International Journal of Advance Research in Science and Engineering
Vol. No.6, Issue No. 01 , January 2017
www.ijarse.com
IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

# EXPERIMENTAL INVESTIGATIONS ON PHYSICAL AND MECHANICAL PROPERTIES OF CARBON-GLASS HYBRID COMPOSITE RODS

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**ABSTRACT**

*This paper describes the mechanical characteristics of a new ductile hybrid reinforcement which simulates the stress-strain characteristics of conventional steel reinforcement. In this study, the hybrid rods are manufactured with a combination of glass (60 %) and carbon (40%) of fibre loading impregnated with epoxy resin. The hybrid rods are produced by pultrusion process. Pultrusion is a continuous process for manufacturing composite materials with constant cross-section. Reinforced fibres are pulled through a resin, possibly followed by a separate performing system, and into a heated die, where the resin undergoes polymerization. The mechanical characteristics studied in the present work are tensile, compressive, Hardness and Impact strengths. Using ASTM (American Society for testing and Methods) standards the Hybrid rods have been tested and compared with GFRP and conventional rods. From the results it has been noted that hybrid rods perform superior than the other rods.*

***Keywords: ASTM methods, Hybridization, hybrid Rods, GFRP Rods, Mechanical Properties, Steel Rods.***

## I.INTRODUCTION

Researchers are always concerned much in the development of new structural materials, technologies and design concepts [1-18]. This is a major challenge that can only be met through an understanding of the relationships between materials, architecture and mechanical response. New combination of materials may result in super improved performance leading to a advanced material system called hybrid composites. In this regard, the present work put forth the examination of some important physical and mechanical characteristics of the hybrid rod which is a combination of carbon and glass. The formation of hybrid reinforcements is achieved by the continuous fiber rovings glass and carbon fiber reinforced polymer matrix composites. Hybrid reinforcements used in this study are manufactured by Meena Fiberglass Industries Puducherry, India**.** The fibres are reinforced with epoxy resins and are manufactured by pultrusion process.

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

In 1994, the tensile behavior of hybrid which consist of an FRP skin and a steel inner core has been evaluated (Nanni et al.,1994).It has been observed that the failure of hybrid rods occurred in the FRP Skin and then to the inner core. To increase the strength it has been suggested to use vinylon 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. The stress-strain characteristics between new bars and steel have been predicted and compared with experimental values.M.A.Aiello and L.Ombres, (2000) investigated the effect of temperature and moisture for mechanical properties of glass and aramid FRP rods.. The elastic modulus and tensile strength of FRP rebar exposed to cyclic actions were compared with those obtained for unexposed ones, to evaluate the mechanical damage caused by environmental conditions. It was concluded that the thermal actions cause a loss in strength that increase with the number of cycles and the degradation of mechanical properties under wetting-drying cycles is higher than thermal cycles.

Jong-pil won and changi park, (2006) studied the Mechanical and durability properties of CFRP , GFRP, and two types of hybrid FRP rebars which were exposed to twelve different environments. Two types of fibres used were multiple fibers embedded in an epoxy resin matrix and braided FRP rebar with different core materials. Tensile tests were carried in accordance with the ACI 440K standard. The hybrid FRP rebar had more residual tensile strength than the CFRP and GFRP rebar, because the hybrid FRP rebar failed due to fiber damage rather than resin degradation and cracks.Chensong Dong and Ian J Davies,(2012) studied the three combinations of the carbon and glass fibers.The three combinations were chosen to make hybrid composite specimens and made by the hand lay-up process in an intra-ply configuration with varying degrees of glass fibers added to the surface of a carbon laminate. These specimens were then tested in the three point bend configuration in accordance with ASTM D 790-07 at a span to depth ratio of 32. The flexural behaviour simulated using FEA, and the flexural modulus, flexural strength and strain to failure were calculated. The study concluded that the positive hybrid effects exist by substituting carbon fibres with glass fibres, and applying a thin layer of GFRP on the compressive surface yields the highest flexural strength.

From all these literature studies,a common technology observed is that the efficiency of reinforcement essentially depends on the adhesion between matrix and fiber, so this is an important factor in determining the mechanical properties or strength of the composite material. Several journals have been referred related to the mechanical properties of FRP rods as given above and accordingly, the present work depicts the influence of carbon-glass fiber reinforced epoxy polymer matrix on the mechanical properties. As per the ASTM standards, the tensile properties, compressive properties, hardness, impact strengths were studied.

## II. MATERIAL AND MANUFACTURING METHOD

Hybrid reinforcements used in this study are manufactured by Meena Fiberglass Industries Pondicherry, India. All the reinforcements supplied by these industries are manufactured by pultrusion process with the E-glass fibre volume approximately 60% and these fibres are reinforced with epoxy resins.

The glass fibers and carbon fibers are selected as reinforcements and epoxy as matrix material. The epoxy resin , hardener Tri Ethylene Tetra Amine (TETA) and Catalyst (Methyl ethyl Kethone Peroxide) are used.The glass fiber of bi-directional woven mat with 200 gm and the density of 2.5 gm/cc are used. The carbon fiber of bi-directional woven mat with 200 gm and the density of 1.78 gm/cc are used. The glass fiber and carbon fiber used in the fabrication of hybrid fiber reinforced composites are shown in figure 1.

**Fig.1:Raw Carbon and Glass fibres**

Pultrusion process is the pulling of material such as any type of fibres and resin, through a shaped die having a constant cross section. The raw resin is always a **thermosetting resin**, and is sometimes combined with fillers, catalysts, and pigments .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. The manufactured hybrid rods are subjected to tensile test, compression test, hardness test and impact test according to ASTM standards.

## III. EXPERIMENTAL PROGRAMME

The main purpose of this study is to investigate experimentally the mechanical and physical properties of hybrid reinforcement and its feasibility for use in concrete structures subjected to worst environments. This paper includes four important characters such as tensile properties, compressive properties, impact and Hardness properties of reinforcements used in concrete. 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 conducted and it was found that Hybrid and GFRP rods poses 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 Tensile Strength

As per ASTM D638 rods (GFRP, Hybrid and Steel rods) should be cut into pieces of 600 mm. The specimens were tested in universal testing machine (UTM). The tension test is generally performed on flat or round specimens. An uniaxial load is applied through the ends. The specimen was loaded between two manually adjustable grips of a 60 KN computerized Universal Testing Machine (UTM) with an electronic extensometer and the surrounding temperature is 35 °C. The specimen was placed in the testing machine between the grips perfectly and load was applied until it fractures. Due to the application of load, the elongation and maximum load of the specimen is recorded. Test was repeated thrice and the average value was taken to calculate the

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

tensile strength of the composites. Ultimate tensile strength is the force required to fracture a material. The tensile strength can be experimentally determined by the given equation (1).

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

The ultimate tensile strength can be determined by the stress strain graph. The unit used for tensile strength is $N/mm^2$. The Tensile test and the rupture of hybrid rods is shown in Fig.2.The tensile properties of reinforcements are shown in Table.1.The stress-strain relationship is shown in Fig.3.

**Fig.2:Tensile test and the rupture of hybrid rods**

**Table.1: Tensile properties of reinforcements**

| Type of Specimen | Dia (Mm) | Area $Mm^2$ | Yield Load (N) $10^4$ | Yield Stress ($N/Mm^2$) | Ultimate Load(N) $10^4$ | Ultimate Stress ($N/Mm^2$) | Breaking Load (N) $10^4$ | Breaking Stress ($N/Mm^2$) |
|---|---|---|---|---|---|---|---|---|
| G2 | 10 | 78.54 | 3.95 | 502.92 | 4.35 | 553.85 | 4.1 | 522.02 |
| H1 | 10 | 78.54 | 7.1 | 903.99 | 8.5 | 1082.25 | 8.2 | 1044.05 |
| S1 | 10 | 78.54 | 3.2 | 407.23 | 3.9 | 496.56 | 3.19 | 407.3 |

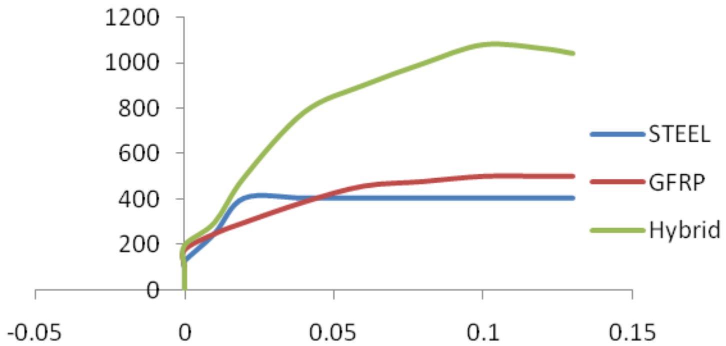


**Fig.3: Stress Vs Strain Graph for various types of reinforcement**

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. Unlike steel rods the hybrid and GFRP rods exhibit the rupture of rods along the longitudinal direction without yielding at the breaking stage.

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3.2 Compressive strength

Generally, the strength property of FRP bars resisting the compressive stress is not recommended. Any how to fully identify the characteristics of hybrid it is essential to carry out the compression test .The test was performed on all the rods according to ASTM D695 in UTM . The length of the specimen must be 5 or 10 cm. The specimen was placed Co-axially between the platens of the compression testing machine. The load was applied at the 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.4 shows the Experimental setup for compression and the failure of the specimen and Table.2 depicts the Compressive properties of various reinforcements.

**Fig.4:Experimental setup for compression and the failure of the specimen**

**Table.2: Compressive properties of various reinforcements**

| **Specimens** | **Diameter (mm)** | **Area ($mm^2$)** | **Compressive load (N) $10^3$** | **Compressive stress ($N/mm^2$)** |
|---|---|---|---|---|
| GFRP | 10 | 78.5 | 35 | 445.86 |
| Hybrid | 10 | 78.5 | 37.8 | 481.28 |
| Steel | 10 | 78.5 | 30 | 381.97 |

3.3Impact Test

Izod impact testing is a standard method (ASTM D256) of determining the impact resistance of materials. A pivoting arm is raised to a specific height (constant potential energy) and then released. The arm swings down hitting the sample, breaking the specimen as shown in Fig.5.. The energy absorbed by the sample is calculated from the height the arm swings to after hitting the sample. A notched sample is generally used to determine impact energy and sensitivity of the notch. Notched Izod Impact is a single point test that measures a materials resistance to impact from a swinging pendulum. Izod impact is defined as the kinetic energy needed to initiate fracture and continue the fracture until the specimen is broken. Izod specimens are notched to prevent deformation of the specimen upon impact. This test can be used as a quick and easy quality control check to determine if a material meets specific impact properties or to compare materials for general toughness. The depth under the notch of the specimen is 10.2 mm.The specimen is clamped into the pendulum impact test fixture with the notched side facing the striking edge of the pendulum. The pendulum is released and allowed to strike through the specimen.

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

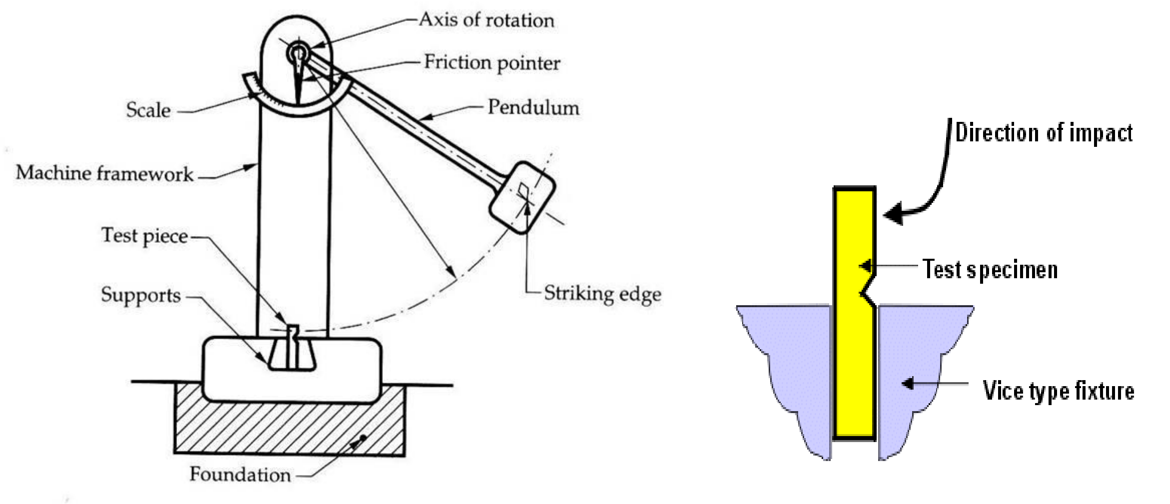


**Fig.5: Izod impact tester and the position of the specimen in the tester**

**Table.3: Izod impact test of rods**

| **Types of rods** | $\beta_1$ | $\beta_2$ | $\beta_3$ | **Total correction e** | $\beta_4$ | **Corrected angle of rise '$\beta$'** | **Energy absorbed in Nm** |
|---|---|---|---|---|---|---|---|
| GFRP | 54° | 54° | 53°5′ | 0°0′3.08" | 47°5′ | 47°7′25.02" | 59.85 |
| Hybrid | 54° | 54° | 53°5′ | 0°0′3.08" | 46°5′ | 46°7′21.94" | 64.06 |
| Steel | 54° | 54° | 53°5′ | 0°0′3.08" | 53° | 53°2′43.24" | 33.56 |

In the Izod impact test, the test specimen is a cantilever, clamped upright in an anvil, with a V notch at the level of the top of the clamp. The test piece is hit by a striker carried on a pendulum which is allowed to fall freely from a fixed height, to give a blow of 120 ft.lb energy. The correction factor was determined first since the angle of fall and rise will be distributed slightly by the friction and air. Initially the pointer on the graduation scale was set at 60° (extreme right position) and the pendulum is released in the normal manner this reading is indicated as $\beta_1$. Then the pendulum was allowed to swing once again, and this reading was indicated as $\beta_2$.After this the pendulum was set at its initial position and it was allowed for 10 swings (5 forward and 5 backward) from its rest position. When the pendulum began the 11$^{th}$ swing, the pointer is distributed through a small angle of about 1$^{o}$ against the motion of the pendulum this is the final reading and it was indicated by the pointer as $\beta_3$.From the known values of $\beta_1, \beta_2, \beta_3$ the correction factor $e_1$ and $e_2$ are calculated. The pendulum was then released from its rest position at an angle of60° and allowed to fracture the specimen. The reading indicated by the pointer was recorded as $\beta_a$. After fracturing the test specimen, the height to which the pendulum rises was recorded by a slave friction pointer mounted on the dial, from which the absorbed energy amount was calculated using the equation (2) and the results were compared and discussed in the following Table 3 From this test the greater impact strength are achieved by HYBRID rod than the steel and GFRP rods.

$$E = WR(\cos\beta - \cos\alpha) \quad (2)$$

Where, W – Weight of striking hammer = 272.15N; R– Distance of centre of gravity of the pendulum from the point of suspension = 1.219m; $\beta$ - Angle of rise in degrees; $\alpha$ - Angle of fall in degrees= 60°; and the Correction

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

factors are Frictional correction, $e_1 = \frac{(\beta_2 - \beta_1)}{\beta_2}$; Air drag correction, $e_2 = \frac{(\beta_2 - \beta_3)}{10(\beta_2 + \beta_3)}$; Total correction, $e = e_1 + e_2$; Corrected angle of rise, $\beta = \beta_4(1+e)$.The test result is typically the average of 5 specimens.

The energy absorbed by the specimen gives the impact resistance of the rods. Higher the resulting values of energy absorbed , tougher the material.

3.4 Hardness Test

According to ASTM E-18 the hardness of the reinforcements were measured. The Rockwell Hardness test is a hardness measurement based on the net increase in depth of impression as load is applied. Hardness numbers have no units and are commonly given in the scales. Higher the number in each of the scales implies harder the material. Hardness is generally defined as resistance to local penetration, scratching, machining, wear or abrasion, and yielding. The indenter may either be a steel ball of some specified diameter or a spherical diamond-tipped cone of 120° angle and 0.2 mm tip radius, called Brale. The type of indenter and the test load determine the hardness scale.


**Fig.6: Rockwell Hardness tester**

The Rockwell hardness tester is shown in Fig.6. A minor load of 10 kg was first applied, which causes an initial penetration and holds the indenter in place. Then, the dial was set to zero and the major load 100 kg was applied. Upon removal of the major load, the depth reading was taken while the minor load was still on. The Rockwell Hardness Number (RHN) was then read directly from the scale.

**Table.4: Hardness properties of various reinforcements**

| **Types of reinforcements** | **Minor load(N)** | **Major load(N)** | **RHN** |
|---|---|---|---|
| GFRP | 100 | 1000 | C35 |
| Hybrid | 100 | 1000 | C62 |
| Steel | 100 | 1000 | C48 |

The hardness was measured at three different locations on the specimens and the average value was taken as the hardness number of that specimen.

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

## IV. DISCUSSION OF RESULTS

The experimental results were discussed and presented to anticipate the performance of the hybrid rods in comparison with GFRP and steel rods. The stress strain curve shows that the hybrid and GFRP rods behave bilinerly. All the FRP and Hybrid rods clearly exhibited a point at which the steel rebar started yielding. The young's modulus obtained from the stress strain curve for the steel, GFRP and HYBRID FRP reinforcements are $2.08\times 10^5$, $6.47\times 10^3$ and $1.83\times 10^4$ MPa respectively. Regarding the tensile strength, the ultimate tensile

strength of hybrid is found to be 49% greater than GFRP and 54% greater than steel reinforcements.

From the compression test results, the mode of failure for GFRP and hybrid rebars subjected to longitudinal compression reflect the transverse tensile failure, fibre micro buckling, or shear failure. The mode of failure depends 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. Impact resistance of the rods depends upon the yield strength and ductility, notches, temperature and strain rate and fracture mechanism. The impact energy is decreasing for the rebar which is having more yielding capability.

Regarding the impact strength conducted in the laboratory it has been noted that the HYBRID has 6.7% and 47.6% greater toughness than that of GFRP rebars and steel rebars respectively. The notch serves as a stress concentration zone and materials are more sensitive towards notches. The notch depth and tip radius are therefore very important. Greater toughness of the material shows a good binding between the matrix and the fibre orientation. Similarly, the hardness number of hybrid rebar is 43.5% higher than GFRP and 22.6% higher than steel rebars confirming the tough binding of hybrid fibre with the surrounding matrix.

## V. CONCLUSION

The present study peeps through the excellent mechanical properties of hybrid rods over the GFRP and conventional rods. The carbon - glass fibre reinforced hybrid composites have been fabricated by putrusion method. Experimental evaluation of mechanical properties like tensile, compressive, impact and hardness strength of hybrid composites as per ASTM standards has been successfully carried out. 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 rebars is higher than GFRP composite rebars. Similarly from the Izod test it has been evaluated that HYBRID rod has 6.7% greater toughness than that of GFRP rebars and 47.6% than that of steel rebars. Through Rockwell hardness test it has been observed that Hybrid rebar is 43.5% harder than GFRP and 22.6% harder than steel rebars confirming the tough binding of hybrid fibre with the surrounding matrix. The present investigation can be extended in the future for different mix proportions of two different FRP materials using different manufacturing technique

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

## VI. ACKNOWLEDGMENTS

The authors wish to express their gratitude and sincere thanks to the Meena Fiberglass Industries Pondicherry, India for manufacturing and testing the Hybrid and GFRP Reinforcements used in the present study.

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