



Novel hybrid composites based on glass and sisal fiber for retrofitting of reinforced concrete structures



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HIGHLIGHTS

- Novel method for retrofitting of concrete structures by hybrid fiber reinforcements.
- Increase in the axial load carrying capacity upon FRP wrapping.
- Ductility of hybrid fiber wrapped concrete same as that of carbon fiber counterparts.
- Hybridization of natural and synthetic fibers is a substitute for carbon fiber in retrofitting.

ARTICLE INFO

Article history:

Received 18 August 2016

Received in revised form 7 December 2016

Accepted 12 December 2016

Keywords:

Hybrid fiber composites

Confinement

Axial compressive behaviour

Ductility

Durability

ABSTRACT

In this work an attempt has been made to assess the efficacy of hybrid composite system as a potential choice for the retrofitting of reinforced concrete structures. The combination of synthetic and natural fibers are used for the external confinement of concrete cylinders. A comparative performance analysis of hybrid sisal-glass fiber reinforced polymer (HSGFRP) confinement vis a vis carbon fiber reinforced polymer (CFRP), glass fiber reinforced polymer (GFRP) and sisal reinforced polymer (SFRP) individual confinement is carried out. The axial compressive behaviour, stress-strain response and energy absorption characteristics are studied. The inclusion of sisal fibers along with glass fiber is found to improve the energy absorption characteristics. For predicting the ultimate strength of HSGFRP confined concrete, a new equation was developed based on the lateral confining pressure which shows good agreement with the experimental results. Durability performance studies indicated that exposure to wet/dry conditions and temperature variations resulted an increase in strength for all FRP confined specimens and whereas it decreased for unconfined ones.

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1. Introduction

The deterioration of reinforced concrete structures can be attributed to several reasons viz., fatigue failure, insufficient reinforcement, exposure to aggressive surroundings leading to steel reinforcement corrosion etc. Hence, for maintaining the structural integrity, retrofitting techniques are to be developed, which ensures the safety and serviceability criteria of the structures. Earlier days prestressed or non prestressed steel was used for the repair but exposure to moisture, chloride penetration and temperature variations reduced the alkalinity of the concrete, leading to corrosion of steel. Such methods are found to be suitable in certain cases where intensity of corrosion was within acceptable limits. Consequently, the need for development of effective and econom-

ical strengthening strategies resulted in extensive utilization of fiber reinforced polymers (FRP) as reinforcing material in concrete. The salient properties of FRP's like high tensile strength, high strength to weight ratio, corrosion resistance, ease of installation and high specific strength makes them the most popular material for structural strengthening [1]. Recent reports [2,3] indicate that confinement of concrete columns with FRP significantly improve the ultimate strength and ductile behaviour of concrete. The advantage of FRP confinement on structures is mainly the improvement in load carrying capacity and ductility without considerable increase in cross sectional area and weight.

Carbon Fiber Reinforced Polymer (CFRP), Glass Fiber Reinforced Polymer (GFRP), Aramid Fiber Reinforced Polymer (AFRP) etc. are the most commonly used ones for the reinforcement of concrete structures. Several researches has been done in the past related to the use of FRPs in strengthening of concrete structures [4–8]. However, their high cost is a limiting factor and efforts are on for

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the development of composites from alternate materials. Natural fibers like sisal [9], jute [9], flax [10] etc. were tried out for retrofitting of concrete. In comparison with synthetic fibers, natural fibers exemplify low density, moderate tensile and flexural properties and are less costly. Studies have shown that natural fibers have great potential in reinforcing cement matrix [9–14]. As the production of synthetic fibers warrants higher energy, the application of natural fibers are preferred from the sustainability point of view [15]. Nevertheless, natural fibers also have disadvantages such as low durability and strength compared to synthetic fibers. Studies have therefore shown that hybridisation [16,17] of natural fibers with synthetic fibers will help in improving the properties of natural FRP composites [18–20]. Upon hybridization, there is a synergy of the positive features of both the fibers. Studies performed on hybrid composites like Sisal-Jute-GFRP, Sisal-GFRP [18], and Abaca-Jute-GFRP [19] indicated superior properties compared to the individual natural fiber reinforced system. The present work is oriented towards the performance analysis of plain concrete cylinders confined with hybrid Sisal-GFRP composite systems. Uniaxial compression test is performed on cylinders externally confined with FRP composite systems in order to determine the confinement effect on axial load carrying capacity. Ductility, stiffness, ultimate strength, and failure mode are also determined to find out the axial and hoop performance of the confined cylinder. The performance of the hybrid system is compared with different natural and artificial individual FRP composite systems such as CFRP, GFRP, and Sisal FRP etc. The peak strength obtained from experiment is compared with existing models proposed for FRP confined concrete systems. In order to evaluate the ultimate compressive strength of Sisal-GFRP confined hybrid system a mathematical model is made use of proposed in earlier reports [21–25]. For determining the behaviour of FRP confined specimen on a long term basis durability studies are performed. Unconfined specimens and FRP confined specimens are subjected to three different exposure conditions like temperature variation, wet/dry cycle and alkaline environment. The results of the tests performed is expected to give an indication for feasibility of FRPs as reinforcing material in structural applications.

2. Methodology

2.1. Materials

2.1.1. Concrete

For concrete preparation Ordinary Portland Cement of grade 53 conforming to IS 12269-2013 [26] was used. The fine aggregates used was clean river sand with a fineness modulus of 2.88 and coarse aggregate having bulk density of 1.58 kg/l and maximum size 20 mm. The mix proportioning of concrete was carried out according to IS 10262-2009 [27] and characteristic compressive strength observed was 23 MPa. The mix proportion by weight of cement: sand: coarse aggregate was maintained as 1:2.61:3.60. Water cement ratio of 0.5 was selected. Fifty concrete cylinders with 100 mm diameter and 200 mm height were cast and cured for 28 days.

2.1.2. Fiber reinforced polymer (FRP) composite

For the preparation of the composite epoxy resin araldite LY 556 and hardener HY 991 was used as matrix by taking a mix ratio of 100:15 by weight. Epoxy resin has a tensile strength of 85 MPa and modulus of 3.8 GPa. Sisal fiber was obtained in the form of bidirectional woven fabric of thickness 1.15 mm from M/S Dc Mills, Cherthala, Kerala and Glass fiber woven mat of 300 gsm and Carbon fiber fabric of 200 gsm was supplied by M/S Hindoostan Composite Solutions. The tensile strength test results of hybrid sisal-

GFRP (HSGFRP) composites obtained after hand lay up process is given in Table 1.

2.2. Wrapping of concrete cylinders with FRP

The concrete cylinders after curing for 28 days are kept for drying and the surface defects are removed. The FRP sheets are cut according to required dimensions of the cylinder. Epoxy and hardener was mixed in the ratio 100:15 by weight. A coat of epoxy hardener mix was applied initially on concrete cylinder to fill the voids. Then the respective natural and synthetic sheets are placed on the outer surface of respective concrete cylinders and another coat of epoxy resin-hardener was again applied immediately on top of the sheet. This step was repeated till the required number of layers was achieved. All the FRP confined cylinders are kept for curing at room temperature before the axial compression test. Fig. 1 illustrates the different steps involved in the specimen preparation.

2.3. Mechanism of confinement

FRP composite system provides passive confinement effect where the confinement action starts after concrete expands laterally. As the concrete axial stress increases, lateral strain increase and confinement mechanism develops a hoop tensile stress equalized by uniform radial pressure acting against concrete lateral expansion. For circular columns, the circumferential lateral confining pressure is assumed to be uniform. On application of axial compression, tensile stress acts on FRP in hoop direction. The confining pressure increases as the concrete expands laterally. Failure occurs when FRP reaches ultimate tensile strain due to maximum value of confining pressure.

The Lateral confining pressure is calculated using the following equation [24]

$$f_l = \frac{2t f_{frp}}{D} = \frac{2t E_{frp} \epsilon_u}{D} = \frac{\rho_{frp} f_{frp}}{2} \quad (1)$$

$$\rho_{frp} = \frac{\pi D t}{\pi D^2 / 4} = \frac{4t}{D} \quad (2)$$

where E_{frp} the modulus of elasticity of FRP, f_{frp} is the ultimate tensile strength of FRP, D is the diameter of concrete cylinder, t is the thickness of FRP, ρ_{frp} is the volumetric ratio of FRP.

3. Results and discussion

Two different cases are analysed in the present study to evaluate the compression behaviour of FRP wrapped plain concrete cylinder. All the specimens are subjected to axial compressive loads in a testing machine of 2000 kN capacity. The various parameters like load, stress, displacement, strain etc. are measured and compared.

Table 1
Strength properties of HSGFRP composites.

HSGFRP	Ultimate tensile strength (MPa)	Modulus of Elasticity (GPa)	Elongation at break (%)
1 Layer	233.2	11.81	1.60
2 Layer	368.4	12.42	1.94
3 Layer	441	13.36	2.26

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