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Flexural Behaviour Of Hybrid Fibre Reinforced Concrete Beams Containing Metakaolin And Nano Alumina

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ABSTRACT
In this research study, an effort has been made to examine the effect of incorporating hybrid fibres on the performance of concrete beams containing metakaolin and nano alumina. A total of nine beams were cast and tested for this study. The beams were 150 mm x 250 mm in cross section and 3000mm long. The specimens were tested under static loading condition. The performance of the beam specimens was assessed in terms of first crack load, deflection at first crack load, yield load, deflection at yield load, ultimate load, deflection at ultimate load, deflection ductility, deflection ductility ratio, energy ductility, energy ductility ratio. It is evident from the test results that inclusion of hybrid fibres appreciably improved the performance of concrete beams containing metakaolin and nano alumina in all fronts.
Keywords: *Cracking, deflection, ductility, fibre reinforced concrete, metakaolin, nanoalumina, strength.*

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, metakaolin, alccofine.The inclusion of a 0.3% volume fraction of PP fibres increased compressive strength by 18.93%, reduced crack area by 53.1% and reduced crack width by 51.51% (Banthia et al. 2006). The beams increased bending resistance by 5.17% and increased tensile strength by 50% with the inclusion of 0.8 kg/m3 PP fibres in concrete (Hiep et al. 2020). The addition of a 0.35% volume fraction of polypropylene fibres increased deflection by 14.28% at ultimate load, decreased crack width by 43.90%, increased energy absorption capacity by 157.14%, and increased ductility factor by 97.36% and increased ultimate flexural strength by 19% (Arivalagan 2012). The addition of 0.6 kg/m3 PP fibres increased the cracking load by 33.98% (Yang, 2021). The addition of a 0.4% volume fraction of PP fibres increased compressive strength by 5%, increased tensile strength by 65%, increased flexural strength by 80% and reduced shrinkage cracking by 83% (Ahmed, 2016). The addition of 0.5% polypropylene fibres increased compressive strength by 15% and increased initial crack load by 10% (Sundar -2017). The addition of a 0.2% volume fraction of PP fibres increased flexural toughness by 95% and increased impact resistance by 90% (Alhozaimy-1996). The addition of PP fibres increased compressive strength by 16%, increased split tensile strength by 23%, and increased flexural strength by 36% (Patel-2011).

2. EXPERIMENTAL PROGRAMME

2.1 Materials used

2.1.1Cement

OPC 53 grade cement conforming to **IS 12269:** 2013 has been used in this study. The specific gravity of cement used was 3.15.

2.1.2Fine Aggregate

The specific gravity of fine aggregate was 2.67 and conforms to grading zone-III.

2.1.3Coarse Aggregate

Crushed granite aggregate conforming to IS 383-2016 with a maximum particle size 20 mm has been used. The specific gravity of coarse aggregate was 2.72.

2.1.4Nano Alumina and Metakaolin

Nano Alumina (Fig.1) and Metakaolin (Fig.2) have been used in the present investigation. The propertiesof Metakaolin and Nano alumina are presented in Table 1.

Table 1Properties of Metakaolin and Nano silica

Properties	Metakaolin	Nano Alumina
Specific gravity	2.4	1.2
Colour	White or Gray	White
Specific Surface Area (m^2/g)	19	100

2.1.5Water

Water conforming to **IS 456:2000 has** been used for preparing and curing the concrete specimens.

2.1.6Super Plasticizer

In this research study, Conplast SP430, a sulphonated naphthalene formaldehyde based superplasticizer was employed to impart workability to the concrete mixes.It has a specific gravity of 1.18 and conformsto ASTM C494. The SP dosage for all the mixes was obtained by trials.

Fig.1 Nano Alumina

Fig.2Metakaolin

2.1.7Polypropylene Fibres

Polypropylene fibres (Fig 3) procured from Stewols India (P) Ltd, Nagpur were used in this investigation. The properties of pp fibres are presented in Table 2.

Table 2 Properties of Polypropylene Fibres

Properties	Test Value
Length (mm)	12
Diameter (mm)	0.04
Aspect Ratio	300
Tensile Strength (MPa)	480
Specific Gravity	0.910
Elasticity Modulus (GPa)	5

2.1.8 Glass Fibre

Glassfibres(Fig 4) procured from Stewols India (P) Ltd, Nagpur were used in this investigation. The properties of glass fibres are presented in Table 3.

Table 3 Properties of Glass Fibre

SNo	Properties	Test Value
1	Length (mm)	12
2	Diameter (mm)	0.014
3	Density(g/cm^3)	1.29
4	Specific Gravity	2.68
5	Elongation (%)	7

6	Elasticity Modulus (GPa)	72

Fig.3 Polypropylene Fibre

Fig.4Glass Fibre

The nomenclature of specimens are presented in Table 4.Two groups of concrete mixtures have been prepared. In the first group, the concrete mixturehas been prepared with 1% nanoalumina and varying percentages of metakaolin (10%, 15% and 20%). The idea is to find the optimum combination of nanoalumina(1%) and metakaolin (15%) from the point of view of workability and strength. In the second group, the concrete mixture hasbeen prepared with the optimum combination of nanoalumina and metakaolin and varying volume fraction of PP fibres (0.1 %, 0.2 %, 0.3 %,and 0.4 %)to find the optimum PP fibre content considering both workability and strength. The constituents of beams are presented in Table 5.

Table 4 Nomenclature of Specimens

S.No	Test Specimen	Description
1	CB	Control Specimen
2	MK	15% Metakaolin
3	NMK	15% Metakaolin and 1% Nano Alumina
4	NMKP	15% Metakaolin, 1% Nano Alumina and 0.3% Polypropylene fibre
5	NMKH-1	15% Metakaolin, 1% Nano Alumina and 0.3% fibre (70%Polypropylene fibre+30% Glass Fibre)
6	NMKH-2	15% Metakaolin, 1% Nano Alumina and 0.3% fibre (60%Polypropylene fibre+40% Glass fibre)
7	NMKH-3	15% Metakaolin, 1% Nano Alumina and **0.3% fibre** (50%Polypropylene fibre+50% Glass Fibre)
8	NMKH-4	15% Metakaolin, 1% Nano Alumina and 0.3% fibre (40%Polypropylene fibre+60% Glass Fibre)
9	NMKH-5	15% Metakaolin, 1% Nano Alumina and 0.3% fibre (30%Polypropylene fibre+70% Glass Fibre)

Table 5 Details of Tested Beams

S.No	Beam Designation	MK Content	NA Content	Fibre Volume Fraction, v_f (%)	Nature of Test
1	CB	15%	1%	-Nil-	Static
2	MK	15%	1%	-Nil-	Static
3	NMK	15%	1%	-Nil-	Static
4	NMKP	15%	1%	0.3% PP	Static

5	NMKH-1	15%	1%	0.3% (70%PP+30%Glass)	Static
6	NMKH-2	15%	1%	0.3% (60%PP+40%Glass)	Static
7	NMKH-3	15%	1%	0.3% (50%PP+50%Glass)	Static
8	NMKH-4	15%	1%	0.3% (40%PP+60%Glass)	Static
9	NMKH-5	15%	1%	0.3% (30%PP+70%Glass)	Static

2.2 Details of Test Beams

A total of nine beams were cast and tested for this study. The beams were 150 mm x 250 mm in cross - section and 3000 mm long. The beams were reinforced with two numbers of 12 mm diameter bars at bottom, two numbers of 10 mm diameter bars at top and two-legged 8 mm diameter stirrups at 125 mm c/c. Fig. 5 shows the reinforcement details of the beam specimens.

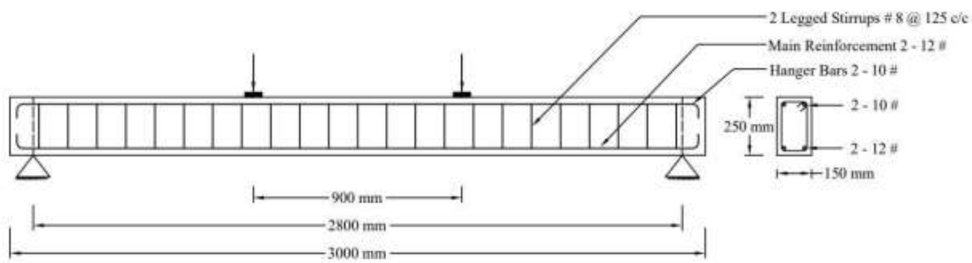


Fig 5 Reinforcement Detailing of Tested Beam

2.3 Test Instrumentation and Loading

Fig.6 shows the loading arrangement and instrumentation adopted for the test. Nine beam specimens were tested under static loading condition. The beam specimen was mounted in a testing frame of 500 kN capacity. The beam specimens were simply supported in such a way that the test span was 2.8 m and subjected to two concentrated loads placed symmetrically on the test span. The load was applied at third points. Dial gauges of 0.01 mm precision were used for measuring the deflection under the load points and at mid-span. Crack detection microscope of 0.02mm precision was used for measuring the crack width. The dial gauge readings were recorded at different loading stages.

Fig 6Static Test Set-up

3. TEST RESULTS AND DISCUSSION

A total of nine beams were cast and tested under static loading condition. The beams were designated as CB, MK, NMK, NMKP, NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5. The study parameters considered were first crack load, deflection at first crack load, yield load, deflection at yield load, ultimate load, deflection at ultimate load, number of cracks, average spacing of cracks and crack width.

3.1 Impact of Fibres on Strength

Fig.7 shows the impact of fibres on ultimate load. The beam specimen MK showed an increase of 6.31% over the control specimens. The beam specimen NMK and NMKP showed an increase of 13.11% and 33.01% when compared to control specimens. The beam specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 35.92%, 40.78%, 46.60%, 51.46% and 55.83% when compared to control specimens.

The beam specimens NMK and NMKP showed an increase of 6.39% and 25.11% when compared to MK specimens. The beam specimens NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 27.85%, 32.42%, 37.90%, 42.47% and 46.58% when compared to MK specimens.

The beam specimen NMKP showed an increase of 17.60% when compared to NMK specimens. The beam specimens NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 20.17%, 24.46%, 29.61%, 33.91% and 37.77% when compared to NMK specimens.

The beam specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 2.19%, 5.84%, 10.22%, 13.87% and 17.15% when compared to NMKP specimens.

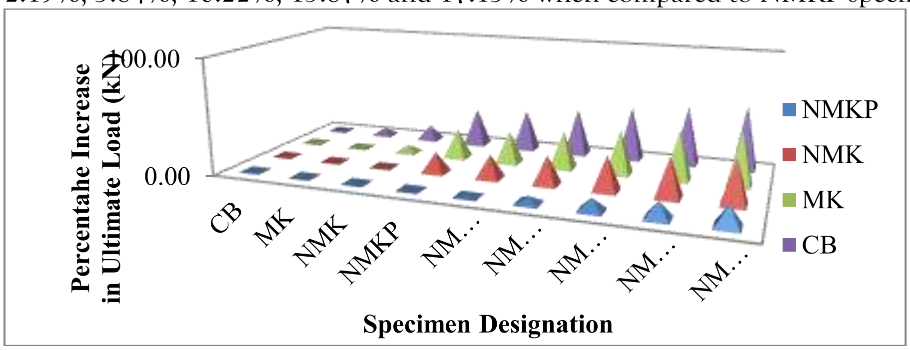


Fig.7 Impact of Fibres on Ultimate Load

3.2 Impact of Fibres on Deflection

Deflections of a beam primarily depends on span, loading, moment of inertia of the section and elasticity modulus of concrete. The addition of fibres to a ternary concrete beam results in an increase of stiffness. During the pre-cracking, cracking and post-cracking stages, this increase in stiffness influences the deflection behavior of fibre reinforced concrete beams.

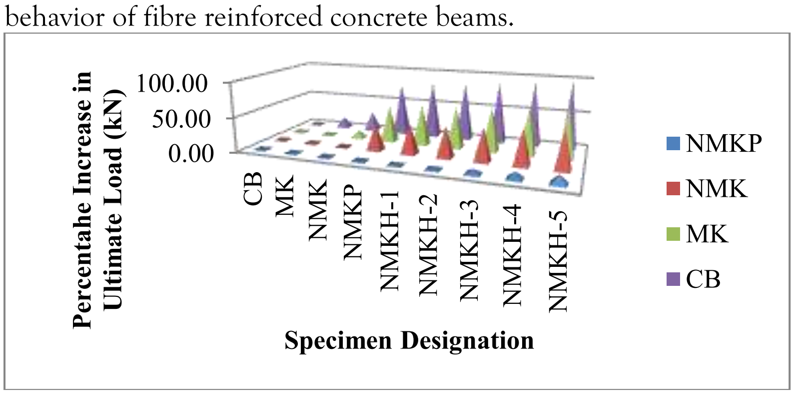


Fig.8 Impact of Fibres on Deflection at Ultimate Load

Fig.8 shows the impact of fibres on deflection at ultimate load. The beam specimen MK showed an decrease of 15.87% over the control specimens. The beam specimen NMK and NMKP showed an decrease of 28.09% and 77.20% when compared to control specimens. The beam specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an decrease of 83.04%, 85.10%, 89.22%, 93.96% and 99.04% when compared to control specimens.

The beam specimens NMK and NMKP showed an decrease of 10.55% and 52.93% when compared to MK specimens. The beam specimens NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an decrease of 57.97%, 59.75%, 63.31%, 67.40% and 71.78% when compared to MK specimens.

The beam specimen NMKP showed an decrease of 38.34% when compared to NMK specimens. The beam specimens NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an decrease of 42.90%, 44.50%, 47.72%, 51.42% and 55.39% when compared to NMK specimens.

The beam specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an decrease of 3.29%, 4.46%, 6.78%, 9.46% and 12.33% when compared to NMKP specimens. Inclusion of fibres resulted in enhanced stiffness leading to a considerable reduction in deflection at different load levels.

3.3 Load- Deflection Relationship

Fig.9 shows the load-deflection response of beam specimens. The load-deflection curves of all beam specimens were linear and had a high slope until the first crack appeared. The number of cracks increased beyond this loading stage. The slope of the curves significantly decreased after the yielding stage, showing higher deflections with increasing loads until the ultimate stage was reached.

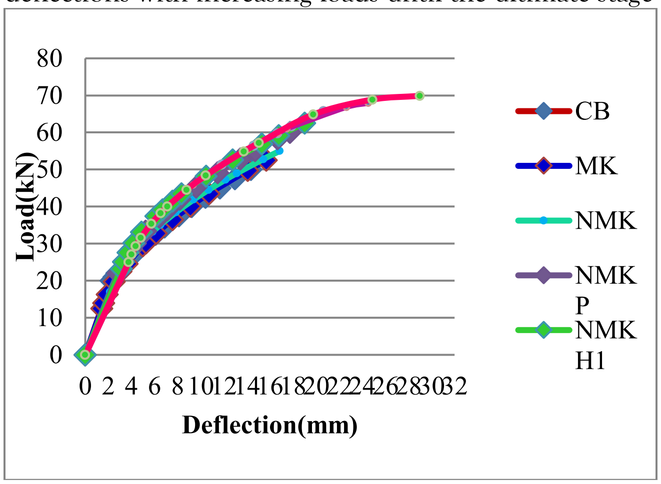


Fig.9 Load Vs Deflection Curve

3.4 Cracking Characteristics and Failure Modes

The crack width, number of cracks and the average spacing of cracks at the ultimate stage are furnished in Fig.10, Fig.11 and Fig.12. It can be seen from the Fig. 10 that the fibre reinforced ternary blended concrete beams exhibit increased crack width and large number of cracks in comparison to the control beams .This may be due to the higher resilience of the micro-fibre**.** The crack pattern of all the beam specimens tested in this investigation is shown in Fig. 13. In early stages of loading, cracks were observed in the constant moment zone. With increase in loading, new cracks formed and the existing cracks propagated further with increase in size along the loaded span.

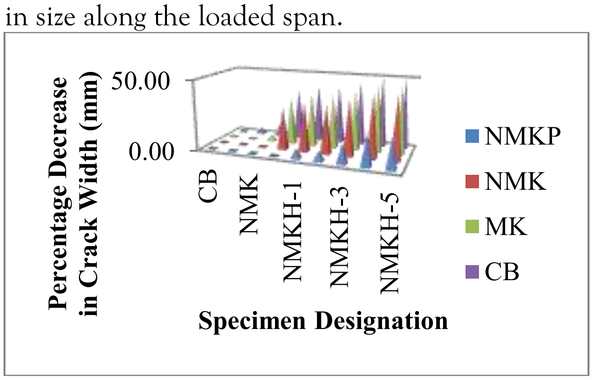
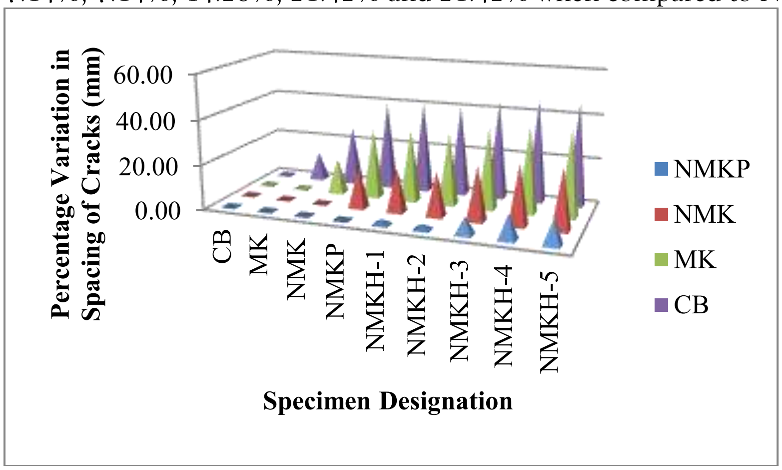


Fig.10 Impact of Fibres on Width of Crack

The beam specimen MK showed andecrease of 4.54% over the control specimens. The beam specimen NMK and NMKP showedandecrease of 9.09% and 36.36% when compared to control specimens. The beam specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an decrease of 40.90%, 40.90%, 45.45%, 50.00% and 50.00% when compared to control specimens.The beam specimens NMK and NMKP showed andecrease of 4.76% and 33.33% when compared to MK specimens. The beam specimens NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an decrease of 38.09%, 38.09%, 42.85%, 47.61% and 47.61% when compared to MK specimens.

The beam specimen NMKP showed a decrease of 30.00% when compared to NMK specimens. The beam specimens NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed andecreaseof 35.00%, 35.00%, 40.00%, 45.00% and 45.00% when compared to NMK specimens.

The beam specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an decrease of 7.14%, 7.14%, 14.28%, 21.42% and 21.42% when compared to NMKP specimens.

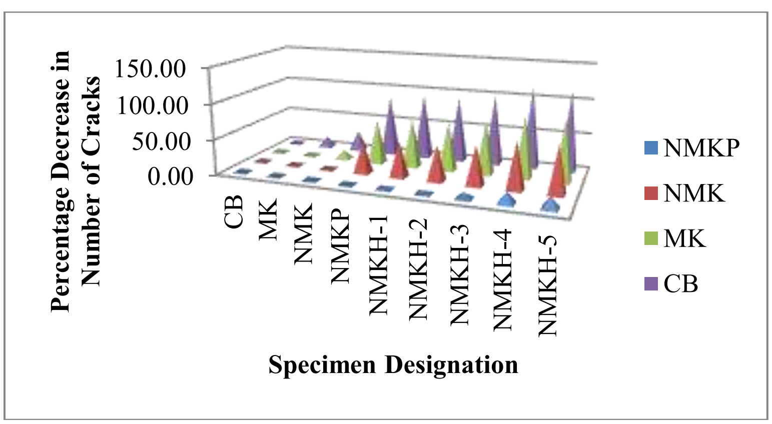


Figs. 11 Impact of Fibres on Spacing of Cracks

The impact of fibres on spacing of cracks is shown in Fig.11. The beam specimens NMK and NMKP showed andecrease of 15.78% and 30.82% when compared to MK specimens. The beam specimens NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an decrease of 32.33%, 32.33%, 36.09%, 38.34% and 38.34% when compared to MK specimens.

The beam specimen NMKP showed andecrease of 17.85% when compared to NMK specimens. The beam specimens NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed andecreaseof 19.64%, 19.64%, 24.10%, 26.78% and 26.78% when compared to NMK specimens.

The beam specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an decrease of 2.17%, 2.17%, 7.60%, 10.86% and 10.86% when compared to NMKP specimens.



Figs. 12 Impact of Fibres on Number of Cracks

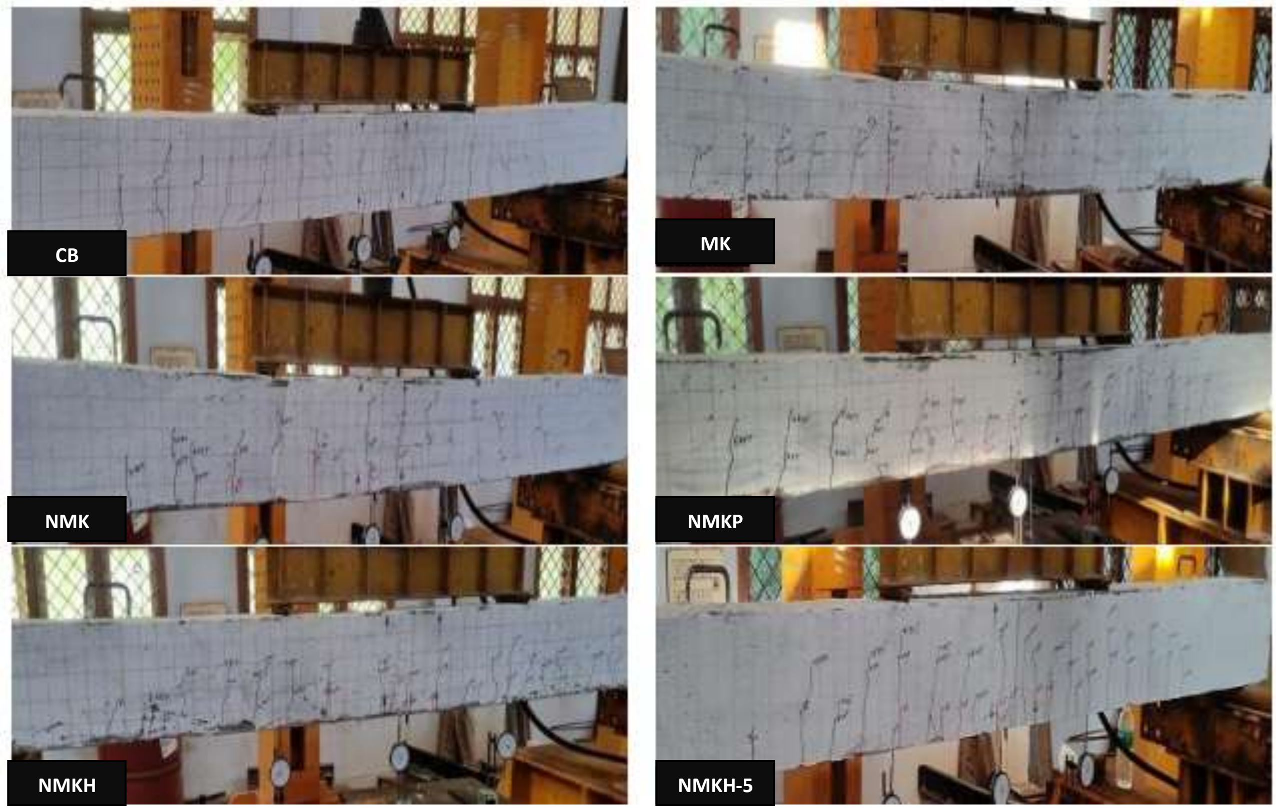


Fig 13 Crack Pattern on Tested Beams

3.5 Ductility Index

Ductility of a beam is essentially its ability to sustain inelastic deformation without any loss in its load carrying capacity, prior to failure. Ductility can be expressed in terms of deformation or energy. The ductility indices of all the beam specimens tested in this investigation are presented in Fig. 14. It can be inferred from the results presented in Fig. 8 that fibre inclusion has noticeable effect on the beam ductilities. The ductility increased with an increase in fibre volume fraction.

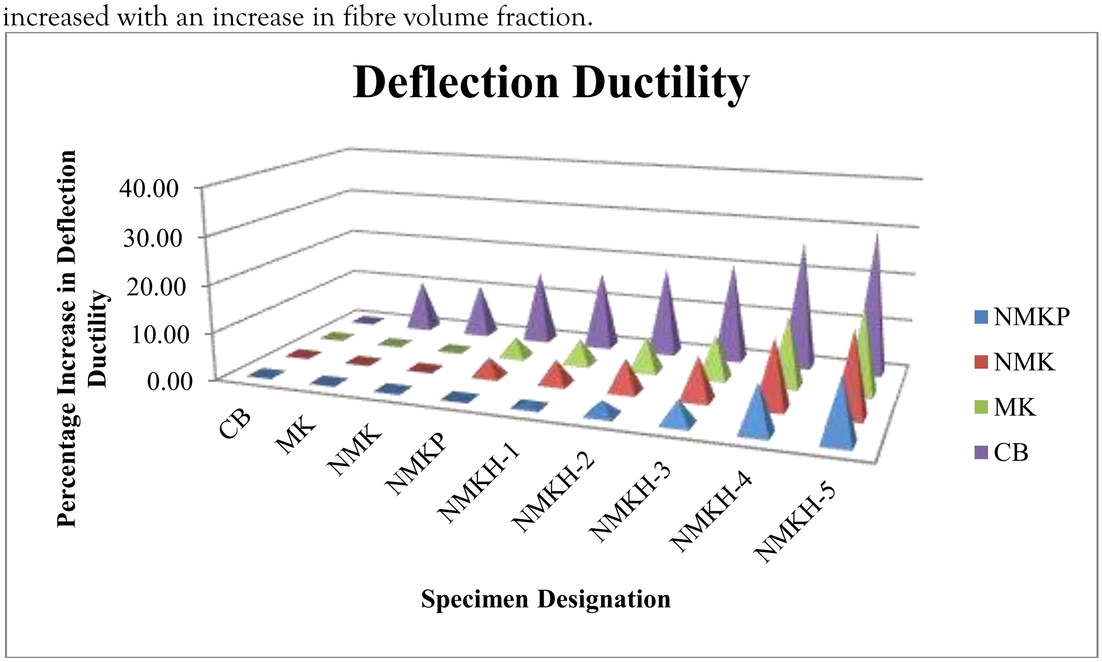


Fig. 14 Effect on Beam Ductility

Fig.14shows the impact of fibres on deflection ductility. The beam specimen MK showed an increase of 10.66% over the control specimens. The beam specimen NMK and NMKP showed an increase of 10.96% and 15.35% when compared to control specimens. The beam specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 16.52%, 18.59%, 20.91%, 26.81% and 30.30% when compared to control specimens.

3.6 Energy Capacity

The energy capacity of all the beam specimens tested in this investigation are presented in Fig. 15. It is a known fact that, for any structural member, larger ductility would lead to larger energy capacity. Assessment of energy capacity has been made based on the area available under the load-deflection response plots. The energy capacity increased with an increase in fibre volume fraction.

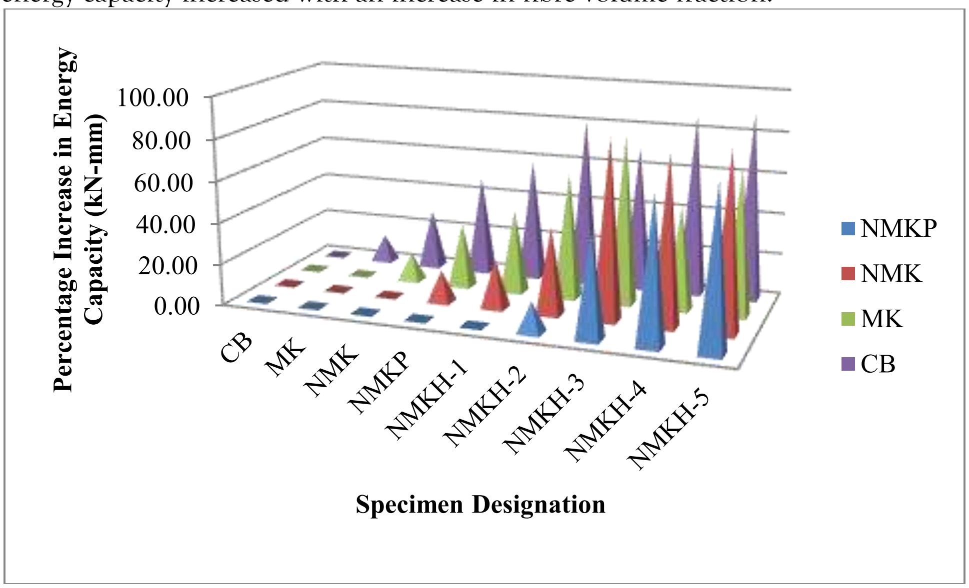


Fig.15 Impact of Fibres on Energy Capacity

4.CONCLUSIONS

- The beam specimen MK showed an increase in strength of 6.31% over the control specimens. The beam specimen NMK and NMKP showed an increase in strength of 13.11% and 33.01% when compared to control specimens. The beam specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase in strength of 35.92%, 40.78%, 46.60%, 51.46% and 55.83% when compared to control specimens.
- The beam specimen MK showed an decrease in deflection of 15.87% over the control specimens. The beam specimen NMK and NMKP showed an decrease in deflection of 28.09% and 77.20% when compared to control specimens. The beam specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an decrease in deflection of 83.04%, 85.10%, 89.22%, 93.96% and 99.04% when compared to control specimens.
- The beam specimen MK showed an increase in deflection ductility of 10.66% over the control specimens. The beam specimen NMK and NMKP showed an increase in deflection ductility of 10.96% and 15.35% when compared to control specimens. The beam specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase in deflection ductility of 16.52%, 18.59%, 20.91%, 26.81% and 30.30% when compared to control specimens.
- The beam specimen MK showed an increase in energy capacity of 13.10% over the control specimens. The beam specimen NMK and NMKP showed an increase in energy capacity of 28.46% and 48.11% when compared to control specimens. The beam specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase in energy capacity of 58.65%, 81.59%, 69.79%, 87.32% and 90.23% when compared to control specimens.

➢ The fibre reinforced ternary blended concrete beams experienced flexural failure. The width and spacing of cracks are much less than those of the control beams.

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