Earthquakes and Structures, *Vol. 16, No. 3 (2019) 369-373*
DOI: https://doi.org/10.12989/eas.2019.16.3.369

Investigation of the bending behavior of 3D glass fabric-reinforced composite panels as slabs in buildings

S.A. Sabet[1], Sh. Nazari[2], M. Akhbari[2] and R. Kolahchi[*1]

[1]*Department of Civil Engineering, Islamic Azad University, Kashan Branch, Kashan, Iran*
[2]*Department of Textile Engineering, Islamic Azad University, Kashan Branch, Kashan, Iran*

(Received January 8, 2019, Revised February 14, 2019, Accepted February 20, 2019)

Abstract. Construction industry is one of the largest markets for composite materials. Composite materials are mostly utilized as surface coatings or concrete reinforcements, and they can hardly be found as a load bearing member in buildings. The three-dimensional composite structures with considerable bending, compressive and shear strengths are capable to be used as construction load bearing members. However, these composites cannot compete with other materials due to higher manufacturing costs. If the cost issue is resolved or their excellent performance is taken into consideration to overcome disadvantages related to economic-competitive challenges, these 3D composites can significantly reduce the construction time and result in lighter and safer buildings. Sandwich composite panels reinforced with 3D woven glass fabrics are amongst composites with highest bending strength. The current study investigates the possibility of utilizing these composite materials to construct ceilings and their application as slabs. One-to-one scale experimental loading of these composite panels shows a remarkable bending strength. Simulation results using ABAQUS software, also indicate that theoretical predictions of bending behavior of these panels are in good agreement with the observed experimental results.

Keywords: composite; sandwich panel; three-dimensional; building

1. Introduction

While the growth of countries is measured based on their annual consumption of composite materials, this value remains around zero in many countries in the world. Composites are materials made from two or more constituent materials with characteristics completely different from the individual components. Although the field of composite materials is relatively new, the idea of improving properties by combining different materials goes back to long time ago, when the thatch and metallic alloys were invented.

Collapse of load bearing wall is the cause of many casualties during extreme loading events. The test results clearly demonstrate the efficiency of using CFRP strips as a repair and strengthening technique for unreinforced load-bearing walls to increase the stiffness and ultimate bearing load (Amer *et al*. 2015).

Composite materials have gained a considerable attention due to their high strength-to-weight ratio, easy of manufacturing and formability, long fatigue life, and excellent corrosion resistance. They are mostly utilized in aerospace applications, civil engineering, and automotive industries. Construction industry holds 42% of the total consumption of composite materials, and thus, it isthe largest market for composites among other industries.

The use of precast concrete sandwich panels has increased significantly in the past few years due to their superior thermal and acoustic insulation properties. They are composed of two reinforced concrete layers (wythes) separated by a layer of rigid foam insulation. Unlike traditional noncomposite panels that rely only on the interior wythe to resist the load, composite Sandwich panels rely on the composite action between the wythes, which can be achieved by using shear connectors that are mainly made from nonmetallic, diagonal fiber-reinforced-polymer (FRP) materials (Hamed 2017).

Among reinforcing materials for composites, glass has the highest amount of consumption, which is over 90%. Glass fibers possess an excellent thermal resistance, high tensile strength, good chemical resistance, and interesting isolation characteristics. Moreover, glass fibers are cheaper than other common fibers such as carbon fiber and Kevlar (Shokrieh 2013).

Glass fibers are one of the most widely used synthetic fibers for composite materials. This is mainly because they are inexpensive (Kistaiah *et al*. 2014) but at the same time possesses many advantages such as good resistance to chemical attack, excellent insulating properties, no moisture absorption and high tensile strength. Pourabbas *et al*. (2016) presented effect of recycled Glass powder on asphalt concrete modification.

Glass fibers come in form of yarns, short fibers, mat,etc. In the form of mat, chopped strand mat (CSM)is quite common (Naughton *et al*. 1985) and several types of woven fabric are used, including unidirectional (UD), plain weave (PW), twill weave (TW), basket weave (BW) and satin weave (SW) mats (Mallick 2007). other than UD mat, the performance of all others is affected to various

∗Corresponding author, Professor
E-mail: r.kolahchi@iaujasb.ac.ir

ISSN: 2092-7614 (Print), 2092-7622 (Online)

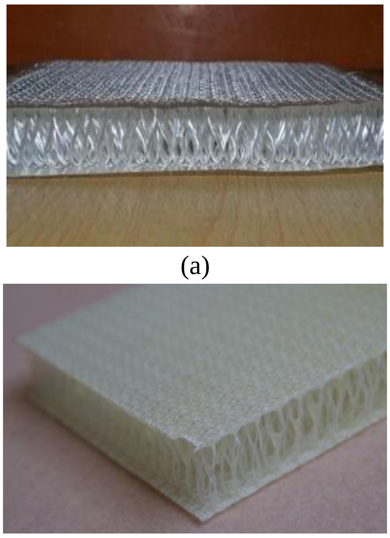
(a)
(b)

Fig. 1 (a) 3D glass woven fabric, (b) resin-impregnated fabric

Table 1 Mechanical and thermal properties of E-glass yarns

Fiber	Strength (MPa)	Tensile modulus (GPa)	Density (kg/m^3)	Elongation at break (%)	Liquid temperature (℃)	Polson's Ratio
E-Glass	3200	78	2540	3.3	1159	0.27

Table 2 Mechanical properties of YD128 epoxy resin

Resin	Strength (MPa)	Tensile modulus (GPa)	Density (kg/m^3)	Elongation at break	Compressive Strength (MPa)	Flexural strength (MPa)
YD128	85	10.5	1.12	0.8	190	112

Table 3 Structural properties and type of the fabric

Thickness (cm)	Weight (grm^{-2})	density	Yarn count	Roving type	direction
3.2	1954±12	3.2 (/cm)	600 (Tex)	E-Glass	Warp
		4.2 (/cm)	600 (Tex)	E-Glass	Weft
		4.3 (/cm)	600 (Tex)	E-Glass	Pile

levels because of the presence of crimp (Carvelli *et al*. 2010).

Glass fiber-reinforced polymer (GFRP) panels have been increasingly used for structural applications due to their light weight, corrosion resistance and construction-easiness. In 2018 it is found that while GFRP wall panels cannot replace RC walls in multi-story buildings due to their low stiffness, their performances are comparable to RC walls for low-rise buildings. Therefore, GFRP wall panels can be potentially used in low-rise buildings in seismic regions (Hao and Chen 2018). Belalpour Dastjerdi and Ahmadi (2018) studied characterizing the damage mechanisms in mode II delamination in Glass/epoxy composite using acoustic emission.

The research on 3D woven sandwich panels itself has been going on for several years. The production process and the basic mechanical properties of the material have been studied thoroughly (Judawisastra *et al*. 1998).

In 1991, a U.S. patent was approved on the utilization of 3D fabric-reinforced composites for structural applications (Bompard 1991). The inventor claims that the mechanical properties of these composite panels make them suitable material for different parts of the building. However, their cost prevents them to be economically efficient for the construction industry. The greatest advantage of the composite made from this new structure over traditional sandwich panels is the bonding of core to face sheets. It is noted that one of the main reasons for the failure of sandwich panels is the separation of face sheets from the core material (Delamination failure mode). However, such failure mode has not been observed in the composites reinforced by 3D glass woven fabrics (Niu 1992).

Study of the behavior of 3D AR glass fabric cement-based composites under impact loading demonstrate that 3D fabrics significantly improve the toughness and energy absorption of cement-based composites under impact loading, compared to short AR glass fibers reinforcement. The 3D fabric improves the toughness in as high as 200 folds compared to short fiber composites. The energy absorption was highly affected by the thickness of the element and the location of the 3D fabric faces. Greater toughness was obtained when the fabric faces were located in the direction of the hammer drop (Peled *et al*. 2010).

Fig. 1 shows an image of the raw and resin-impregnated woven fabrics. The resin can be polyester or epoxy.

These panels can be made from one smooth and impermeable face and one porous face. Therefore, the impermeable face can make good moisture isolation, and the porous face can make a strong adhesion between the panel and the mortar. The trapped air in between two face sheets would improve thermal isolation of the panel. Millions of fibers in the core material also play a sound isolation role duetotheir acoustic diffraction effects. Accordingly, in addition to load bearing applications, this composite can be utilized as the moisture, thermal and sound isolating materialin ceiling and wall coatings.

2. Experimentals

2.1 Materials:

a) E-glass yarnswere used in the structural texture. Mechanical and thermal properties of glass yarns are presented in Table 1.

b) Epoxy resin with properties shown in Table 2 was selected.

c) Structural characteristics of the glass woven fabric are presented in Table 3. Also, Table 4 shows theresin-fabricmixing ratio and properties of the resulting composite material. The economic weave of fabrics was performed at an industrial scale for the first time in Iran.

d) Ceiling beams: C-shaped galvanized steel sheets with the thickness of 1.25 mm were back-to-back connected and then located on tubular columns as ceiling beams. Composite panels were screwed to these beams. To evaluate the possibility of load bearing of composite panels up to

Table 4 Geometry, resin, mixing ratio, and the weight of composite panel

Panel weight (grm^{-2})	resin	Weight percent (resin-fabric)	Final composite thickness (cm)
3908±50	epoxyYD128	50-50	2.7

Fig. 2 Cutting composite panels and screwing them to galvanized sheets

2000 kg m^{-2} loading and prevent deformation of beams under such loading, steel plates were welded into C-shaped galvanized sheets.

2.2 Methods

Fabrics were first cut for one-, two-, and three-span testing conditions. The span length for all tests were 60 cm. Resin impregnation of fabrics were perform using the hand lay-up method. Composite panels were then fabricated with lengths of 60, 120, and 180 cm. After placing beams on columns of 50-cm height, composite panels were screwed on them. The connection of composite panels and galvanized sheets were done by 5-cm drill bits. The process of sample preparation is shown in Fig. 2.

3. Testing

Standard two-point bending tests were performed on panels according to evaluate their mechanical properties such as bending strength and tension due to bending. Figure 3 illustrates the performance of four-point bending tests by ELE machine as well as one-to-one scale loading of panels and the measurement of mid-span deflections.

Experimental tests were conducted in the Azad University of Kashan Concrete Lab. After each step of loading, the mid-span deflection was recorded by micrometers and the bending strain was calculated.The allowable dynamic loading for lightweight ceilings with a 60-cm span was calculated to be 350 kg m^{-2}. Accordingly,

Fig. 3 Performance of bending tests on composite panels

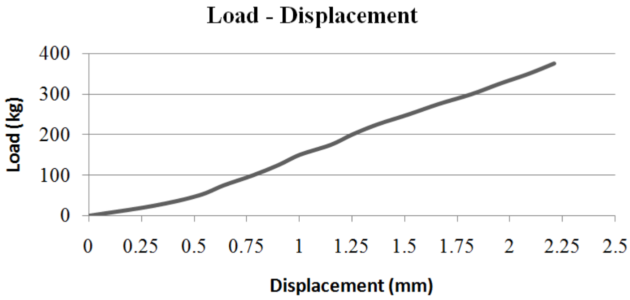

Fig. 4 Variations of mid-span deflections with the distributed loading

panels were loaded by blocks up to 1, 2, 3, and 6 times this allowable loading.To evaluate the deflection of panels over time, mid-span deflection values were recorded for 4 months. It should be noted that the temperature of experimental environment was between 17℃ to 42℃.

4. Results and discussion

In a two-point bending test, the tensile strength of the bottom face is calculated using the concrete equation ($F_t = \frac{2PL}{bh^2}$). Results show that composite panels without concrete coating exhibit a higher tensile strength than the unreinforced concrete.

If we consider a maximum allowable deflection of 3 mm for these L.S.F structures with 60-cm span, the composite panels would have a less deflection than this allowable value. The bending behavior of panels under distributed loading is presented in Fig. 4.

Since it is required to study the deformation of composite panels over time, the mid-span deflection values under 2-span distributed loading condition were illustrated in Fig. 5. As seen in the figure, the deformation of these panels reaches to a saturated state after 20 days, and then,

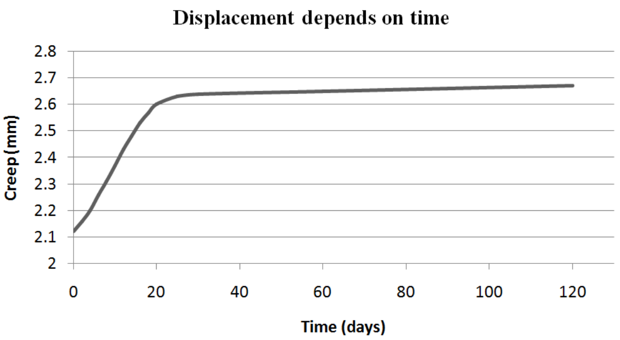

Fig. 5 Mid-span deflection as a function of time

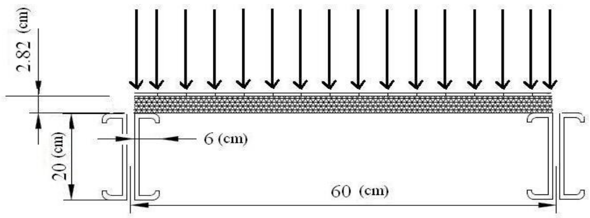

Fig. 6 Dimensions of the model used in ABAQUS software

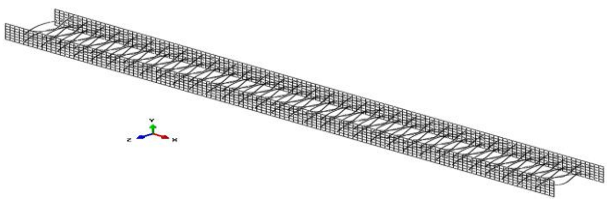

Fig. 7 The structure of 3D fabric modeled for ABAQUS simulations

their deformation remains in the order of 10^{-2} mm.

4.1 Simulation of the bending behavior of composite panels

The purpose of this simulation is to evaluate the bending behavior of a sandwich panel made of the epoxy resin reinforced with a 3D glass woven fabric. The simulation was performed using ABAQUS software with embedded technique. Fig. 6 shows the geometry of the model and loading conditions. Since the shape of yarns is complicated in z-direction, the structure of fabric material was modeled in CATIA software and the model transferred to ABAQUS. We also assumed that in the sandwich panel, fabric yarns are completely engaged with the top and bottom face sheets.

This was performed by defining “Tie” connections at their interfaces. The modeled fabric structure is illustrated in Fig. 7.

After creating the structural texture of the fabric, it was embedded into epoxy resin. The properties in Tables 2 and 3 were used for simulations. The loading was defined as distributed loading and meshing the model (with the size of 4) was done before running simulations. To avoid a sudden loading of the model, a 5-sec loading period was chosen for a distributed load of 350 kg m^{-2}.

The schematic configuration of the model after completion of the simulation is shown in Fig. 8.

The simulated mid-span deflection of the panel over loading time is presented in Figure 9. It can be seen that the maximum deflection of these panels is around 2 mm at the mid-span.

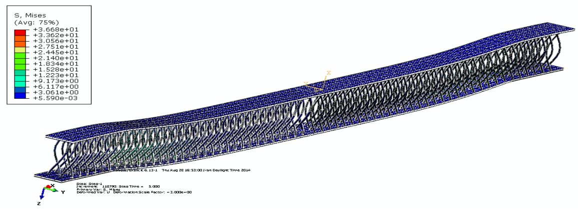

Fig. 8 Visual and quantitative results of a simulation

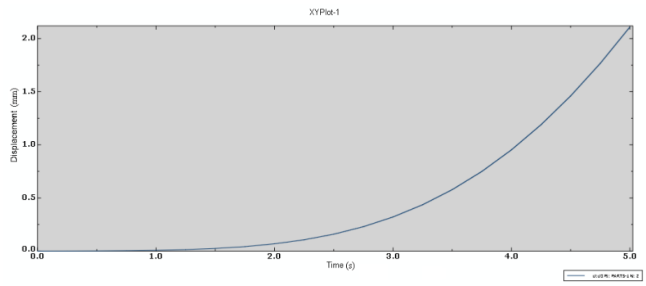

Fig. 9 Simulated mid-span displacement-time behavior of the sandwich panel under distributed load of 350 kg m^{-2}

5. Summary

Sandwich panels in which the resin is reinforced with a bulky entangled structure of glass filaments would exhibit better mechanical properties than traditional bulky composite structures. The high cost of these composite panels has turned them into a suitable material only for military applications in industrial countries. Now the low-cost production of these materials in Iran can make them a good candidate for the construction industry. This product can be an alternative material for reinforced concrete slabs, separation blades, and separation walls. Also, they can be utilized as coating material for composite ceilings, brick ceilings, steel roof decks, LSF structures, etc. In the ceilings mentioned above, composite panels reinforced with 3D glass woven fabrics can be replaced by all layers on beams. In this condition, the thick composite panel is directly screwed on the beam and instead of several layers, it can hold multiple characteristics such as bending resistance and moisture, thermal and acoustic isolation. Considering the good agreement between theoretical and experimental results, it is suggested that other mechanical properties of this material can be estimated using simulation software. This will save the time and cost for conducting experimental tests.

References

Amer, I., Salman, D., Wissam, X. and Qusay, A. (2015), “Behavior and Strength of Bearing Wall Strengthening by CFRP”, *Int. J. Eng. Res. Technol*., **4**, 122-127.

Belalpour Dastjerdi, P. and Ahmadi, M. (2018), “Characterizing the damage mechanisms in mode II delamination in

Glass/epoxy composite using acoustic emission", *Earthq. Eng*., **67**, 545-553.
Bompard, B. (1991), "US patent", **5**, 21-28.
Carvelli, V., Gramellini, G., Lomov, S.V., Bogdanovich, E., Mungalov, D.D. and Verpoest, I. (2010), "Fatigue behavior of non-crimp 3D orthogonal weave and multi -layer plain weave E-glass reinforced composites", *Compos. Sci. Technol*., **70**, 2068-2076.
Hamed, E. (2017), "Load-carrying capacity of composite precast concrete sandwich panels with diagonal fiber-reinforced-polymer bar connectors", *PCI J*., **62**, 34-44.
Hao, W. and Chen, X. (2018), "Seismic Behavior of Glass Fiber-Reinforced Polymer Wall Panels", *Compos. Struct*., **203**, 300-309.
Judawisastra, H., Ivens, J. and Verpoest, I. (1998), "The fatigue behaviour and damage development of 3D woven sandwich composites", *Compos. Struct*., **43**, 35-45.
Kistaiah, N., Udaya Kiran, C. and Ramachandra Reddy, G. (2014), "Mechanical characterization of hybrid composites: A review", *J. Reinfor. Plas. Compos*., **33**, 1364-1372.
Mallick, P.K. (2007), "Fiber-reinforced composites: Materials, manufacturing, and design", *CRC Press.*, **22**, 581-582.
Naughton, B., Panhuizen, P. and Vermeulen, A.C. (1985), "The elastic properties of chopped strand mat and woven roving in grlaminae", *J. Reinfor. Plast. Compos*., **42**, 195-204.
Niu, M.C.Y. (1992), *Composite Air Frame Structures*, Conmilit Press Ltd.
Peled, A., Zhu, D. and Barzin, M. (2012), "Impact behavior of 3D fabric reinforced cementitious composites", *RILEM Bookseries*, **2**, 543-550.
Pourabbas Bilondi, M., Marandi, S.M. and Ghasemi, F. (2018), "Effect of recycled Glass powder on asphalt concrete modification", *Earthq. Eng*., **59**, 373-385.
Shokrieh, M.M. (2013), *Proceeding book, the first composite Conference*.

CC