COMPUTATIONAL RESEARCH PROGRESS IN APPLIED SCIENCE & ENGINEERING (CRPASE)

CRPASE: TRANSACTIONS OF CIVIL AND ENVIRONMENTAL ENGINEERING

Journal homepage: http://www.crpase.com

CRPASE: Transactions of Civil and Environmental Engineering, Vol. 06(04), 259-262, December 2020 ISSN 2423-4591

Review Article

Composite Sandwich Structures in Advanced Civil Engineering Applications – A Review

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Keywords

Composite Sandwich Structure; Structural Beams, Construction; Damage mechanisms

Abstract

In this review paper, the applications of composite sandwich structures in structural engineering are presented. Composite sandwich structures are getting a special attention in most engineering applications as they provide beneficial replacement to the traditional construction materials. This is attributed to their unique mechanical properties such as high specific flexural stiffness, ultra-low structural weight, excellent flammability and corrosion resistance. The use of composite sandwich structures in construction and housing, railway sleepers, huge building frames, and roofs is discussed in detail in this article. Furthermore, a comparison between the numerous types of composite sandwich structures and their most common applications is provided. Also, this study dedicates a section to review the damage mechanisms of composite sandwich structures.

1. Introduction

Over the last decade, researchers have considered composite sandwich structures to be the future of cnstruction materials. This is due to the unique mechanical properties that composite sandwich structures have. The lightweight, corrosion resistance, high stiffness and strength, long durability compared to traditional materials, created opportunities for sandwich composites to shape the new generation of materials in civil engineering applications and construction [1].

Composite sandwich structures are also extensively used in aerospace shuttles, naval ships, medical equipments and huge building frames whereby the lightweight and high strength are needed. Composite sandwich structures consist of two thin layers always (skin or facesheet), and a thicker lightweight layer known as the core layer (Fig.1).

The core layer is sandwiched between a front facesheet and a back facesheet. The facesheets are responsible fore carrying the in plane flexural and compression loads while the thicker core layer distributes the shear load. The most common types of facesheets are carbon fiber reinforced polymer composites (CFRP) and glass fiber reinforced polymer composites (GFRP).

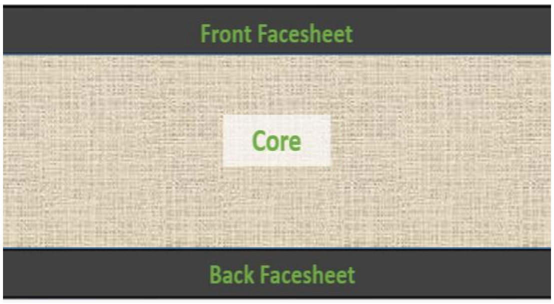

Figure 1. A schematic of the composite sandwich structures

Regarding the core layer, honeycomb cores and foam cores are the most common types used in the composite sandwich structure systems. Those layers have a significant effect on the performance and in determining the best possible application.

Daniel and Abot [2] found that the maximum strength of composite sandwich structures can be achieved by modifying the material type of the facesheets. Changing the

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Received: 12 September 2020; Revised: 10 November 2020; Accepted: 18 November 2020

Please cite this article as: I. Elfaki, S. Abdalgadir, Composite Sandwich Structures in Advanced Civil Engineering Applications – A Review, Computational Research Progress in Applied Science & Engineering, CRPASE: Transactions of Civil and Environmental Engineering 6 (2020) 259–262.

facesheet type would affect the failure mechanism and hence the overall performance and reliability of the composite sandwich structure. Daniel and Abot [2] investigations also revealed that the type of the core layer has a significant effect on the damage behavior of the entire sandwich panel.

In this review work, the applications of composite sandwich structures in civil engineering including sandwich beams, building frames, roofs, and railway sleepers are studied.

Furthermore, a brief explanation on the damage mechanisms within the facesheets and core layers are reviewed in the last section of this article.

This review work aims to provide a guideline for future studies about the role of composite sandwich structures in the advancement of civil engineering and technology.

2. Applications of Composites in Civil Engineering

Numerous studies have showed that the construction needs of more durable and economical infrastructures could be achieved by using composite sandwich structures [3].

For instance, sandwich beams are composite systems with high stiffness-to-weight ratio made up of three components, face sheets which carry in-plane and bending loads, the core which resists shear forces and adhesive interface layer [4]. The optimal design of the sandwich beam aims to have the least weight possible for a specific load.

Steeves and Fleck [5] investigated the performance of the sandwich beams using a different combination of materials (glass fiber reinforced plastic faces, carbon fiber reinforced plastic faces, medium strength steel faces, square steel honeycomb core, and PVC foam core).

They found that a carbon fiber composite facesheet with polymer foam core is ideal when light loads are applied. Whereas at higher loads, the hybrid carbon-fiber steel honeycomb core beam is found to be the best option. Similar observations of the polymeric foam superiority are presented in a study about the performance of composite sandwich structures by Elamin et al [6].

In the last few years, engineers and scientists dedicated great efforts to improve the performance of the core layer in the sandwich structure system. Purushothaman [4] studied the behavior of a sandwich beam using multiple core configurations (circular, square, truss, and honeycomb) and their mechanical response under dynamic events. It was found that the truss core is more reliable as it provides a lower deformation extension.

Mahfuz et al. [7] enhanced the flexural strength of the a foam cored composite structure by adding titanium dioxide nanoparticles into the polyethylene foam material. The flexural strength increased by 53% just by adding 3% of the titanium dioxide nanoparticles.

Zhang et al. [8] studied the behavior of a sandwich composite beam composed of glass fiber reinforced polymer composite skins, polyurethane (PU) foam, and longitudinal glass fiber reinforced plastic webs.

Based on the experimental results in [8], it was found that the bending strength of the sandwich beams increased drastically when using GFRP webs. Moreover, increasing the thickness of the GFRP webs with smaller webspace would increase the the bending strength of composite beams.

Elamin et al [9] showed that doubling the facesheet thickness resulted in a higher overall strength by at least 80%. Daniel and Gdoutos [10] studied the failure behavior of composite sandwich beams and found that the failure modes vary according to the beam dimensions, material characteristics, and the type of loading.

Fore beams under bending and shear, the mode of failure is governed by the magnitude of the shear component. Face wrinkling takes place first when the shear component is low. When the shear component is high enough, core shear failure occurs before face wrinkling [11].

As a result of the advancement of technology in the field of construction materials, composite sandwich structures have been introduced in housing and construction where lightweight, less cost, and quicker construction operations are desired. Particularly, the lightweight of the structures facilitates handling and reduces transportation costs [3]. Keller et al. [12] designed a function integrated GFRP sandwich roof structure for a building in Switzerland.

Another common use of composite sandwich structure is in the design of railway sleepers. Railway sleepers are among the most important components of the railway track. They are used to provide additional support to the rail track [13]. Railway sleepers are primarily made of wood, concrete, and steel. Hardwood timber is currently the most common material used in railway production [14].

Recent studies suggested that the fibrous composites could be a potential option for railway sleepers materials. Ghorbani and Erden [14] concluded that the polymeric composites are very good option for hardwood timber railway due to their special properties such as high strength and corrosion resistance. A composite sleeper made of polymer concrete and glass fiber reinforcement (Fig.2) has been used in Australia as an alternative for timber, concrete, and steel sleepers.

Figure 2. Glass fiber reinforced polymer concrete sleeper (reproduced from Ghorbani and Erden [14])

Manalo et al. [15] further studied the suitability of the adhesive laminated composite sandwich structure for railway turnout sleepers. An experimental investigation on different configurations was conducted. Fig.3 shows a beam section made of sandwich panels in the flatwise position, edgewise position, and a combined section with sandwich lamination in both edgewise and flatwise positions.

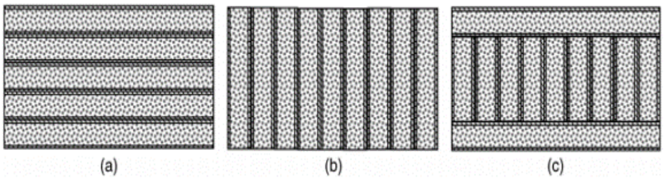

Figure 3. Cross-sections of the full-scale composite sandwich beams: (a) flatwise; (b) edgewise; (c) combined (reproduced from Manalo et al. [15])

Flexural and shear tests were conducted, the results from the experimental investigations show that the sandwich beam in the edgewise position had the highest failure load in both shear and bending compared to all other configurations.

The high failure load of the sandwich beam in the edgewise position is due to the presence of the vertical beam, which leads to an increase in the loading capacity of the beams. The specimens with edgewise sandwich laminations have a loading capacity of 20% more than the flatwise and combined sandwich laminations.

The orientation of the sandwich laminations significantly affects the structural behavior of sandwich beams. The addition of one layer of fiber wraps increases the shear strength by 10%.

The American Railway Engineering and Maintenance-of-Way Association (AREMA) determined the structural properties of the laminated fiber composite sandwich beams. Similarly, Ticoalu [16] determined the mechanical properties of the timber turnout sleeper.

The recommendations of the AREMA and Ticoalu are listed in table 1. The strength and stiffness of the turnout sleeper made of adhesive-laminated composite sandwich structures are much higher than the minimum requirements of the fiber composite sleepers recommended by the AREMA.

Manalo et al. [15] found that a minimum stiffness of 4 GPa is required to maintain the allowable vertical deflection and sleeper pressure. Therefore, all of the above beam types meet the required elastic modulus of a railway turnout sleeper.

The design parameters for the composite sandwich structures turn out sleepers determined by Manalo et al. [15] have a size of 150 mm x 230 mm of timber turnout sleeper. This size of timber sleeper will create bending and shear stresses of 22 and 4.6 MPa, respectively.

Charvade et al. [17] proposed a method of moment resisting frames. Bank [18] determined the required safety factors of the composite beams (described in table 2). Bank [18] recommended that the safety factors for the allowable stresses should be considered when designing composite beams. Thus, the beams with flatwise section can not satisfy these requirements for the turnout sleepers if the safety factors for the turnout sleepers are applied. However, the beams with edgewise section and combined laminations have satisfied the requirements.

3. Failure modes of Composite Sandwich Structures

Composite sandwich structures are very susceptible to impact damages [19]. Barely visible impact damage (BVID) is the most common failure mode in composite sandwich structures. BVID initiates matrix cracks, fiber breakage and core failure. When a specimen is impacted, a considerable amount of impact energy is absorbed by the facesheets and core layers, and therefore results in complex damage mechanisms.

Researchers have utilized imaging techniques to investigate the damages in foam core sandwich panels [20-23]. They found that fiber breakage and delamination of the facesheets occurred as the result of tensile failure of the front facesheets and compression of the back facesheet respectively (Fig.4).

Further analysis showed that the core layer is teared and crushed due to the punch shears failure.

Table 1. Structural Properties of the adhesive-Laminated Sandwich Beams

Sleeper Type	Modulus of Elasticity, GPa	Bending strength, MPa	Shear strength, MPa
Flatwise	5.01	75.5	7.3
Edgewise	5.19	103.5	18.7
Combination	5.05	66.8	16.8
Timber	7-26	64-160	2-7
AREMA	1.17	13.8	6.2

Table 2. Safety factors for composite turnouts sleepers

Description	Safety Factor
Stiffness	1
Bending	2.5
Shear	3

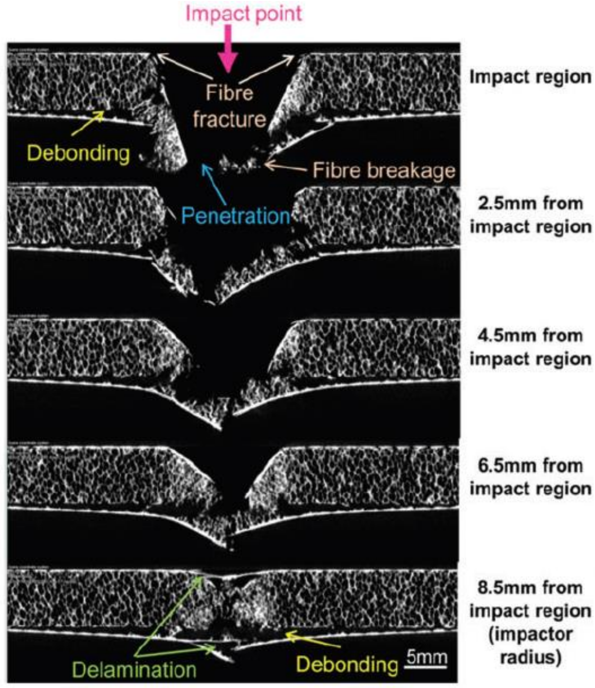

Figure 4. Damage modes in PVC composite sandwich panels (reproduced from Khan et al. [21])

4. Conclusions

In this review paper, the applications of composite sandwich structures in structural engineering were discussed. Composite sandwich structures are extensively used in civil engineering applications as alternatives for traditional construction materials. This is attributed to their unique mechanical properties such as high specific flexural stiffness, ultra-low structural weight, and excellent flammability and corrosion resistance.

The use of composite sandwich structures in constructions and housing, railway sleeper, huge building frames and roofs was studies in detail. Furthermore, the types of composite sandwich structures alongside their most common damage mechanisms were investigated in this review article.

Conflict of Interest Statement

The authors declare no conflict of interest.

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