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Studies on Steel Fibres Reinforced Ternary Blended Concrete Involving Nano Silica and Zeolite

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Abstract

The experimental study conducted to evaluate the material characteristics of ternary blended concrete containing Nano-Silica and Zeolite along with steel fibre 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 trials from the viewpoint of workability and strength. Steel fibres have been added in varying volume fractions of 0.5,1.0 &1.5%. Tests have been conducted on cubes, cylinders and prism specimens to assess the impact of steel fibres on various physical properties of the ternary blended concrete. The test results clearly show that the addition of steel fibres significantly influences the material characteristics of the ternary blended concrete which includes compressive strength, indirect tensile strength, flexural strength, and elasticity modulus.

Disciplinary: Material Science.

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1 Introduction

The addition of Nano silica improves the compressive strength of concrete, reduces the setting time and provides higher strength to the concrete (Ren et al., (2017). Nano silica had a high specific surface area and acts as binder material (Jalal et al., 2012). The addition of steel fibres increases ductility, and the split tensile strength of concrete and provides resistance against the formation and growth of cracks and SFRC has a higher ultimate strain than plain concrete (Ding et al., 2000). The optimal replacement of cement with zeolite is recommended by 10% and 15% by other authors (Behzadian et al., 2019). Although zeolite is superior to silica fume for its low-cost and eco-friendly nature (Ying et al., 2017). Although various aspects of the effect of nano-silica, zeolite (Swetha et al., 2022) and steel fibre on concrete have been studied (Bayasi and Soroushian, 1992), this work has been done to cover all these effects in a single research paper.

2 Experimental Plan

2.1 Materials

The ternary blended concrete containing Nano-Silica and Zeolite along with steel fibres to act as micro-reinforcement specimens has shown a compressive strength of 47.40 MPa. The concrete consisted of 387 kg/m^3 of 53 grade ordinary Portland cement, 654 kg/m^{3}of fine aggregate with a specific gravity of 2.80, 731.4 kg/m^{3}of 20 mm size coarse aggregate with a specific gravity of 2.78 and 487.6 kg/m^{3}of 12.5 mm size coarse aggregate with a specific gravity of 2.78. 0.48 water/cement ratio (IS 10262:2019). Zeolite 38.7 kg/m^3 and Nano-Silica 3.87 kg/m$^{3.}$ The ternary blended concrete mix specimens are made with cement replacement of Zeolite-10% and Nano-Silica-1% and added with different volume fractions (0.5%, 1.0%, 1.5%) of steel fibres.

2.2 Cement

Dalmia cement of OPC 53 grade was used for all mixes of concrete. whose specific gravity of cement is 3.14. As shown in Table 1.

Table 1: Properties of Cement

Properties	Value observed in Investigation
Fineness (%)	1.70
Specific Gravity	3.14

2.3 Aggregate

The Crushed granite with angular shape is selected with different proportions of sizes 20mm and 12mm of 60% and 40% respectively used as coarse aggregate (IS 2386:2016). Natural river sand with a specific gravity of 2.80 and confirming to grading Zone-III was used as fine aggregate (IS 383:2019). The specific gravity of aggregate is obtained by test results are furnished in Table.2.

Table 2: Properties of Aggregate

Aggregate	Specific Gravity	Grading Zone
Fine aggregate	2.61	Angular shape
Coarse aggregate	2.80	Zone III

2.4 Water

Portable water is used for preparing a design mix of M30 grade concrete of water content 0.48 (TABLE-5 AS PER IS 10262-2019), with a workability of 50mm-70mm slump value.

2.5 Super Plasticizer

Fosroc Conplast SP 430 Super Plasticizers were used for all mixes of concrete. The properties of the superplasticizer are shown in Table 3.

Table 3: Properties of Superplasticizer

Properties	Value observed in Investigation
Colour	Dark brown
Form	Liquid
Specific gravity	1.26

2.6 Zeolite and Nano-Silica

The Zeolite and Nano-Silica are procured from Astra Chemicals (CHENNAI). The basic properties of materials are given in Figures 1&2 and Table 4.

Table 4: Physical Properties of Materials

Materials	Specific Surface Area (m2/g)	Specific Gravity
Zeolite(Z)	20	2.6
Nano-Silica (NS)	202	1.2

Figure 1: Zeolite (Z)

Figure 2: Nano-Silica(N.S)

2.7 Steel Fibre

Steel Fibre is Procured from STEWOLS INDIA PVT. LTD (NAGPUR). The properties of Steel fibre are given in Table 5 and Figure 3.

Table 5: Properties of Steel fibre

Properties of Steel	Specifications
Shape	Hooked End
Length	30mm
Diameter	0.75mm
Aspect Ratio	40
Density	7850 kg/m^3
Tensile Strength	1225Mpa
Specific Gravity	7.85
Elasticity of Modulus	200Gpa

Figure 3: Steel fibre

2.8 Test Specimens

The investigation includes laboratory tests such as the Compressive Strength test (IS 516:2018), Flexural Strength test (IS 516:2018), and Elasticity of Modulus test (IS 516-2018). The nomenclature of all concrete specimens is shown in Table 6.

Table 6: Nomenclature of Test Specimens

Sl. No	Test Specimen	Description
1	CC	Control Specimen
2	ZS	Specimen with 10% Zeolite (Z)
3	ZNS	Specimen with 10% Zeolite (Z),1% Nano-Silica (NS)
4	ZNFS-1	Specimen with 10% Zeolite (Z), 1% Nano-Silica (NS) and 0.5% Steel fibre
5	ZNFS-2	Specimen with 10% Zeolite (Z), 1% Nano-Silica (NS) and 1.0% Steel fibre
6	ZNFS-3	Specimen with 10% Zeolite (Z), 1% Nano-Silica (NS) and 1.5% Steel fibre

3 Results and Discussions

3.1 Compressive Strength of Cube

Table 7 and Figure 4 provide the results of compressive strength of specimens and rate of strength development in the different concrete mixes with a water-cement ratio of 0.48. Compare to the control specimen zeolite incorporated 10% showed a 5.10% increase in compressive strength. Zeolite 10% & Nano-Silica 1% showed a 7.68% increase in compressive strength compared to the control specimen. 10% Zeolite & Nano-Silica 1% with steel fibres 1.0% volume fraction showed a maximum increase of 19.01% compressive strength compared to the control specimen.

Table 7: Cube Compressive Strength Test Results

Sl.no	Test Specimen	Compressive Strength of Cubes (MPa)
1	CC	39.83
2	ZS	41.86
3	ZNS	42.89
4	ZNFS-1	45.20
5	ZNFS-2	47.40
6	ZNFS-3	46.89

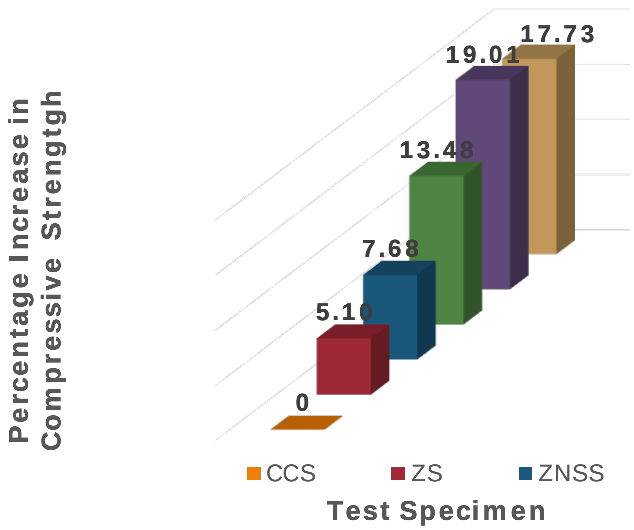

Figure 4: Effect of Steel Fibres on Cube Compressive Strength

3.1.1 Failure Modes

The failure modes of the concrete specimens during axial compression testing are presented in Figure 5. In the process of failure, cracks are observed on the surface layer of the concrete cube which is prolonged from the middle to both ends. There was a rapid brittle failure following the cracking of the high-strength concrete without steel fibre. Concrete with steel fibres increases the ductility of the concrete and reduces the stress concentration.

Figure 5: Failure Mode of Cube Specimens

3.2 Tensile Strength

Figure 6 exhibits the splitting tensile strength of all concrete mix specimens. The highest tensile strength for all the specimens was obtained at 10% Zeolite,1%Nano-Silica material dosage with 1.0% volume fraction of steel fibres. This amount is considered the optimum amount of fibre. The maximum increase in split tensile strength is 21.16 % Greater than plain specimens. The results are presented in Table 8.

Table 8: Split Tensile Test Results

S.no	Test Specimen	Split Tensile Strength (MPa)
1	CC	4.82
2	ZS	4.98
3	ZNS	5.22
4	ZNFS-1	5.48
5	ZNFS-2	5.62
6	ZNFS-3	5.84

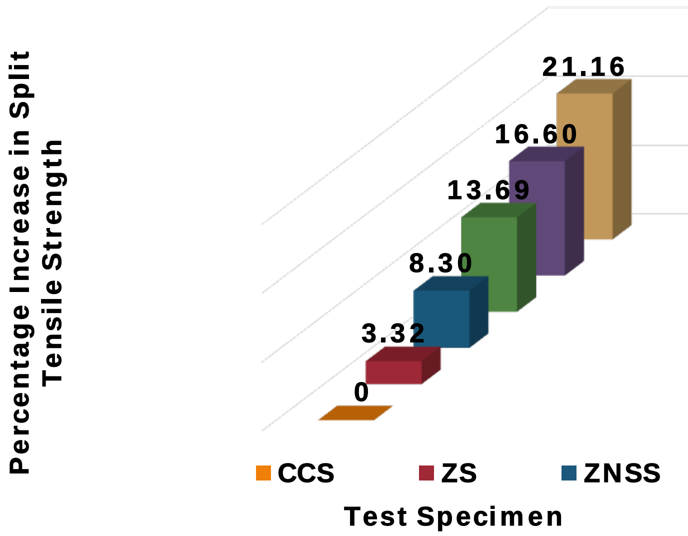

Figure 6: Effect of Steel fibre on Split Tensile Strength

3.2.1 Failure Modes

Figure 7 shows crack results under the effect of indirect tension on the specimens. The first cracks were observed near the top and progressively propagated as wider cracks to the base. Failure patterns of concrete specimens with steel fibre develop crack-resisting mechanisms and improve ductility. Cracks developed at the final failure of the specimen at 1.5% of steel fibre were less wide-opened cracks with several micro and medium cracks.

Figure 7: Failure Mode of Cylinder Specimens Under Indirect Tension

3.3 Modulus of Elasticity

The increase in modulus of elasticity observed for 10% Zeolite was 5.64% In comparison to control specimens. The ZNS specimen had increased in modulus of elasticity by 7.28% compared to the control specimens. Specimens with 0.5% of steel fibre had increased in modulus of elasticity to 7.92%, the Specimens with 1.0% of steel fibre increased by 11.23% and the Specimens with 1.5% of steel fibre had increased in modulus of elasticity to 13.71% with compare to control specimens. As shown in Table 9 & Figure 8.

Table 9: Modulus of Elasticity Test Results

S.no	Test Specimen	Elasticity of Modulus (Gpa)
1	CC	31.56
2	ZS	33.34
3	ZNS	33.86
4	ZNFS-1	34.06
5	ZNFS-2	35.24
6	ZNFS-3	35.89

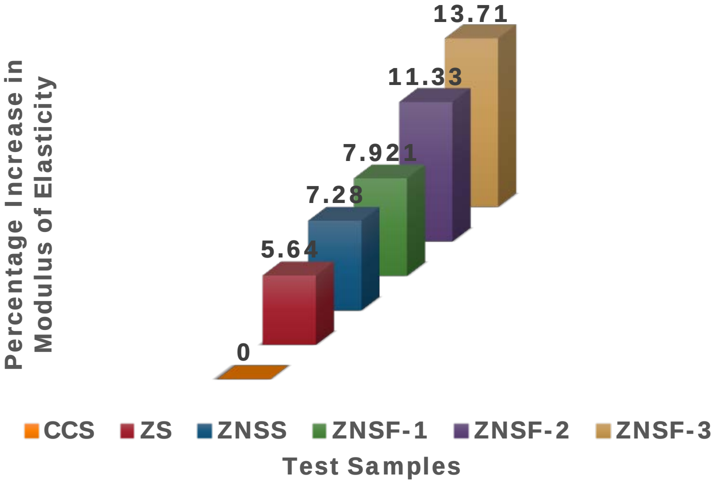

Figure 8: Effect of Steel fibre on Modulus of Elasticity

3.3.1 Failure Modes

Axial loading of specimen crack was observed over the depth of the cylindrical specimens of ternary blended concrete without steel fibre. specimens with steel fibre attain a high modulus of elasticity which enhances the capacity to deform before cracking and resist the formation of micro-cracks by decreasing the stress concentration.

3.4 Modulus of Rupture

Figure 9 & Table 10 exhibits the flexural strength results of all concrete mix specimens. Strength at 10% zeolite was observed to be increased by 2.29% compared to control specimens. The highest flexural strength for all the specimens was obtained at 10% Zeolite,1%Nano-Silica material dosage of 1.5% volume fraction of steel fibre. The maximum increase in flexural strength was 23.56 % Greater than plain specimens.

Table 10: Modulus of Rupture Test Results

S.no	Test Specimen	Modulus of Rupture (MPa)
1	CC	6.47
2	ZS	7.07
3	ZNS	7.33
4	ZNFS-1	7.93
5	ZNFS-2	8.33
6	ZNFS-3	8.56

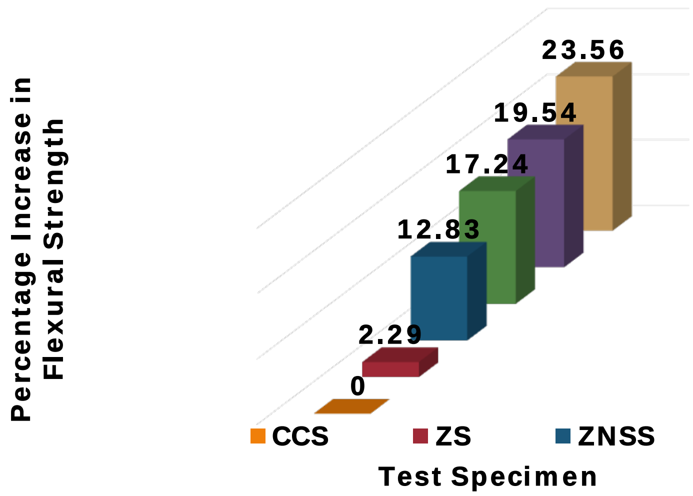

Figure 9: Effects of Steel Fibres on Modulus of Rupture

3.4.1 Failure Modes

The two-point load is used for testing prism specimens to find the deflection load is kept constant till the prism collapse. the flexural strength was increased by increasing the volume fraction of steel fibre which is effective in increasing the shear strength of the prism. The crack size decreases with the increasing volume fraction of steel fibre in concrete. Hence it is absorbed that steel improves the properties of concrete towards the deflection and flexural capacity. Failure patterns are shown in Figure 10.

Figure 10: Failure Mode of Prism Specimens

4 Conclusion

This paper addressed the application of natural Zeolite 10% and Nano-Silica 1% as supplementary cementitious material with steel fibre to act as micro reinforcement. In this study, different properties of ternary blended concrete made with different volume fractions of steel fibre (0.5%,1.0% and 1.5%) were investigated in comparison with ternary blended concrete and normal concrete. The results can be conducted as follows:

The incorporation of Zeolite -10% and Nano-Silica -1% in concrete shows an improvement in compressive strength of 7.68% compared to control specimens. Whereas 15 to 20 % replacement has caused a modest reduction in strength at the same age of concrete

The ternary blended concrete containing Nano-Silica and Zeolite along with steel fibre to act as micro reinforcement were observed to the improvement of mechanical properties of concrete

The steel fibre in concrete improves the deflection capacity of concrete and also improves the shear capacity of the concrete.

5 Availability of Data and Material

Data can be made available by contacting the corresponding author.

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