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Fabrication and Testing of a Wood-Framed FRP Structural Panel

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Abstract: This paper presents an experimental program performed on a structural panel fabricated from glass fiber reinforced polymer (GFRP) and a wooden frame. The tested panel consists of a timber frame with the dimensions of 1200 x 600 x 25 mm covered by GFRP layers which were manufactured by a hand-layup process. Tensile and flexure tests were conducted for the GFRP specimens and for GFRP-covered wood sections to evaluate the material properties. The results showed brittle failure under average maximum load of 9.28 kN, average maximum elongation of 7.7 mm and the modulus of elasticity for the GFRP was about 2400 MPa. The obtained bending stress for GFRP-covered wood sections ranged between 90-115 MPa. Additionally, full-scale panels were tested under distributed loads until failure to study their flexural behavior. The experimental results demonstrated good mechanical and physical properties for the presented GFRP-wood panels, which renders the use of such composite GFRP-wood panel promising in prefabricated structures.

Keywords: Structural panel; composite material; glass fiber-reinforced polymer; tensile test; flexural test.

1. INTRODUCTION

Fiber Reinforced Polymers (FRP) have been used in aerospace, automotive and marine industries since the 1930s [1, 2] and have recently been used in buildings and construction applications as well [3, 4]. The construction field uses 26% of the global production of FRPs [4–6]. Light weight, fatigue resistance, stiffness, high strength-to-weight ratio, corrosion resistance, lower maintenance cost over their lifetime and flexibility in design compared to traditional construction materials are the key advantages of FRPs [1,7]. Glass FRP (GFRP) are considered the least expensive composite amongst FRP materials and is therefore most often used; the global marketplace for GFRP was valued over 9.7 billion USD in 2021 and is expected to grow rapidly in the next decade [8]. Also, FRP composites are regarded as eco-friendly construction materials; with an ecological effect of approximately one-third that of conventional materials, GFRP can lead to lower carbon emission [9, 10].

FRP materials are especially advantageous when it comes to lightweight building structures [11, 12]. Das et al. [13] tested coupons of different types of GFRP with different fiber orientation manufactured by the hand layup process. The tensile tests results revealed that the tensile strength was 98.9 MPa, 40.9 MPa and 50.9 MPa for 0º, 45º and 30º orientations, respectively, and concluded that the strength of GFRP composite is suitable for the skin of the sandwich structure. Three prototype GFRP panels with dimensions of 3000 x 1000 x 300 mm were manufactured using the hand lay-up process by Alagusundaramoorthy and Reddy [14] and were subjected to a rectangular patch load representing AASHTO HS20/IRC Class A wheeled vehicle applied at the center of each panel. The load/deflection behavior of the decks was also evaluated through numerical modeling by finite elements and the results conformed to the experimental data and the specified performance criteria. The GFRP skin was tested by Adbolpour et al. [15] to be used as panels for emergency houses; the results showed elastic behavior until brittle failure, elastic modulus (E) of 28.10 GPA and ultimate tensile strength of 327.10 MPa. A composite sandwich panel was fabricated and tested and achieved modulus of elasticity of 9.6 GPA and ultimate tensile strength of 117 MPa. Mousa and Uddin [16] constructed and tested a composite panel made of glass/polypropylene laminate as face sheet and expanded polystyrene foam as a core; failure occurred due to facesheet/core debonding. Compared to traditional wood panels. The results showed that the proposed panels are cost effective, 80% lighter and provide higher safety than the traditional wood panels, and thus have the potential to be used as structural wall-, floor-, and roof elements [16]. Nadir et al. [17] compared the load-deflection behavior, stiffness, ductility, ultimate flexural capacity and failure mechanisms of laminated wood beams that have been reinforced with manually applied GFRP and CFRP composite sheets on the lower surface against those which were left unfortified. Applying a single layer of GFRP onto the timber beam's soffit increased the flexural rigidity, modulus of rupture and ductility by 26.29%, 36.91% and 44.37%, respectively [17]. Sharda et al. [18] tested a full-scale modular wall system made of GFRP rectangular hollow section frames and GFRP sheathing under in-plane shear load and reported that inserting steel angle brackets improved the loading capacity and stiffness of the wall panel.

The present research aims at introducing a structural panel suitable for use in erection of lightweight structures. An experimental program was conducted where innovative hybrid GFRP-timber structural panels composed of a timber frame covered by GFRP skin were fabricated using the lay-up technique and were tested in flexure. Additionally, tests were conducted to evaluate the materials mechanical properties. The experimental procedures are explained and the results analyzed in the following sections.

2. EXPERIMENTAL PROGRAM

The experimental program consists of fabrication and testing of hybrid GFRP-timber structural panels composed of a timber frame covered by a GFRP skin, as well as material tests made for the materials used. The fabrication process was conducted in the factory of ‘Polyin for Fiberglass’ factory at Giza, material tests were carried out in the laboratory of National Research Center (NRC) and the laboratory of the Faculty of Engineering, Misr University of Science and Technology (MUST). The bending tests were carried out at the Materials and Concrete Laboratory at the Faculty of Engineering at Shoubra, Benha University.

2.1 Materials

For the preparation of the GFRP coupons and panels, E-glass fibers was used as reinforcing fibers in a polyester resin matrix, having the properties indicated in Table 1. The hardener peroxide, polyester resin Siropol 8341[19], glass fiber mat 300 [20] and wood are shown in Fig. 1. Pinewood was used as frame for the panels with cross-section dimensions of 25x25 mm and having the properties given in Table 2 [21].

TABLE 1. Mechanical properties of the GFRP components and GFRP layer

Material	Tensile modulus (MPa)	Tensile strength (MPa)
Glass-fiber - mat300 - (300 g/m^2)	76,000	2940
Orthophthalic polyester resin	4,000	55
Glass – orthophthalic polyester composite [18]	26,000	-

(a) Peroxide hardener (b) Polyester resin c) Glass fiber mat (d) Pine wood

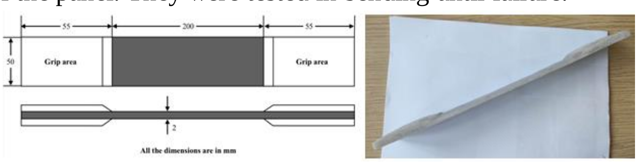
Fig 1. Materials used for GFRP panel fabrication

TABLE 2. Mechanical properties of timber

Property	**Value**
Density (kg/m^3)	500
Compressive strength (MPa)	50
Tensile modulus (MPa)	10,000
Shear modulus (MPa)	4,000
Shear strength interlaminar (MPa)	14
Moisture content (%)	10

2.2 Preparation of specimens for material tests

Tensile tests were performed for samples of GFRP skin. Three coupons of the GFRP skins with randomly orientated glass fibers were prepared with dimensions of 500 x 50 x 2 mm as shown in Fig. 2. The coupons were tested at the National Research Center materials laboratory in a universal testing machine with a grip distance of 50 mm according to ASTM D3039 [22]. The tensile load was applied and increased monotonically with a head displacement rate of 4mm/min until failure. Additionally, nine specimens of timber-fiberglass were prepared with the dimensions indicated in Figs. 3 and 4 to represent the different sections of the panel. They were tested in bending until failure.



(a) Dimensions in mm (b) Sample ready for tension test

Fig 2. GFRP specimen for tensile test

(a) Type A (b) Type B (c) Type C

Fig 3. Composite timber-GFRP specimens ready for flexural test

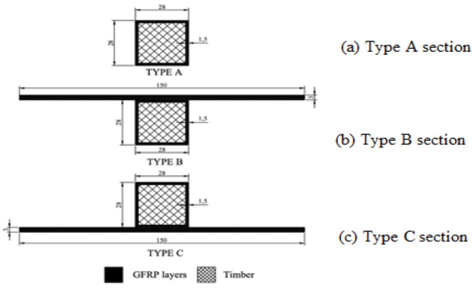


Fig 4. Composite timber-GFRP cross-sections and dimensions in mm

2.4 Fabrication of GFRP structural panel

Three panels with dimensions of 600 mm x 1200 mm were prefabricated at 'Polyin for Fiberglass' factory for the flexural test. Each panel is composed of a skin of two layers of GFRP skin applied by hand lay-up process over a frame made of timber; the finished panel is shown in Fig. 5. While the function of the skin is to support bearing and bending loads, the timber frame is responsible for shear loads and stability of the skin against buckling and wrinkling; it is also used for connecting the panels. The timber frame was completely covered from all sides with GFRP, so it has high resistance against water and is weatherproof. The main sections of the panel, which are made of GFRP skin with timber support are shown in more detail as Type A, B and C in Fig. 4.

Fig 5. Timber-GFRP panel after fabrication and painting

2.4.1 Fabrication of wooden frame

A timber frame was prepared at the workshop using 25 x 25 mm cross-section wooden members, cut to 1200 mm and 600 mm length, and then attached with glue and screws. Wooden pieces in triangle shapes were cut and attached in each corner of the frame to ensure good fixation. The wooden frame fabrication and the covering process by GFRP layers are shown in Figs. 6 and 7, respectively.

Fig 6. Fabrication of wooden frame

Fig 7. Covering the wooden frame by fiberglass from all directions

2.4.2 Fabrication of hybrid GFRP-wood panel

Three panels with dimensions 1200 x 600 x 3 mm were fabricated by hand lay-up process in 'Polyin for Fiberglass' factory as follows. The fiberglass mat was cut into two pieces of 0.6 m^2 each as shown in Fig. 8. Having prepared all the necessary materials, the polyester and peroxide hardener were mixed. According to suppliers' instructions the hardener is usually from 0.5 to 2%, the exact amount of resin is estimated based on the weight of the fiber cloth; the weight is also estimated by assuming 50% polyester and 50% fiber by volume. The fiber reinforcement layer is laid in the mold, wetted with resin and gently pressed with a brush or roller. A second layer of glass fiber is added and the air bubbles removed using a roll or brush. The process was repeated until the desired thickness is reached. The wooden support is placed after the first layer of fiberglass had been applied along with 2 minutes of pressure before the second layer is applied to ensure the wood is fully covered as shown in Fig. 9.

Fig 8. Cutting the fiberglass two layers to fit the mold

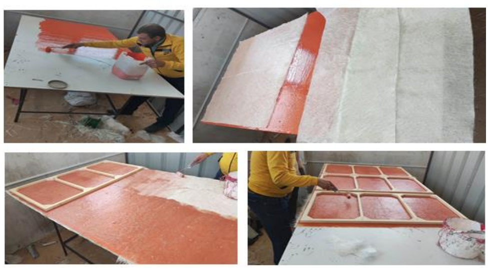


Fig 9. Fabrication of the GFRP wood panel by hand layup procedure

2.5 Tests procedures for material properties determination

The GFRP samples were tested in a universal testing machine in the materials laboratory of the National Research Center, shown in Fig. 10. The tension load was gradually increased until failure.

2.6 Bending test for composite GFRP-wood specimens

Specimens were prepared for the connection of the timber frame and GFRP, three samples from each group, as previously shown in Figs. 3 and 4. The three groups of specimens of each type were tested by applying vertical loads at two points while supporting the samples with two supports as simply supported beams. The load was applied as displacement-controlled at a rate of 0.01 mm/s until failure, as shown in Fig. 11.

Fig 10. Tension test for GFRP specimens

(a) Type A specimen (b) Type B specimen (c) Type C specimen

Fig 11. Bending test setup for composite GFRP-wood composite

2.7 Test setup and test procedure for panels

Three samples were been prepared to be tested in flexure on both sides (flange on top once and web on top once). The panel was tested in flexure until failure to study its flexural behavior, plot the moment-displacement curve and examine the failure mode. The panel was fixed from both sides using steel angles 50x50x4 mm; vertical and horizontal lines were drawn 200 mm apart to place loads simulating uniformly distributed loads, as shown in Fig. 12. The panel was tested by adding uniform loads gradually with 7 N/m^2 intervals until failure. A dial gauge was fixed at the panel mid-span to measure the corresponding displacement.

Fig 12. Test setup and bending test for panel

3. EXPERIMENTAL RESULTS

3.1 Results of material tests

The results of the tensile tests made for three GFRP laminate samples are given in Table 3. The variation in ultimate load may be explained by the variation of the amount of polyester resin during the preparation of the GFRP laminate by the hand-layup process, where it is quite difficult to reach the perfect polyester/fiberglass ratio; this variation of properties is regarded as the main disadvantage of this manufacturing method. The average values for the three samples failure load is 9.28 kN and average maximum elongation prior to failure is 7.7 mm. The stress-strain relations recorded during tension testing of the three specimens are plotted in Fig. 13. All the specimens exhibited similar failure modes, shown in Fig. 14.

TABLE 3. Results of tension tests of GFRP specimens

Specimen	Failure load (kN)	Maximum elongation (mm)	Max. stress (N/mm^2)	Max. strain
Sample 1	8.2	8	92	0.042
Sample 2	10.45	7.7	104	0.038
Sample 3	9.2	7.4	118	0.044

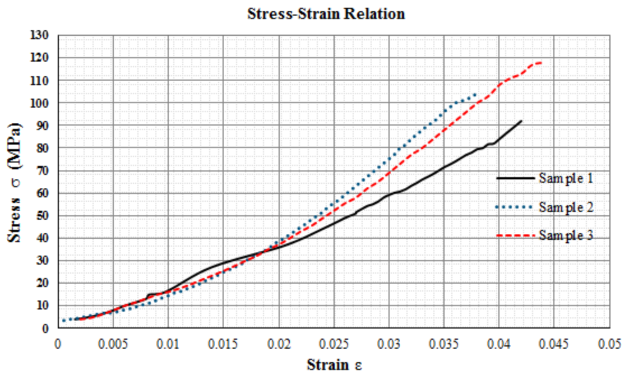


Fig 13. Stress-strain relations for GFRP laminates in tension

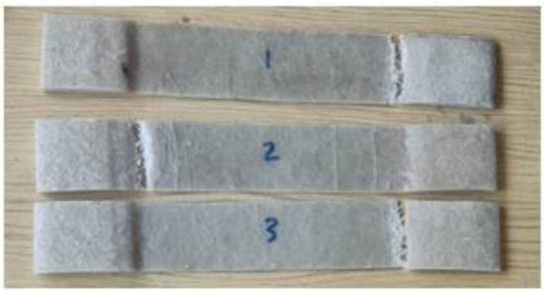


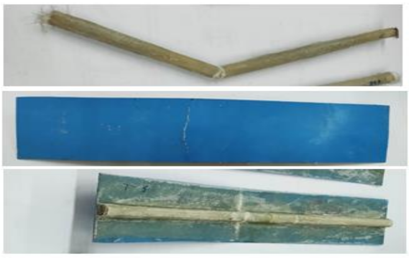
Fig 14. Failure of GFRP laminates in tension

3.2 Results of bending tests of composite GFRP-wood specimens

The results of testing of GFRP-timber specimens in bending are given in Table 4. According to observations, the T-section specimens (types B and C) exhibit greater moment carrying capacity compared to box section specimens (type A). The mean stress of T section sample is 90.4 MPa when tested as flange on top, and is 100.5 MPa when tested as web on top, while for the box section, the maximum mean stress is 113.4 MPa. It was noticed that failure of the specimens occurred by fretting the GFRP layers and timber together around the mid-span, as shown in Fig. 15.

TABLE 4. Results of flexural test of timber-GFRP composite specimens

Specimen	Description	Failure moment (Nm)					Average failure stress (MPa)
		Sample 1	Sample 2	Sample 3	Average	COV	
TYPE A	Box section	30	35.1	36	33.7	0.078	113.4
TYPE B	T-section	60.75	61.2	61	61	0.003	90.4
TYPE C	Inverted T-section	66.2	64.8	73	68	0.053	100.5



(a) Type A

(b) Type B

(c) Type C

Fig 15. Failure shapes of the three types of timber-GFRP composite specimens

TABLE 5. Results of flexural test of timber-GFRP panels

Panel type	Panel	First crack moment (Nm)	Failure moment (Nm)		COV	Maximum deflection (mm)		COV
Flange on top	Panel B-01	123	132	130.67	0.0095	5.45	5.52	0.0238
	Panel B-02	115	129			5.7		
	Panel B-03	118	131			5.4		
Web on top	Panel T-01	227	276.6	276.2	0.0031	8.4	8.4	0.0291
	Panel T-02	248	275			8.7		
	Panel T-03	243	277			8.1		

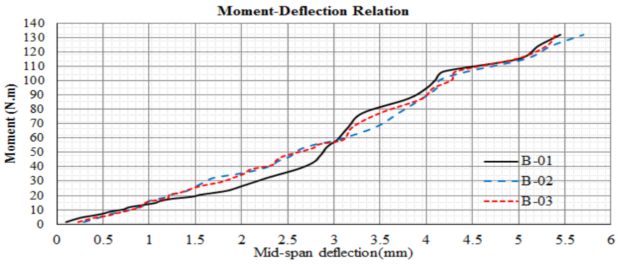


Fig 16. Moment-displacement relations for panels with flange on top

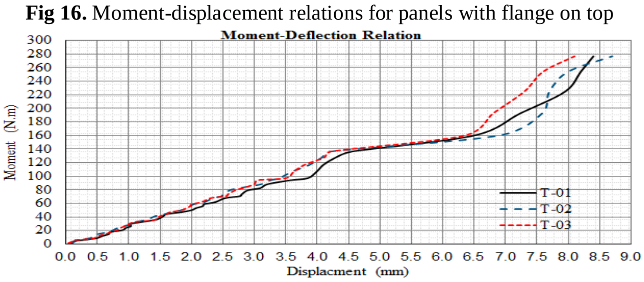


Fig 17. Moment displacement relations for panels with web on top

(a) Panel with flange on top (b) Panel with web on top

Fig 18. Failure shapes for panels in flexure

3.3 Results of bending test of GFRP panels

Flexural testing of the panels was conducted by gradually adding uniformly distributed load from 7 N/m^2 to 1280 N/m^2 on the flange side of three panels (B-01, B-02 and B-03) , as was shown in Fig. 12, while three other panels (T-01, T-02 and T-03) were tested with the webs on top. The results are provided in Table 5, and the measured moment-deflection relationships throughout the tests are plotted in Figs. 16 and 17 for the panels tested with flange on top and webs on top, respectively. The end of each loading operation is recognized by the sudden change in the curves. The failure mode was sudden failure at average load of about 600 N/m^2 and moment at mid span of 131 Nm for samples with flange on top; while average maximum failure load and moment at mid span for panels with web on top were 1280 N/m^2 and 276 Nm, respectively. The failure occurred at mid span as shown in Fig. 18.

4. CONCLUSION

In this research, a new type of structural panel was designed and fabricated to be suitable for lightweight prefabricated construction. The panels are composed of GRRP sheets placed by hand-layup process over a timber frame for support and assembly. The characteristics of the materials were determined through laboratory testing; the panel was subjected to out-of-plane bending to investigate its flexural behavior.

The main conclusions deduced from the production and experimental results can be outlined as follows.

- Fabrication of the panel was made using materials commercially available in the market and a simple hand lay-up procedure, which renders the production and application of this panel simple and economic.
- The tensile strength for the GFRP specimens ranged from 90-110 MPa and maximum strain was 3.5-4.5 %.
- It is observed from the strength that the GFRP is suitable as skin applied on a timber frame for application in prefabricated structures.
- No separation or de-bonding occurred between the wood and fiberglass.

- The presented timber-GFRP panels can be regarded as potential for erection of fast assembled and de-assembled houses.
- Further studies can investigate experimentally panels made of other FRP materials, other types of timber, alternative manufacturing techniques and also other configurations for panels.

Further research may explore the potential environmental benefits of using composite timber-GFRP panels in the construction of lightweight structures.

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