Carbon Fibre Reinforced Gypsum Buildings

S.Bharathidasan[1] and T.K.Krushnadesikan[2]

[1,2]Department of Civil Engineering,
Sri Sairam Engineering College, Chennai-44, Tamil Nadu, India

Abstract

There is a huge growing requirement of building materials in India due to the existing housing shortage, mainly for the low income groups in urban India. Estimated urban housing shortage in 2012 is 26.53 million, while the housing shortage of rural India in 2012 is 42 million units. Thus total estimated housing shortage for urban and rural India in 2012 is 68.53 million units. To meet this challenge, India requires innovative, energy efficient building materials for strong and durable housing in fast track method of construction at affordable cost. It is also important that housing and buildings are disaster resistant to protect the lives and properties of people. Carbon fiber reinforced gypsum (CFRG) wall panel is made essentially of gypsum plaster reinforced with carbon fibers. The panels are hollow and can be used as load bearing walls. The hollow cores inside the walls can be filled with in-situ plain or reinforced concrete. This paper describes the method of construction of building using CFRG panels and also it presents guidelines for the use of CFRG wall panel as a lateral load resisting component in buildings.

Keywords: *Carbon Fibre, Gypsum, Rapid wall, Shear wall*

1. Introduction

The threat of climate change caused by the increasing concentration of greenhouse gases in the atmosphere is pushing the whole world into a catastrophic crisis situation with universal concern. The need of the 21st century is for energy efficient and eco-friendly products. The building industry accounts for 40% of CO_2 emissions. Building construction causes CO_2 emissions as a result of embodied energy consumed in the production of energy intensive building materials and also the recurring energy consumption for cooling and heating of indoor environment. Rapidwall, also called gypcrete panel is an energy efficient green building material with huge potential for use as load bearing and nonload bearing wall panels. Rapidwall is a large load bearing panel with modular cavities suitable for both external and internal walls. It can also be used as intermediary floor slab/roof slab in combination with RCC as a composite material.it has been used for buildings ranging from single storey to medium-high rise buildings. Light weighted Rapidwall has high compressive strength, shearing strength, flexural strength and ductility. It has very high level of resistance to fire, heat, water, termites, rot and corrosion. Concrete infill with vertical reinforcement rods enhances its vertical and lateral load capabilities. Rapidwall buildings are resistant to earthquakes, cyclones and fire.

2. Carbon Fibre

Carbon fibre is the reinforcement material of choice for "advanced" composites, Carbon fibre exhibits excellent fatigue resistance which will not suffer from stress rupture compared with other fibres. Carbon fibres can be supplied in tows and may vary from 1000 fibres per tow to hundreds of thousands per tow. Untreated carbon fibres do not wet easily, so adhesion to the matrix will be achieved by mechanical interference coupled with surface treatment and chemical bonding between the fibre and the matrix.

Carbon reinforced composites are often used for low strength applications requiring good electrical properties due to the high conductivity of carbon fibre. Most carbon fibres are derived from polyacrylonitrile, but for even higher conductivity, fibres derived from pitch can have three times the conductivity of copper. Carbon fibre properties depend on the structure of the carbon used. Carbon fiber is lighter and stiffer than any other fiber. The nature of a carbon fiber is very light, rigid, and strong. This is why most weight-critical performance products are being manufactured with carbon fiber. Applications where a small amount of flexibility is desired, carbon fiber is the material of choice. The carbon fiber has a relatively small flex window. Typically they come defined as standard, intermediate and high modulus fibres.

Table 1: Indicative materials properties are:

Class	Young's modulus (GPa)	Tensile strength (GPa)	Strain to failure (%)
PAN based high modulus	350-550	1.9-3.7	0.4-0.7
PAN based intermediate modulus	230-300	3.1-4.4	1.3-1.6
PAN based High strength	240-300	4.3-7.1	1.7-2.4

3. Why Carbon Fibre?

1) Carbon fibres are very attractive to gypsum, due to its high chemical stability and this is the main

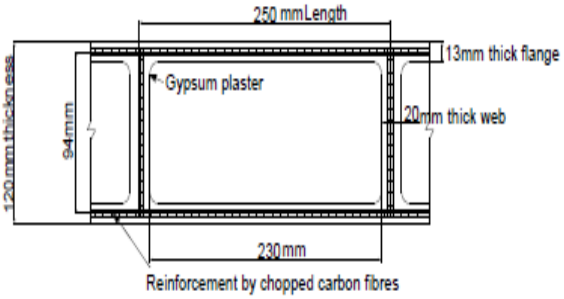
2) The carbon fibres have a very small diameter but, they have large strength and high flexibility.

These fibres can be used as a reinforcing material for gypsum mold.
3) Carbon fiber reinforced gypsum can increase strength against mechanical external force and uneven temperature distribution.
4) A very small mixing ratio of the carbon fibers to that of the gypsum is enough.
5) The tensile strength and the tensile modulus of carbon fibre is more than any other fibre.
6) Even though the oxidation of carbon is catalyzed by the alkaline environment the chemical stability of carbon in gypsum is apparently sufficient.

4. Manufacturing process of CFRG panels

- Phosphogypsum which is a byproduct of phosphoric acid plant will be calcined in calciner at 140-150° C at the rate of 15MT/hr of calcined plaster. This plaster can be stored in product silo having capacity of 250MT.
- The plaster will be then transferred to batch hopper by screw conveyors and through Entoleter in wall panel manufacturing area.
- This area will consists of 6 casting tables having dimensions of 3m*12m, one crab having mixer and carbon fiber roving delivery system is for delivering slurry and carbon fiber roving for three tables. The chemicals can be added in water & mixed and then plaster can be added & mixed to form slurry.
- One layer of slurry will be laid on the table by the crab followed by a layer of carbon fiber roving. This carbon fiber roving can be embedded in to the slurry with the help of screen roller.
- Another layer of slurry will be poured followed by a layer of carbon fiber roving this layer can be pushed inside the rib with the help of temping bar. Finally a layer of carbon fiber roving can be laid for the top face of the wall panel.
- After getting the final wall panel will be lifted from the casting table to ACROBA frame and shifted to dryer for drying. The wall panel can be dried at a temperature of 275°C for 60 minutes.
- After drying, the wall panel can either shifted to storage area or on the cutting table. The wall panel may be cut as per dimensions supplied by the consumer and the cut pieces can be transferred to stillage which are specially made for transporting wall panel.
- The liquid effluent generated during manufacturing process can be recycled back in the system for manufacturing of new wall panels.
- The solid waste which is generated while manufacturing wall panels will be recycled back to the calciner after crushing and separating plaster & carbon fiber roving in recycles plant.

Fig 1: The cross section of CFRG panel



5. Construction of building using CFRG

5.1 Foundation

For Rapidwall buildings/ Housing a conventional foundation like spread footing, RCC column footing, raft or pile foundation can be used as per the soil condition and load factors. All around the building RCC plinth beam can be provided at basement plinth level. For erection of panel as wall, 12 mm dia vertical reinforcement of 0.75m long of which 0.45m protrudes up and remaining portion with 0.15m angle can be placed into the RCC plinth beams before casting. Startup rods may be at 1m center to center.

5.2 Rapidwall for rapid construction

As per the building plan and design, each wall panel shall be cut at the factory using an design, each wall panel shall be cut at the factory using an automated cutting saw. Door/window/ventilator and openings for AC unit etc. shall also be cut and panels for every floor marked as per the building drawing. Panels can be vertically loaded at the factory on stillage for transportation to the construction site on trucks. The stillage shall be placed at the construction site close to the foundation for erection using crane with required boom length for construction of low, medium and high rise buildings. Panels shall be erected over the RCC plinth beam and concrete is in filled from top. All the panels shall be erected as per the building plan by following the notation. Each panel shall be erected level and plumb and shall be supported by lateral props to keep the panel in level, plumb and secure in position. Embedded RCC lintels shall be provided wherever required by cutting open external flange. Reinforcement for

lintels and RCC sunshades shall be provided with required shuttering and support.

5.3 Concrete infill

After inserting vertical steel reinforcement as per the structural design and clamps for wall corners are in place to keep the wall panels in perfect position, concrete having 12mm aggregate shall be poured from the top into the cavities using a small hose to go down at least 1.5 to 2m into the cavities for directly pumping the concrete from ready mixed concrete truck. For small building construction, concrete can be poured manually using a funnel. Filling the panels with concrete shall be done in three layers of 1m height with an interval of 1 hour between each layer. There is no need to use vibrator because gravitational pressure acts to self-compact the concrete inside the water tight cavities.

5.4 CFRG panel for floor/roof slab in combination with RCC

CFRG panel for floor/roof slab shall be cut to required size and marked with notation. First, wall joints, other cavities and horizontal RCC tie beams are in-filled with concrete; then wooden plank 0.3 to 0.45m wide shall be provided to room span between the walls with support wherever embedded micro beams are there and then panels shall be lifted by crane. Each panel shall be placed over the wall in such a way that there will be a gap of at least 40mm. This is to enable vertical rods to be placed continuously from floor to floor and provide monolithic RCC frame within Rapidwall. Wherever embedded micro-beams are there, top flanges of roof panel shall be cut leaving at least 25mm projection. Reinforcement and weld mesh is placed for micro beams and then concrete shall be poured for micro beams and RCC slab.

5.5 Erection of wall panel and floor slab for upper floor

Vertical reinforcement of floor below shall be provided with extra length so as to protrude to 0.45m to serve as startup rods and lap length for upper floor. Once the wall panels are erected on the upper floor, vertical reinforcement rods, door/windows frames fixed and RCC lintels shall be casted. Then concrete where required and joints shall be filled. Thereafter, RCC tie beams all around shall be concreted.

5.6 Finishing work

Once concreting of ground floor roof slab is completed, wooden planks with support slabs shall be removed after 4^{th} day. Finishing of internal walls and ceiling corners shall be done using wall putty by experienced POP plasterers. Simultaneously, electrical work, water supply and sanitary work, floor tiling, mosaic or marble works, staircase work etc. shall also be carried out for each upper floor.

6. CFRG PANELS –act as Shear walls

6.1 Why are buildings with shear walls preferred in seismic regions?

In a high seismic intensity zone, resistance of buildings to earthquakes is often ensured by adopting structural systems where seismic actions are assigned to structural walls (shear walls), designed for horizontal forces and gravity loads while columns and beams are designed only for gravity loads. Structural walls provide a nearly optimum means of achieving the important objectives, viz., *strength*, *stiffness* and *ductility*. Buildings braced by structural walls are invariably stiffer than framed structures, reducing the possibility of excessive deformations under small earthquakes. The necessary strength to avoid structural damage under moderate earthquakes can be achieved by properly detailed longitudinal and transverse reinforcement. Special detailing measures need to be adopted to achieve, dependable ductile response under major earthquakes.

Table 2: The Comparison of Rapidwall and Conventional Building

Materials / items	Rapidwall Building	Conventional Building	Saving in %
Cement	16 tons	32.55 tons	50.8
Steel	1800 kg	2779 kg	35.2
River sand	20 cum	83.37 cum	76
Granite metal	38 cum	52.46 cum	27.56
Bricks		57200	
CFRG Panel	500sqm		
Water	50000 lit	200000 lit	75
Built Area	143sqm	154.45sqm	8
Labour	389mandays	1200mandays	67.59

Materials / items	Rapidwall Building	Conventional Building	Saving in %
Construction Time	21 days	120 days	82
Total Weight of Super structure	170 tons	490 tons	65
Construction Cost	Rs 20.57 lakhs	Rs 18.27 lakhs	
Embodied energy kWh	82921	215400	61.5

7. Conclusion

The carbon fiber is very light, rigid and strong. Further, the carbon fiber used, have good affinity towards gypsum due to its superior chemical stability. The carbon fibre also has very high strength and has good flexibility. The tensile strength and tensile modulus of carbon fiber is much higher than any other fiber. Thus, the CFRG Panel provides a new method of building construction in fast track, fully utilizing the benefits of prefabricated, light weight large panels with modular cavities and time tested, conventional cast-in-situ constructional use of concrete and steel reinforcement. By this process, man power, cost and time of construction is reduced. The use of scarce natural resources like river sand, water and agricultural land is significantly reduced. CFRG panels have reduced embodied energy and require less energy for thermo-regulation of interiors.

CFRG buildings thereby reduce burdening of the environment and help to reduce global warming. CFRG also protect the lives and properties of people as these buildings will be resistant to natural disasters like earthquakes, cyclone, fire etc. This will also contribute to achieve the goal of much needed social inclusive development due to its various benefits and advantages with affordability for low income segments also. Fast delivery of mass dwelling/ housing is very critical for reducing huge urban housing shortage in India. CFRG panels will help to achieve the above multiple goals.

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