IJCRT.ORG ISSN : 2320-2882
INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Studies on Natural rubber latex modified high performance fibre reinforced concrete

Sreelekshmi M
M. Tech in Structural Engg.
Dept. of Civil Engg.
College of Engineering Trivandrum
Thiruvananthapuram, Kerala.

Dr. Beena P R
Associate Professor
Dept. of Civil Engg
College of Engineering Trivandrum
Thiruvananthapuram, Kerala.

Abstract— **Modern civil engineering construction tends to progress towards more economic, design and construction of structures through, gradually improved methods of design and the use of higher strength materials. The application of polymer latex provides an additional approach when optimizing the properties of high- performance concrete thereby improving the plain concrete from porous to an impermeable structure by forming a lining of latex film across voids, pores and micro cracks. Optimum natural rubber latex in cement concrete is very effective in avoiding the chemical attacks on concrete by blocking the aggressive agents which attacks the cement paste. Since concrete is a significantly brittle material and exhibits a very poor tensile strength, it cracks Therefore, to sort out these issues, fibers are added to concrete to control the cracks and crack growth. The paper investigates the effect of Natural rubber latex, basalt and sisal fibres on the flexural behaviour and drying shrinkage of metakaolin added high- performance concrete. The results revealed that the drying shrinkage has decreased for Natural rubber latex specimens compared to control specimens by 38.14% and sisal fibres exhibited significant reduction in drying shrinkage over control specimens by about 47.44%. Also, the flexural load carrying capacity of natural rubber latex modified beam with metakaolin was increased by 3.54% whereas those with mono fibres showed an increased percentage of 8.55% and 15.47% with sisal and basalt respectively. Thus, Natural Rubber Latex modified fibre reinforced HPC enhances the flexural behaviour and also results in decreased drying shrinkage compared to control specimens.**

Keywords: High- performance concrete, Natural rubber latex, metakaolin, drying shrinkage, basalt fibres, sisal fibres, flexural capacity etc.

I. Introduction

Concrete, unlike any other structural building material, has revolutionized the construction industry. Over the last decades, vast advancement has been made in material technology and in production control, which resulted in the emergence of higher strength grades of concrete. The strength of concrete used in the construction industry has increased gradually over the years. i.e., normal strength concrete (NSC) has developed to high strength concrete (HSC). Modern civil engineering construction tends to progress towards more economic, design and construction of structures through, gradually improved methods of design and the use of higher strength materials. The application of high- performance concrete has overcome the limiting features of ordinary reinforced concrete for the design and construction of civil engineering structures. High- performance concrete (HPC) is the latest catch phrase in concrete technology and replaced the high strength concrete of the past. High- performance concrete is a performance enhanced concrete, which is a specialized sense of concrete, designed to provide several benefits in the construction sector, that cannot always to be achieved usually by using conventional ingredients, normal mixing and curing practices. A high performance refers to certain characteristics developed for a particular application and environment, so that it will give excellent performance in the structure when placed in the environment and subjected to loads during its design life. In the recent past, interest in the development and production of high- performance concrete has increased due to the enhanced properties viz, higher compressive strength, improved modulus of elasticity, increased bond and fatigue strengths, lower permeability and better durability. These qualities make it a very competitive material.

Nowadays, the use of polymer in concrete is being enriched by the researches. By the use of polymer, the permeability of concrete can be reduced, workability could be improved and other characteristics can be enhanced to greater extent. Polymer latexes are being increasingly used in the construction industry as modifiers, especially in hydraulic cement concrete and mortar.

II. Literature Review

Vishwanath et al., attempted to examine the impact of natural sisal fibre on concrete by partially substituting cement. For usage in concrete, sisal fibre is chemically processed in this instance. When compared to standard M25 concrete, fibre reinforced concrete with 1%,2%,3% of fibre replacing cement by volume has mechanical parameters such as compressive strength, split tensile strength, and flexural strength that are higher. Comparing fibre replacements of 1%, 2%, and 3% to ordinary concrete, the compressive strength at 28 days increased by 13.8%, 21%, and 16.3%, respectively. When compared to normal M25 concrete, fibre substitutions of 1%, 2%, and 3% enhance split tensile strength at 28 days by 24%, 56%, and 80% and first cracking load in flexure by 12.5%, 27.5%, and 20%. The use of natural sisal fibre improves concrete. The best sisal fibre percentage for maximal strength was 2% for compressive strength and 2% for split tensile strength. The flexural strength of the sisal of fibre supplemented beam achieved is more than that of regular strength concrete. When the initial fracture load value increases, it shows that the strength of the concrete is greater than in traditional concrete. At 2% sisal fibre concrete replacement, the maximum ultimate flexure strength of the beam was achieved [1].

Mallikarjuna *et al.*, investigated the combined effects of Metakaolin (MK) and Hybrid fibers on High-Performance Concrete's (HPC) mechanical properties. A constant proportion of 0.25% for polypropylene fibers (PF) and varying proportions of 0%, 0.5%, 0.75% and 1.0% for steel fibers (SF) making a total fiber volume fraction of 0%, 0.75%, 1.0% and 1.25% were used to develop hybrid fiber-reinforced high-performance concrete (HFRHPC). Four replacement levels for hybrid fibers by volume of the binders and four partial replacement levels for Metakaolin (0%, 10%, 20% & 30%) by weight of cement have been considered for three different water binder ratios (0.275, 0.325 & 0.375). An aggregate binder ratio of 1.75 was kept constant. The test results reveal a maximum increase of 31.83%, 37.05%, and 36.53% in compressive strength for curing periods of 7, 28, and 56 days, respectively. The split tensile strength, flexural strength, and impact strength test results show an increase of 42%, 74.41%, and 68.32% for a curing period of 28 days, respectively. With the incorporation of metakaolin and hybrid fibers into the concrete matrix, very high mechanical properties could be achieved. The results indicate that a combination of 1.25% hybrid fibers and 10% Metakaolin gains all the water-binder ratios' highest strength [5].

Sunny *et al.*, investigated the combined effect of rubber latex and PET fibers in M40 grade concrete. Various tests are conducted on the laboratory cast concrete specimens and their behaviors are observed and documented for 7 days and 28 days testing. The solution offered in the project by using waste plastic is one of the answers to the long-standing menace of waste disposal. The Natural Rubber Latex modification significantly improves the plain concrete from porous to an impermeable and denser microstructure by forming a lining of latex film across voids, pores, and micro-cracks [8].

Ghorpade *et al.*, in the investigation, Natural Rubber Latex Modified Fibre Reinforced High Performance Concrete (NRLMHPC) has been produced with locally available aggregates and mineral admixture (Metakaolin) and Natural Rubber Latex based Fibre Reinforced HPC mixes were designed by absolute volume method. Cubes of 150 x 150 x 150 mm in dimension were cast and cured for 28 days and then tested for compressive strength to assess the strength characteristics of NRLMFRHPC. Workability has been measured by conducting compaction factor test on fresh NRLMFRHPC mixes. The experimental results indicate that Natural Rubber Latex can be utilized in producing durable Fiber Reinforced High Performance-Concrete. The various results which indicate the effect of Steel Fibers and Natural Rubber Latex on the strength and workability characteristics of high performance-concrete were also presented [18].

Review of literature can be concluded as follows:

- Natural Rubber Latex modification significantly improves the plain concrete from porous to an impermeable and denser microstructure by forming a lining of latex film across voids, pores, and micro-cracks.
- With the incorporation of metakaolin and hybrid fibers into the concrete matrix, very high mechanical properties could be achieved.
- Inclusion of natural rubber latex and Poly Vinyl Alcohol Fiber (PVA) concrete improves the performance properties of the concrete and workability of concrete through ball bearing actions.
- The addition of PVA Fibers improves tensile strength, modulus of elasticity and durability, and also it helps to reduce the quantity of coarse aggregate in concrete.
- Optimum percentage weight of natural rubber latex and fibers to be made use in achieving the high strengths compared to conventional concrete.

III. Materials

The cement used throughout the experiment was Ordinary Portland Cement (OPC) of 53 grade. The 28 days compressive strength and specific gravity of cement were 56 MPa and 3.14 respectively determined as per IS: 4031 (Part-6) 1988 and IS: 4031 (Part- 11) 1988 respectively. Fine aggregate of size less than 4.75mm having specific gravity 2.465 was used throughout the experimental investigation. Crushed stone aggregates (of nominal maximum size 20 mm were used as coarse aggregate with a specific gravity of 2.8. The physical properties of aggregates were determined as per IS: 2386-199712. Ordinary tap water was used for all the mixes to prepare fresh concrete. Metakaolin was used as mineral admixture. Basalt and sisal fibres were used as reinforcing materials and the properties are listed in TABLE I. Poly-Carboxylic ether- based superplasticizer (Cera Hyperplast XR W40) with set retarding effect was used as high range water reducing admixtures (HRWRA).

TABLE I. Properties of Fibres

Fibre	Length (mm)	Dia (mm)	Density (kg/m^3)	Tensile strength (MPa)	Elongation (%)
Basalt	12	0.012	2800	2000-2400	2.6-3.0
Sisal	18	0.1-0.2	1100	511-700	2.0-2.5

* Provided by the supplier

IV. Mix Proportion

The mix chosen for the study is with reference to M. Narmatha & Dr. T. Felixkala, 2016, and trial mixes were developed by varying the dosage of superplasticizer. Finally arrived mix proportion is 1: 1.6: 1.98: 0.28: 0.012 which corresponds to M60 grade High performance concrete and is given in TABLE II.

TABLE II. Mix Proportion of M60 Mix

Mix	Cement (kg)	M-Sand (kg)	Coarse Aggregate (kg)	Water (liters)	Super plasticizer (liters)
M60	521.43	821.68	1034.24	146	6.25

V. Experimental Investigations

A. Determination of optimum doses of various constituents

In order to conduct crack and shrinkage studies it is required to obtain the optimum dosages of metakaolin, natural rubber latex, mono fibres and hybrid fibres.

1) Optimum Metakaolin dose: It was determined by conducting compressive strength test on cubes of standard size 150 x 150 x 150 mm. Various metakaolin dosages were chosen such as 0%, 5%,10%, 15% and 20% and the test results are given in TABLE III. The values can be graphically plotted as shown in Fig. and it is clearly understood that the maximum compressive strength is obtained corresponding to 15% metakaolin dosage. The compressive strength values for the control mix is obtained as 56.43 MPa and 71.06 MPa for 7 days and 28 days respectively.

TABLE III. COMPRESSIVE STRENGTH OF VARIOUS METAKAOLIN MIXES

Mix ID	Dosage of MK (%)	Avg. 7 days compressive strength (MPa)	Avg. 28 days compressive strength (MPa)
MK0	0	56.43	71.06
MK5	5	57.76	72.58
MK10	10	58.79	74.79
MK15	15	60.63	76.43
MK20	20	59.33	75.05

2) Optimum Natural rubber latex dose: The NRL inclusion at optimum level enhances the impermeability and water exclusion properties of normal concrete. The optimum latex dosage is obtained by compressive strength test on cubes of 150 x 150 x 150 mm thereby varying the latex dose as 0.5%, 1%, 1.5% and 2% respectively and the test results are tabulated in TABLE IV.

TABLE IV. COMPRESSIVE STRENGTH OF NRL ADDED MIXES

Mix ID	MK Dose (%)	NRL Dose (%)	Avg. 28 days compressive strength (MPa)
NRL 0	15	0	76.43
NRL 0.5	15	0.5	77.83
NRL 1.0	15	1.0	79.26
NRL 1.5	15	1.5	79.07
NRL 2.0	15	2.0	78.32

It is observed that the optimum dosage of NRL modification for obtaining improved compressive strength is 1% and with increase in dosages above 1% there is a reduction in compressive strength by 3.45% and 2.47% for NRL1.5 and NRL 2.0 mixes respectively.

3) Optimum Basalt fibre dose: Chopped basalt fibers are used as an additive to enhance the mechanical properties of concrete. The optimum content of fibre required in natural rubber latex modified high performance concrete (NRLMHPC) mix is determined by Split tensile strength test using cylindrical specimens of 150 mm diameter and 300 mm height. The split tensile strength is calculated by the following equation and results are listd in TABLE V.

$$\text{Split tensile strength} = \frac{2P}{\pi DL}$$

TABLE V. SPLIT TENSILE STRENGTH OF BSALT FIBRE REINFORCED MIXES

Mix ID	Fibre Content (%)	28 days split tensile strength (MPa)
BF0	0	6.87
BF1	0.5	7.52
BF2	0.75	7.94
BF3	1.0	7.82

It can be concluded from the observations that the optimum basalt fibre content to be incorporated into NRLMHPC mix is 0.75% since maximum split tensile strength corresponds to it.

4) Optimum Sisal fibre dose: Sisal fibres are chemically treated for controlled removal of some *fiber* constituents, including hemicellulose, lignin, pectin, waxy substances, and natural oils. This treatment is referred to as Mercerization treatment in which sisal fiber is treated with 5% solution of NaOH (0.1 conc.) for 2 hours and washed several times with water till it becomes colourless and later with 1% acetic acid to remove any excess NaOH to balance the pH. Finally, sisal fiber is dried at room temperature for about 3 days followed by an exposure to sunlight and then used in concrete mix. The optimum sisal fibre content is also obtained in a similar manner to that of basalt fibres. The observations are given in TABLE VI.

TABLE VI. SPLIT TENSILE STRENGTH OF SISAL FIBRE REINFORCED MIXES

Mix ID	Fibre Content (%)	28 days split tensile strength (MPa)
SF0	0	6.87
SF1	1	7.01
SF2	2	7.26
SF3	3	7.12

Based on the above observations, optimum sisal fibre content to be incorporated into the NRLMHPC mix is taken as 2% as it possesses highest split tensile strength.

*5) Optimum hybrid fibre dose:*The specimens were prepared by adding different percentages of fibres to the concrete. Sisal fibres (adding 0%, 1%, 2%, and 3%) and basalt fibres (adding 0%, 0.5%, 0.75% and 1%). The specimens were tested and compared to standard mix for split tensile strength test. The test results are given in TABLE VII.

TABLE VII. SPLIT TENSILE STRENGTH OF HYBRID FIBRE REINFORCED MIXES

Mix ID	Fibre Content, (%)		28 days split tensile strength (MPa)
	SF	BF	
HY1	1.0	0.75	7.58
HY2	2.0	0.75	7.82
HY3	2.0	0.5	7.51

From the three hybrid combinations tried HY2 achieved highest split tensile strength compared to HY1 and HY3. Thus 2% of sisal fibres and 0.75% of basalt fibres are incorporated into latex modified metakaolin admixed HPC.

B. Drying Shrinkage

Drying shrinkage is a very important property of cementitious composites influencing their durability. It results from the loss of capillary water from the hardened cement mixture thus causing contraction and crack formation within concrete. This chapter discusses the effect of latex addition, mono and hybrid fibre incorporation into HPC mix based on drying shrinkage.

1) Specimen Preparation

The study conforms to IS 2185-1: Concrete masonry units, Part 1: Hollow and solid concrete blocks. Specimens are beams of size 7.5 x 7.5 x 15 cm, provided with two reference points consisting of 5mm diameter steel balls which are cemented with neat Rapid hardening Portland cement at the center of each end of each specimen after drilling or cutting a shallow depression. After fixing the surface of steel balls are wiped and coated with grease to prevent corrosion. The specimens shall then be immersed in water for 28 days, the temperature being maintained at 27 ± 2°C. A total of 15 specimens are prepared, three specimens each for control, latex admixed, mono and hybrid fibre mixes.

2) Testing Procedure

Immediately after removal of the specimens from the water, the grease shall be wiped from the steel balls and the length of each specimen measured to an accuracy 0.0025 mm by the Length comparator and it is reported as original wet measurement. The specimens shall then be dried in an oven for 24 hrs and then cooled to record the dry measurement. Then drying shrinkage shall be calculated as the difference between the original wet measurement and dry measurement expressed as a percentage of the dry length.

The specimens which have been previously used for conducting drying shrinkage test, after the completion of that test are immersed in water for 4 days while test temperature being maintained at 27 ± 2°C for at least 4 hrs prior to the removal of the specimen and the wet length is measured. The moisture movement shall be determined as the difference between the dry and wet lengths and expressed as a percentage of the dry length for each specimen.

3) Results and Discussions

Test results for drying shrinkage and moisture movement are given in TABLE VIII and TABLE IX respectively.

TABLE VIII. TEST RESULTS FOR DRYING SHRINKAGE

Specimen ID		Original Wet Measurement	Dry Measurement	Drying Shrinkage	% Reduction from M60
S1	M60	8.3715	8.347	0.0312	-
S2		8.6015	8.5575		
S3		9.867	9.795		
S4	NRL	10.759	10.743	0.0193	38.14
S5		10.091	10.062		
S6		10.715	10.673		
S7	SF	10.7855	10.766	0.0164	47.44
S8		11.6025	11.6		
S9		12.064	12.012		
S10	BF	11.8345	11.8239	0.0185	40.705
S11		11.8651	11.8543		
S12		11.9365	11.9302		
S13	Hybrid	13.6011	13.5982	0.0153	50.96
S14		12.865	12.8605		
S15		13.2405	13.225		

TABLE IX. TEST RESULTS FOR MOISTURE MOVEMENT

Specimen ID		Wet Measurement after 4 days of water immersion	Dry Measurement	Moisture Movement	% Reduction from control mix
S1	M60	8.385	8.347	0.0574	-
S2		8.677	8.5575		
S3		9.896	9.795		
S4	NRL	10.806	10.743	0.0397	30.83
S5		10.098	10.062		
S6		10.753	10.673		
S7	SF	13.33	10.766	0.0526	8.36
S8		13.6235	11.6		
S9		12.985	12.012		
S10	BF	11.865	11.8239	0.0405	29.44
S11		11.898	11.8543		
S12		11.9825	11.9302		
S13	Hybrid	11.8765	13.5982	0.0492	14.29
S14		11.6415	12.8605		
S15		12.082	13.225		

The test results for drying shrinkage are found to be within the prescribed limit of 0.06 as recommended by the IS 2185 (Part 1). The control specimen is found to have maximum drying shrinkage which may be due to higher cement content compared to other mixes. On adding latex and fibres into the mix by replacing water and cement respectively helped in reducing the drying shrinkage which is well evident from the tabulated results. A large number of micropores of concrete were reduced by using 1% of natural rubber latex resulting in decrease in shrinkage significantly compared to M60 mix.

Later, shrinkage value decreased by 40.705%, 47.44% and 50.96% compared to control specimens on addition of basalt, sisal and hybrid fibres in their optimum dosages. The fibres restrain the expansion and extension of the microcracks and disperse the stress caused by shrinkage, which reduces the shrinkage strain of fibre incorporated specimens.

Thus, it can be concluded that use of sisal fibres helps in reduction of drying shrinkage which can result in crack formation in concrete due to the loss of capillary water. Studies recommend the use of renewable sisal fibre as a shrinkage reducing material can reduce the production cost and carbon footprint, thus it is of great significance to the sustainable production. The moisture movement values are also found to be within the specified limit of 0.09 as per as IS 2185 (Part 1).

C. Flexural behaviour of HPC beams

HPC beam of dimension 120 mm x 180 mm x 1200 mm were cast using optimum dosages of metakaolin, natural rubber latex, sisal fibres, basalt fibres and hybrid fibres with reinforcement details as shown in Fig.1, and their behaviour is compared with control specimen of grade M60. The test was carried out using two- point loading as depicted in Fig.2 and load was applied by the movement of piston, when the movement of the piston is resisted load is applied gradually and it can be measured using a load cell that was placed below the piston. Load was applied directly from the piston to the load cell. A load cell indicator was connected to the load cell which was placed nearer to the test setup. In order to record deflections two LVDTs are placed as in the loading diagram shown in Fig. 8.3. Load cell indicator, LVDT indicator are connected to software VAROS Q by a Bluetooth connection and simultaneously readings were recorded in the software and can be retrieved through an excel file.

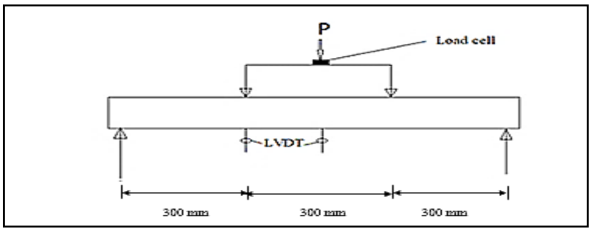

Fig. 1. Reinforcement details of flexural beams

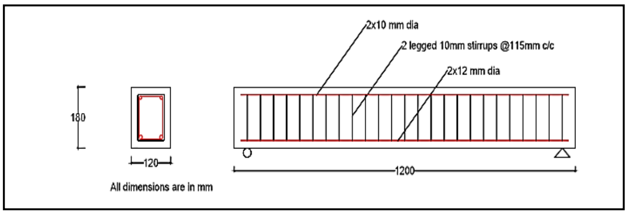

Fig. 2. Two point test loading diagram.

TABLE X. DETAILS OF BEAM SPECIMENS

Beam Designation	Details of specimen
M60	Control specimen
NRL- M60	Beams modified with NRL and metakaolin
BASALT	NRL modified beams incorporating basalt fibres
SISAL	NRL modified beams incorporating sisal fibres
HYBRID	NRL modified beams incorporating basalt and sisal fibres

1) *Crack Patterns*

All beam specimens exhibited flexural tension failure, initiated by yielding of steel reinforcement followed by crushing of concrete at compression side of the beam. In this type of failure, the development of cracks starts at the tension side of the beam which further extend to the compression side. These cracks are mostly vertical and located at the middle third of the beam as shown in Fig.3.

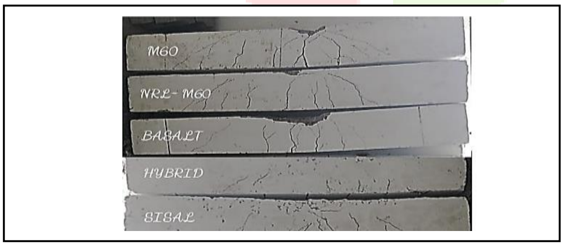

Fig. 3. Crack pattern in beams.

The crack details of the specimens are summarized in TABLE XI.

TABLE XI. DETAILS OF CRACKS FORMED

Beam ID	First crack load (kN)	Crack width (mm)	Avg. Crack Spacing (mm)
M60	52.98	0.2	7.13
NRL-M60	55.9	0.15	5.54
Sisal	59.75	0.12	5.03
Hybrid	65.9	0.1	4.56
Basalt	75.54	0.1	4.12

Cracks appeared as the loading reached the first crack load of the specimen. Further increase of load resulted in the formation of additional cracks and widening of earlier cracks. Loading the beam until the ultimate stage, most of the cracks propagated towards top of the beam in case of control and NRL added specimens while crack propagation was at a slow pace for fibre reinforced HPC beams. Addition of latex improved the first crack load and at ultimate load the deflection was found to be higher. Latex fills the voids present in concrete and improves the bond strength of the concrete, causing an improvement in the first crack load and ultimate load. Also, latex controls the widening of cracks due to the presence of latex film. The crack width in case of specimens without fibres was greater in comparison to the beams of fibre reinforced concrete. Fibres allowed the development of multiple diagonal cracks and widening of at least one of them prior to failure thus warning about the imminence of failure. At first, the perpendicular cracks appeared in normal and NRL added specimens as a result of exceeding the tensile strength of concrete whereas in fibre reinforced concrete specimens the perpendicular cracks developed at a later stage due to increased tensile strength of fibres. It is well evident from the first crack load values with basalt fibre specimens having greater load followed by specimens with hybrid and sisal fibres.

2) *Load- deflection curve*

Load- deflection curves and moment curvature curves were plotted as given in Fig. 4 and Fig. 5.

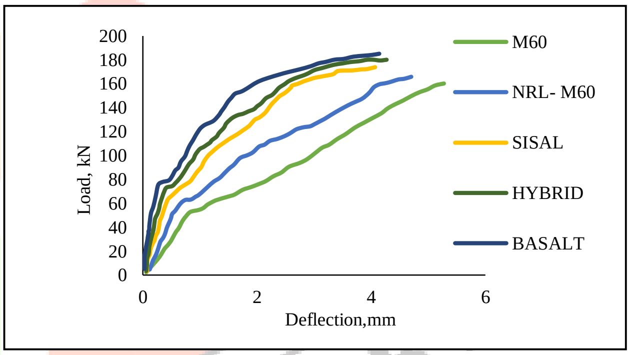

Fig. 4. Load- deflection curve.

Flexural load carrying capacity of natural rubber latex modified beam with metakaolin was increased by 3.54% whereas those with mono fibres showed an increased percentage of 8.55% and 15.47% with sisal and basalt respectively. HPC beams modified with latex incorporating hybrid fibres exhibited an increase in flexural load carrying capacity by 12.38%. Addition of latex improved the first crack load and at ultimate load the deflection was found to be higher because latex fills the voids present in concrete and improves the bond strength of the concrete, causing an improvement in the first crack load and ultimate load. Also, latex controls the widening of cracks due to the presence of latex film.

3) Moment- curvature curves

The moment curvature can be said to have three stages. First stage is till cracking, second stage till yielding of tension steel and third stage up to limit of useful strain in concrete. Moment value for a simply supported beam subjected to two-point loading is calculated using the given equation.

$$M = \frac{PL}{6}$$

Deflections of two LVDTs were used to measure the curvature.

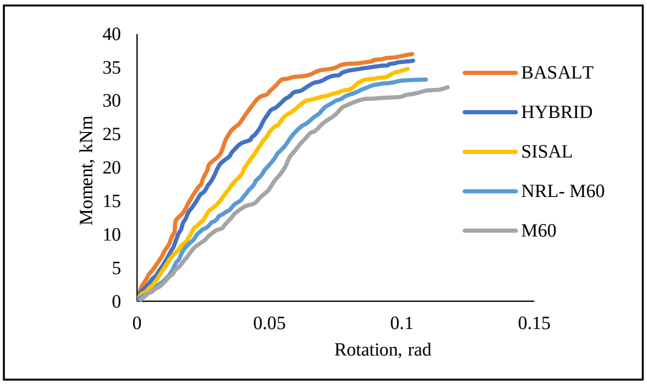

Fig. 5. Moment curvature curve.

Fibre incorporated NRL added specimens showed greater moment capacity compared to control and NRL added specimens without fibres. The combination of fibres and conventional reinforcement may lead to failure at lower deformations compared to specimens without fibres, hence compromising both bearing capacity and degree of ductility at the ultimate limit state.

4) Energy absorption & Ductility

Energy absorption capacity was found by calculating area under the load deflection plot up to 80% of the peak load in the descending portion of the curve. Due to the limitations in the experimental set up, the load deflection graph could be plotted only up to peak load. Thus, the energy absorption was calculated as the area under the curve up to the peak load. Ductility is defined as structure's capability to undergo inelastic deformation after initial output without lowering its load resistance. Ductility (Δu/Δy) and rotational ductility (Øu/Øy) can be found from the load-deflection graph and moment-rotation graph respectively. The notations have the following indications.

Δu, Øu -Ultimate displacement and rotation of the beam
Δy, Øy -Yield displacement and rotation of the beam corresponding to 75% loading.

Parameters like crack pattern, load- deflection curve, moment- moment curve, energy absorption and ductility index are analysed for each of the specimens are the data is provided in TABLE XII.

TABLE XII. BEAM BEHAVIOUR COMPARISON DATA

Beam ID	Ultimate load (kN)	Deflection at ultimate load (mm)	Ultimate moment (kNm)	Rotation at ultimate moment (rad)	Energy Stored (J)	Ductility (Δu/Δy)	Rotational ductility (Øu/Øy)
M60	160.27	5.27	32.05	0.1173	488.32	1.44	1.89
NRL-M60	165.95	4.70	33.19	0.1062	498.96	1.61	1.81
Sisal	173.98	4.06	34.79	0.1021	501.78	2.05	2.033
Hybrid	180.12	4.27	36.02	0.1042	533.55	2.44	2.22
Basalt	185.06	4.14	37.01	0.1038	599.27	2.95	2.59

VI. CONCLUSIONS

This paper studies the effect of natural rubber latex, mono fibres and hybrid fibres on the drying shrinkage and flexural behaviour of HPC beams with metakaolin admixture. The summary of the research findings include:

- The drying shrinkage has decreased for Natural rubber latex specimens compared to control specimens by 38.14%.
- Sisal fibres exhibited significant reduction in drying shrinkage over control specimens by about 47.44% which is followed by hybrid fibres having a reduction of 50.96% from the control mix.
- Flexural load carrying capacity hybrid fibre reinforced beam modified with Natural rubber latex increased by 12.38% compared to control specimen.
- The crack width in case of specimens without fibres was greater in comparison to fibre reinforced concrete beams and fibre addition decreased the crack formation compared to control specimens because of enhanced flexural capacity due to tensile properties of the fibres incorporated.
- Ductility of the control beam specimens was found to improve with the addition of latex and hybrid fibres into it by about 11.81% and 69.44% respectively.
- Energy absorbed by latex modified and hybrid fibre incorporated beams were also found to be 2.17% and 9.26% higher due to better deformation capacity.

Thus, to conclude Natural Rubber Latex modified fibre reinforced HPC enhances the flexural behaviour and also results in decreased drying shrinkage.

VII. SCOPE OF THE WORK

The work can be carried out with various other type of organic fibres without compromising the strength and performance criteria thus moving towards sustainable approach.

REFERENCES

[1] Vishwanath Kumbhar, & Sandip Nirmal, (2023), "Experiment Study: Sisal Fiber Reinforced Concrete", Journal of Advanced Cement & Concrete Technology, 6(1), 8–12. https://doi.org/10.5281/zenodo.7624516.

[2] Xi, Yun-Feng, Jin Lee, Bao-Ling Chen, Bing Yang, Miao-Zhang Yu, Xiao-Zhou Yan, and Li Zhu, (2023), "Impact of High-Performance Expansion and Shrinkage-Reducing Agents on the Mechanical Properties and Shrinkage Compensation of High-Strength Concrete" *Buildings* 13, no. 3: 71. https://doi.org/10.3390/buildings13030717

[3] I. Boglaev, "A numerical method for solving nonlinear integro-differential equations of Fredholm type," *J. Comput. Math.*, vol. 34, no. 3, pp. 262–284, May 2016, doi: 10.4208/jcm.1512-m2015-0241.

[4] Guosheng Ren, Bin Yao, Miao Ren, Xiaojian Gao, (2022), "Utilization of natural sisal fibers to manufacture eco-friendly ultra-high-performance concrete with low autogenous shrinkage", *Journal of Cleaner Production*, Volume 332, 130105, ISSN 0959-6526. https://doi.org/10.1016/j.jclepro.2021.130105.

[5] B. Zuccarello, F. Bongiorno, and C. Militello, (2022), "Basalt Fiber Hybridization Effects on High-Performance Sisal-Reinforced Biocomposites," *Polymers*, vol. 14, no. 7, p. 1457. https://doi.org/10.3390/polym14071457.

[6] Adanagouda, H.M. Somasekharaiah, M.S. Shobha, H.M. Mallikarjuna, (2022), "Combined effect of metakaolin and hybrid fibers on the strength properties of high-performance concrete, *Materials Today: Proceedings*, Volume 49, Part 5, Pages 1527-1536, ISSN 2214-7853. https://doi.org/10.1016/j.matpr.2021.07.310.

[7] Anas Muhammad, Majid Khan, Hazrat Bilal, Shantul Jadoon, and Muhammad Nadeem Khan, (2022), "Fiber Reinforced Concrete: A Review" *Engineering Proceedings* 22, no. 1: 3. https://doi.org/10.3390/engproc2022022003.

[8] Cheng, Daxiang, Xiaosheng Li, Xu Gao, Xiaochun Fan, Rui Zhao, and Tingli Yang, (2022), "Influence of Polymer Latexes on the Properties of High- Performance Cement–Based Materials" *Crystals* 12, no. 6: 789. https://doi.org/10.3390/cryst12060789

[9] John E. M and Sunny S, (2021), "Experimental Study on the Effect of Natural Rubber Latex and Plastic Fiber in Concrete", *Springer, Singapore*, Vol 83. https://doi.org/10.1007/978-981-15-5644-9_19.

[10] A.N. Swaminathan, C. Vivek Kumar, S. Robert Ravi, Sohang Debnath, (2021), "Evaluation of strength and durability assessment for the impact of Rice Husk ash and Metakaolin at High Performance Concrete

mixes", *Materials Today: Proceedings*, Volume 47, Part 14, Pages 4584-4591, ISSN 2214-7853. https://doi.org/10.1016/j.matpr.2021.05.449.

[11] M.D de Klerk, M Kayondo, G M Moelich, W I de Villiers, R Combrinck, W P Boshoff, (2020), "Durability of chemically modified sisal fibre in cement-based composites, Construction and Building Materials**",** Volume 241, 2020, 117835, ISSN 0950-0618, https://doi.org/10.1016/j.conbuildmat.2019.117835.

[12] Piotr Smarzewski, (2019), "Influence of basalt-polypropylene fibres on fracture properties of high- performance concrete", *Composite Structures*, Volume 209, Pages 23-33, ISSN 0263-8223. https://doi.org/10.1016/j.compstruct.2018.10.070.

[13] Luitel, Suman, Thapa.K. Seema, Imran, Mohammed, (2018), "Effect of Natural Rubber Latex on Mechanical Properties of Concrete with Manufactured Sand as a Complete Replacement to River Sand", *International Research Journal of Engineering and Technology (IRJET),* e-ISSN: 2395-0056, Volume: 05 Issue: 02. https://doi.org.10.13140/RG.2.2.22012.80001.

[14] Ahana K Reji, Athira Ajithan B, Fouzia Hussain M, Alfiya J, Minsurya Shajahan, (2018), "Latex Modified High Performance Concrete", *International Journal of Engineering Research & Technology (IJERT),* ISSN: 2278-0181, Vol. 7 Issue 04, April-2018. https://doi.org.10.17577/IJERTV7IS040221.

[15] Nanna Chandra Gupta , Puram Satish, Venkat Ram Reddy, (2018), "Performance of natural rubber latex admixed concrete", *International journal of current engineering and scientific research (IJCESR),* ISSN (PRINT): 2393-8374, Volume-5, Issue-5. http://troindia.in/journal/ijcesr/vol5iss5/10-18.pdf.

[16] Murugesan, Balasubramanian & Senthilselvan, S & Kv Sabarish, (2016), "Experimental investigation on strength and durability properties of sisal fiber reinforced concrete", International Journal of Chemical Sciences. 14. 241-246.

[17] M. Narmatha, Dr. T. Felixkala, (2016), "Metakaolin –The Best Material for Replacement of Cement in Concrete", *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 13, Issue 4 Ver. I (Jul. - Aug. 2016), PP 66-7. https://doi.org.10.9790/1684-1304016671.

[18] Rendon Diaz Miron, Luis & Lara de Rendon, Maria**,** (2015), "Superplasticizer for High Strength Concrete", MRS Proceedings. 1768. 10.1557/opl.2015.324.