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An Experimental Evaluation of Mechanical Properties of Hybrid Reinforcements

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Abstract. This paper presents the mechanical properties of unidirectional hybrid reinforcements formed from continuous fibres impregnated with a fibre binding material which are used for reinforcing the concrete. Recently FRP (Fibre Reinforced Polymer) manufacturers and suppliers have been increased all over the world because of the superior performance of FRP products in the construction industry. Its non-corrosive nature has turned the attention of many researchers to make several studies on different type of FRP products. Through a vast research, several standards also have been formulated. In this regard a new combination of FRP materials is tried in this paper and its properties have been derived. Carbon fibre and glass fibres fuse in this study to form a new hybrid rebar. The design properties such as tensile strength, tensile modulus, and compressive strength have been studied as per ASTM standards and it has been identified that the Hybrid rebar show a superior performance in comparison with GFRP (Glass FRP) and Steel rebars. This extraordinary performance of hybrid composite material increases the extensive engineering applications such as transport industry, aeronautics, naval, automotive industries.

Keywords: Hybrid, FRP, Mechanical properties, tensile property, compressive property

1. Introduction

For the past two decades, the hybrid composites have been successfully substituted universally which possess superior properties than their parental composites such as Glass, Carbon, Aramid and Basalt fibre composites. The performance of composite materials can be improved based on the fusion of two or more fibers in a single polymeric matrix which leads to the advanced material called hybrid composite with a great diversity of material properties. The main purpose of the combination of two or more materials is to bypass the demerits of those materials. Thus it is mandatory to investigate the properties of hybrid composites in order to substitute the conventional steel reinforcements.

It is well known that the concrete structures suffers deterioration due to external loading and severe environmental conditions such as corrosion of steel rebar, alkali reaction, de-icing salt, and freeze-thaw among which the corrosion dominates. As a consequence the serious structural damage and, structural failure takes place. Several studies are going on to find a solution to this corrosion problem [1-24] and in this regard the present study has been carried out with carbon-glass hybrid composite reinforcements.

In 1994, the tensile behavior of hybrid which is a combination of FRP skin and a steel inner core has been evaluated [6].It has been observed that the failure of hybrid rods occurred in the FRP Skin and then to the inner core. Vinylon has been introduced to increase the strength as protection. Harry G.Harris and Frank K.Ko (1998) investigated a new ductile hybrid fibre reinforced polymer bar of carbon core with epoxy and used as reinforcement in new or repaired concrete structure.
Due to the anisotropic nature of the specimen being tested in this analysis, the bending failure may be caused by tensile, compressive, shear or a combination of these stresses.

The mechanical properties like bending, fatigue, stiffness and strength of carbon-glass/epoxy hybrid laminates were reported by the researchers [7,8].Jones *et al.* have performed experiments on the combined composites of carbon/carbon, glass/glass, aramid/carbon, glass/carbon fibers, and then obtained pseudo-ductile behaviors when small amounts of fibers with low stretch were well distributed. In these cases, however, there was a problem of increasing the unit price of products.
From all these literature studies, it has been observed that the efficiency of composite reinforcement depends on the adhesion between matrix and fiber; hence it is needed to determine their mechanical properties. The present work depicts the mechanical properties such as the tensile properties and compressive properties of Carbon-glass Hybrid composite reinforcements as per ASTM standards.

2. Materials and methods

Hybrid reinforcements used in this study were manufactured by Meena Fiberglass Industries, Pondicherry, India. **Using Pultrusion process,** the reinforcements were manufactured with a volume of 60% of E-glass fibre and 40% carbon fibre and are reinforced with epoxy resins. The epoxy resin, hardener Tri Ethylene Tetra Amine (TETA) and Catalyst (Methyl ethyl Kethone Peroxide) were used. The glass fiber of bi-directional woven mat with 200 gm and the density of 2.5 gm/cc were used. The carbon fiber of bi-directional woven mat with 200 gm and the density of 1.78 gm/cc were used. The glass fiber and carbon fiber in the form of rovings used in the fabrication of hybrid fiber reinforced composites are shown in Figure 1.

Figure 1. Raw Carbon and Glass fibres

The weight fraction of fibers and epoxy matrix materials were determined by considering the density, specific gravity and mass. Initially, the fabrication of the composite was done at room temperature by Pultrusion technique. Pultrusion process is used to pull any type of fibre and resin , through a shaped die having a constant cross section. The resin matrix gives form and protection from the external environment to the fibres. Chemical, thermal, and electrical performance can be affected by the choice of matrix resin. As the resin rich fiber exits the resin impregnation system, the un-cured composite material is guided through a series of tooling which helps to arrange the fibre into the correct shape, and the excess resin is squeezed out known as debulking. The die is heated to a constant temperature of 145^{o}, which will cure the thermosetting resin. The profile that exits the die is now a cured pultruded Hybrid Fiber Reinforced Plastic (H- FRP) composite and the hybrid rod manufactured for the present study is shown in Figure 2.

Figure 2. Hybrid Rebar

The manufactured hybrid rods are subjected to tensile test and compression test, according to ASTM standards.

3. Experimental Programme

This paper mainly presents the tensile properties and compressive properties of the Hybrid rod. A minimum of three identical test specimens were prepared for each test. The density which is considered as an important physical property was at first studied and observed that Hybrid and GFRP rods possess lighter densities such as 2502.43 and 2122.33 kg/m^3 which is almost three times lesser than that of steel rods (7480.58 kg/m^3).

3.1 Uniaxial Tensile Test

As per ASTM D638 rods a total of 15 specimens i.e., 5 specimens in each variety (GFRP, Hybrid and Steel rods) were cut into pieces of 600 mm. The specimen was fixed in universal testing machine (UTM) between the adjustable grips. The load was applied perfectly on the rod till the failure of the specimen. The test was repeated for five times on the five identical specimens. The tensile strength was calculated using the following Equation (1) and the average of the five values was taken as the ultimate tensile strength of the specimen.

$$\text{Tensile strength} = \frac{Maximum\ applied\ Load}{Original\ Cross\ sectional\ area} \tag{1}$$

Figure 3. Test set up and rupture of rebars

Table 1. Tensile properties of reinforcements

Type of specimen	Diameter (mm)	Area (mm^2)	Initial modulus (MPa)	Tensile strength (MPa)
GFRP	10	78.54	1.83×10^4	553.85
Hybrid	10	78.54	6.47×10^3	1082.25
Steel	10	78.54	2.08×10^5	496.56

The ultimate tensile modulus can be determined by the stress strain graph. Since the hybrid is brittle in nature ,it exhibits a linear behavior until it fails.The test setup and the rod failure are shown in Figure.3.The tensile properties of reinforcements are shown in Table.1.The stress-strain relationship of a Hybrid rod sample is shown in Fig.4 showing strain along X axis and stress along Y axis. The ultimate strain was range between 4.1 to 4.7%.

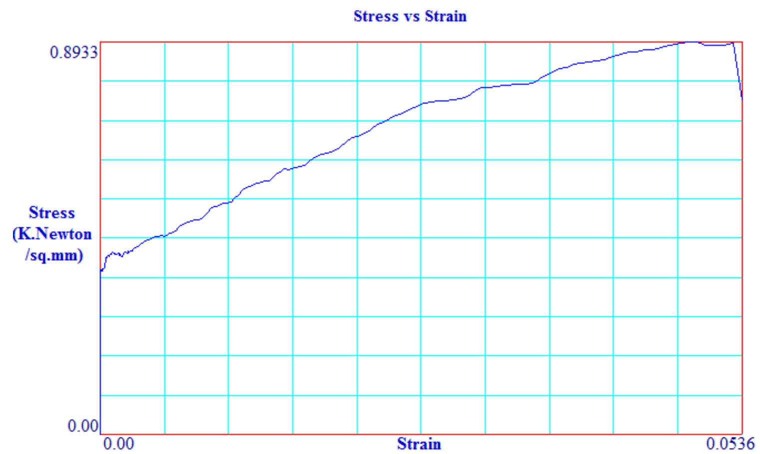

Figure 4. Stress Vs Strain Graph for various types of reinforcement

It was found that the FRP rods display a linear elastic behaviour up to failure with a modulus of elasticity lower than that of steel. The elastic modulus is mainly dependent on fibre type and volume percentage. The applied load is transferred to the core through the bond between core and skin. Unlike steel rods the hybrid and GFRP rods exhibit the rupture of rods along the longitudinal direction without yielding at the breaking stage.

3.2 Compressive Strength

According to ASTM D695 the compressive strength of Hybrid rods were determined in UTM. Usually due to the anisotropic nature the compressive property of composite rods is not recommended. But a thorough knowledge of strength characteristics is important and hence the load carrying capacity in the opposite direction has been studied.The specimens were fixed in between the platens of UTM.The length of the specuimen is taken as 50 mm . The load was applied at an uniform rate till the specimen fails and the failure load was noted from the dial indicator, the load dial gauge was adjusted to read zero before the load application. Fig.5 shows the Experimental setup for compression and the failure of the specimen and Table.2 depicts the Compressive properties of various reinforcements.

Figure 5. Experimental setup for compression and the failure of the specimen

Table 2. Compressive properties of various reinforcements

Specimen	Diameter (mm)	Area (mm^2)	Compressive load (kN)	Compressive stress (N/mm^2)
GFRP	10	78.5	35.0	445.86
Hybrid	10	78.5	37.8	481.28
Steel	10	78.5	30.0	381.97

4. Discussion of Results
The test results can be used for material specifications, quality control and assurance, structural design and analysis, and research and development. From the tensile test, it has been noted that the hybrid rods perform superior than the other specimens. The stress strain curve shows that the hybrid and GFRP rods behave bilinearly. All the FRP and hybrid rods clearly exhibited a point at which the steel rebar started yielding. The modulus of elasticity of GFRP rods is improved due to the addition of carbon core. If the volume fraction of carbon increases, the ductility will improve. Since the carbon is a good conductor of electricity its volume fraction is kept low in this study. Anyhow, the ultimate tensile strength of hybrid is found to be 49% greater than gfrp and 54% greater than steel reinforcements.

The compression modes of failure reflects the transverse tensile failure, fibre micro buckling, or shear failure. The modes of failure depend on the type of fiber, the fiber-volume fraction, and the type of resin. In general, compressive strengths are higher for rods having higher tensile strengths. From the present study it has been observed that hybrid rods show 7.4% and 20% higher compressive strength than GFRP and steel rebars respectively.

5. Conclusion
It has been observed from the tests that the combination of Glass and Carbon FRP has a predictable performance based on the law of mixtures. The present study peeps through the excellent mechanical properties of hybrid rods over the GFRP and conventional rods. Pultrusion technique has been used to fabricate the hybrid rods. The fusion of glass and carbon fibre in a volume fraction 60:40 enhanced the ultimate tensile strength, yield strength and peak load of the composite. The ductility of hybrid rebarsis higher than GFRP composite rebars. The glass is used as outer core to prevent the corrosion as well as to prevent conduction of electricity as we know the carbon is a good conductor of electricity. The present investigation can be extended in the future for different mix proportions of two different FRP materials using different manufacturing technique to increase the strengths in all aspects.

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