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An Experimental Study on Hybrid Fibre Reinforced Concrete Containing Nano Alumina and Metakaolin

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Abstract

The paper presents the results of research study carried out on ternary blended concrete containing Nano Alumina (NA), Metakaolin (MK) and Hybrid fibres (Polypropylene & Glass fibres). The optimum combination of nano alumina and metakaolin has been arrived at using standard procedures from the point of view of mobility and strength. The optimum combination has been found to be 1% nano alumina and 15% metakaolin. Fibreshave been added in 0.3% volume fractions at different ratios (70% PP&30%glass, 60% PP& 40%glass, 50% PP& 50%glass, 40% PP& 60%glass, 30% PP& 70%glass) to examine theirimpact on the mechanical properties of concrete involving nano alumina, metakaolin. Compressive Strength, Flexural Strength and Elasticity Modulus for the above concrete mixtures have been found using appropriate specimens such as cube, cylinder and prism following the standard test protocols.

1.Introduction

Cement is one of the important components of concrete. The production of portland cement is not only costly and energy intensive, it also involves large amount of carbon emission. The application of pozzolanic materials is increasing day-by-day as partial replacement for cement in concrete preparation [Somasekharaiah, PushpalathaGadag and Chhayadevi,2017].Concrete containing 15% metakaolin along with 1% fibre volume fraction of steel fibres showed improved strength properties in comparison with concrete without metakaolin[YogeshUlape, GiridharNarule,2020].Metakaolin is acquired from purification of kaolinite clay at temperature between 650°C to 800° C.It is an efficient pozzolona and react with the calcium hydroxide which comes from the cement hydration by pozzolanic reaction which produce the calcium aluminosilicate hydrates and calcium silicate hydrates.Nano-Silica is a new pozzolanic material in the form of water emulsion of colloidal silica [PrasadaRao,VenkataMaruthi, 2016]. The incorporation of nano- SiO_2 can optimize the pore structure [ChenglongZhuang, Yu Chen, 2019].Combined action of metakaolin and nano silica in concrete fills the micro and nano pores thereby improving its microstructural arrangement which produces a well dense concrete[Raheem, Abdulwahab, Kareem,2021]. Addition of 2% nano silica and 10% metakaolin improves mechanical properties as well as durability properties of high strength concrete [Meet Shah, Abbas Jamani (2017)]. Concrete incorporated with combined nano silica (2%) and metakaolin (5%) exhibited enhanced strength properties compared to concrete containing only metakaolin [Dr.Prasada Rao, VenkataMaruthi (2016)].Incorporation of steel fibers and metakaolin showed remarkable improvement in bonding and tensile strength capacities of the concretes[ErhanGuneyisi, Mehmet Gesoglu et al,2016] Addition of 10% volume fraction of steel fibres showed increased strength properties in high strength concrete made with metakaolin[Ghugal, Sabale et al,2017]. The strength properties increased substantially by the addition of 1% volume fraction of steel fibre in concrete with 12% metakaolin[HimanshuShukla,Vikas Srivastava. et al,2014].

2.TestProgramme

2.1 Concrete Mix

Mix design has been done as per IS 10262:2019 for ternary blended concrete incorporating

Metakaolin, Nano-Alumina and Hybrid fibres. Fig 1 represents the mix details used in the testing program. The mix details, details of test specimens and nomenclature of specimens are mentioned in Tables 1 and 2.

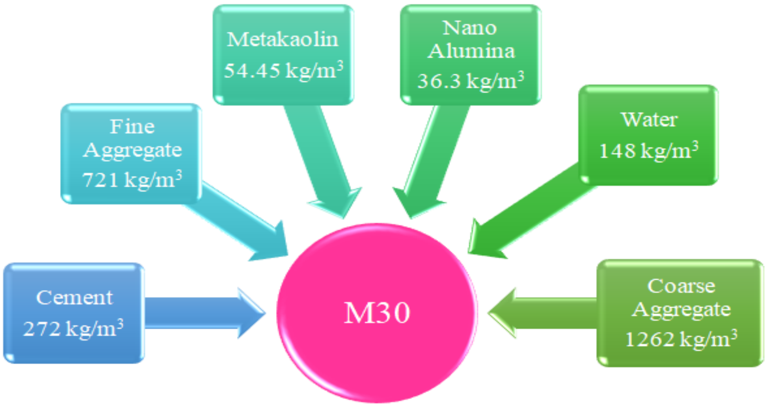

Fig.1 Constituents of Concrete Mix Used

Table 1 Details of Tests Specimens

Specimen Designation	Micro Filler+Nanofiller+Fibre	Hybrid Fibre Volume Fraction, v_f (%)	No. of Specimens		
			Cubes	Cylinders	Prisms
CB	0	-	9	6	3
MK	15%MK	-	9	6	3
NMK	15%MK+1%NA	-	9	6	3
NMKP	15%MK+1%NA	0.3%PP	9	6	3
NMKH-1	15%MK+1%NA+HF	(70%PP+30%Glass)	9	6	3
NMKH-2	15%MK+1%NA+HF	(60%PP+40%Glass)	9	6	3
NMKH-3	15%MK+1%NA+HF	(50%PP+50%Glass)	9	6	3
NMKH-4	15%MK+1%NA+HF	(40%PP+60%Glass)	9	6	3
NMKH-5	15%MK+1%NA+HF	(30%PP+70%Glass)	9	6	3
Total No. of Specimens			81	54	27

Table 2 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)

2.2 Materials

2.2.1Cement

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

2.2.2Fine Aggregate

In this research work, the specific gravity of fine aggregate was 2.67 and conforms to grading zone-III.

2.2.3Coarse 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.

2.2.4Nano Alumina and Metakaolin

Nano Alumina (Fig.2) and Metakaolin (Fig.3) has been used in the present investigation. The properties of Metakaolin and Nano alumina are presented in Table 3.

Table 3 Properties 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

Fig.2 Nano Alumina

Fig.3 Metakaolin

2.2.5Water

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

2.2.6Super Plasticizer

In this research study, Conplast SP430 (Fig 4), a sulphonated naphthalene formaldehyde based superplasticizer was employed to impart workability to the concrete mixes.It has a specific gravity of 1.18 and conforming to ASTM C494. The SP dosage for all the mixes was obtained by trials. The properties of super plasticizer are presented in Table 4

.Table 4 Properties of Super Plasticizer

Properties	Value
Colour	Brown
Form	Liquid
Specific Gravity	1.26 at 25°C

Fig. 4Super Plasticizer

2.2.7Polypropylene Fibres

Polypropylene fibres (Fig.5) procured from Stewols India (P) Ltd, Nagpur were used in this investigation. The properties of ppfibres are presented in Table 5.

Table 5 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
Shape	Triangular

2.2.8Glass Fibre

Glass fibres (Fig.6) procured from Stewols India (P) Ltd, Nagpur were used in this investigation. The properties of glass fibres are presented in Table 6.

Table 6 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.5 Polypropylene Fibre

Fig.6 Glass Fibre

2.3Preparation of Specimens

The ingredients were first mixed in a dry state and then fibres were added in smaller quantities to avoid balling of fibres. The water plus Super plasticizer was added slowly and mixed thoroughly to avoid clustering. The specimens were cast in steel moulds and vibrated using a vibrating table. All the specimens were de-moulded after 24 hours of casting and then cured for 28-days before being tested.

2.4 Test Methods

2.4.1 For Compressive Strength, Cubes and Cylinders were cast and tested in a standard manner in a 1000 kN capacity compression testing machine. A total of 18 Cubes and 18 cylinders were tested as per IS516: 2004 (Reaffirmed). Concrete Cubes of size 150X150X150mm and Cylinder Specimens of size 150 X 300mm were tested. The test set-up with appropriate instrumentation is shown in Figs.7 and 8.

Fig .7 Cube Compression Strength Test

Fig.8 Cylinder Compression Strength Test

2.4.2Flexural Strength

A total of 18 Concrete prisms Specimens of size 100 x 100x 500 mm were cast and tested as per IS 516: 2004 (Reaffirmed) for flexural strength. Fig.9 shows the experimental setup.

Fig.9 Flexural Strength Test

2.4.3Modulus of Elasticity

A total number of 18 cylinders of size 150x300 mm were tested as per IS 516: 2004 (Reaffirmed) in a standard Compression Testing Machine. The experimental setup is shown in Fig.10.

Fig.10 Elasticity ModulusTest

3.Results and Discussion

3.1Impact of Fibres on Compressive Strength

The compressive strengths of cube and cylinder specimens with and without metakaolin, nano alumina and fibres are presented in Table 7

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Table 7 Compressive Strength of Cube and Cylinder Specimens

Mix No.	Specimen Designation	MK Content	NA Content	Fibre Volume Fraction, v_f (%)	Cube Compressive Strength (MPa)
1	CB	15%	1%	-Nil-	39.06

2	MK	15%	1%	-Nil-	40.98
3	NMK	15%	1%	-Nil-	42.04
4	NMKP	15%	1%	0.3% PP	46.59
5	NMKH-1	15%	1%	0.3% (70%PP+30%Glass)	46.75
6	NMKH-2	15%	1%	0.3% (60%PP+40%Glass)	46.92
7	NMKH-3	15%	1%	0.3% (50%PP+50%Glass)	47.22
8	NMKH-4	15%	1%	0.3% (40%PP+60%Glass)	47.67
9	NMKH-5	15%	1%	0.3% (30%PP+70%Glass)	48.44

Each value represents average of the test results of three specimens. Concrete with and without fibres showed a noticeable improvement in compressive strength when compared to the control specimen.

The percentage increase in compressive strength of cube specimen is shown in Fig.11.The cube specimen MK showed an increase of 4.92% over the control specimens. The cube specimen NMK and NMKP showed an increase of 7.63% and 19.28% when compared to control specimens. The cube specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 19.69%, 20.12%, 20.89%, 22.04% and 24.01% when compared to control specimens.

The cube specimen NMK and NMKP showed an increase of 2.59% and 13.69% when compared to MK specimens. The cube specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 14.08%, 14.49%, 15.23%, 16.33% and 18.20% when compared to MK specimens.

The cube specimen NMKP showed an increase of 10.82% when compared to NMK specimens. The cube specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 11.20%, 11.61%, 12.32%, 13.39% and 15.22% when compared to NMK specimens.

The cube specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 0.34%, 0.71%, 1.35%, 2.32% and 3.97% when compared to NMKP specimens. The interfacial bond is significantly improved by the inclusion of nano silica and metakaolin resulting in increased compressive strength.

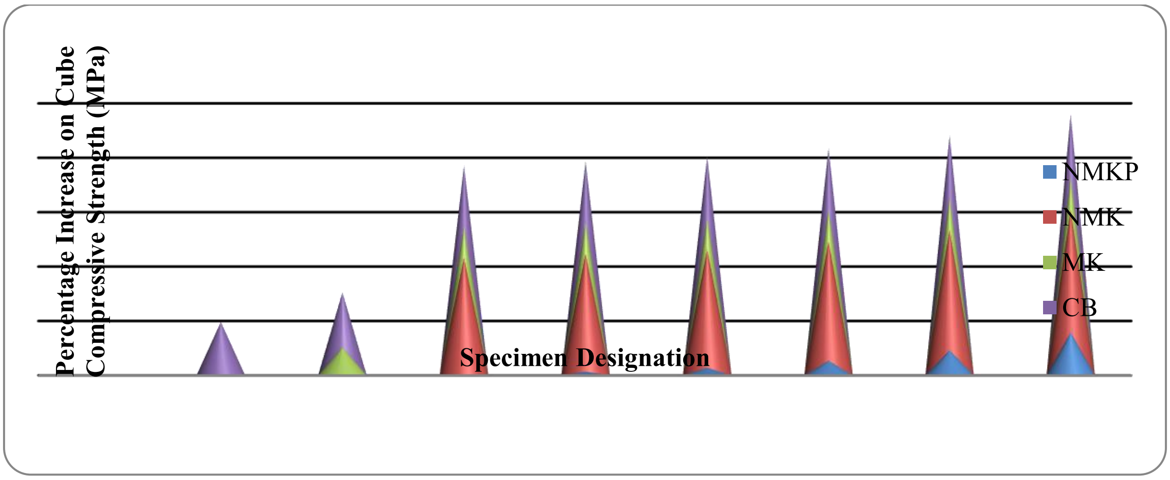

Fig.11 Impact of Fibres on Compressive Strength of Cube Specimens

Failure Mode

Fig.12 shows the failure pattern of cube specimens. The cracks were initially localized on the concrete surface, but as the external load increased, the cracks propagated to the internal areas of the concrete, resulting in spalling. Cracking and spalling were less severe in the MK specimen compared to control specimen. Different failure patterns were observed in the specimens NMK, NMKP, NMKH. The inclusion of nano alumina and metakaolinincreases the bond between the aggregate and the cement matrix.The initiation and propagation of cracks was seen to be delayed, but the extent of cracks was more pronounced. This observation may be attributed to the mechanism of internal restraint caused by the internally added discontinuous discrete fibres.

CB MK NMK NMKH

Fig.12 (a)-(d) Failure Pattern of Cube Specimens

3.2Impact of Steel Fibres on Flexural Strength

The flexural strength of prism specimens with and without nano alumina, metakaolin and fibres are presented in Table 8.

Table 8 Flexural Strength of Prism Specimens

MixNo.	**Mixture ID**	**Flexural Strength (MPa)**
1	CB	4.46
2	MK	4.63
3	NMK	4.92
4	NMKP	5.12
5	NMKH-1	5.24
6	NMKH-2	5.45
7	NMKH-3	5.92
8	NMKH-4	6.16
9	NMKH-5	6.57

Each value represents average of the test results of three specimens. The prism specimen MK showed an increase of 3.81% over the control specimens. The prism specimen NMK and NMKP showed an increase of 10.31% and 14.80% when compared to control specimens. The prism specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 17.49%, 22.20%, 32.74%, 38.14% and 47.31% when compared to control specimens.

The prism specimens NMK and NMKP showed an increase of 6.26% and 10.58% when compared to MK specimens. The prism specimens NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 13.17%, 17.71%, 27.86%, 33.05% and 41.90% when compared to MK specimens.

The prism specimen NMKP showed an increase of 4.07% when compared to NMK specimens. The prism specimens NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 6.50%, 10.77%, 20.33%, 25.20% and 33.54% when compared to NMK specimens.

The prism specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 2.34%, 6.45%, 15.63%, 20.31% and 28.32% when compared to NMKP specimens.

The bridging action of fibre is responsible for the increase in flexural strength.The percentage increase in flexural strength of prism is shown in Fig.13.

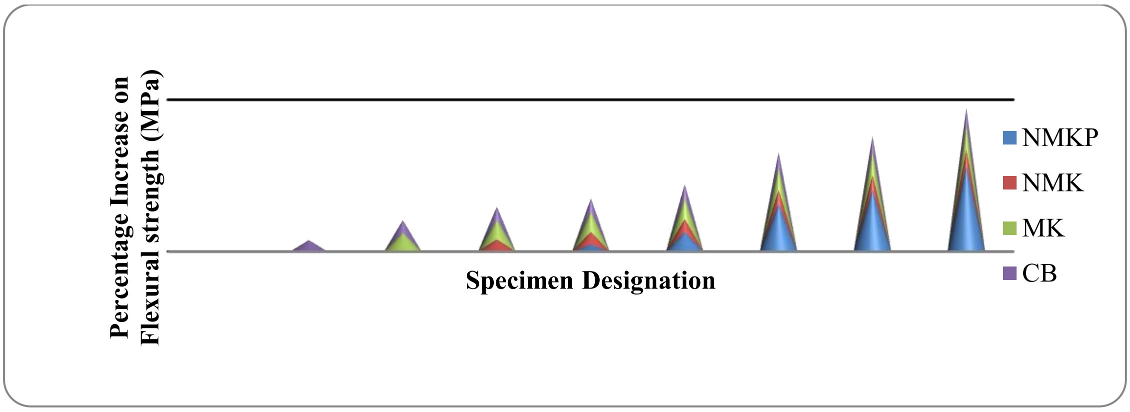

Fig.13 Impact of Fibres on Flexural Strength

Failure Mode

The prism specimens were subjected to four point bending in a standard loading frame. In both the control specimen and MK specimen, a primary crack got initiated at the mid-span section which subsequently travelled upward resulting in a sudden failure. In the case of specimens with micro - reinforcement, the same mode of failure has been observed excepting that the size of crack decreased with increasing fibre volume fraction. The bridging actionof fibres would have contributed to a restraint action enabling the specimens to sustain higher flexural loads. The failure pattern of all the specimens are presented through Fig.14.

a) CB

b) MK

c) NMK

d) NMKH

Fig.14(a)-(d)Failure Pattern of Prism Specimens

3.3Impact ofFibres on Modulus of Elasticity

The elasticity modulus of cylinder specimens with and without nano alumina, metakaolinand fibres is presented in Table 9.

Table 9 Modulus of Elasticity of Cylinder Specimens

Mix No	Mix ID	Modulus of Elasticity (GPa)
1	CB	31.34
2	MK	32.81
3	NMK	33.42
4	NMKP	34.43
5	NMKH-1	34.98
6	NMKH-2	35.25
7	NMKH-3	35.89
8	NMKH-4	36.44
9	NMKH-5	36.99

Each value presented is the average of the test results of three specimens. The cylinder specimen MK showed an increase of 4.69% over the control specimens. The cylinder specimen NMK and NMKP showed an increase of 6.64% and 6.67% when compared to control specimens. The cylinder specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 11.61%, 12.48%, 14.52%, 16.27% and 18.03% when compared to control specimens.

The cylinder specimens NMK and NMKP showed an increase of 1.86% and 1.89% when compared to MK specimens. The cylinder specimens NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 6.61%, 7.44%, 9.39%, 11.06% and 12.74% when compared to MK specimens.

The cylinder specimen NMKP showed an increase of 0.03% when compared to NMK specimens. The cylinder specimens NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 4.67%, 5.48%, 7.39%, 9.04% and 10.68% when compared to NMK specimens.

The cylinder specimen NMKH-1, NMKH-2, NMKH-3, NMKH-4 and NMKH-5 showed an increase of 4.64%, 5.44%, 7.36%, 9.00% and 10.65% when compared to NMKP specimens. The increase in modulus of elasticity may be attributed to the higher modulus of elasticity of fibres. Fig.15 shows the percentage increase in modulus of elasticity.

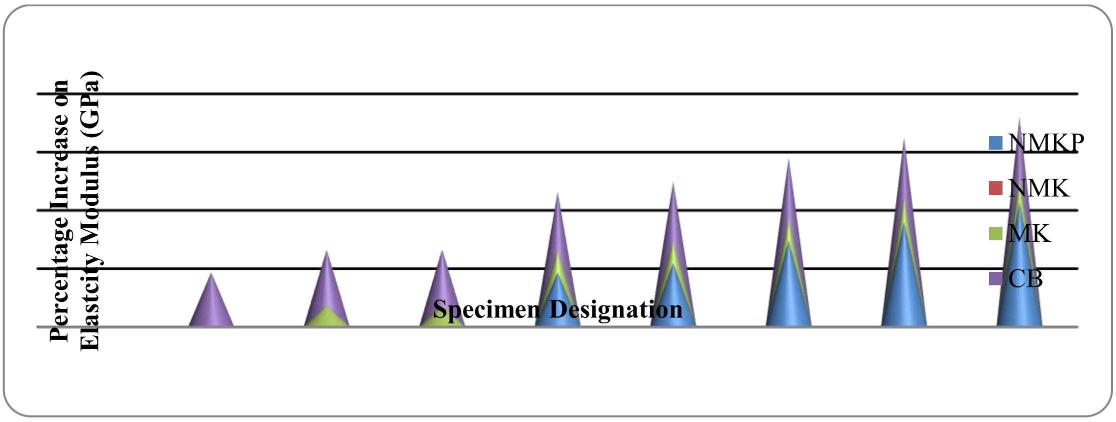

Fig.15 Impact of Fibres on Modulus of Elasticity

Failure Mode

The cylinder specimens were tested under uni-axial compression. In the early stages, a primary crack was observed extending over the height of the cylinder specimens. In the case of specimen made with fibres, it took time for the formation of the primary crack due to improved bond between the aggregate and matrix consequent to the inclusion ofmetakaolin and nano alumina. With increased axial stress, secondary cracks formed parallel to the first formed primary crack. Different failure patterns have been seen in specimens with micro - reinforcement. With less concrete spall, the primary crack took longer time to form and the extent of cracking was also more. This is because the internally included fibres created a confinement mechanism preventing the tendency of concrete to crack and spall.The failure pattern of all the specimens are shown in Fig.16.

CB **MK** **C) NMK** **d) NMKH**

Fig.16 (a)-(d) Failure Pattern of Cylinder Specimens

4.

Conclusions

- For this study, the ternary blended concrete showed a maximum 24.01% increase in compressive strength with the inclusion of a 0.3% volume fraction of fibre (30%polypropylene+70%glass fibre) when compared to control concrete,18.20% increase in strength when compared to MK specimen, 15.22% and 3.97% strength increase when compared to NMK and NMKP specimen.
- The ternary blended concrete showed a maximum 47.31% increase in flexural strength with the inclusion of a 0.3% volume fraction of fibre (30%polypropylene+70%glass fibre) when compared to control concrete,41.90% increase in strength when compared to MK specimen, 33.54% and 28.32% strength increase when compared to NMK and NMKP specimen.
- The ternary blended concrete showed a maximum 18.03% increase in elasticity modulus with the inclusion of a 0.3% volume fraction of fibre (30%polypropylene+70%glass fibre) when compared to control concrete,12.74% increase in strength when compared to MK specimen, 10.68% and 10.65% strength increase when compared to NMK and NMKP specimen.
- Incorporating fibres is very effective in improving the mechanical properties of ternary blended concrete.

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