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Reinforced Concrete Beams with Rural Composites under Cyclic Loading

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Abstract: Concrete composites are increasingly becoming important structural materials as they overcome many of the shortcoming of conventional reinforced concrete like weakness in tension, brittle response and less post-yield energy absorption. Recent innovations in the development of concrete composites are in the use of locally available organic and waste materials making them technologically easier to fabricate and at the same time make them eco-friendly. Typical materials are fibres from organic materials like coir and synthetic ones like plastic and nylon. This study reports the response of reinforced concrete beams with the local fibre composites with 0.5 and 1% volume fractions under cyclic loading which simulates the seismic excitation. The seismic aspects of conventional reinforced composite beams like ductility and energy absorption capacity are compared with fibre reinforced composites through hysteric load-deflection and moment -rotation curves. And also the critical parameters like first crack strength, yield and maximum strength are compared. The results indicate 20 to 40% performance enhancement in fibre reinforced composite concrete over the conventional one.

Key words: Rural composites, fibre reinforced concrete, cyclic loading, ductility, energy absorption

INTRODUCTION

Reinforced concrete is a versatile material and its use in India is increasing in every sphere of activity mainly due to its economical material content and easy technology in construction. This has led to finding ways and means of improving its basic weakness in tension and inherent brittleness proving to be a major thorn in using it for seismic resistance. One of the popular and technologically easier ways is to add fibres while casting the beam making the cracking evenly spread and at the same time increasing its resilience by a larger failure strain. Concrete composites with fibres are known to possess increased compressive strength, distributed minor cracking for better energy absorption. In the last 40 years, discovery and acceptance of reinforcement and fibres for enhancement of concrete properties rapidly increased for use in concrete industries, research and development. Numerous types of fibres have successfully been adapted in the different applications of concrete. In developing countries like India, most of the population is living in slums and medium towns. The constructions made in the rural areas are mostly non-engineered ones. So, expensive construction materials and complicated technologies are not suitable\ for the medium level constructions. Locally, easily and economically available waste materials will be suitable for making earthquake resistant structures. Reuse of waste materials in construction industry is not a new thing. More number of earlier research have shown the possibilities of reusing waste materials in various forms like aggregates, cement etc. and fibre composites from waste stream are also studied by many researchers. Aziz *et al*. (1994) reported that coconut coir, sisal, sugarcane waste etc., as cement composites had already investigated in more than 40 countries world wide. Some authors, notably Romildo *et al.* (2003) had indicated that problems experienced with the poor durability of fibres in some reinforced cement composites were probably due to alkali attack of the fibres by the pore water present in the cement matrix. Suggestions to resist this deterioration included changing the alkalinity of the pore water, replacing part of the cement with silica fume, using natural pozzolans in the mix. Therefore, in order to build up momentum in the research programme by investigating applications in which the fibre durability problem could probably be ignored. Kenneth and Gary (1998) reported a study to investigate the feasibility of recycling commingled plastic fibre in concrete. Plastic wastes are separated into two categories based on their use, post-consumer or public waste and manufacturing waste. The post-consumer plastic waste represents the largest constituent going into the municipal waste stream. The concrete containing recycled plastics fibre showed promising results in compression, flexure, but inconsistent results in freeze-thaw testing. Wang *et al*. (2000) had developed and demonstrated new technologies for the conversion of carpet nylon and carpet waste into useful materials and thereby prevent the unnecessary land filling

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of potentially useful materials. Fibre reinforced concrete with carpet nylon materials were made and tested to study the enhancement in mechanical strength properties. Mechanical characterization and impact behaviour of concrete reinforced with natural fibres from palm trees was done by Al-Oraimi and Seibi (1995) improvement in post-cracking performance and impact resistance was reported.

Mechanical Strength properties and structural behaviour of concrete with waste materials like nylon, plastic, tyre, rice husk and sugarcane as concrete composites under static loading was already carried out by the same authors (2007). It was concluded that both the system and section parameters of concrete were enhanced. But it is necessary to study the performance of the local composites in concrete under cyclic loading which gives the clear idea about the earthquake resistance. Spadea and Bencardino (1997) and Tong *et al.* (2003) had done some works on fibre reinforced concrete beams under cyclic loading. In this present study, three waste materials namely nylon, plastic and coir are taken and randomly distributed in concrete during mixing at two volume fractions 0.5 and 1%. Reinforced and fibre reinforced concrete beams were tested under cyclic loading and the seismic performance was ascertained. The critical parameters like load carrying capacity, ductility and energy absorption capacity are discussed and it is concluded that performance enhancement in all the factors are achieved due to the addition of rural waste fibres in concrete.

MATERIALS AND METHODS

Specimens preparation: In preparation of test specimens, 43 grade ordinary Portland cement, Natural River sand and granite stone aggregate were used. The maximum size of coarse aggregate is 20 mm. The concrete mix was designed to achieve 28 days cube strength of 20 MPa with constant water cement ratio of 0.5. To avoid the balling effect on concrete during mixing the volume fraction of fibres was restricted to 0.5 and 1.0%. For 7 different mixes, 21 beams of 2 m length having identical cross section of 100×150 mm were casted. The cross section of beam specimen is shown in Fig. 1. To avoid balling effect of fibres, the following procedure was followed in casting. First aggregates and cement were taken and allowed to get mixed for 1 min and water was added within 2 min. Then fibres were uniformly dispersed throughout the mass with slow increment. Now concrete was allowed to mix for 3 min. All the specimens were well compacted using table vibrator. The specimens were demolded after 1 day and then placed in a curing tank with 90% relative humidity and 23°C for 28 days of curing. For 12 h prior to the testing, the specimens were allowed to air dry in the laboratory. The properties of fibres taken for the study are given in Table 1.

Table 1: Physical properties of different fibres

Fibre	Length	Aspect ratio	Specific gravity	Water absorption	Ultimate tensile	Load density
Nylon	50 mm	113.63	0.70	66.66%	0.31 kN	657 kg m^{-3}
Plastic	50 mm	33.11	1.25	66.66%	0.30 kN	763 kg m^{-3}
Coir	50 mm	104.17	0.67	210.6%	0.09 kN	2057 kg m^{-3}

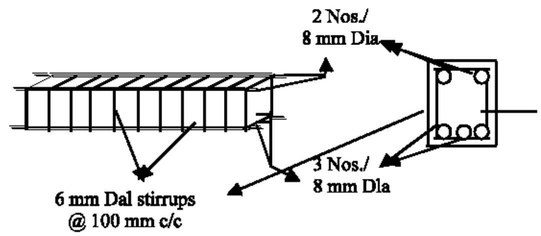

Fig. 1: Reinforced concrete beam specimen details

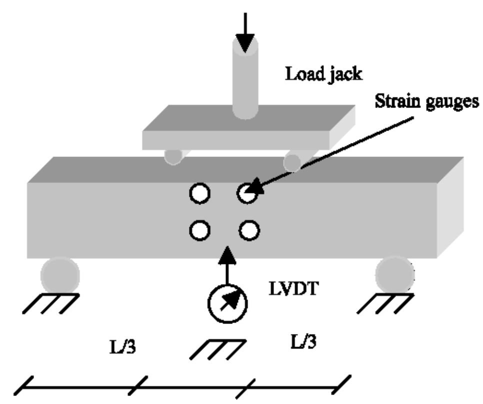

Fig. 2: Loading arrangement

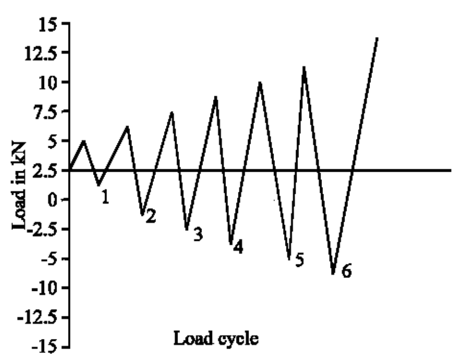

Fig. 3: Sequence of cyclic loading

Experimental set up: Tests were carried out at room temperature and as per the Indian standards. Structural properties are ascertained by conducting middle third loading test. The testing arrangement is shown in Fig. 2. Four point bending was applied on reinforced concrete beams through hydraulic jack. The specimens were placed in 100 T Loading frame and dial gauges were attached to measure the deflection readings. DEMEC as well as Electrical strain gauges with strain indicator were used to measure the strain readings both in steel reinforcement and concrete. To simulate seismic loading, cyclic loading with the step of 2.5 kN, 5 kN etc., was applied. Figure 3 shows the loading sequences of the test beams. All the specimens were tested under cyclic loading up to 6 cycles, further were loaded up to failure.

RESULTS AND DISCUSSION

Mode of failure: All the beams have failed in flexural mode by yielding of tension steel. Crushing and spalling of concrete takes place after yielding in tension zone for conventional reinforced concrete beams and fibre reinforced concrete beams. Composite beams suffer lesser damage as compared to other beams. It is also observed that the cracks are closely spaced in all the fibre reinforced concrete beams and also the crack widths in composite beams are consequently less than in the conventional beams. All the composite concrete beams show increased neutral axis depth to their comparision beams without fibres. The effectiveness of the rural waste composites in resisting external loads is thus evident right up to failure.

Load-displacement and moment -rotation response: The load-displacement and moment- rotation hysteresis loop of conventional and fibre reinforced composite beams at two volume fractions are shown in Fig. 4 and 5. It is observed that fibre reinforced concrete beams had spindle shaped hysteresis loop compared to controlled specimen. Three important loading points namely cracking, steel yielding and ultimate are noted and the corresponding load, moment, deflection and rotation values are shown in Table 2. The cracking load itself increases for fibre reinforced concrete beams correspondingly ultimate carrying capacity also increases more than conventional concrete beams. The ultimate load carrying capacity of nylon, plastic and coir fibre reinforced concrete beams are 26, 12 and 15% at 0.5% volume fraction and 40, 16 and 28% at 1% volume fraction greater than the conventional reinforced concrete beam. Yielding point was occurred in 4th cycle for conventional beam whereas in 6th cycle for nylon, 5th cycle for plastic and coir fibre reinforced concrete beams.

Ductility and energy-dissipation parameters: It is desirable to response indices to describe the beam behaviour quantitatively. In seismic design, the inelastic deformation is generally quantified using ductility parameters. This includes displacement ductility, rotational ductility and cumulative energy absorption capacity by system and section (Aziz *et al*., 1994). Ductility is the ratio of ultimate to yield deflection.

Energy absorption capacity can be obtained by calculated the area under the curve. Cumulative ductility enhancement of fibre reinforced concrete beams over

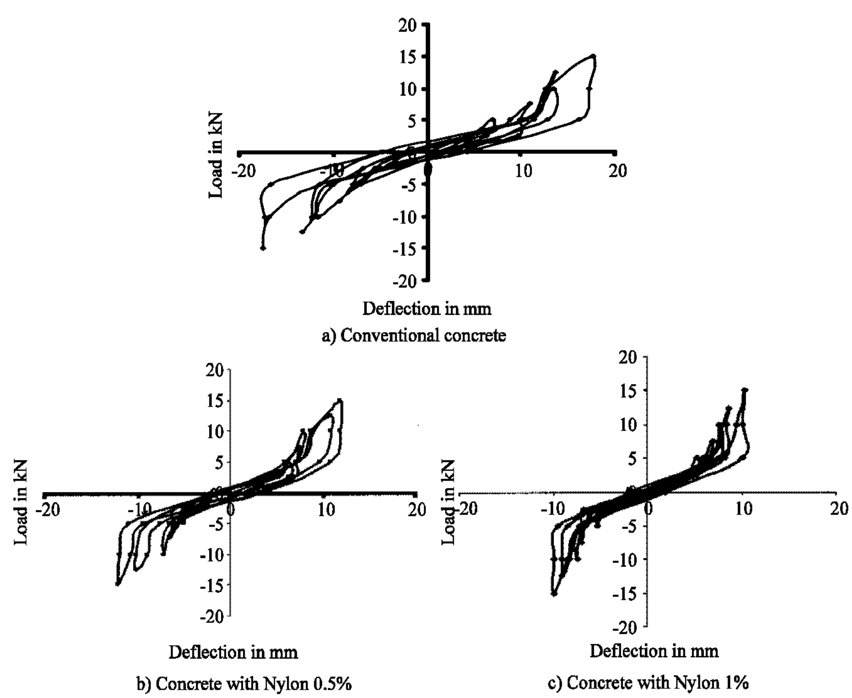

Fig. 4: Load-diplacement curve

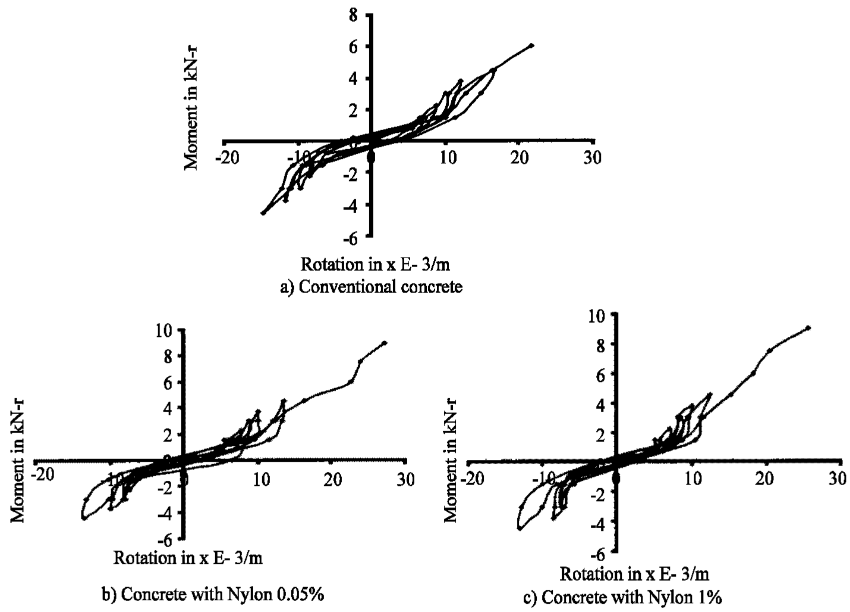

Fig. 5 Moment-rotation curve

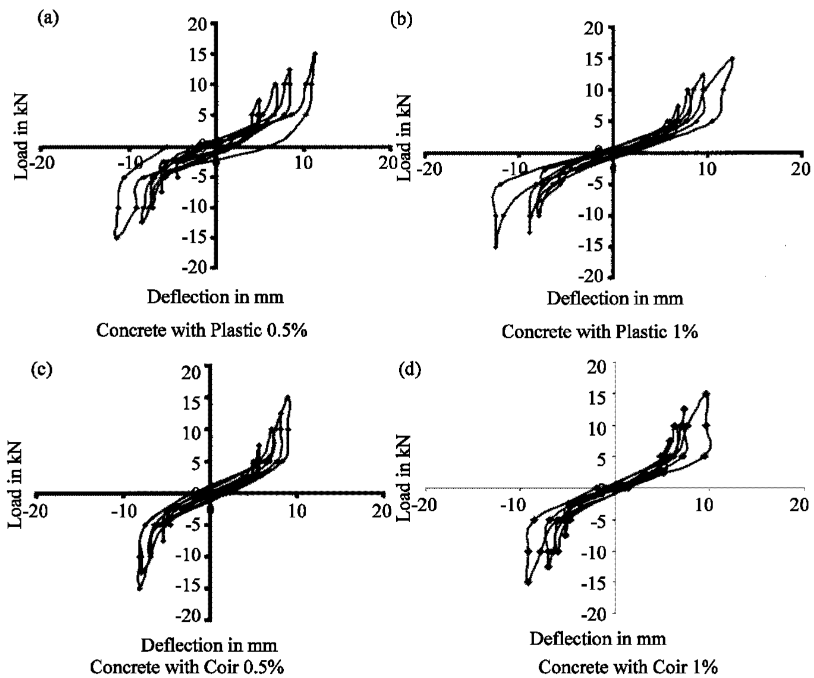

Fig. 6: Clear indication of displacement

Table 2: Load-deflection parameters

	Cracking		Yielding		Ultimate	
Mix	Load in kN	Deflection in mm	Load in kN	Deflection in mm	Load in kN	Deflection in mm
Conventional	5.0	2.0	20	10.50	25.0	21.75
Nylon 0.5%	5.0	2.1	25	9.50	31.5	23.0
Nylon 1%	5.2	2.5	26	9.50	35.0	20.0
Plastic 0.5%	5.0	2.2	20	9.00	27.5	19.5
Plastic 1%	5.1	2.5	24	10.50	29.0	20.5
Coir 0.5%	5.5	2.0	20	10.00	30.0	24.5
Coir 1%	5.2	2.5	21	10.25	32.0	24.0

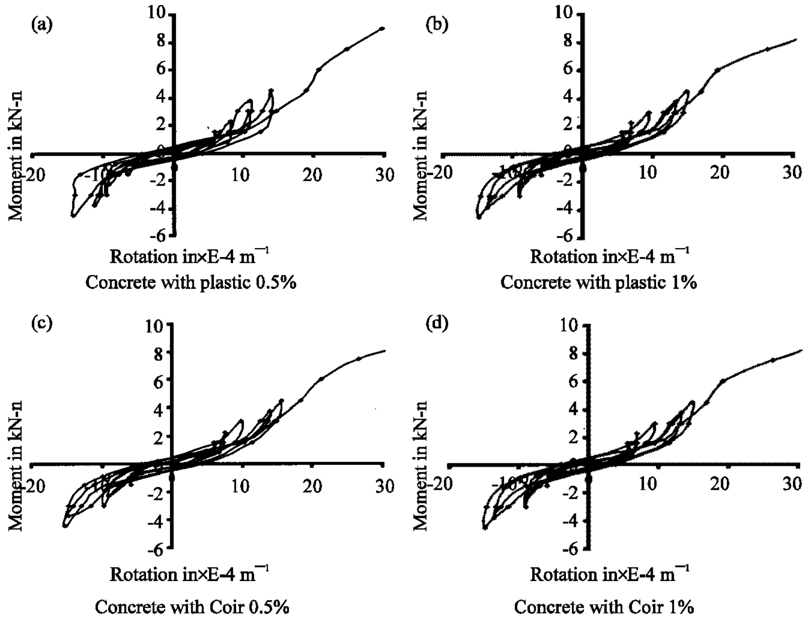

Fig. 7: Rotational ductility enhancement

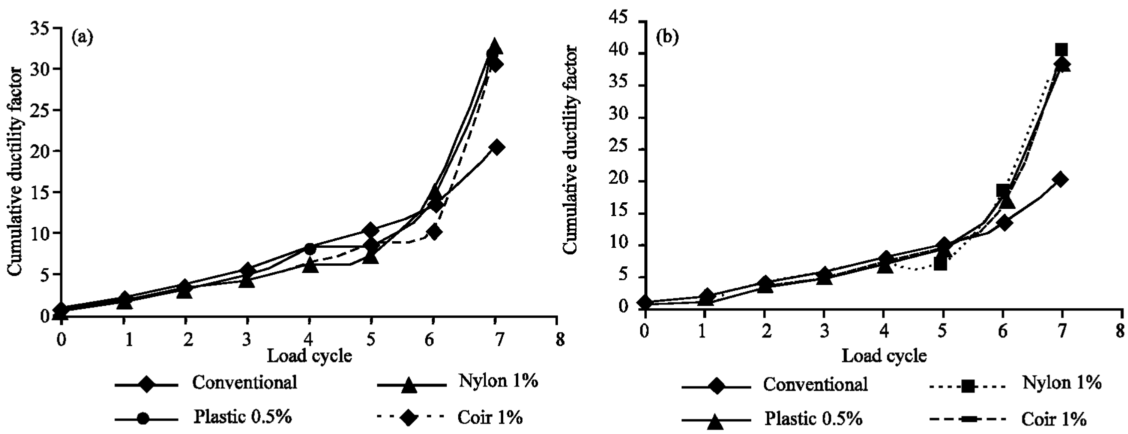

Fig. 8: Comparision of displacement ductility

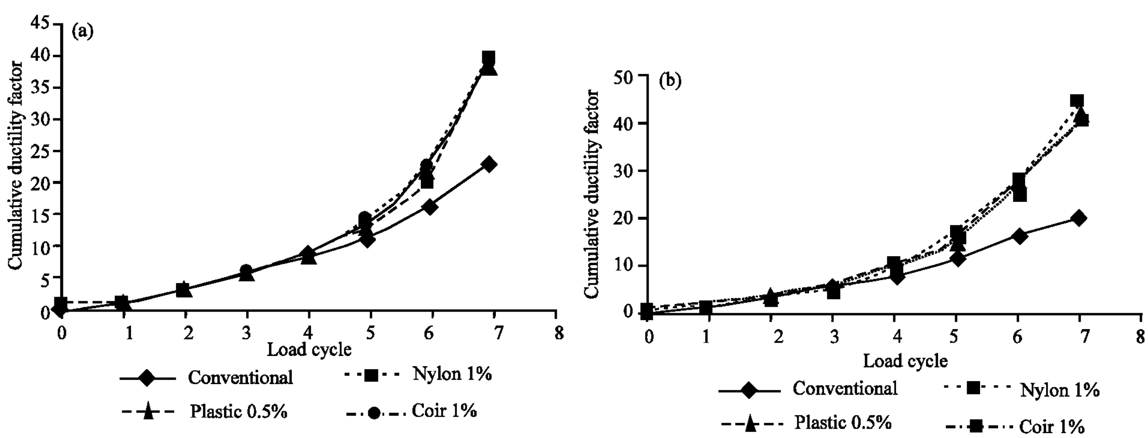

Fig. 9: Comparision of rotational ductility

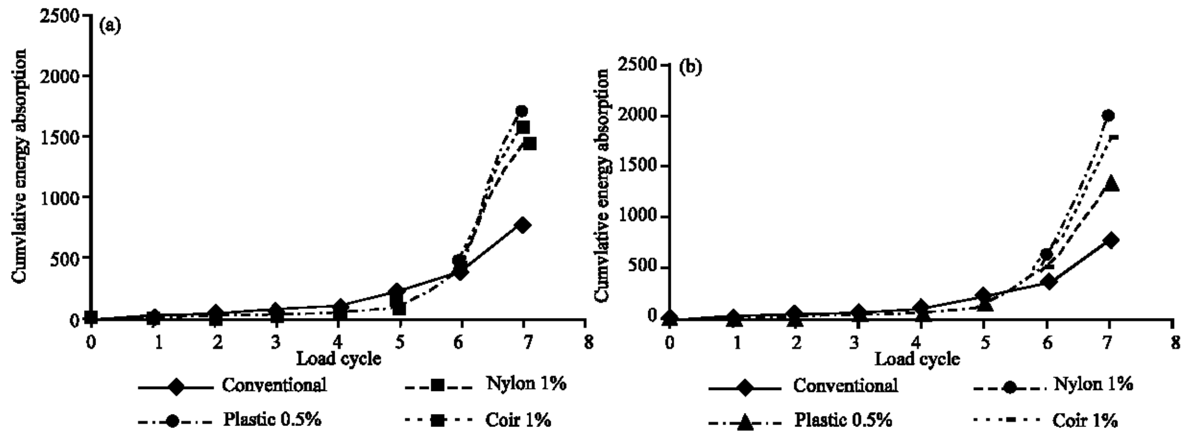

Fig. 10: Comparision of cumulative system energy absorption

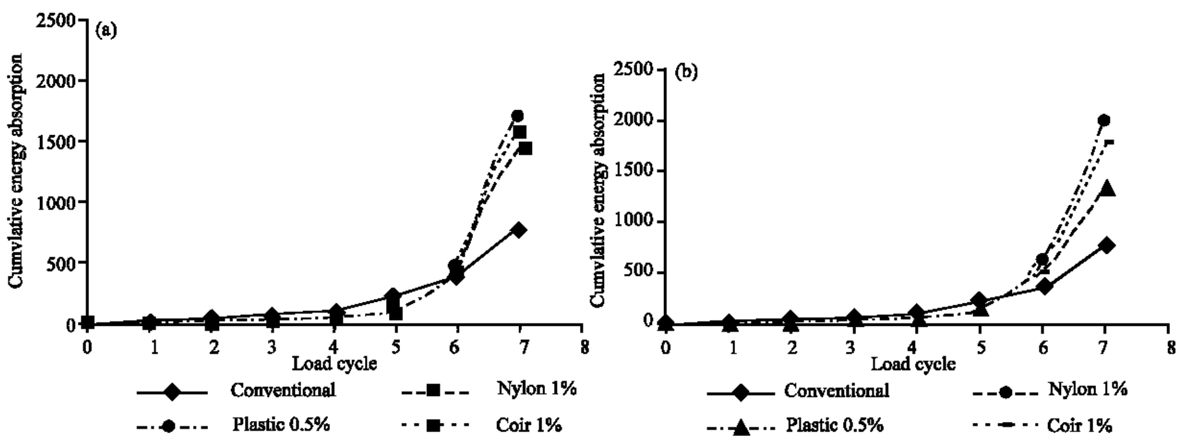

Fig. 11: Comparision of cumulative section energy absorption

Table 3: Moment-rotation parameters

	Cracking		Yielding		Ultimate	
Mix	Moment in kN m	Rotation in E -3/m	Moment in kN m	Rotation in E -3/m	Moment in kN m	Rotation in E -3/m
Conventional	1.50	6	6.00	22.5	7.50	34
Nylon 0.5%	1.80	7	6.75	14.0	10.13	44
Nylon 1%	1.50	6	7.20	14.0	11.10	44
Plastic 0.5%	1.50	7	6.00	16.0	8.25	40
Plastic 1%	1.50	7	7.20	20.0	8.70	38
Coir 0.5%	1.65	6	6.00	13.0	9.00	44
Coir 1%	1.50	6	6.30	12.0	9.60	46

controlled beam is shown in Fig. 6 and 7. The figure shows the clear indication of displacement as well as rotational ductility enhancement of fibre reinforced concrete composite beams. Nylon fibre possesses higher ductile performance. Coir and plastic fibres are also increasing the post-cracking behaviour of concrete considerably.

Figure 8 and 9 show the energy dissipation along the system and section. Energy absorption capacity also increased because of the addition of fibre composites. Table 3 shows the increment ratio of ductility and energy absorption capacity of the beam specimens. Nylon fibre increases the ductility of conventional concrete by 60 to 140%, whereas plastic possesses 50 to 130% enhancement. Natural inorganic coir fibre gives an increment of 40 to 120% in ductility Table 4. Similarly all the fibres increase both the section and system energy absorption capacity of conventional concrete by 100 to 300% shows in Fig. 10-11. Among all, nylon fibre gives the greatest performance of 257 at 0.5% and 320 at 1%

Table 4: Ductility and energy absorption parameters

	Ductility		Energy absorption capacity	
Mix	Displacement	Rotation	Displacement	Rotation
Conventional	6.67	3.64	1080	350
Nylon 0.5%	8.00	7.14	1648	680
Nylon 1%	8.63	7.85	2364	776
Plastic 0.5%	7.90	6.84	1546	664
Plastic 1%	8.43	7.20	1940	720
Coir 0.5%	7.90	6.69	1596	667
Coir 1%	8.68	7.33	2191	728

volume fraction. Plastic and coir possesses the same amount of better energy enhancement nearly 220 at 0.5% and 290 at 1% volume fraction.

CONCLUSION

To ascertain the seismic performance of local material composites of length 50 mm and 2 th 0.5 and 1% volume fractions in concrete, seven types of specimens were tested under cyclic loading and the following conclusions are made.

- Both the load and moment carrying capacity of fibre reinforced composite concrete were significantly increased. Among all the 3 fibres, nylon possesses higher value than others. Next to nylon both coir as well as plastic fibres plays a better role in strength enhancement.
- Ductility is the major parameters in seismic resistant design. In both the displacement as well as rotation ductility, concrete with the local fibre composites have much better performance than conventional concrete. It was about 40% in displacement ductility and 50% in rotational ductility.
- Energy dissipation through load-deflection as well as moment -rotation curves of fibre reinforced concrete beams is shown the improvement about 200-300% than conventional concrete.
- Failure of conventional concrete is sudden whereas in composite beams multiple cracking was formed before failure and also there was no crushing and spilling of concrete during the failure.
- Finally it is concluded that locally available cost effective waste fibre composite materials perform well in seismic resistant structures.

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