

The Structural Behavior of Reinforced Concrete Beams Containing Zeolite Made of Polyvinyl Alcohol (PVA) Fibre

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Abstract: The results of a research study have been made to evaluate the material characteristics of concrete beams containing Zeolite(Z) and Polyvinyl alcohol fibre (PVA). A total of ten beams were cast and tested for this study. The beams were 150mm x 250mm x 3000mm were evaluated for their flexural capacity in a standard testing frame. The beam specimens were tested for their behaviour under static loading conditions. Two beams were cast in each designation and averages were taken. The performances of the beam specimens were assessed in terms of first crack load, deflection at first crack load, yield load, deflection at yield load, ultimate load, deflection at ultimate load Cracking history, and failure modes. It is evident from the test results that the inclusion of PVA fibres significantly enhanced the performance of concrete beams at a certain stage.

Keywords: Beam deflection, Cracking, Ductility, Strength, fibre-reinforced concrete, Polyvinyl alcohol (PVA) fibre, Zeolite.

1. Introduction

Cement is one of the major ingredients for concrete production. The production of cement emits CO₂ around 5 to 7 % of the world's emissions [1]. The concrete can be moulded into many shapes or sizes, with considerable high compressive strength and durable behavior. These properties combined with relatively low cost, make concrete one of the most popular materials in the construction industry. However, the concrete brittle nature is a disadvantage mostly for its tensile strength which provides low resistance to crack opening and propagation [2].

Since the second half of the 20th century, the addition of fibres in concrete has been studied to overcome its brittle behavior. The fibre reinforced concretes (FRC) can support loads even in cracked conditions during the service life when they are designed to it or in an accidentally induced crack. FRC elements are widely used in applications submitted to cyclic loadings as offshore structures [3]. In order to improve the mechanical properties, various kinds of fibres, such as steel fibres (4, 5), jute fibres (6), carbon fibres (7), polyvinyl alcohol (PVA) fibres (8), etc., have been added into concrete. They can effectively inhibit the initiation and development of micro-cracks in the early hardening process of concrete, and bring better tensile, bending and crack-control properties to concrete. Steel fibre concrete received attention first. However, it has non-ignorable downsides, such as increased concrete density and non-uniform distribution of fibres in concrete, as well as steel fibre corrosion. In recent years, synthetic fibres, such as PVA fibres, attracted wide attention due to their high acid and alkaline resistance, high bonding strength with the cement matrix, and relatively low cost. At present, PVA fibre concrete has been applied in some engineering practices (9,10 &11).

Cyclic loads develop tensile stresses which can start the crack, and its propagation results in the loss of performance. The potential collapse is reasonably higher if the cracks are already developed in the structure [12,13]. The crack-opening increment is increased by each cycle turning microcracks into macrocracks and occasional cracking in the fibre-matrix interface that leads to a reduction in the fibre-concrete bond and residual strength [14].

2. Test materials

2.1 Materials

The concrete mix was made using OPC 53 grade (IS 12269-2013) cement, whose specific gravity of cement obtained is 3.14. 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). The specific gravity of the coarse aggregate used was 2.74. A combination of Natural River sand (60%) and M-sand (40%) obtained from a nearby quarry was used as fine aggregate. The specific gravity of fine aggregate combine was 2.67 and conforms to grading zone-III of IS 383. The Zeolite was manufactured in RX Chemicals Maharashtra, India. Zeolite was delivered in a 30-kg package with a particle size of 50 μm . Physical analysis of zeolite, bulk density 0.4-0.5 (Kg/Lit), Specific surface area 19.20 m^2/g , Ph (10% solids) 4.5-5.5 and Initial setting time is 33 min. The specific gravity of zeolite was used at 2.6. PVA fibre were procured from Lakhani fabrics, Rajasthan. The length of the fibres 6mm, the density is 1.084 g/mL , melting point is 220 degrees Celsius (493 K). They are wrinkle-proof and highly resistant to abrasion and chemicals such as acids and alkalis. The fibres can absorb up to 2.4% of water, although this lowers tensile strength. Fosroc Conplast SP 430, a sulphonated naphthalene formaldehyde-based superplasticizer was employed to increase the workability of the concrete mixes. It has a specific gravity of 1.18 and conforms to ASTM C494. High Yielding Strength Deformed (HYSD) bars were utilised for the main and shear reinforcement.

2.2 Mix proportions

In this experimental research mix design has been designed according to IS 10262:2019. The target strength of the control concrete mix contains 39 MPa. A water/binder (W/B) ratio was kept constant at 0.45 for the control concrete and binary blended concrete. The required slump in each mix has been attained through the use of SP in suitable dosages. The mix details are given in Table 1.

Table 1: Mix proportions of concrete

Details		BCC	BZ	BZP1	BZP2	BZP3
Cement (kg/m ³)		387	348.3	344.43	344.43	344.43
Fine aggregate (kg/m ³)	River sand	390.6	390.6	390.6	390.6	390.6
	M-sand	260.4	260.4	260.4	260.4	260.4
Coarse aggregate (kg/m ³)	20mm	726	726	726	726	726
	12mm	484	484	484	484	484
W/B ratio		0.45	0.45	0.45	0.45	0.45
Water (kg/m ³)		186	186	186	186	186
Zeolite (kg/m ³)		-	38.7	38.7	38.7	38.7
PVA Fibre (%)		-	-	0.1	0.2	0.3

2.3 Preparation of control specimens

The definite volume method recommended by ACI 318-18 was used to compute the quantities of materials. Cubes of size 150X150X150mm have been used for assessing the compressive strength, Prism's specimens of size 100X100X500 mm were cast and experimented to find the modulus of rupture and Cylinder specimens of size 150X300mm were cast and tested to determine the modulus of elasticity. The nomenclature of beam specimens is given in Table 2.

Table 2: Nomenclature beam specimens

Designation of beams	Description
BCC	Conventional Concrete
BZ	Specimen with 10% Zeolite
BZP1	Specimen with 10% Zeolite and 0.1% PVA fibre
BZP2	Specimen with 10% Zeolite and 0.2% PVA fibre
BZP3v	Specimen with 10% Zeolite and 0.3% PVA fibre

2.4 Beam specimens

A total of ten beams were cast in this study. Two beams were made with control concrete. Two beams were made with Zeolite-based concrete. Six beams were fabricated with binary blended concrete containing Zeolite and PVA fibres in varying volume fractions. The beam specimens were of size 150X250X3000mm. The longitudinal reinforcement contained 8 mm-diameter stirrups, 2-legged links at 125 mm c/c. A reinforced index of 0.603% was adopted for the beam specimens. The details of the beam specimen are shown in Figure 1.

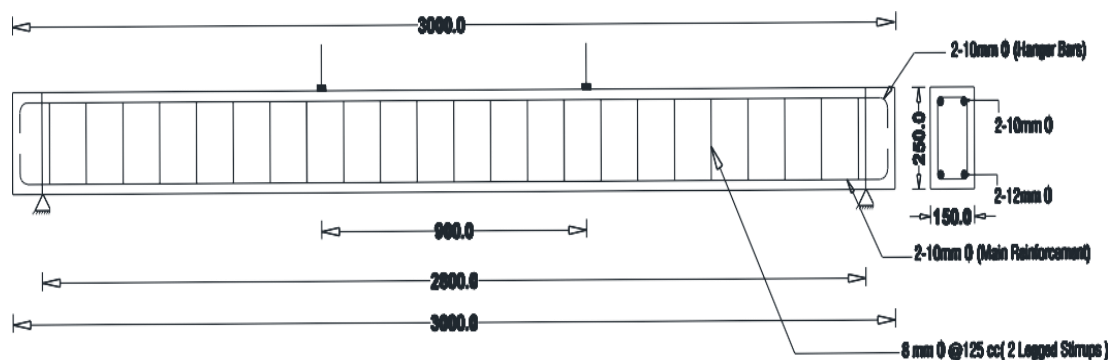


Figure 1: Reinforcement Details of Beam Specimen



Figure 2: Steel cages



Figure 3: Beam Specimens

2.5 Test Instrumentation and Loading

Rc beams were tested under four-point-bending in a static loading frame of 1000 kN capacity. The beams were supported on the hinge at one end and a roller at the other end. The details of the test set-up are shown in Fig. 2. The beams had 100 mm bearing at both ends, resulting in a test span of 2800 mm. Two-point loads were applied through a spreader beam. The deflections were measured at mid-span and at load points using mechanical dial gauges of 0.01mm accuracy. The crack width was measured using a crack detection microscope having a least

count of 0.02 mm. Crack expansion and propagation were observed during the process of testing. All the above measurements were obtained at various load levels until failure.



Figure 4: Static Loading Arrangements and Instrumentation

3. Results and Discussion

Two beams were cast in each designation and averages were taken and results of the experimental investigation were carried out on ten beams which include the control concrete beam (B1-CC, B2-CC), Zeolite contains beam (B1-Z, B2-Z) and Zeolite plus Polyvinyl Alcohol fibre concrete beams (B1-ZP1, B2-ZP1) (B1-ZP2, B2-ZP2) (B3-ZP3, B3-ZP3).

3.1 Load Deflection Relationship

The loads carried by all the tested beams were measured experimentally at the first crack stage, yield stage and ultimate stage. The deflection experienced by the beam specimens was measured using pertinent instrumentation at all stages of loading. The conclusion reached from this study is presented in Fig.5. The load-deflection graphs showed different deformation and behaviour under load for all beams. The curves of all the tested beams were linear until the first crack was formed. With increased loading, the load-deflection curves are decreased. With further development in load, the steel started yielding and the slope of the curves initiated to reduce largely. The beam specimen started to show an increase in the number of cracks. The beam specimens appeared higher deflections and the number as well as the size of cracks increased further. This tendency comes to an end in the ultimate stage.

Table 3: Experimental results of beam specimens

Beam Designation	First crack Load (KN)	Deflection at first crack load (mm)	Yield Load (KN)	Deflection at Yield Load (mm)	Ultimate Load (KN)	Deflection at Ultimate Load (mm)
BCC	17.50	2.10	34.50	7.10	52.50	14.38
BZ	19.00	2.53	35.50	7.20	55.00	16.54
BZP1	21.00	2.76	37.50	7.30	58.50	18.15
BZP2	24.5	3.79	42	8.79	70	23.81
BZP3	22.50	3.61	38.00	8.50	62.50	21.25

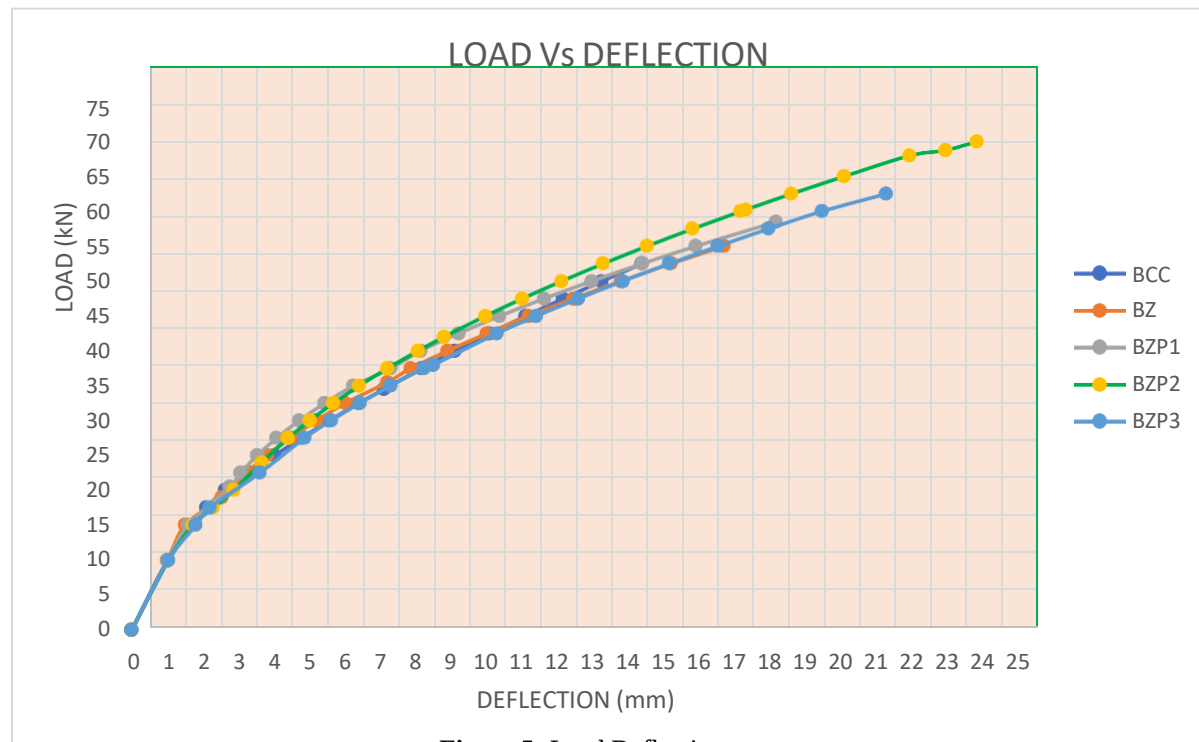


Figure 5: Load Deflection curve

A maximum increase of 40% in the first crack load was shown by the binary blended concrete beam having a 0.2% volume fraction of PVA fibres (BZP2) over the control beam CC. An increase of 8.57% was exhibited by the beam specimen BZ over the BCC beam. The beam specimen BZP1 showed an increase of 10.52% and 20% in comparison with the beam specimens BZ and BCC. The beam specimen BZP2 showed an increase of 16.67%, 28.57% and 40% when compared to the beam specimens BZP1, BZ and BCC. The beam specimen BZP3 exhibited a decrease of 11.43% over the beam specimen BZP3. The percentage gain in the first crack load is shown in Figure 6.

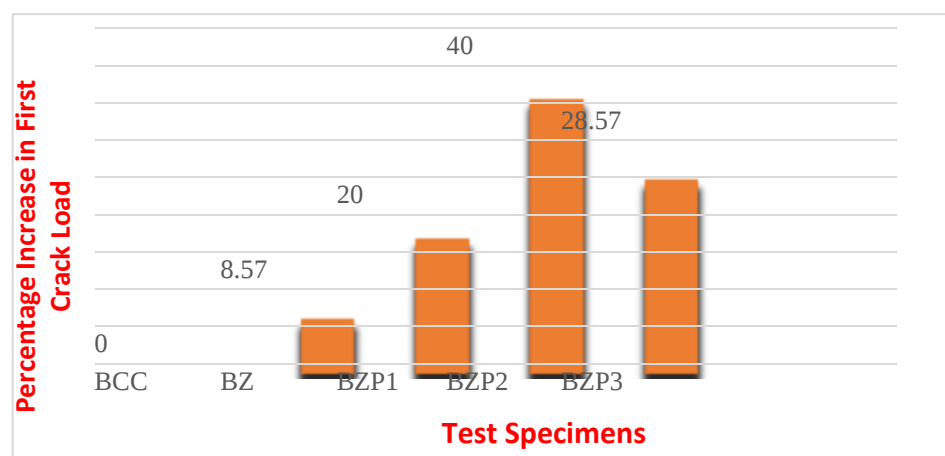


Figure 6: Effect of strength on First Crack Load

3.2 Deflection at First Crack Load

The beam BZP2 exposed an increase of 80.47% in deflection compared to the control beam BCC at the first crack stage. An increase of 20.47% was exhibited by the beam specimen BZ over the BCC beam. The beam specimen BZP1 exhibited an increase of 9.09% and 31.42 % in comparison with the beam specimens BZ and BCC. The beam specimen BZP2 exposed an increase of 37.31%, 49.80% and 80.47% when compared to the beam specimens BZP1, BZ and BCC. Figure 7 exhibits the percentage increase in deflection of PVA is provided.

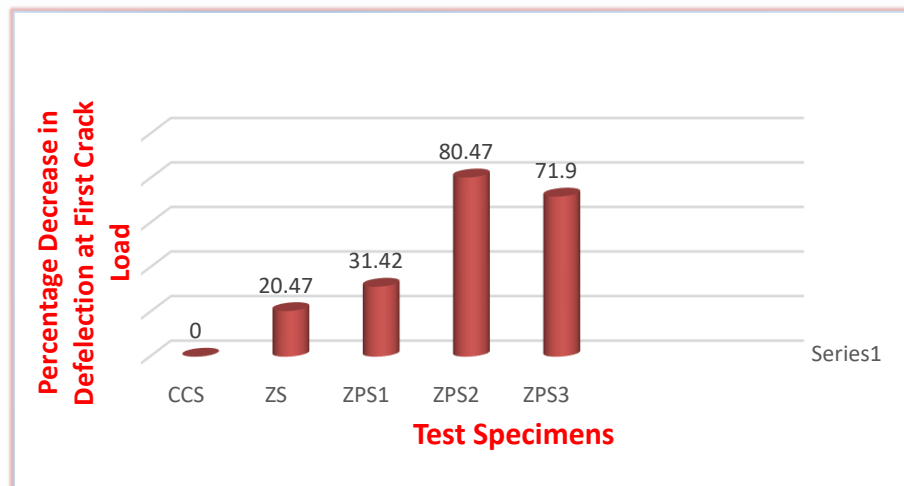


Figure 7: Effect on Deflection at First Crack Load

3.3 Yield load

From the load-deflection curve, the yield load was attained. A maximum increase of 21.73% in yield load was presented by the BZP2 concrete beam (Zeolite 10% and 0.2% of PVA fibre) over the control beam BCC. The increase of 2.89% was shown by the beam specimen BZ compared to the control beam BCC. The beam specimen BZP1 exposed an increase of 5.63% and 8.69% in comparison with the beam specimens BZ and BCC. The beam BZP2 exhibited an increase of 12%, 18.30% and 21.73% when compared to the beam specimens BZP1, BZ and BCC. The results relating to the percentage increase in yield load are provided in Figure 8.

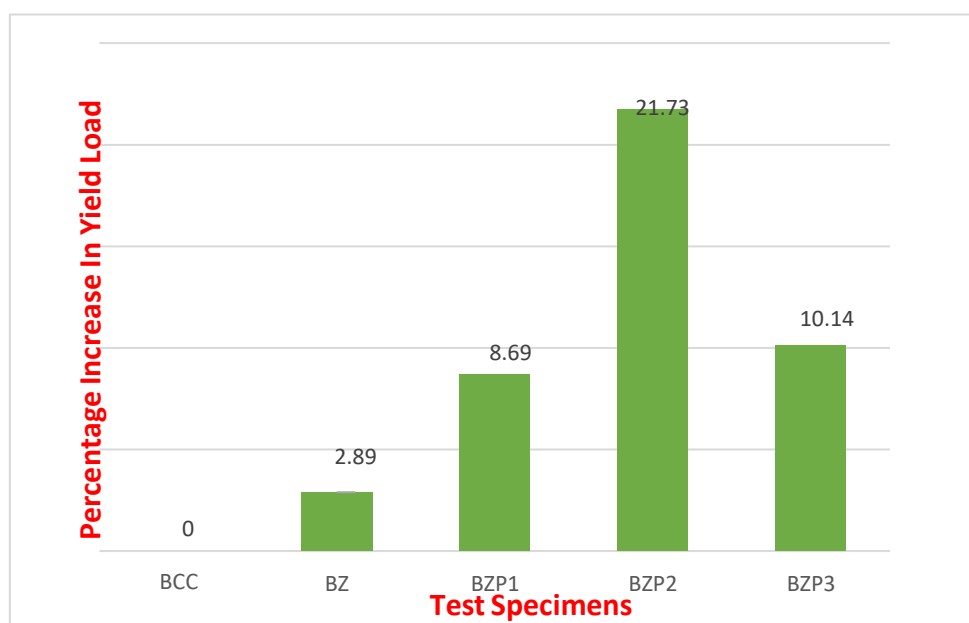


Figure 8: Effect of Strength on Yield Load

3.4 Deflection at Yield Load

From the load-deformation plots, the deflection at yield load was achieved. A maximum increase of 23.8% in deflection at yield load was shown by the binary blended concrete beam having a 0.2% volume fraction of PVA fibres (BZP2) over the control beam BCC. An increase of 1.4% was exhibited by the beam BZ compared to the BCC beam. The beam specimen BZP1 exhibited an increase of 1.38% and 2.81% in comparison with the beam specimens BZ and BCC. The beam BZP2 showed an increase in deflection was 20.41%, 22.08% and 23.80% when compared to the beam specimens BZP1, BZ and BCC. The results relating to the percentage increase in deflection at yield load are shown in Figure 9.

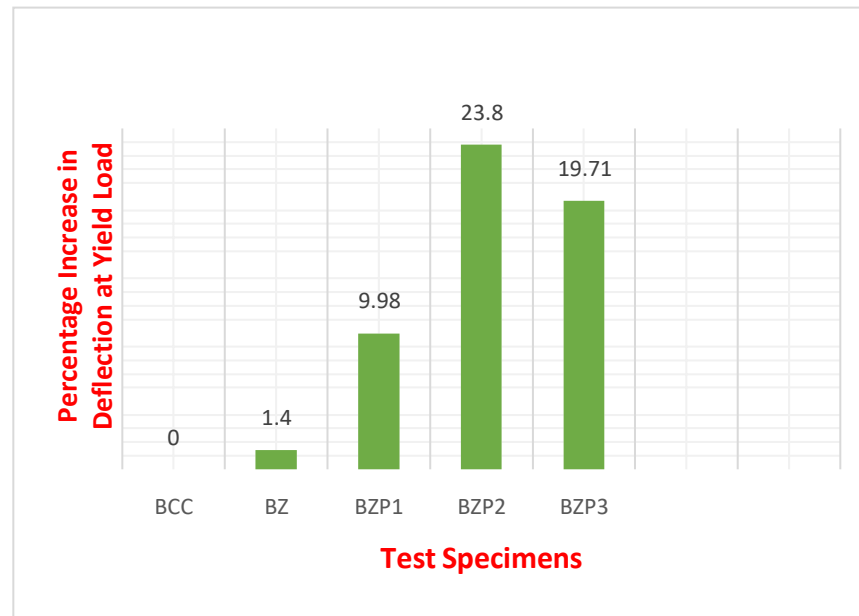


Figure 9: Effect on Deflection at Yield Load.

3.5 Ultimate Load

The peak load was determined to be the loading level at which the beam is unable to resist any additional deformation at the same load intensity. With a 0.2% volume fraction, the binary concrete mix beam showed a maximum increase in ultimate load of 70%. PVA fibers (BZP3) over the control beam BCC. A 4.76% increase was shown by the beam BZ specimen over BCC beam. The BZP1 beam specimen displayed increases of 10.0% and 6.36% in comparison with the BZ and BCC beam specimens. The BZP2 beam specimen indicated an increase of 19.65%, 27.27% and 33.33% when compared to the BZP1, BZ and beam specimens BCC. Figure 10 provides the percentage increase in peak load.

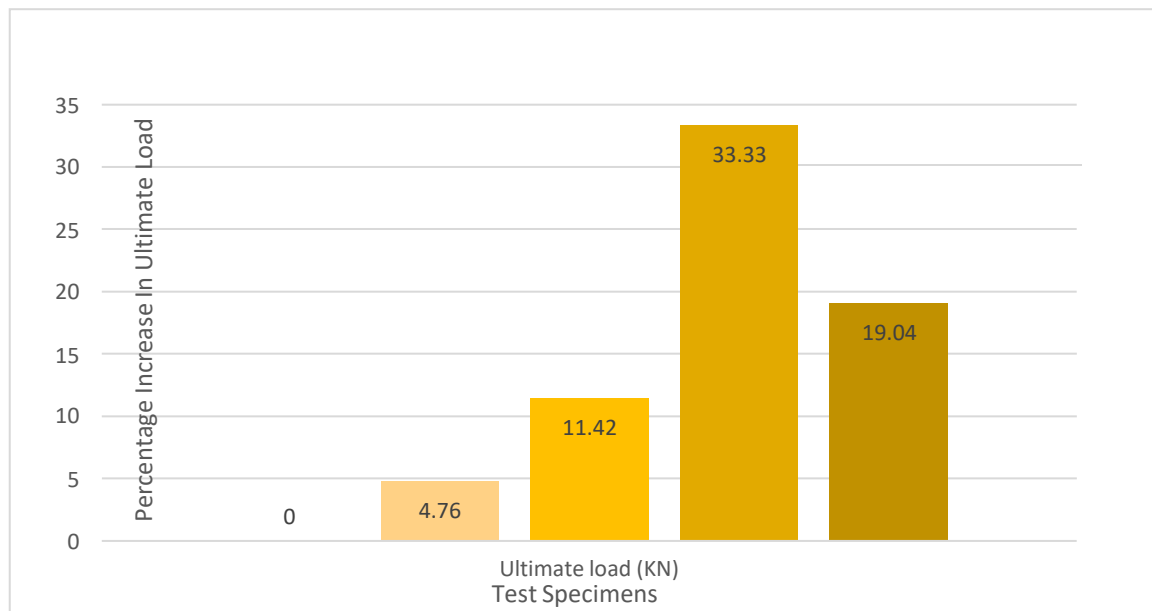


Figure 10: Effect of Strength on Ultimate Load

3.6 Deflection at Ultimate Load

Figure 11 shows the percentage increase in deflection for the binary blended concrete beam with a 0.2% volume fraction of PVA fibers (BZP2) over the control beam BCC, and for the beam specimen BZ over the BCC beam, an increase of 15.02%. The beam specimen BZP1 showed increases of 9.73% and 26.21% compared to the beam specimens BZ and BCC, and the beam specimen BZP2 showed increases of 31.18%, 43.95%, and 65.57% compared to the beam specimens BZP1, BZ, and BCC.

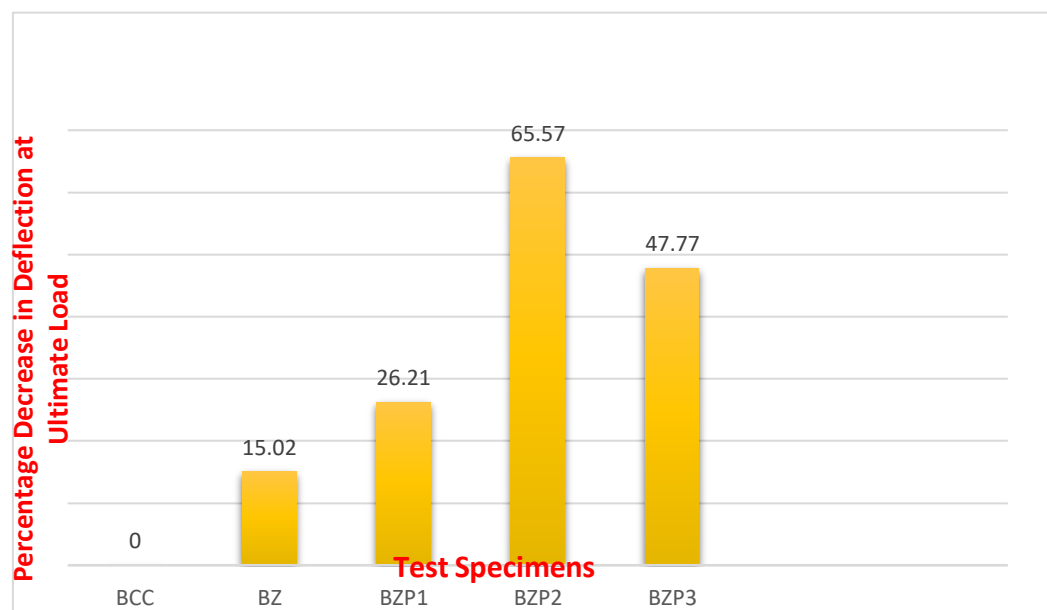


Figure 11: Effect on Deflection at Ultimate Load

3.7 Cracking History and Failure Modes

The crack width, crack number and the average spacing of cracks are provided in Table 4. The process of the loading of reinforced concrete beams is accompanied by the process of crack formation. Cracks formed in a vertical manner during the initial stages of loading. As the load increases, initially rapid changes in the crack pattern form in the direction of the top of the beam. The beam specimen made out of control concrete (BZZ) exposed a larger crack width at the ultimate stage. The incorporation of a Zeolite-based concrete beam specimen exhibited reduced crack width when compared to the same load level of the control beam.

The addition of PVA fibre allowed the beams to experience large deformation preceding failure. The beam specimens included with the different volumes of PVA fibres showed a large number of cracks, decreased crack spacing and increased crack width. This may lead to a higher energy absorption capacity. Table 4 illustrates that, in comparison to the control beam BCC and beam BZ, the PVA fibre-reinforced binary blended concrete beams exhibit increased crack width and a large number of cracks.

Table 4: 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
BCC	0.49	16	140	Flexure
BZ	0.45	17	138	Flexure
BZP1	0.41	18	125	Flexure
BZP2	0.39	19	112	Flexure
BZP3	0.33	21	104	Flexure

3.8 Crack width

With a 0.2 % volume percentage of PVA fibers, the binary concrete beam (BZP3) showed a 32.65% reduction in crack width at peak load over the control beam BCC. Beyond the control beam BCC. The beam specimen BZ showed an 8.57% decrease over the BCC beam. When compared to the beam specimen BZP1 shows increases of 16.32% and 8.88% of beam specimens BCC and BZ. The BZP2 beam specimen displayed increases of 4.87%, 13.33%. and 20.40% when compared to the BZP1, BZ, and BCC beam specimens. The proportion of a reduction in crack width is shown in Figure 12.

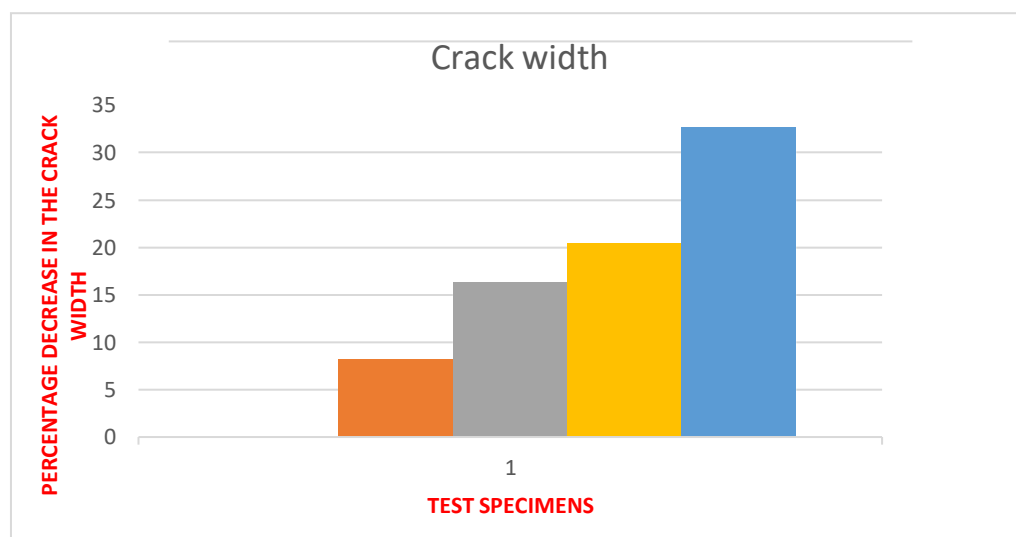


Figure 12: Effect on Crack Width

3.9 Number of Cracks

The concrete beam with a 0.2% volume percentage of PVA fibers (BZP3) showed a 31.25% increase in the number of cracks at the ultimate load compared to the control beam BCC. Compared to the beam specimen BZ, the beam specimen BZP1 exhibited a 5.88% increase. Comparing the beam specimens BZP1, BZ, and BCC to the beam specimen BZP2, the results indicated increases of 5.55%, 11.76%, and 18.75%. Figure 13 provides information on the percentage increase.

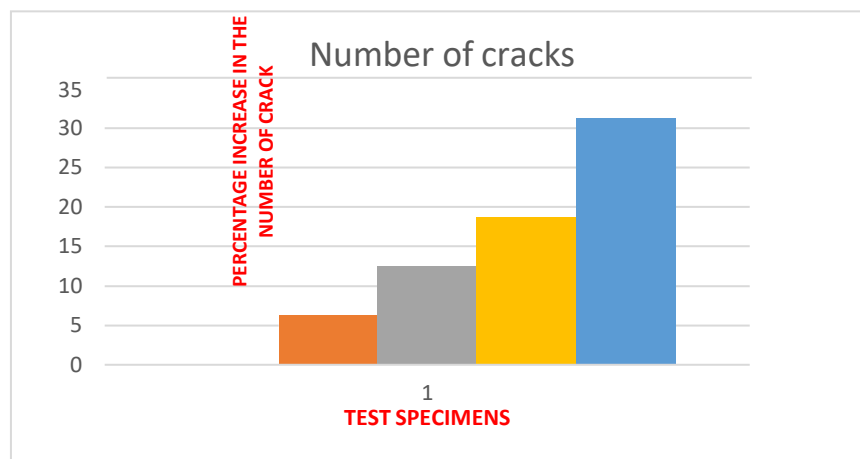


Figure 13: Effect on Number of Cracks

3.10 Spacings of Cracks

The beam containing 10% Zeolite and 0.2% PVA volume fraction (BZP3) showed a 37.33% decrease in spacing of crack at the ultimate load level compared to the control beam BCC. The beam specimen BZ showed a 10% decrease in comparison to the BCC beam. When compared to the beam specimens BZ and BCC, the BZP1 showed an increase of 11.85% and 20.67%. The increases for the beam specimens BZP2, were 12.60%, 22.96%, and 30.67% when compared to beam BZP1, BZ and BCC respectively. Figure 14 shows the percentage decrease in the spacing of cracks.

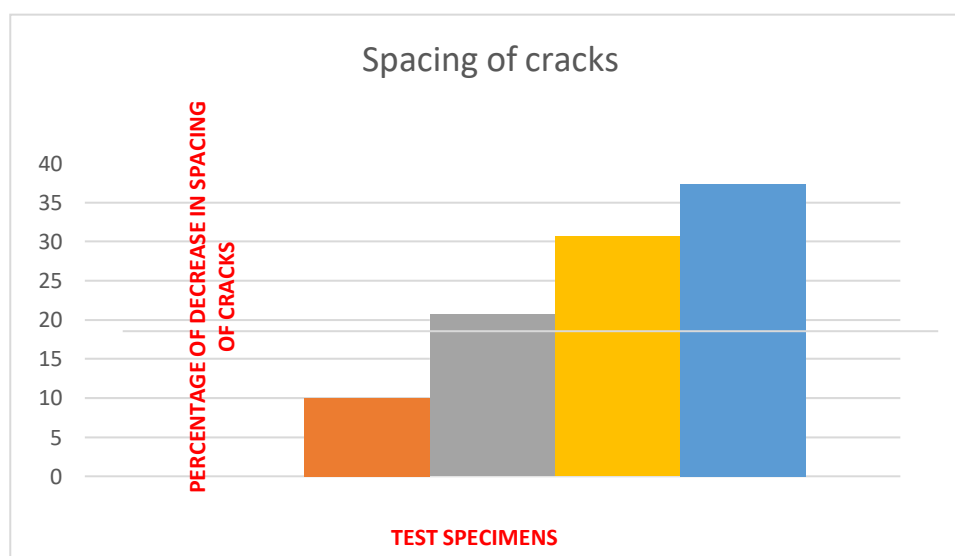


Figure 14: Effect on Crack Spacing

Figure 15 presents the crack pattern of every beam specimen that was evaluated for this study. Hairline cracks were seen in the constant moment zone early in the loading process. New cracks started to emerge as the load increased, and the already-existing cracks grew larger and spread throughout the loaded span.



(a) Crack Pattern of B1-CC Beam



(b) Crack Pattern of B2-CC Beam



(c) Crack Pattern of B1-Ze Beam



(d) Crack Pattern of B2-Ze Beam



(e) Crack Pattern of B1-ZP1 Beam



(f) Crack Pattern of B2-ZP1 Beam



(g) Crack Pattern of B1-ZP2 Beam



(h) Crack Pattern of B2-ZP2 Beam



(i) Crack Pattern of B1-ZP3 Beam



(j) Crack Pattern of B2-ZP3 Beam

Figure 15: Crack Pattern of Beam Specimens

4. Conclusion

The following conclusions are drawn based on the results obtained from the experiments.

The inclusion of PVA can enhance the load capacity substantially. The binary blended beam BZP2 (with 10% Zeolite and 0.2% fibre volume fraction) exhibited a maximum increase of 65.57% in the ultimate load capacity. PVA can significantly increase the load capacity. With 10% Zeolite and 0.2% fibre volume fraction, the binary blended beam BZP2 showed a maximum increase in ultimate load capacity of 65.57%. Zeolite and varying volume fraction of PVA fibre showed increased deflections compared to the control beam. At all load levels, the deflections in the fibre included beams significantly reduced crack width and spacing and increased the number of cracks. A maximum of 32.65% has been experienced with the beam BZP3. The PVA fibre-reinforced binary blended concrete beams experienced flexural failure. The width and spacing of cracks are much less than those of the control beams.

5. Accessibility of Information and Materials

Information can be made accessible by communicating with the corresponding author.

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