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RESEARCH ARTICLE

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INFLUENCE OF FIBER CONTENT AND LOADING POSITION ON FRACTURE TOUGHNESS OF NATURAL FIBER REINFORCED CONCRETE

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ABSTRACT

The present study investigates the influence of fiber content and loading position on fracture toughness of natural fiber reinforced concrete. The cement was replaced with 10% natural steatite powder. The natural fibers such as basalt, coir and jute are added in various combinations. The fracture toughness was determined by using three point and four point bending test. It was found that the mix of high coir content and less jute content shows higher fracture toughness. Fracture toughness determined by four point bending was higher than that of three point bending. The fracture toughness increases up to 1% fiber addition. The 1% fiber addition shows 12% to 36% increase of fracture toughness in three point bending and 11% to 38% in four point bending.

Key Words—Fracture toughness, Natural fibers, Basalt fibers, Jute fibers, Natural steatite powder.

INTRODUCTION

Nowadays one of the main challenges of construction industry is to improve their image in terms of sustainability. The addition of natural fibres and supplementary cementitious materials will enhance the sustainable construction. Natural fibres are easily available and less in cost. The addition of natural fibres in concrete provides many advantages such as low cost, minimal health hazards, biodegradability, low density, desirable aspect ratio and relatively high tensile and flexural modulus. The inclusion of chopped fibre in concrete can increase many of the engineering properties such as fracture toughness, tensile strength, flexural strength, resistance to fatigue, ductility and improve crack resistance. The fibres provide bridging action in concrete during cracking which will control the crack propagation and increase the fracture toughness. Debonding, sliding and pulling - out of the fibres are the local mechanism that control the bridging action.

Mostly Portland cement (PC) is used as binder in fibre reinforced concrete. The high alkali environment of PC dissolves the lignin and other hemi cellulose phases thus weakening the fibre structure. The PC is partially replaced with supplementary cementitious materials for reducing the alkali environment. On the other hand, using these pozzolanic materials to replace PC can help to improve the sustainability image of cement industry which produces the world's second most used material after water. The 5 to 8% of global manmade carbon emission was contributed by the production of cement. Construction industry has been looking for alternative binding materials/ mineral admixtures such as steatite powder to replace PC so that to reduce its negative environment impact for decades.

The objective of this study is to evaluate the influence of fibre content and loading position on fracture toughness of natural fibre reinforced concrete. The basalt, coir and jute fibres were added as various combinations on each mix. A material fails by fracture when the stress intensity factor reaches a critical value K_{IC}, called fracture toughness which is given by the equation (2) [7]. The fracture toughness was determined by conducting three point and four point bending test on notched specimens.

experimental program

Materials used

i) CEMENT

Ordinary Portland cement type (grade 53) was used for this investigation and it is confirm to the IS 12269-1987. The initial and final settlement and consistency of cement were determined by conducting various experiments.

ii) FINE AGGREGATE

Locally available sand was used as fine aggregate. The sand confirming to IS: 2386 (part I) 1963 is used as fine aggregate. Various laboratory tests were conducted for determining the physical properties of sand.

iii)COARSE AGGREGATE

Coarse aggregates of 20 mm nominal size were used for this study. Various laboratory tests were conducted for determining the physical properties of coarse aggregate.

iv)WATER

Ordinary tap water was used for concrete preparation. Water should be clean and free from organic materials and deleterious amounts of dissolved acids, alkalies, and salts.

v)NATURAL STEATITE POWDER

Steatite is a type of metamorphic rock, largely composed of talk ore and it contains large amount of magnesium. It is the softest known mineral and listed as 1 on the Mohs hardness scale. Physical and chemical properties of steatite were given in table 1 and 2.

TABLE: 1 CHEMICAL COMPOSITION OF NATURAL STEATITE POWDER

Chemical composition of natural steatite powder	
constituents	***Contents (%)***
SiO_2	62.67
Al_2O_3	0.24
Fe_2O_3	0.30
CaO	0.2
MgO	33.26

TABLE: 2 PHYSICAL PROPERTIES OF NATURAL STEATITE POWDER

Physical properties of natural steatite powder	
Colour	White
Bulk density (g/cm^3)	0.6
Specific gravity	2.75
pH	8
Crystal structure	Hexagonal

vi) BASALT FIBRE

Basalt fiber used in this work is collected from Mukthagiri Industrial Corporation, Maharashtra. Basalt is a natural inorganic fiber. The properties of basalt fibers were given in table3.

TABLE: 3 PROPERTIES OF BASALT FIBER

Properties of basalt fiber	
Length (mm)	12
Diameter (mm)	0.013
Aspect ratio	923
Tensile strength (MPa)	4100 - 4840
Modulus of elasticity (GPa)	93.1 - 110
Specific gravity	2.63 – 2.8
Elongation (%)	3.1

vii) COIR FIBRE

Coir is a biodegradable organic fiber obtained from husk of coconut fruit. The brown colour coir fiber that is obtained from matured coconut is used for this study. The properties of coir fibers were shown in table 4.

TABLE: 4 PROPERTIES OF COIR FIBER

Properties of coir fiber	
Length (mm)	18
Diameter (mm)	0.01 – 0.02
Aspect ratio	900 - 1800
Tenacity (g/tex)	10
Elongation at break (%)	30

viii)JUTE FIBRE

Jute is soft and shiny material extracted from the fibrous bark of jute plant. It is one of the cheapest natural fibers. The properties of jute fibers were shown in table 5.

TABLE: 5 PROPERTIES OF JUTE FIBER

Properties of jute fiber	
Length (mm)	18
Diameter (mm)	0.015 – 0.02
Aspect ratio	900 - 1200
Specific gravity	1.5
Elongation at break (%)	1.7
Moisture regain (MR%)	13.75

Mix proportion

A mix design for M20 grade concrete was done as per IS 456 – 2000. The water to cement ratio in the production of concrete was taken as 0.4 wt % of cement. The mix proportion was shown in table 6.

TABLE: 6 MIX PROPORTION

Description (Mix)	Cement (Kg/m^3)	NSP (Kg/m^3)	Fine aggregate (Kg/m^3)	Coarse aggregate (Kg/m^3)	Water (Kg/m^3)
CM	0.2367	-	0.24087	0.5755	0.0946
M1	0.21303	0.02367	0.24087	0.5755	0.0946

The mix proportion of M1 mix was adopted for mixes with fibre addition. The percentage additions of fibres were shown in table 7.

TABLE: 7 FIBER ADDITIONS

Mix	Basalt (%)	Coir (%)	Jute (%)	Total fiber content (%)
CM	0	0	0	
M1	0	0	0	0
M2	0.2	0.2	0.1	
M3	0.3	0.1	0.1	
M4	0.2	0.1	0.2	
M5	0.1	0.2	0.2	0.5
M6	0.1	0.3	0.1	
M7	0.1	0.1	0.3	
M8	0.5	0.25	0.25	
M9	0.25	0.5	0.25	
M10	0.5	0.25	0.5	
M11	0.3	0.3	0.4	1
M12	0.3	0.4	0.3	
M13	0.4	0.3	0.3	
M14	0.75	0.25	0.5	
M15	0.5	0.25	0.75	
M16	0.5	0.75	0.25	
M17	0.4	0.4	0.7	1.5
M18	0.7	0.4	0.4	
M19	0.4	0.7	0.4	

Pre-treatment of natural fibres

The natural organic fibres have higher water absorption capacity. The moisture content present in the raw fibre should be eliminated. Heat treatment was provided to coir and jute fibre for eliminating the absorbed moisture. The chopped fibres were placed into the oven at 50˚C for two days. After that these samples were kept in an air tight container so that atmospheric moisture could not be absorbed by these samples.

Casting of specimens

Chopped jute fibres were mixed with sand and one by third of water for 5 minutes. After that coir and basalt fibres were added for another 5 minutes mixing. Finally cement, NSP, aggregates and remaining water were added and mixed homogeneously. Immediately after mixing, the fresh concrete was filled in the mould. All specimens were cast horizontally in three layers. Each layer was compacted using a tamping rod. After casing, all specimens were kept at room temperature for one day. Then it was removed from the mould and kept in water for 28 days.

Fracture test

For the fracture study, three point and four point bending tests were performed on beam specimens of 360 x 80 x 60mm. A notch was provided at the centre of the beam with 18mm depth and 3mm width. The fracture toughness (K_{IC}) was determined using the following formula.

$K_{IC} = \quad PS \quad x\ f(\alpha)$

$BW^{3/2}$

Where f(α) was determined using the equation,

$$f(\alpha) = \frac{3 \times \alpha^{3/2}\,[1.99 - \alpha(1-\alpha)(2.15 - 3.93\alpha + 2.7\alpha^2)]}{2(1+2\alpha)(1-\alpha)^{3/2}}$$

α – a/W

S – Span of the beam

P – Applied load

B – Width of the beam

W – Depth of the beam

a – Depth of notch

Three point bending test

The three point bending beam testing was performed on a flexural testing machine of 100kN capacity. The beam was placed on two supports at a distance of 240mm. The loading was provided at centre that was exactly above the notch position. The test set up was shown in figure 1.

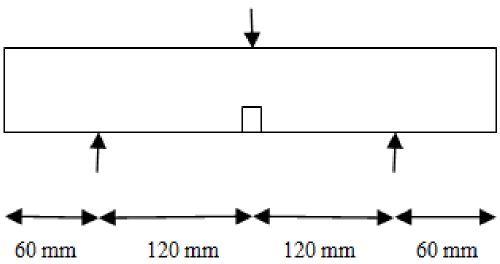

Figure 1. Three point bending test set up

Four point bending test

The four point bending test was performed on a flexural testing machine of 100kN capacity. Four point loading position was fixed at ¼ th of span length from both supports. This loading was chosen for obtaining pure bending at middle half portion of the beam where crack was present. The test set up was shown in figure 2.

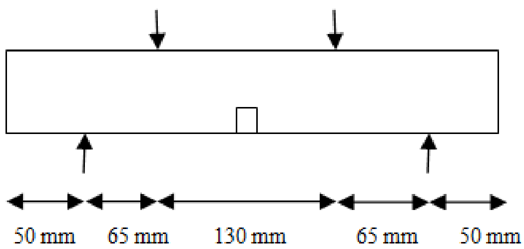

Figure 2. Four point bending test set up

RESULT AND DISCUSSION

The crack was starting from the existing crack. The ultimate load was observed for all the specimens. The failure modes of specimens under three point bending and four point bending tests were shown in figure 3 and 4.Table 8 shows the fracture toughness of all mixes from three point bending test and table 9 shows the fracture toughness of all mixes from four point bending test. Figure 5, 6, and 7 shows fracture toughness of various mixes in 0.5%, 1% and 1.5% of fiber addition.

Figure: 3 Failure modes of beams in three point bending

Figure: 4 Failure modes of beams in four point bending

TABLE: 8 THREE POINT BENDING TEST RESULTS

Mix	Ultimate load (N)	Fracture toughness ($N/m^{3/2}$)
CM	3000	9.32×10^5
M1	3500	10.88×10^5
M2	3000	9.32×10^5
M3	2500	7.77×10^5

M4	2000	6.21×10^5
M5	2500	7.77×10^5
M6	3500	10.88×10^5
M7	2000	6.21×10^5
M8	4000	12.43×10^5
M9	5500	17.09×10^5
M10	4000	12.43×10^5
M11	4500	13.98×10^5
M12	5000	15.54×10^5
M13	5000	15.54×10^5
M14	3500	10.88×10^5
M15	3500	10.88×10^5
M16	5000	15.54×10^5
M17	4000	12.43×10^5
M18	4500	13.98×10^5
M19	4500	13.98×10^5

TABLE: 9 FOUR POINT BENDING TEST RESULTS

Mix	Ultimate load (N)	Fracture toughness ($N/m^{3/2}$)
CM	3000	9.32×10^5
M1	4000	12.43×10^5
M2	4000	12.43×10^5
M3	3500	10.88×10^5
M4	3000	9.32×10^5
M5	3500	10.88×10^5
M6	4500	13.98×10^5
M7	3000	9.32×10^5
M8	4500	13.98×10^5
M9	6500	20.20×10^5
M10	4500	13.98×10^5
M11	5500	17.09×10^5
M12	6000	18.65×10^5
M13	6000	18.65×10^5
M14	4000	12.43×10^5
M15	4000	12.43×10^5
M16	5500	17.09×10^5
M17	4500	13.98×10^5
M18	5000	15.54×10^5
M19	5000	15.54×10^5

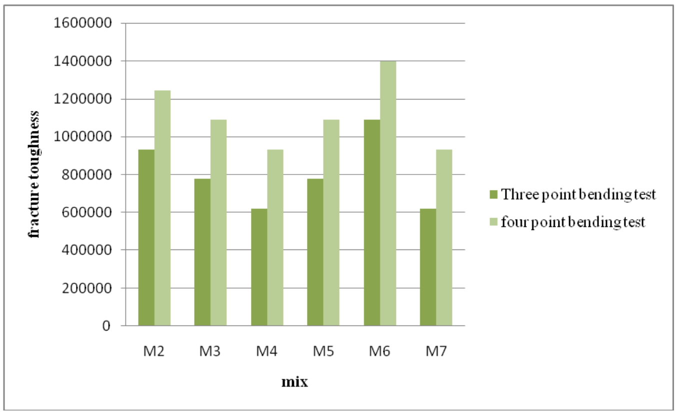

Figure: 5 Fracture toughness in 0.5% fibre addition

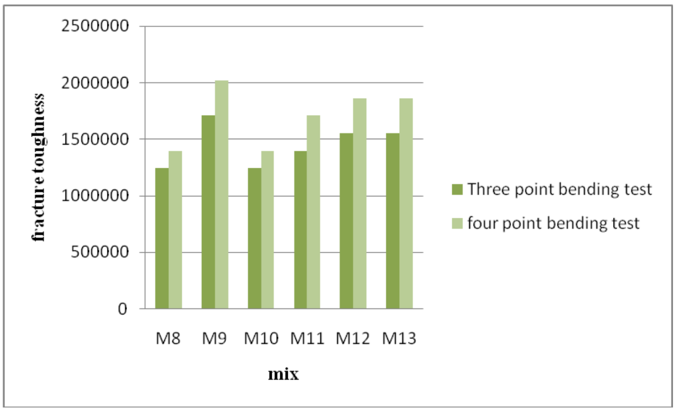

Figure: 6 Fracture toughness in 1% fibre addition

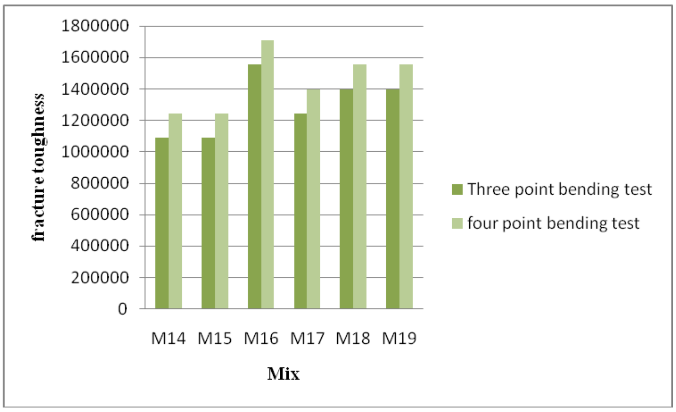

Figure: 7 Fracture toughness in 1.5% fibre addition

It can be seen that the concrete with 10% replacement of PC with NSP shows higher fracture toughness than plain concrete. M1 mix shows 14% increase of fracture toughness in three point bending and 25% in four point bending test.

It can be found that from all combinations of fibers, the mix with higher coir content and less jute content shows higher fracture toughness. The coir fiber had more elongation at break compared to basalt and jute fibers. At the time of break coir fiber provide more fiber bridging and elongation of fiber so the failure was more ductile.

The addition of natural fibers in concrete shows increase in fracture toughness. The failure was brittle in the case of concrete without fibers. The addition of natural fibers provides a control of cracking and increase the ductility. The fracture toughness increases up to 1% fiber addition. In 1.5% fiber addition, the fracture toughness was decreases but it was more than that of control mixes. The higher fiber fraction creates voids in the concrete which will reduce the fracture toughness.

It can be seen that the fracture toughness of all mixes obtained from four point bending test was higher than that of three point bending test. In the case of four point bending, the volume under stress was bigger the one under three point bending. The four point bending method allows uniform distribution of stress between the two loading noses while stress in the three point bending method was located under the loading nose. The crack was initiated from the existing notch. In the case of three point bending the load was provided exactly above the notch position. More stress was concentrated at the notch so the beam fails immediately. The fracture toughness was critical in the case of three point bending test. The 1% fiber addition shows 12% to 36% increase of fracture toughness in three point bending and 11% to 38% in four point bending.

CONCLUSIONS

Based on the experimental results, the following conclusions were obtained.

- The concrete with 10% replacement of PC with NSP shows14% increase of fracture toughness in three point bending and 25% increase in four point bending test.
- The addition of natural fibers shows 14% to 40% increase of fracture toughness in three point bending and 14% to 54% increase in four point bending.
- From all combinations of fibers, the mix with higher coir content and less jute content shows higher fracture toughness.
- The fracture toughness of all mixes obtained from four point bending test was higher than that of three point bending test. The fracture toughness was critical in the case of three point bending test. So three point bending test was more suitable for finding fracture toughness.
- The fracture toughness was increases up to 1% fiber addition. The 1% fiber addition shows 12% to 36% increase of fracture toughness in three point bending and 11% to 38% in four point bending.

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