Nano Fillers Incorporated FRP Rebars For The Marine Constructions

[1]Rahul A.R, [2]Arundev K.Y, [3]Hemalatha G, [4]Mandal A.B, [5]Suguna Lakshmi M

[1,2,3]School of Civil Engineering, Karunya University, Coimbatore-641114, India
[4,5*] Industrial Chemistry Lab, Central Leather Research Institute, Chennai-600020, India
Email: msugunalakshmi.clri@gmail.com

Abstract - A novel combinations of resin such as vinylester, montmorrilonite nanoclay, metakaolin and plaster of paris have been blended and fabricate FRP rebars using glass fibres as reinforcing fibres. The unique combination was achieved though several trials of compositions prepared and investigated. Thus five different combination of resin matrix alone was characterised for their physical and chemical properties prior to the fabrication of rebars. The best of three combination of resin blends considered for using them to make FRP rebars. All the three rebars having 12mm dia prepared was tested for their tensile properties and found to be excellent in their characteristics.

Index Terms – FRP Rebar, Glass fibre, Nanoclay, Vinyl ester.

I. INTRODUCTION

Steel rebars are used to improve tensile strength of the concrete for the constructions. Steel reinforced concrete posses excellent mechanical properties but lacks in chemical corrosion resistance. When the steel rebars starts corroding, the shape of the steel rebars is destabilised and results in detrimental failure of the concrete and thus collapsed structures in the sea pollutes the sea water. To mitigate the corrosion problem caused by steel reinforcement, a study was initiated to develop a nonferrous hybrid reinforcement system for concrete beams by incorporating continuous fiber-reinforced polymer (FRP) rebar and fiber-reinforced-concrete (FRC) containing randomly distributed polypropylene fibers.

The addition of fibers has been proved to be an effective way to enhance the corrosion resistance of FRP reinforced system. Research studies on the influence of fibers on flexural behavior and ductility of concrete beams reinforced with GFRP bars showed reasonable strength properties in the concretes[1]. The short-term flexural behaviour by varying the reinforcement ratio and the effective depth-to-height ratio has reasonably performed onto service load. However, seems to have some limitations at the ultimate limit state and their load bearing capacity[2]. Many investigations were done on using experimental programme on the cracking and deflections of 14 Glass-FRP RC beams. The influence of the most relevant parameters and the suitability of different prediction models, as well as the adjustment of empirical coefficients were analysed[3]. The flexural and tensile response of FRP RC elements is investigated and concluded that the contribution of shear and bond induced deformations can be of major significance in FRP RC elements having moderate to high reinforcement ratios[4].

However in the case of FRP bars, they exhibit low ductility when compared with steel reinforced structures. A great deal of effort has been made to improve and define the ductility of beams reinforced with FRP rebars. The ductility indices increased by more than 30% with the addition of polypropylene fibers along with the glass fibres during the fabrication of FRP rebars[5]. The ductility index increased by as much as 100% Due to the addition of 1% steel fibers was reported[6,7] .Herein the objective of this work is to prepare FRP rebars that would exhibit high tensile strength and other properties required in the marine environment conditions.

II. EXPERIMENTAL PROCEDURE

A. Materials Required

DGEBA epoxy-LY556, Vinyl ester-9911, Promoter-77712, Accelerator(Cobalt napthenate), Catalysts (Methyl ethyl ketone peroxide-MEKP), Glass fibre rowings of Huntsman company Ltd was supplied by Emak glass fibre & accessories Ltd., Montmorrillonite clay was purchased from Aldrich chemical company. Plaster of Paris (POP) and Metakaolin was purchased from local market, Chennai.

Scanning Electron Microscopic (SEM) analysis was done using Hitachi S-4500, SEM machine. Thermogravimetric analysis was carried out using TGA–Jupiter, STA 449 F3 model.

1. Preparations Unreinforced Resin Sheet

The five types of resin compositions (Table 1) was blended with the 2 wt parts of the curatives such as Promoter, Accelerator and Catalyst and blended at room temperature and casted as sheet. The sheets become hard within 35 minutes and were taken for water absorption, thermal, chemical resistance evaluations. Among the five blends the best three resin blends that have exhibited superior properties were considered for rebar preparations.

2. Preparations of Fibre reinforced plastic(FRP) Rebars

A 55Wt % of glass fibre and 45 wt% resin with the curatives were used to fabricate the rebars. The rebar extrusion was done by hand rowing method. The rebars thus made with the Fibre/Resin blend become hard within 35 minutes. Further they were hot air dried for 15 minutes to postcure the rebars. Thus three types of rebars having 12mm dia were prepared. The rebars given code of SHAR-G#1, 2 and 3 and were tested for their thermal, SEM and tensile strength properties.

Table I Compositions blends prepared from vinyl ester resins.

Code	Vinyl Ester/ DGEBA	Nanoclay (MMT)	POP	Metakaolin
SHAR-G#1	100/0	5	5	5
SHAR-G#2	100/0	5	5	-
SHAR-G#3	100/0	5	-	-
SHAR-G#4	100/0	-	-	-
SHAR-G#5	0/100	5	-	-

3. Chemical Resistance Study

The GFRP bars were placed in an alkaline solution under the accelerated laboratory exposure conditions. Alkaline solution (pH = 13.5) was prepared by mixing [0.6 N KOH , 0.2 N NaOH and Saturated Ca(OH)2] with a constant pH of 13.5. This exposure represents the concrete environment. Similarly Alkaline + Chloride solution (pH = 13.4)was prepared from 3% NaCl solution. This exposure represents the aggressive environmental condition where all the offshore and marine structures encounter. Acidic solution (pH = 3.1) was prepared from 0.6% Acetic Acid with a constant pH of 3.1to expose the Glass fiber reinforced plastic (GFRP) bars to an acidic solution Seawater Exposure represents the aggressive condition where all the Off shore and marine structures encounter. The prepared specimens were subjected to continuous immersion in seawater, distilled water exposure was done by immersing GFRP bars with deionized water of pH 7.

In this experiment the GFRP bars have been investigated as stand-alone in different chemical exposure conditions that resemble the actual service environment. The exposure conditions include alkaline solution, seawater solution, acidic solution, thermal variations. This investigation is on the durability study of the GFRP bars when exposed to harsh environments. The stand-alone GFRP bars were exposed to the conditions representative of the actual aggressive service environments in which specimens were removed periodically every one month, checked the appearance of the rebars and placed back to continue the experiments upto three months. The various solutions were maintained at room temperature (RT) and 60 ± 2°C. The high temperature was used to accelerate the impact on the performance properties of GFRP bars.

4. Water Absorption Study

Prior to the immersion in the various solutions, the initial mass of the GFRP bars observed by drying in oven at 60 ± 2°C for 24 hours, after which the change in mass was determined. The bars were immersed in water to observe maximum moisture absorption capacity or moisture resistance capacity of the developed GFRP. The immersed rebars were periodically checked the weight gain and the changes in the mass were regularly recorded drying at 60 ± 2°C for 24 hours and placing them back to waters.

Figure 1: GFRP samples in different stimulated conductions

5. Testing Setup

The GFRP rebars where tested in SERC (Fatigue and fracture) Chennai lab. The dimension of the specimen for testing was 700mm in length and 10 mm in diameter. Three types of GFRP with different combination where tested. The specimens where caped with 200mm long GI pipe as shown in the figure 2 in order to avoid slipping failure, The specimens where fixed with two strain gauges on opposite sides at the middle portion. The specimens where placed in jaws of the testing machine and air pressure was applied in order to hold the GFRP rebars in the position as shown in the figure 2. The machine was operated and the readings from the strain gauge were recorded in the computer. The load was applied until the failure has taken place.

Figure 2: GFRP rebar capping; GFRP rebar with strain gauge; Testing machine

III. RESULTS TESTING OF PHYSICAL, CHEMICAL AND MECHANICAL PROPERTIES REBARS

1) Density and chemical resistance properties

From our experiment the density of newly produced GFRP rebars varies between 1.55 to 1.60 g/cm^3. The newly produced GFRP are compared with the density of steel rebars and the density is found to be $\frac{1}{5}^{th}$, of the steel rebar (7.90 g/cm$^{3)}$. This is in agreement with the ACI 440.1R-9 the density of the GFRP rebars showed the density between 1.25 to 2.10 g/cm$^{3.}$ Hence it is very clear that the GFRP rebars are lighter in weight than the normal steel rebars which indirectly reduce the cost of transportation and increases the work ability.

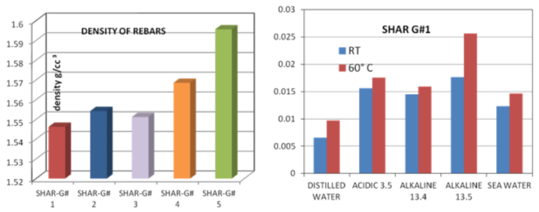

Figure 3: Density and Chemical Resistance Property of the Rebars

In this experiment the GFRP bars have been investigated as stand-alone in different chemical exposure conditions that resemble the actual service environment. The exposure conditions include alkaline solution, seawater solution, acidic solution, thermal variations. This investigation is on the durability study of the GFRP bars when exposed to harsh environments. The stand-alone GFRP bars were exposed to the conditions representative of the actual aggressive service environments in which specimens were removed periodically every one month, checked the appearance of the rebars and placed back to continue the experiments upto three months. The various solutions were maintained at room temperature (RT) and 60 ± 2°C. The high temperature was used to accelerate the impact on the performance properties of GFRP bars

From the chemical analysis, it was observed that there is negligible weight loss in the sample under stimulated conditions. The room temperature conditioned samples have exhibited less weight when compared to the oven conditioned (60 ± 2°C) samples. In the case of alkaline solution conditioned samples (pH = 13.5) the weight loss is higher than all the other conditioned samples. The sample conditioned in distilled water does not show any weight loss. From these observations we can conclude that the GFRP are in all climatic highly stable in all the conditions.

The studies from different types of GFRP rebars, we can conclude that the rebar namely, SHAR-G#1, SHAR-G#2, SHAR-G#3, SHAR-G#4 shows low absorption in distilled water, sea water and in acidic conditions. Whereas in alkaline pH13.5 was observed both at low and high temperature conditions.

2) Thermal studies

The analysis of the change in the mass of a sample on heating is known as thermogravimetric analysis (TGA).TG measures mass changes in a material as a function of temperature (or time) under a controlled atmosphere. Its principal uses include measurement of a material's thermal stability and composition.TG is most useful for dehydration, decomposition, desorption, and oxidation processes. All the rebars found to have thermal stability upto300°Cbeyond that temperature decomposition of resins occurred. The glass fibre content in the rebar was confirmed from the residual weight after the thermal decomposition at 1200°C.

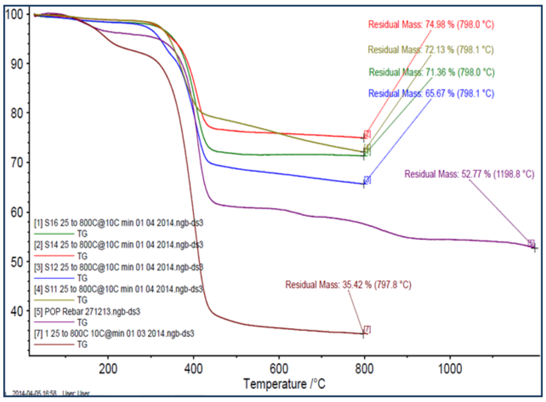

Figure 4: Thermogravimetric Analytical Curves Exhibits the Thermal Stability of the Rebars.

3) Flame retardant properties

The flame retardant property was found out from the limiting oxygen index (LOI) value, using the empirical formula by Krevelen .A numerical index the LOI was representing the minimum concentration of oxygen required to just support burning of a polymer in the mixture. The higher LOI values represent better flame retardancy.,

LOI = 17.5 + 0.4CR; LOI = oxygen index ; CR = char residue in weight

From the value of LOI < 20.95,LOI < 28,LOI < 100,where considered to be flammable, slow burning, and intrinsically non-flammable materials.

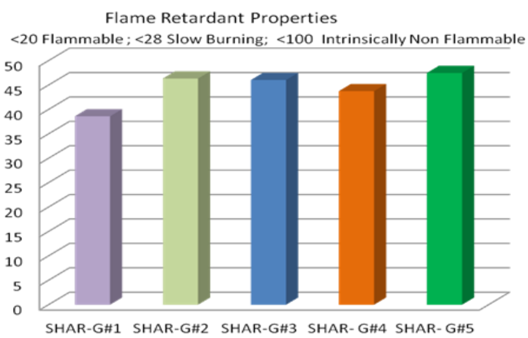

Figure 5: Flame Retardance of Vinyl Ester Resin Blends

From the results obtained from thermal studies of GFRP rebar the flame retardant property is soupier. The LOI values give a clear idea about the material how it reacts with the different stage of temperature varying from 0ºC- 1000ºC . GFRP rebars have an LOI value of more than 28 and less than 100 which shows that it is intrinsically nonflammable.

4) Typographical studies (scanning electron microscope)

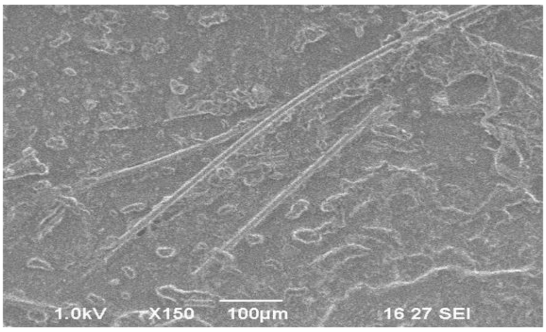

Figure 6: Topographical analysis of Vinyl ester resin blends

SEM micrographs have a large depth of field yielding a characteristic three-dimensional appearance useful for understanding the surface structure of a sample.

5) GFRP rebar test

In this SEM analysis the general topography of the GFRP samples where studied and from the analysis we can articulate that all the glass fibers where well linearly arranged,the matrix have very well despersed with the glass fibers. The absence of holes or cavities or entrapped air baubles observed in the matrix material.

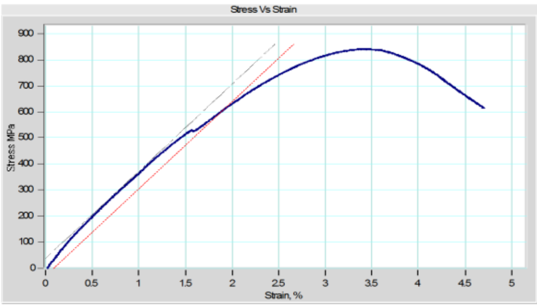

Figure 7(i): Stress Vs Strain curves of Rebar(SHAR # G 1)

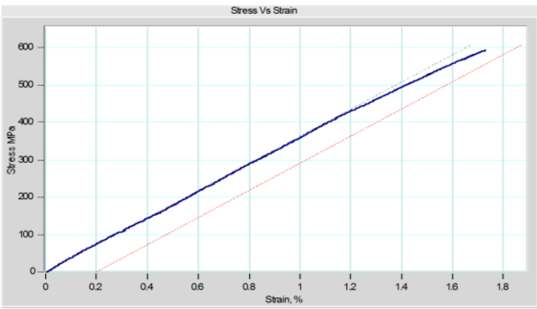

Figure 7(ii): Stress Vs Strain curves of Rebar(SHAR # G 2)

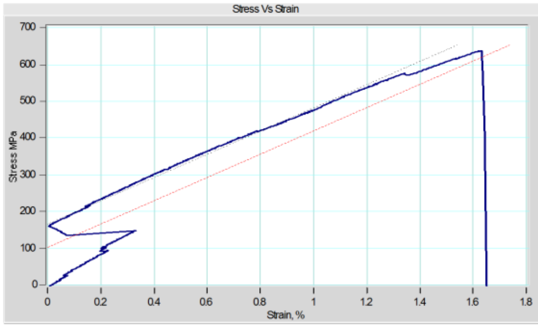

Figure 7(iii): Stress Vs Strain curves of Rebar(SHAR # G 3)

The result obtain from graph SHAR –G# 1 shows high tensile strength when compared with the commercial GFRP rebar available in the market whose tensile strength is from 600-830 Mpa. But the SHAR –G #1 has exhibited 850.955Mpa. It is challenging to the any GFRP rebar available in market. The stress and strain obtained from the strain gauge have shown 26000 µm. This properties obtained was due to the unique combination of binder mixtures present in the vinyl ester resin. The nanoclay, metakaolin and POP have contributed its cohesive binding interation with the glass fibre that was resulted in excellent tensile strength properties.

Table 2: Stress Vs Strain curves properties of Rebar(SHAR # G 1,2 & 3)

Rebar Code	Peak Stress, MPa	Peak Load, kN
SHAR # G 1	845.317	66.4
SHAR# G2	595.198	46.753
SHAR-G# 3	639.474	50.231

IV. CONCLUSIONS

GFRP-rebars have been designed and fabricated using vinyl ester formulated polymers by handmade process. Several GFRP is having diameter of 8mm, 10mm, 12mm, 16mm and length of 700mm. The samples were immersed in sea water, distilled water, Acidic conditions at P^H2.4, alkaline conditions at P^H13.5 and PH13.2. The tested samples were characterised and found to exhibit excellent corrosion resistance properties and tensile strength properties when compared to the conventional steel rebars or commercial FRP rebars used in the concrete.

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