

# Experimental Studies on Hybrid Beam Reinforced with Steel and BFRP Bar

P. Nachiappan, SmithaGopinath, A. Rama Chandra Murthy, Dr. Nagesh R. Iyer, T. Manju

**Abstract**—Fibre Reinforced Polymer (FRP) bars are well known these days for use as reinforcements in concrete structures. Basalt Fibre Reinforced Polymer (BFRP) bars are a new addition to the class of FRP bars. BFRP bars have high tensile strength but do not possess any yielding characteristics. As a result beams reinforced with them show poor ductility but have high moment of resistance. Hybrid beams are a balanced approach towards achieving the required ductility for a particular application by accepting a certain amount of loss of strength. This paper presents experimental results of the flexural behaviour of a hybrid beam reinforced with Steel and BFRP bars. The results are compared with a conventional steel reinforced beam and a pure BFRP bar reinforced beam.

**Index Terms**—FRP bar reinforced beam, BFRP bar, Hybrid beam, Ductility improvement.

## 1 INTRODUCTION

STEEL bars have been used as reinforcements in concrete structures for a long time. The various aspects of such structures have been researched out and are well documented. With the improved knowledge of the ecological impact of using steel (rather over using it), alternatives such as Fibre Reinforced Polymer (FRP) bars came in to picture. FRP bars are anisotropic and are manufactured from continuous fibres through a pultrusion process [1]. They have their own merits and drawbacks.

Structures reinforced with steel often presented durability problems as steel bars are vulnerable to corrosion. Their design life period and performance are affected because of corrosion. FRP bar reinforced structures are highly durable as the FRP bars, being non-metallic in nature, are corrosion resistant. They offer better resistance to chemical attack and fare better in accelerated environments [2] and [3].

The fire resistance of FRP bars is low as the polymer matrix melts soon to loose physical shape and integration [4]. FRP bars have very good tensile strength in the longitudinal direction (direction of orientation of fibres) but are poor in compression and shear. Their tensile behaviour is linear till failure without any yielding. Hence beams reinforced with them are not ductile enough.

Certain structures require certain amount of ductility so that they do not collapse when unexpected magnitudes of forces act on them. This varies from structure to structure and also from place to place. Basalt Fibre Reinforced Polymer (BFRP) bars when used as reinforcements do not provide any ductility [5]. Hence a hybrid beam having a combination of BFRP as well as steel bars maybe advisable [6]. Depending upon what levels of ductility is adequate for a certain structure the proportion of the two can be adjusted. It is obvious that

with an increase in the amount of steel the ductile performance improves. Such beams require proper testing to understand their behaviour. The levels of stress in each bar, their ability to bond together and behave as one etc., needs to be analysed. This paper investigates and compares the flexural behaviour of BFRP reinforced beam, the hybrid beam and the concrete beam reinforced with steel bars.

## 2 EXPERIMENTAL PROGRAMME

### 2.1 Specimens and Materials

Three beams of dimension 100 x 200 x 1500 mm were cast with a designed M45 1:1.48:1.60:0.4 concrete mix (see Table I). All the beams were cast in a single batch of concrete mix. Three 150 x 150 x 150 mm cubes were cast to determine the compressive strength of the concrete mix. The beams were provided with a 6 mm diameter two legged stirrups at a spacing of 50 mm centre to centre to prevent shear failure. To facilitate the provision of stirrups two hanger bars of 6 mm diameter were used. The Materailtension reinforcements were varied in all the three beams as per the study as shown in Fig. 1. Fe 415 grade steel was used.

TABLE I  
MIX DETAILS OF M45 CONCRETE MIX

Material	Weight per m <sup>3</sup> in kg
Cement	538
Fine Aggregate	796
Coarse Aggregate	863
Water	215

The nomenclature of beam IDs is like <diameter of tension reinforcement>\_<no. of BFRP bars in tension>\_<no. of steel bars in tension>. So, the beam with ID 10\_0\_2 is the conventional steel bar reinforced beam, while the 10\_2\_0 beam is the BFRP bar reinforced beam. 10\_1\_1 is the hybrid beam.

- P. Nachiappan is currently pursuing Integrated Masters Degree Program in Structural Engineering in SASTRA University, Thanjavur, India. E-mail: ganesh.nachi@gmail.com
- SmithaGopinath and A. Rama Chandra Murthy are currently Scientists at CSIR-Structural Engineering Research Centre, Chennai, India.
- Dr. Nagesh R. Iyer is currently the Director of CSIR-Structural Engineering Research Centre, Chennai, India
- T.Manju is currently working as Assistant Professor in the School of Civil Engineering in SASTRA University, Thanjavur, India

## 2.2 Tensile Characterisation of BFRP Bar

Simple tension test was carried out on 10mm diameter BFRP bar to characterize its behaviour. Test procedure complies with ASTM D7205 D7205M - 06 [7]. Overall length of the specimen was 500 mm and the gauge length was 350 mm. The test results are tabulated in Table II. Fig. 2 shows the experimental work and Fig. 3 shows the stress strain plot.

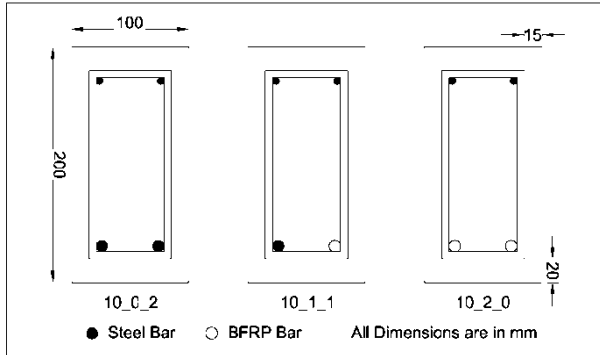


Fig. 1. Reinforcement details of the three beams with their ID

TABLE II  
TENSION TEST RESULTS OF BFRP BAR

Parameter	Values
Ultimate Tensile Strength in MPa	684.5
Ultimate Strain in %	3.75
Modulus of Elasticity in GPa	47.5



Fig. 2. Simple tension test on BFRP bar with failure at the middle region



Fig. 3. Stress strain plot of the BFRP bar

## 2.3 Testing Setup and Procedure

The beams were tested under a steel loading frame and the load was applied using a 500 kN capacity MTS servo-hydraulic actuator. Two point loading was applied using a distribution beam after the span was divided into three equal parts as shown in Fig. 4. A deflection controlled speed of testing of 1mm/min was used for all the beams. Midpoint deflection was recorded using an LVDT.

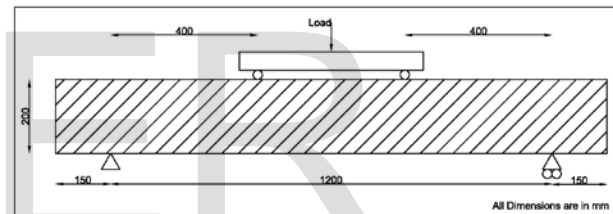


Fig. 4. Testing and loading setup for all the beams

## 3 ANALYTICAL INVESTIGATION AND DESIGN OF BEAMS

ACI 440.1R-06 [8] was used to design the BFRP bar reinforced beam and the hybrid beam using the effective reinforcement ratio approach whereas IS 456:2000 [9] was used to design the steel bar reinforced beam. It is recommended by [8] that over reinforced design philosophy is better for FRP bar reinforced beams. The effective reinforcement ratio for the hybrid beam is given by (1) as suggested by [6]. This approach converts the steel bar into an equivalent BFRP bar using the factor 'm'. The theoretical moment capacity of the beams are evaluated using the tensile characterisation results of BFRP bars and the concrete compressive strengths obtained from the 28th day cube compression tests (see Table III).

$$\rho_{eff} = \rho_s m + \rho_f \quad (1)$$

where,

- $\rho_{eff}$  is the effective reinforcement ratio
- $\rho_f$  is the reinforcement ratio for BFRP bars alone
- $\rho_s$  is the reinforcement ratio for steel bars alone and
- $m$  is a factor given by the ratio of the ultimate tensile strength of steel to BFRP bar

TABLE III  
28 DAY COMPRESSIVE STRENGTH OF THE CUBES

Cube ID	Compressive Load in kN	Compressive Strength in MPa
Cube 1	1508.275	67.03
Cube 2	1431.491	63.62
Cube 3	1202.786	53.45

#### 4 RESULTS AND DISCUSSION

The test results of all the three beams are tabulated (see Table IV) and their load deflection plot is shown in Fig. 5. All the beams take moments more than that predicted by theoretical equations, but the hybrid beam and the BFRP bar reinforced beam take only a little extra moment than predicted unlike the steel bar reinforced beam which has a more safety cushion. It can be seen that the steel bar reinforced beam behaves typically showing good ductility, while the BFRP bar reinforced beam shows no ductility at all, with a linear pattern till failure. The intermediate hybrid beam shows a bi-linear load deflection pattern with some ductility obtained after the change in slope. The point of change of slope is the point at which steel bar starts to yield which provides ductility to the beam.

The ultimate moment of the BFRP reinforced beam is 10% higher than that of the steel bar reinforced beam. The BFRP bar reinforced beam though not ductile, but deflects at a much faster rate than the steel reinforced counterpart. The load deflection plot for the BFRP bar reinforced beam is flatter than the steel bar reinforced beam. With the design philosophy being over reinforced, this excess deflection can produce cracks which can serve as warnings of the impending sudden collapse due to concrete crushing. This is also evident from the fact that first crack moment for steel bar reinforced beam is 6.06 kNm and for BFRP bar reinforced beam is 2.78 kNm.

TABLE IV  
FLEXURE TEST RESULTS OF BEAMS

Beam ID	Theoretical Moment in kNm	Experimental Ultimate Moment in MPa	First Crack Moment in kNm
10_0_2	8.97	15.94	6.06
10_1_1	14.24	15.21	4.16
10_2_0	16.27	17.56	2.78

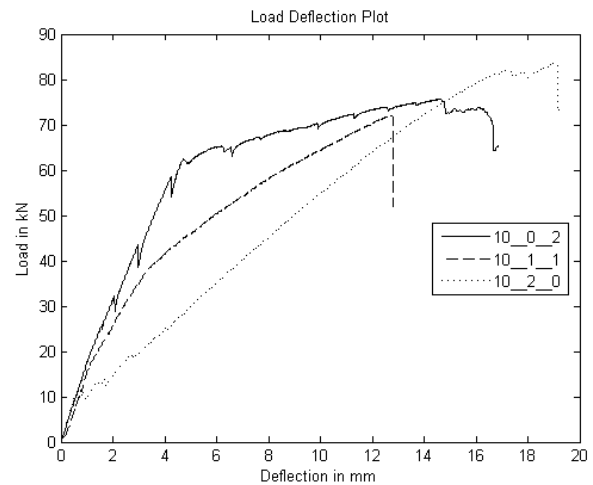


Fig. 5 Load deflection plot of all the three beams



Fig. 6 Flexure testing of beam 10\_1\_1

#### 5 CONCLUSION

The three tested beams show that ductility of a BFRP bar reinforced beam can be improved by adding steel bars to obtain a bi-linear load deflection plot. Beams reinforced with BFRP bar are less stiff than their steel counterparts thereby they deflect at a much larger rate. Hence depending on the application, the requirements of ductility and the maximum allowable deflection the type of reinforcement can be decided.

#### ACKNOWLEDGMENT

The authors thank the staff of Computational Structural Mechanics Group and Structural Testing Laboratory of CSIR-SERC for the co-operation and suggestions provided during the investigation. This paper is being published with the kind permission of the Director, CSIR-Structural Engineering Research Centre.

#### REFERENCES

- [1] Enrico Quagliarini, Francesco Monni, Stefano Lend, Federica Bondioli: Tensile characterization of basalt fiber rods and ropes: A first contribution. Construction and building materials, ELSEVIER. vol 34 (2012), pp. 372-380. (2012)

- [2] BrahimBenmokrane, Peng Wang, Tan Minh ton-That, Habib Rahman, Jean-Francois Robert: Durability of Glass Fiber-Reinforced Polymer Reinforcing Bars in Concrete Environment. *Journal of Composites for Construction, ASCE*. vol. 6 (2002), pp. 143 - 153. (2002)
- [3] Francesco Micelli, Antonio Nanni: Durability of FRP rods for concrete structure. *Construction and building materials, ELSEVIER*. vol. 18 (2004), pp. 491-503. (2004)
- [4] Mohamed Saafi: Effect of fire on FRP reinforced concrete members. *Composite Structures, ELSEVIER*. vol. 58 (2002), pp. 11 - 20. (2002)
- [5] Marek Urbanski, Andrzej Lapko, AndrzejGarbacz: Investigation on Concrete Beams Reinforced with Basalt Rebars as an Effective Alternative of Conventional R/C Structures. 11th International Conference on Modern Building Materials, Structures and Techniques, MBMST 2013, *Procedia Engineering, ELSEVIER*. vol. 57 (2013), pp. 1183-1191. (2013)
- [6] Denvid Lau, Hoatjoen Pam: Experimental study of hybrid FRP reinforced concrete beams. *Engineering Structures, ELSEVIER*. vol. 32 (2010), pp. 3857-3865. (2010)
- [7] Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars, *ASTM D7205/D7205M-06*, 2011
- [8] Guide for the Design and Construction of Structural Concrete Reinforcedwith FRP Bars, *ACI 440.1R-06*, 2006
- [9] Indian Standard Plain and Reinforced Concrete - Code of Practice, *IS 456:2000*, 2000

IJSER