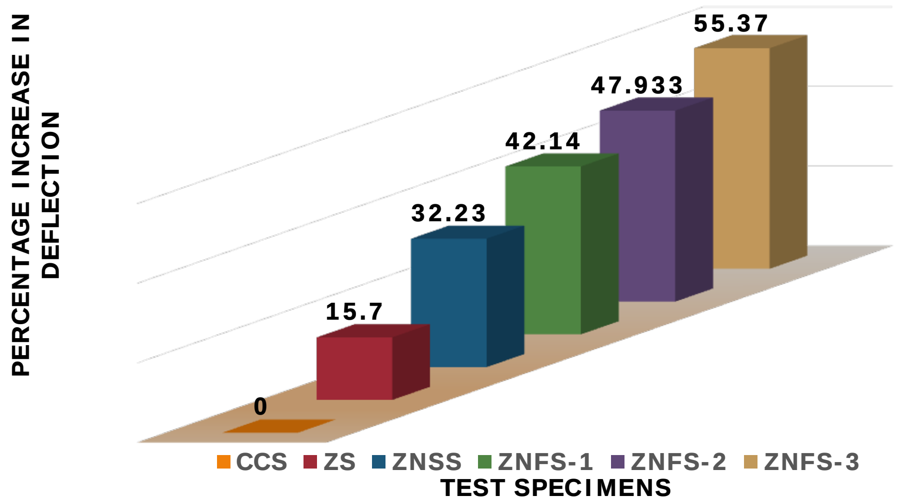


Figure 7: Effect of Steel Fibers on a deflection at First Crack Load

3.5 Moment-Curvature Relationship

The moment-curvature relations of the beam specimens are shown in Figure 8. It has been noticed that up to the first crack, M - Phi curves were linear having high slopes. With increased loading, the slope of the curves started decreasing gradually up to the yield stage. The same trend continued up to the ultimate stage.

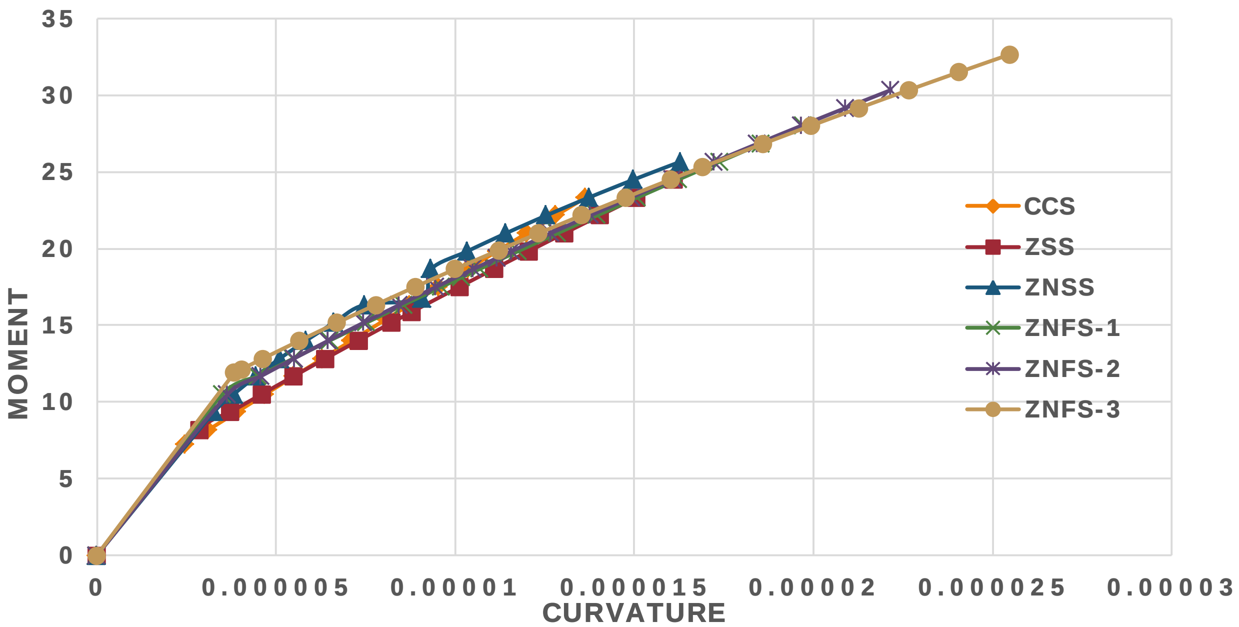


Figure 8: Moment Vs Curvature.

3.6 Yield Load

The yield load was obtained from the load-deflection curve. A maximum increase of 29.24% in yield load was shown by the ternary blended concrete beam having a 1.5% volume fraction of steel fibres (ZNFS-3) over the control beam CC. An increase of 3.03% was exhibited by the beam specimen ZS over the CC beam. The beam specimen ZNSS showed an increase of 5.47% and 8.66% in comparison with the beam specimens ZS and CC. The beam specimen ZNFS - 2 showed an increase of 8.511%,15.99%, 22.23% and 25.93% when compared to the beam specimens ZNFS - 1, ZNSS, ZS and CC. The percentage increase in yield load is furnished in Figure 9.

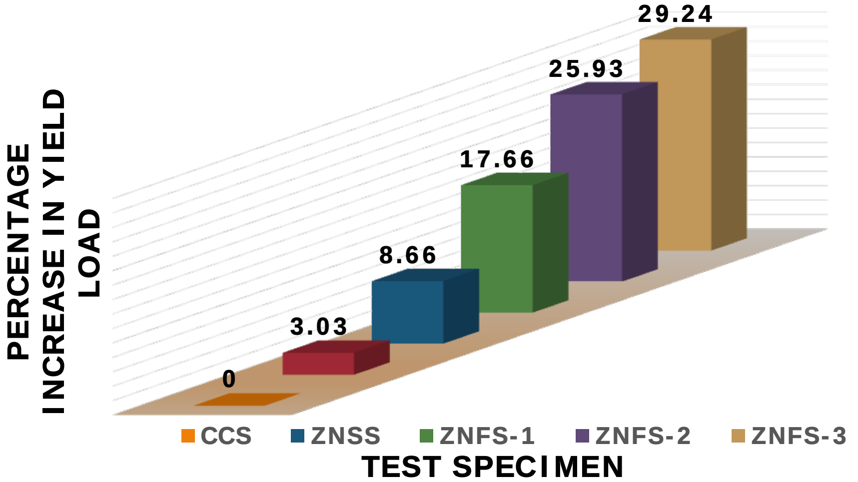


Figure 9: Effect of Steel Fibers on Yield Load

3.7 Deflection at Yield Load

The deflection at yield load was obtained from the load-deformation plots. A maximum increase of 39.06% in yield load was shown by the ternary blended concrete beam having a 1.5% volume fraction of steel fibres (ZNFS-3) over the control beam CC. An increase of 8.84% was exhibited by the beam specimen ZS over the CC beam. The beam specimen ZNSS showed an increase of 3.36% and 12.51% in comparison with the beam specimens ZS and CC. The beam specimen ZNFS - 2 showed an increase of 9.82%,23.03%, 27.17% and 38.43% when compared to the beam specimens ZNFS - 1, ZNSS, ZS and CC. The percentage increase in deflection is provided in Figure 10

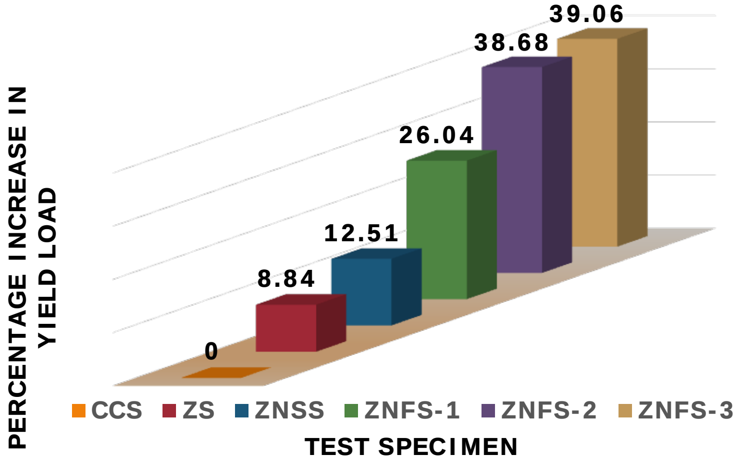


Figure 10: Effect of Steel Fibers on Deflection at Yield Load.

3.8 Peak Load

The Peak load was obtained corresponding to the stage of loading beyond which the beam cannot resist any additional deformation at the same load intensity. A maximum increase of 40.0% in ultimate load was shown by the ternary blended concrete beam having a 1.5% volume fraction of steel fibres (ZNFS-3) over the control beam CC. An increase of 5.0% was exhibited by the beam specimen ZS over the CC beam. The beam specimen ZNS showed an increase of 4.76% and 10.0% in comparison with the beam specimens ZS and CC. The beam specimen ZNFS-2 showed an increase of 8.33%, 18.18%, 23.80% and 30.0% when compared to the beam specimens ZNFS-1, ZNSS, ZS and CC. The percentage gain in peak load is furnished in Figure 11.

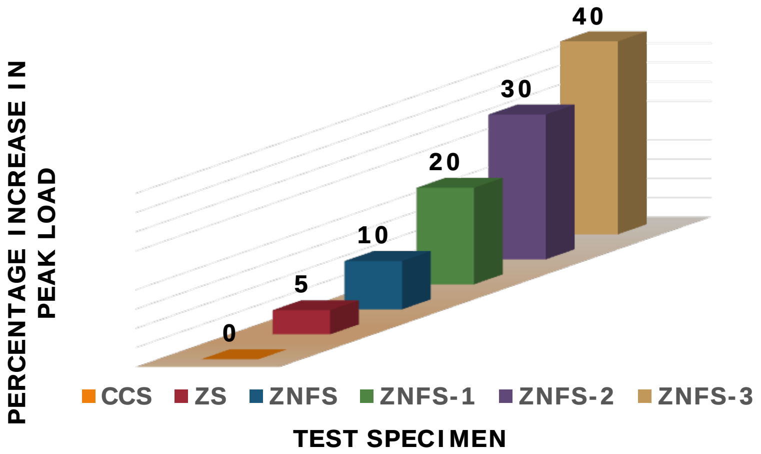


Figure 11: Effect of Steel Fibers on Peak Load

3.9 Deflection at Peak Load

A maximum increase of 86.63% in ultimate deflection has been observed for the ternary blended concrete beam with a 1.5% volume fraction of steel fibres (ZNFS-3) over the control beam CC. An increase of 17.95% was exhibited by the beam specimen ZS over the CC beam. The beam specimen ZNSS showed an increase of 4.50% and 23.06% in comparison with the beam specimens ZS and CC. The beam specimen ZNFS - 2 showed an increase of 12.31%, 31.73%, 37.66% and 62.37% when compared to the beam specimens ZNFS-1, ZNSS, ZS and CC. The percentage increase in deflection is provided in Figure 12

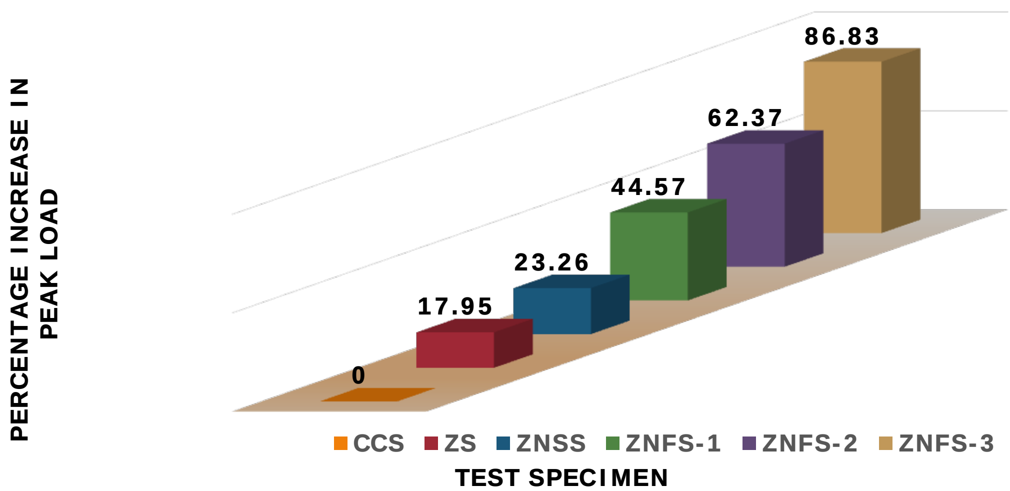


Figure 12: Effect of Steel Fibers on Deflection at Peak Load

3.10 Crack Behaviour

The width of the crack, spacing of cracks and the number of cracks is presented in Table 8. During the initial stages of loading, fine vertical cracks formed in the constant moment section. As the load was increased, additional vertical cracks formed along the beam span and the existing vertical cracks propagated upwards towards the top of the beam. When the load was increased further, the progressing cracks widened and small branches formed near their tip. The beam specimen made out of control concrete showed larger crack width at the ultimate stage. The beam specimen made out of Zeolite-based concrete and that made out of ternary blended concrete containing nano-silica and Zeolite showed reduced crack width at the same load level of the control beam. The inclusion of steel fibres allowed the beams to experience large deformation prior to failure. The beam specimens incorporated with the varying volume of steel fibres exhibited a large number of cracks, reduced crack spacing and increased crack width. This may be attributed to the higher energy absorption capacity of the fibre-reinforced ternary blended concrete. Increasing the steel fibre volume fraction from 0.5% to 2.0% increased the number of cracks but reduced the spacing of cracks as well as the width of cracks.

Table 8: Cracking History and Failure Mode of Tested Beams

Beam Designation	Maximum Width of Crack(mm)	Maximum No. of Cracks	Average Spacings of Cracks (mm)	Mode of Failures
CCS	0.48	14	154	Flexure
ZS	0.46	14	133	Flexure
ZNSS	0.44	16	115	Flexure
ZNFS-1	0.40	19	98	Flexure
ZNFS-2	0.32	21	85	Flexure
ZNFS-3	0.28	22	72	Flexure

3.11 Crack Width

A decrease of 41.66% in crack width at peak load was observed for the ternary concrete beam with 1.5% volume fractions of steel fibres (ZNFS-3). over the control beam CC. over the control beam CC. A decrease of 4.166% was exhibited by the beam specimen ZS over the CC beam. The beam specimen ZNSS showed an increase of 4.54% and 4.166% in comparison with the beam specimens ZS and CC. The beam specimen ZNFS - 2 showed an increase of 25.0%, 37.5%, 43.75% and 50.0% when compared to the beam specimens ZNFS - 1, ZNSS, ZS and CC. The percentage decrease in crack width is furnished in Figure 13.

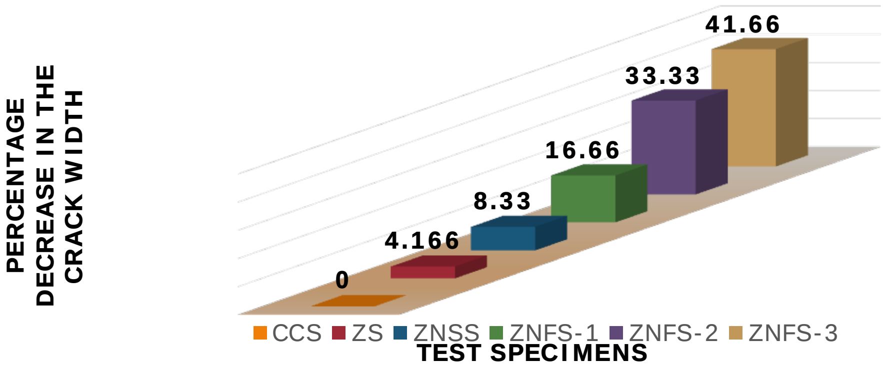


Figure 13: Effect of Steel Fibers on Crack Width

3.12 Number of Cracks

An increase of 57.14% in the number of cracks at ultimate load was observed for the ternary concrete beam with a 1.5% volume fraction of steel fibres (ZNFS-3) over the control beam CC. The beam specimen ZNSS showed an increase of 14.28% in comparison with the beam specimens ZS. The beam specimen ZNFS - 2 showed an increase of 10.52%, 31.25%, 50.0% and 50.02% when compared to the beam specimens ZNFS - 1, ZNSS, ZS and CC. The percentage increase is furnished in Figure 14.

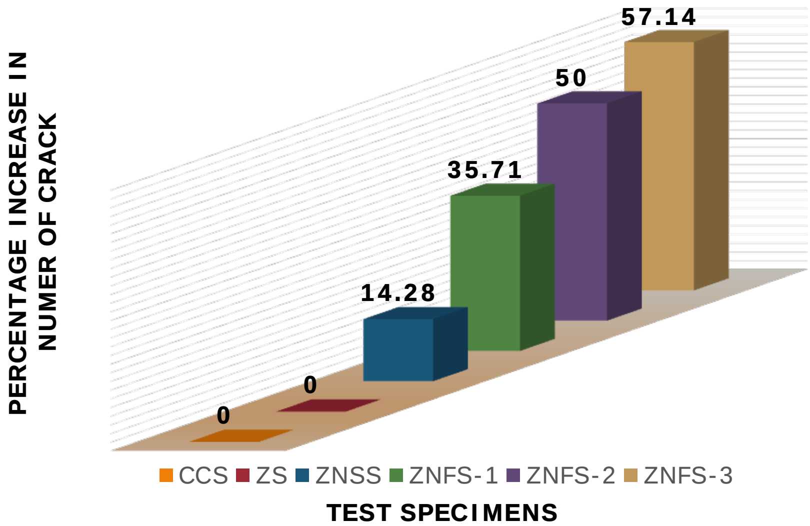


Figure 14: Effect of Steel Fibers on Number of Cracks

3.13 Spacings of Cracks

A decrease of 53.24% in the spacing of cracks at the ultimate load level has been observed for the ternary concrete beam with a 1.5% volume fraction of steel fibres (ZNFS-3). over the control beam CC. The decrease of 13.63% was exhibited by the beam specimen ZS over the CC beam. The beam specimen ZNSS showed an increase of 1.76% and 25.32% in comparison with the beam specimens ZS and CC. The beam specimen ZNFS - 2 showed an increase of 15.29%, 35.29%, 56.47% and 81.17% when compared to the beam specimens ZNFS-1, ZNS, ZNSS and CC. The percentage reduction in the spacing of cracks is provided in Figure 15.

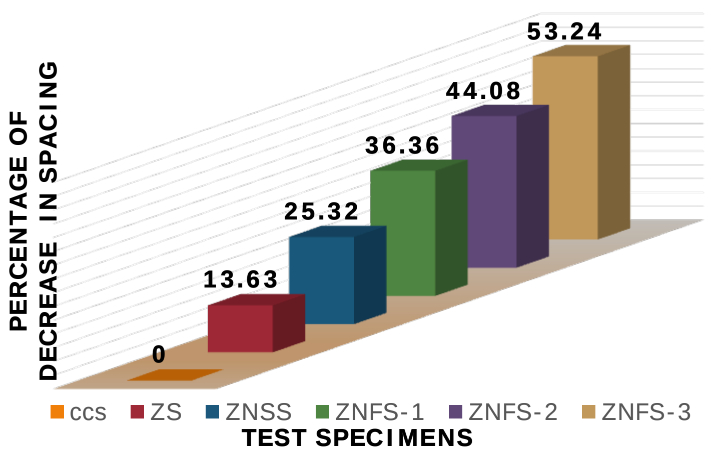
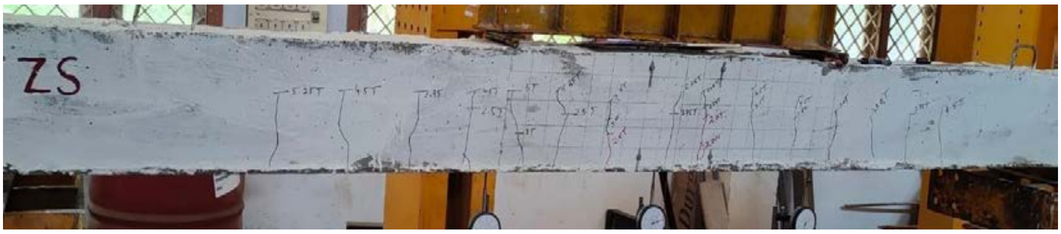


Figure 15: Effect of Steel Fibers on Crack Spacing

(**a**) Crack Pattern of CC Beam

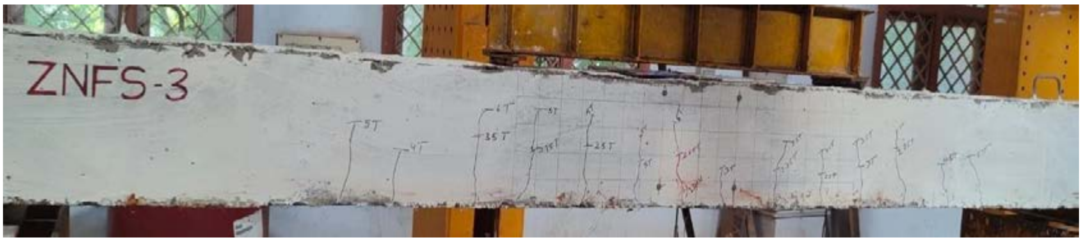


(**b**) Crack Pattern of ZS

(c) Crack Pattern of ZNSS.

(d) Crack Pattern of ZNFS-1.

(e) Crack Pattern of ZNFS-2



(f) Crack Pattern of ZNFS-3

Figure 16: Crack Pattern of Beam specimens

3.14 Deflection Ductility

The ductility indices of beam specimens are furnished in Table 9. An increase in deflection ductility of 34.37% has been observed for the ternary concrete mix with a 1.5% volume fraction of steel fibres (ZNFS-3) over the control beam CC. An increase of 8.40% was exhibited by the beam specimen ZS over the CC beam. The beam specimen ZNSS showed an increase of 0.38% and 8.81% in comparison with the beam specimens ZS and CC. The beam specimen ZNFS-2 showed an increase of 2.26%, 7.83%, 8.24% and 17.33% when compared to the beam specimens ZNFS-1, ZNS, ZS and CC. The percentage increase in deflection ductility is furnished in Figure 22.

Table.9: Deflection Ductility of Beam Specimens

Beam Designation	Deflection Ductility	Deflection Ductility Ratio
CCS	1.690	1.000
ZS	1.832	1.084
ZNSS	1.893	1.061
ZNFS-1	1.939	1.147
ZNFS-2	1.983	1.173
ZNFS-3	2.271	1.344

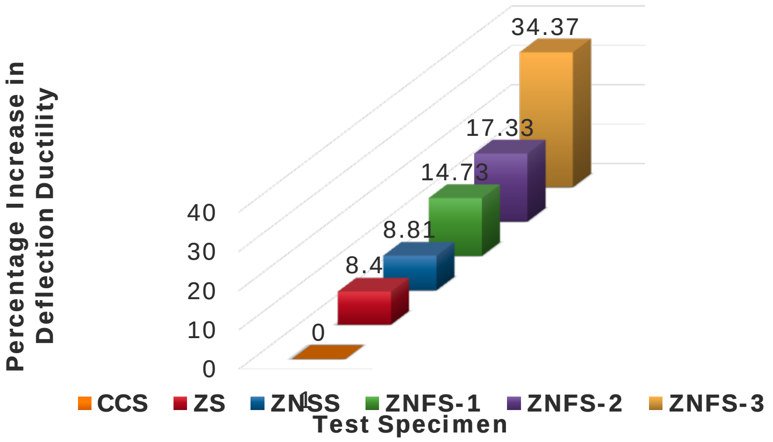


Figure 17: Effect of Steel Fibers on Deflection Ductility

3.15 Energy Ductility

The Energy ductility indices of beam specimens are presented in Table 10. An increase in deflection ductility of 35.32% has been observed for the ternary concrete mix with 1.5% volume fraction of steel fibres (ZNFS-3). over the control beam CC. An increase of 5.08% was exhibited by the beam specimen ZS over the CC beam. The beam specimen ZNS showed an increase of 2.56% and 7.78% in comparison with the beam specimens ZS and CC. The beam specimen ZNFS-2 showed an increase of 4.15%, 11.38%, 14.24% and 20.05% when compared to the beam specimens ZNFS-1, ZNS, ZS and CC. The percentage increase in Energy ductility is furnished in Figure 18.

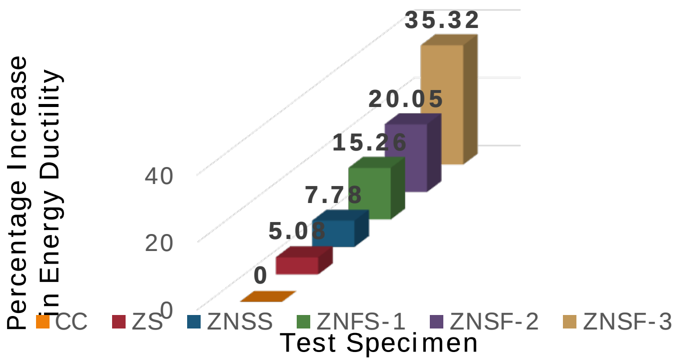


Figure 18: Effect of Steel Fibers on Energy Ductility

Table 10: Energy Ductility of Beam Specimens

Beam Designation	Energy Ductility	Energy DuctilityRatio
CCS	3.34	1.00
ZS	3.51	1.05
ZNSS	3.60	1.08
ZNFS-1	3.85	1.15
ZNFS-2	4.01	1.20
ZNFS-3	4.52	1.35

3.16 Energy Capacity

The energy capacity for all tested beams is presented in Table 11. The energy capacity was obtained as the area denied the load-deflection relationship curve. Concrete beams with micro-reinforcement showed a maximum increase of about 162.93% in energy capacity when compared to the control beam. The energy capacity increased with an increase in the volume fraction of steel fibres. An increase of 20.53% was exhibited by the beam specimen ZS over the CC beam. The beam specimen ZNS showed an increase of 19.55% and 44.10% in comparison with the beam specimens ZS and CC. The beam specimen ZNFS-2 showed an increase of 20.78%, 52.18%, 81.94% and 119.31% over the beam specimens ZNFS-1, ZNS, ZS and CC. The percentage gain in energy capacity is furnished in Figure 19.

Table 11: Energy capacity of Tested Beam

Beam Designation	Energy Capacity(kN-mm)
CCS	509.33
ZS	613.91
ZNSS	733.97
ZNFS-1	924.77
ZNFS-2	1116.99
ZNFS-3	1339.19

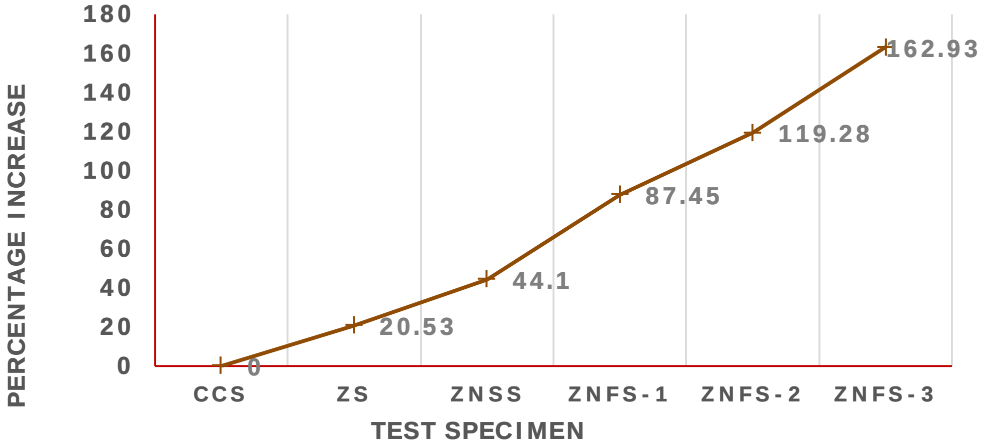


Figure 19: Effect of Steel Fibers on Energy Capacity

4 Conclusion

Ternary Blended Concrete Beams with the inclusion of micro reinforcement exhibit enhance the flexural strength. A maximum increase of 40% has been obtained with the ternary blended concrete beam containing 1% nano-silica, 10% Zeolite and 1.5% volume fraction of steel fibers over the control beam.

At all load levels, the ternary blended concrete beams containing 1% nano-silica, 10%

Zeolite and varying volume fractions of steel fibers showed increased deflections compared to the control beam. The maximum percentage gain in deflection was 86.83%.

At all load levels, the ternary blended concrete beams containing 1% nano-silica, 10% Zeolite and varying volume fractions of steel fibers showed reduced crack width and spacing and an increased number of cracks. The maximum reduction in crack width was 41.66%.

The ternary blended concrete beams containing 1% nano-silica, 10% Zeolite and varying volume fractions of steel fibers provided ample ductility to asset a ductile mode of failure. A maximum increase of 35.32% in energy ductility and 34.37% in deflection ductility has been obtained.

The ternary blended concrete beams containing 1% nano-silica, 10% Zeolite and varying volume fraction of steel fibers provided ample energy capacity. The maximum increase experienced was 162.93%.

5 Availability of Data and Material

Data can be made available by contacting the corresponding author.

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