

Comprehensive Review of Sandwich Composite Materials for Structural Applications-A technical Report

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Abstract:

This Report presents a comprehensive study on the design of sandwich composite panels for passive building roofs, focusing on achieving both structural integrity and energy efficiency. The current work focused on various core materials, such as foam, honeycomb, and thermal insulation capabilities of Ultra light materials, Polystyrene and Water Glass composite. Further discussions are aligned to address the "Integrated Sandwich Composite Material "Finally, the work is summarized with brief of Mechanical Performance (Core design specially), Thermal Insulation and Energy Efficiency of Sandwich Structure.

Keywords:

Multifunctional Composites; Sandwich Structures; Mechanical Properties;Core Structure;Thermal Conductivity;Passive building

1. Introduction:

Passive building design focuses on maximizing energy efficiency and reducing the environmental impact of buildings. One crucial aspect of passive building construction is the use of advanced materials with excellent mechanical properties and thermal insulation performance. Sandwich composite materials have gained significant attention in this regard due to their unique characteristics.

Sandwich composite structures usually consist of two outer thin laminates and a middle core structure [1,2] Sandwich structures are light multifunctional composite structures, constructed by embedding a low-density core between two thin stiff facings. Figure 1[3] The mechanical, thermal, non-flammability, and other essential properties of the sandwich composites have been found directly dependent on the core structure, face panels, and manufacturing technique used. In addition to aerospace engineering, these composites need to be utilized in civil engineering application [4]

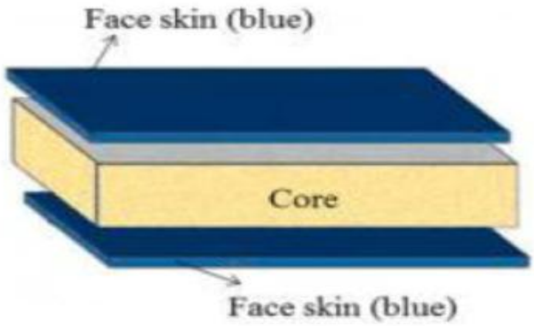

Fig. 1 Sandwich structure [3]

2. Sandwich Composite Structures

2.1. Traditional Core Structure

The traditional core can be broadly divided into two categories: homogeneous and non homogeneous support of the skin. The homogeneous support cores are foam/cellular cores, whereas the non-homogeneous support cores are textile/pin/truss/pyramidal,[4]

2.1.1. Textiles/Lattice/Pin/Truss Core**:** Lattice truss cores are used for load-bearing structures due to their high specific strength and stiffness [5]. These cores may be tetragonal, pyramidal, or Kagome patterns.

Figure 3 shows the lattice core [6]

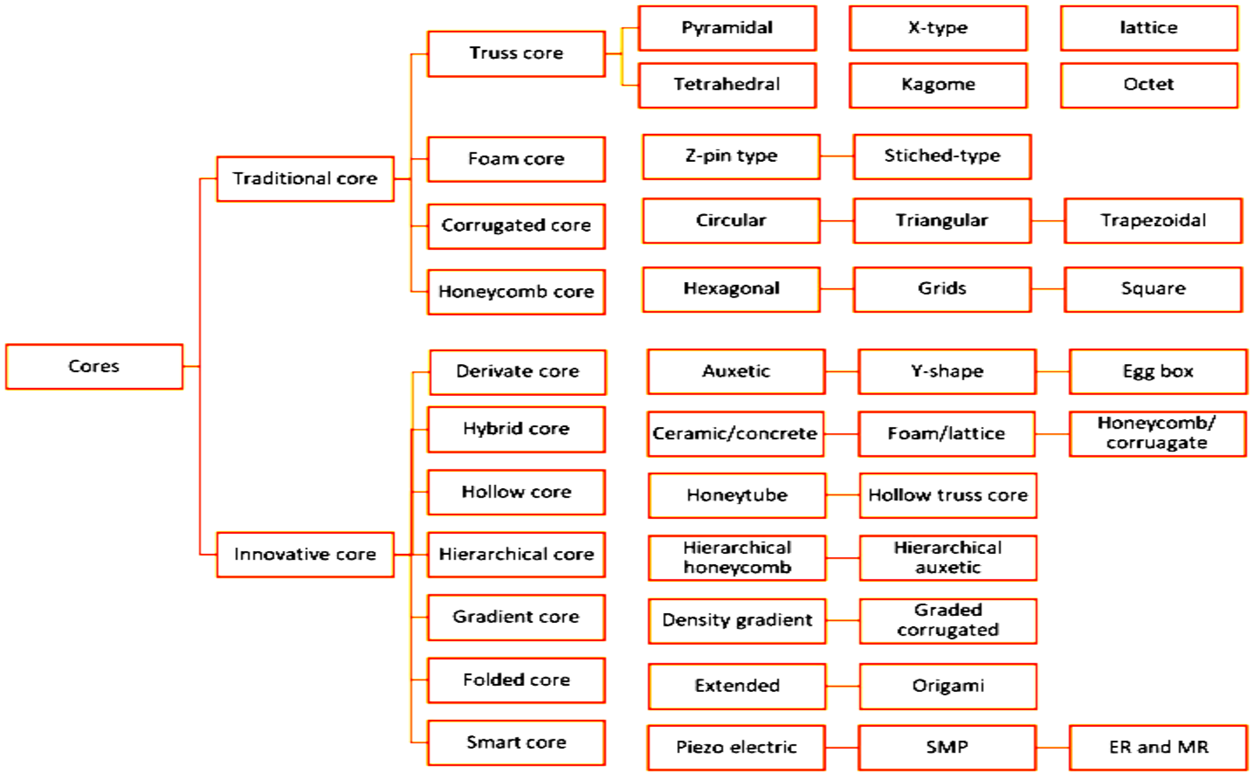

Fig.2 Types of cores. [4]

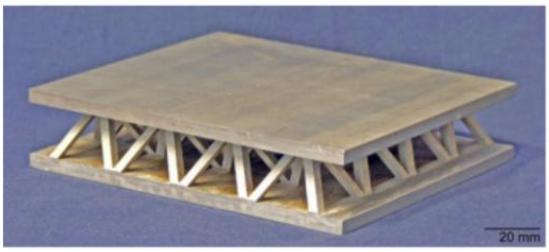

Fig.3 [5]

2.1.2. Corrugated Core: These cores are unidirectional support open to one side. The cardboard corrugated cores are widely used in the packaging industry due to their shock absorbing capabilities and low cost. Figure 4 a-c shows the typical corrugated core [7] Xu et al. [8] investigated the mechanical response of three-dimensional corrugated cores embedded with carbon fiber/epoxy face sheets, which were fabricated by an auto-cutting technique. It was observed that the graded parameter greatly influences the compressive strength. The small-graded size of 0.17 mm showed the highest compressive strength of 2.37 MPa, which decreased by 57% for 0.50 mm graded core due to buckling.

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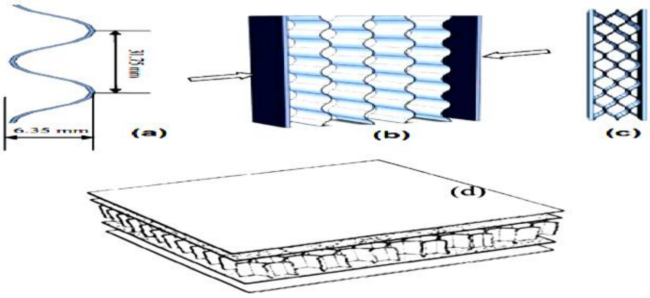
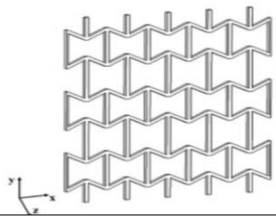
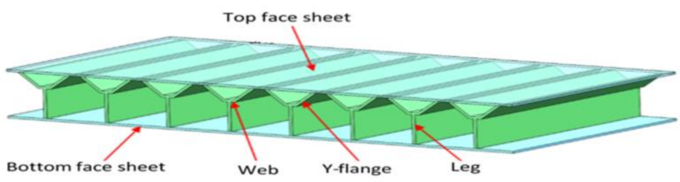
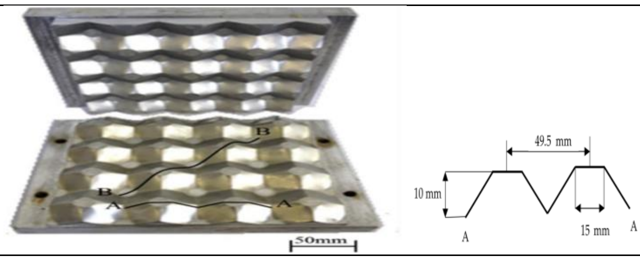


Fig 4(a) Corrugated core sheet dimension; (b) Assembly procedure [7]; (c) Final sandwich panel;(d) Honeycomb sandwich structure [9].

2.1.3. Honeycomb Core: These are cellular structures with bidirectional support that may be open to thickness direction or length direction. The structures when open to thickness direction provide bending resistance, and cushioning ability when opened in length direction. This makes it possible for the honeycomb to achieve high anisotropy in a different direction.[4] The materials used for the fabrication of the honeycomb core were aluminium, thermoplastic polyurethane, Nomex, carbon fiber, foam,etc. Figure 4-d shows the typical honeycomb core [9] Zhang et al. [10] reported the dynamic impact behavior of the aluminium honeycomb core packed with expanded polypropylene foam with varying foam densities (20, 40, and 60 kg/m3) and impact velocities (2, 2.6, and 3.2 m/s). It was observed that with the variation of foam density, there is a decrease in the energy absorption capability of about 3% for 60 kg/m3 compared to the bare core. It was also recorded that with an increase in velocity, there is an increase in energy absorption ability.

2.2. Innovative Core Structure: The innovative cores can be broadly categorized into derivate, hybrid, hollow, hierarchical, graded, folded, and smart core.

2.2.1 Derivate Core: The derivate core is further classified into auxetic, Y-shaped, and egg-box cores, which are below.

Auxetic Structure	Shrinkage behavior. [11]	
Y-Shaped Core	The analytical expressions were presented to predict the compressive stiffness and strength of composite sandwich panels at different temperatures[12]	
Egg-Box Core	The quasi-static and dynamic test revealed that specific energy absorption (SEA) was improved swiftly with the increase in cell wall thickness[13]	

2.2.1 Hollow Core: Circular tube honeycombs are suitable for blast resistance and as protective structures due to their excellent energy absorption ability and well-regulated deformation pattern. Figure 5 shows the typical circular honeycomb core [14]

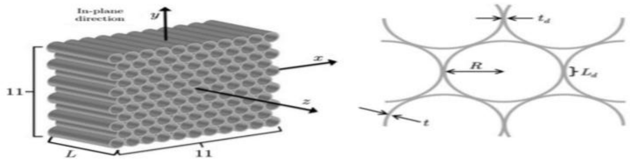


Fig. 5 circular honeycomb core [14]

2.2.2 Corrugated Core: The corrugated core structures have attracted much attention in recent years because they can greatly enhance the energy absorption capability of such structures when the proper corrugated parameters are selected. Figure 6a–c shows the typical corrugated core [15]

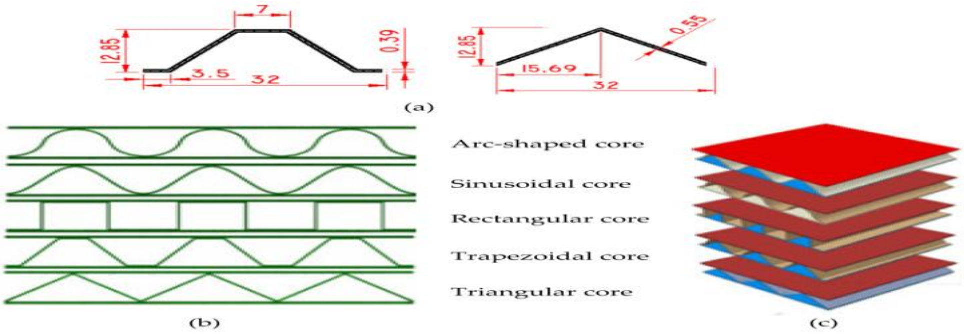


Fig.6 (a)Sketch of five types of unit cell; Maps of the five sandwich panels with corrugated-core geometric configuration: (b) Cross-sections and (c) Axonometric drawing [15].

2.2.3. Hybrid Core: Recently, through inserting various materials into the interstices of monolithic cores, the so-called hybrid core can satisfy the additional functionality requirement of severe engineering applications, such as ballistic and blast resistance, impact noise, and vibration absorption, etc. Figure 7a,b shows the typical hybrid core [16]

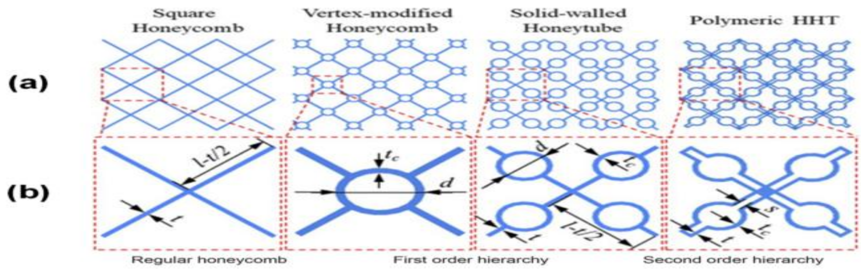


Fig 7(a,b) Illustration of HHTs together with square honeycomb, vertex modified honeycomb, solid walled honey tubes, and polymeric HHT [16]

2.2.5. Graded Core: The growing necessity of lightweight and crash-protecting structures, an innovative class of structural configuration, specifically functionally graded structures (FGSs) whose density changes continuously in one direction, has recently attracted attention due to the specific advantage of tailorable energy absorption and blast protective ability [17]. Figure 8 shows the typical graded core .

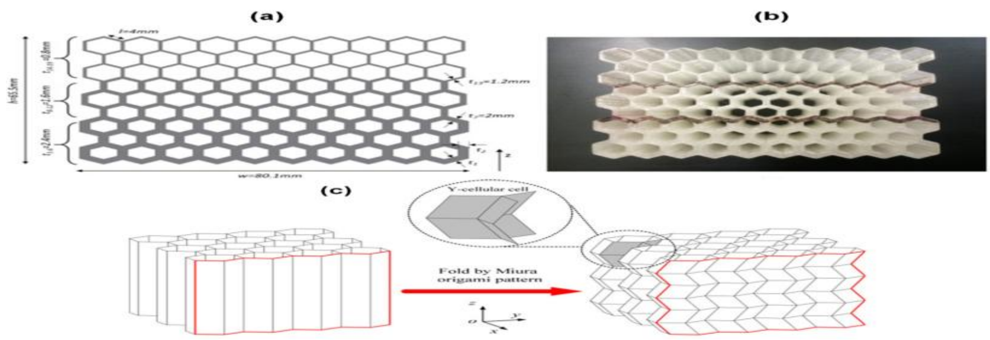


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Fig. 8 (a) Design details of 3 stage graded hexagon; (b) The test specimens produced by FFF 3D printing process [17]; (c) Plan used in the construction of pre-folded honeycomb [18].

2.2.6. Folded Core: The core structure with a periodic bent pattern is well-known as folder core. The folded cores not only resolve the problem of humidity accumulation owing to their exposed ventilation channels, but also serve as efficient energy absorption structures. Figure 10c shows the typical folded core [18].

2.2.7. Smart Core: Smart core materials efficiently utilize the design advantage of the sandwich structure into lightweight load-bearing smart composite sandwich structures for a wide range of applications, which includes noise and vibration control to mechanical power transmission and structural health monitoring systems. The smart core sandwich structure can be classified according to the type of material used, such as: piezoelectric, shape memory polymer (SMP), magnetorheological fluid (MRF), magneto-rheological elastomers (MREs), electrorheological fluid (ERF), and electrorheological elastomer (ERE) sandwich beam.

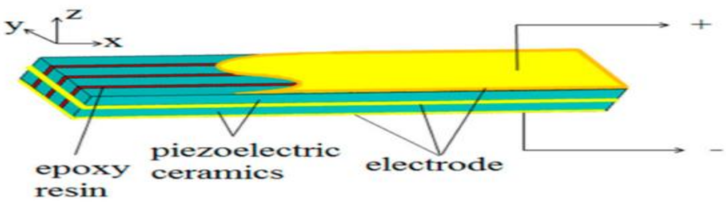

Figure 11. Structure of the piezoelectric composite bi-laminated vibrator [82].

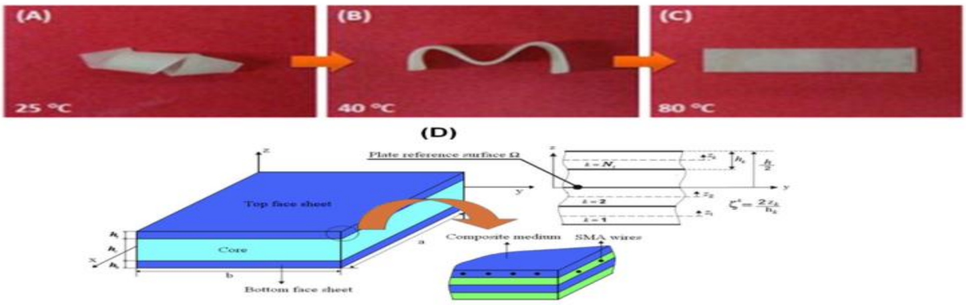

Fig.9 The sequential recovery of the epoxy/polycaprolactone composite (A) Deformation from a temporary shape, (B) Deformation to temporary shape, (C) Deformation to a permanent shape [19],(D) Geometry and coordinate systems of sandwich plate with SMA hybrid composite faces [20].

3. Composite Skin Material:

The indispensable property of skin used in the sandwich structure is to resist in plane shearing and out-of-plane compressive load and to prevent itself from bending and fracturing. Nearly all structural materials which are accessible in the form of thin sheets may be used to form the faces of the sandwich panel. The material for the face sheet should have good toughness, hardness, and impact resistance ability. The composite skin in this particular case can be well suited compared to virgin material that satisfies the above requirement [21]. The composite skin has recently shown applications in various industries. For instance, the panels in aircraft structures make use of composite steel, aluminum, or other metals, even though reinforced plastics are very often adopted in remarkable applications to reduce weight. The skin material is broadly classified into fiber reinforced composites, metal-matrix composites, and polymer matrix composites

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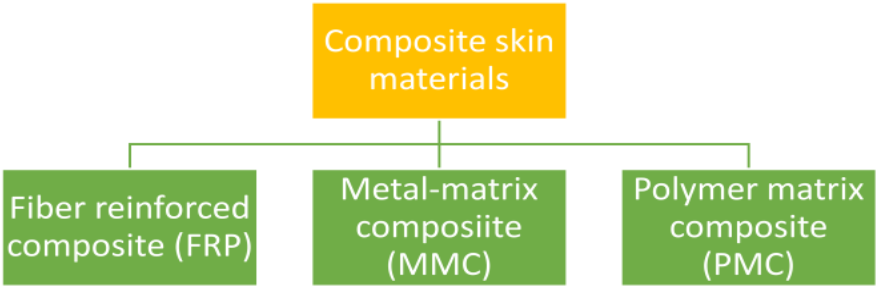


Figure 10. Classification of composite skin material.

3.1 Fiber Reinforced Composites: Fiber reinforced composites (FRCs) are a group of structural composites that consist of a reinforcing material, usually fibrous or particulate. Reinforcing materials, such as glass fiber, carbon fiber, and Kevlar fiber are available in the form of fibrous or particulate form. The matrix can be a thermoset or thermoplastic polymer. In FRCs, elevated strength and rigidity make them able to abolish the fiber direction. Recently, FRCs were widely used in sports apparatus, infrastructure applications, and racing bicycles wherein carbon fiber is the reinforcing material and thermoset polymer is the matrix used. The only one literature survey in the context of FRCs: Barile et al. [22] reported on the mechanical characterization of carbon fiber reinforced plastic under tensile compression test with and without stitching. It is observed that with innovative stitching and fiber arrangement, there is a 14.5 and 11% increase in ultimate tensile and Young's modulus, respectively.

3.2. Metal Matrix Composites: Metal matrix composites (MMCs) are among the fastest growing composite material family due to their potential tailored ability and high-temperature sustainability. Metal matrix composites are extensively employed in the aerospace, nautical, and automobile industries due to their significantly expanded strength, stiffness, outstanding biocompati-bility, and weight diminishment when contrasted with that of conventional materials. In MMCs, the reinforcing material is metal or nonmetal, such as short carbon fiber, which can be continuous or discontinuous in a matrix of metal such as aluminum [23], magne- sium [24], or titanium [25] suspended in a matrix.

3.3. Polymer Matrix Composite: Polymers are commonly used in the manufacture of pipes, storage tanks, gears, bearing materials, automotive body parts, medical instruments, and other applications due to their corrosion resistance, light weight, and low cost. Although polymers exhibit superior properties, they still possess some critical loopholes, such as lack of stiffness, low rigidity, and poor wear resistance. To overcome these, polymer composites are developed in due course. The polymer matrix composites (PMCs) are a new class of composite with improved properties compared to those of parent polymer by the addition of fillers. In polymer composites, the reinforcing material may be made of fibers, flakes, platelets, spheres, or other forms in a matrix of polymer, such as high-density polyethylene

4. Joining Technique:

The performance of load bearing, lightweight sandwich structures requires a novel joining technique to accomplish the prime requirement of firm amalgamation skin with the core. The joining techniques play a vital role in the fabrication of a sandwich structure, which can act as a potential energy transforming unit from the skin to the core. The joining procedures adopted by the researchers are wide and diverse depending on their material properties, such as place of application and overall strength requirement. Among the joining technology, one can find heated press [28], vacuum bagging [29], Z-pinning [30], J-hooking [31], stitching [32], bolting [33], and adhesives [21] are usually adopted in the fabrication of sandwich structures, which is illustrated in Figure 11.

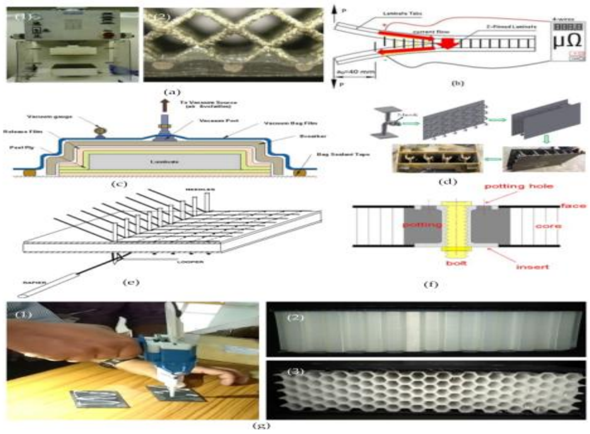


Figure 11. (a) Heated press (1) manufacture setup (2) skin–core bond details of SS316L lattice core and CFRP skins [28], (b) Z-pinning technique [29], (c) Vacuum beg setup [30], (d) J-hooking technique [31], (e) Stitching technique [32], (f) Bolting technique [33], (g) Adhesive technique; (1) Adhesive gun; (2) Sandwich construction in out-of-plane; and (3) In-plane direction [21].

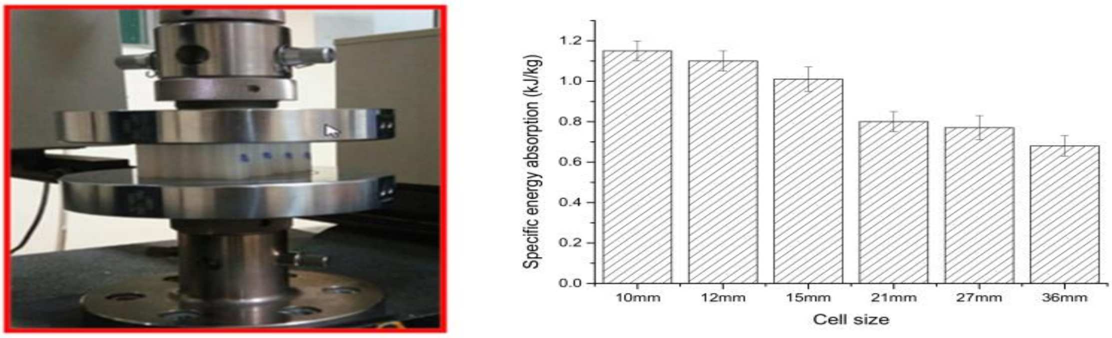
5. Testing and Performance:

5.1. Compression Test: The compressive test for a sandwich core panel is performed according to ASTM C 365 standard [34]. Compressive strength and modulus are usually determined from the above test with a nominal size of the specimen as 75.6 × 75.6 mm. The compressive strength deals with the ultimate compressive stress that a sandwich structure is proficient in withstanding without undergoing fracture, whereas modulus is the slope in the stress vs. strain curve, which measures the stiffness of the structure. The compressive strength and modulus are measured using the following equations [35].

$$\sigma_c = \frac{P_c}{A_c}$$

$$E_c = \frac{m.t}{A_c}$$

The symbols used in the above equation may be referred to in the literature of Zaharia et al. [35].



(a) (b)

Figure 18. (a) Compression test setup; (b) Specific energy absorption vs. cell size [21].

5.2. Three Point Bending Test: The three-point bending test is performed as per ASTM C 393 test standard [36]. The strength (σb) and modulus during bending of the sandwich core beam is measured as per the following equation [37].

$$\sigma_b = \frac{3PS}{2bd^2}$$

$$E_b = \frac{S^3 m}{4bd^3}$$

Where, P = force at a given point; S = length of support span; b = width of the sandwich specimen; d =

thickness of the sandwich specimen.

The energy absorption and specific energy absorption are obtained as per the following equation [37].

$$EA = \int_0^d F(\delta)d\delta$$

$$SEA = \frac{EA}{m} = \frac{\int_0^d F(\delta)d\delta}{m}$$

The symbols used above have similar meanings as in the literature [37]. Sun et al. [38] carried out three-point bending analysis ofaluminum honeycomb core with carbon fiber face sheet toughened by short aramid fiber tissues as well as carbon fiber belts. The cell size and wall thickness of the honeycomb were 6 mm and 0.06 mm, respectively. Figure 19-a shows the load vs. displacement curve of three trials of sandwich core under three-point bending load. It was noted that the average peak load was increased by 39.8, 26.8, and 18.1% for interfacial toughening samples compared without toughening. The bending deformation behaviour is represented in Figure 19-b,c.

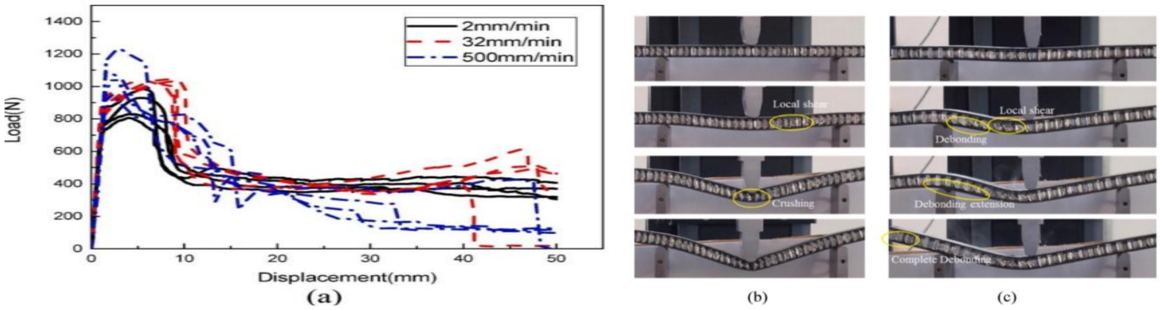


Figure19. (a) Load displacement curve during three-point bending test; (b,c) Deformation mode of a sandwich specimen under three-point bending test [38].

5.3. Impact Test: Impact testing is a crucial practice to measure the factors related to the dynamic fracture of composite sandwich material. The impact range is classified into low velocity and high velocity when the range is <10 m/s and >50 m/s, respectively [178]. The impact test of sandwich structure is normally carried out through a drop tower impact test equipment. The following important equation can be used to analyze the impact velocity [179].

Impact velocity $V = \sqrt{2gh}$

where, 'g' = acceleration due to gravity and 'h' = drop height in meter

Potential energy = mgh

'm' = drop mass

Ozen et al. [40] reported the low velocity impact behaviour of acrylonitrile-butadiene- styrene (ABS) based thermoplastic re-entrant honeycomb cores and carbon fiber reinforced plastic (CFRP) face sheets at various impact energies, i.e., 20, 40, and 70 J. The specimens were fabricated via a 3D printing route and the test was carried out at both out-plane and in- plane orientations. Figure 20 illustrates the force vs. time vs. energy curve, and it was noted that the re-entrant honeycomb along the in-plane orientation revealed superior impact energy dissipation behavior when compared to out-of-plane orientations.

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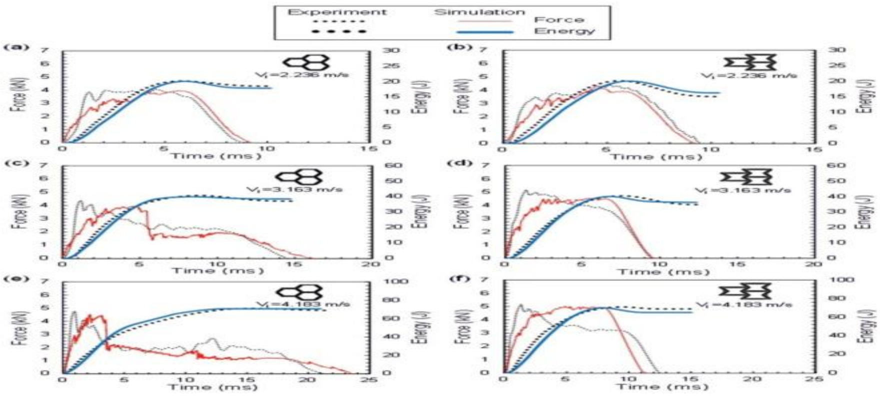


Figure 20. (a–f) Out-of-plane orientation experimental and FEM impact results of the honeycomb and re-entrant sandwich beam at velocities of 2.236, 3.163, and 4.183 m/s [40].

6. Thermal insulation: The concepts on building configuration that can reduce heat gain in varied a hot climate is depicted by various factors like, Walls, Windows, Roofs, and Adjacent Walls etc. Thermal insulation plays a vital role in various areas across different industries and sectors. Here is a comprehensive list of areas where thermal insulation is commonly applied:Buildings and Construction, Industrial and Manufacturing, Transportation, Power Generation and Utilities, Oil and Gas Industry Food and Beverage Industry etc.

N. M. Thanu et al.[41] experimental study conducted on solar passive house, where the single pass earth-air-pipe system was installed. The other passive features of the house include properly sized overhangs, cavity walls, earth bermed walls, pyramid roof enclosures, verandas, and a central patio. It is necessary to enhance the thermal insulation performance of buildings because of the need for reducing the greenhouse gas emission and potential effect of improving energy efficiency. Cork, cellulose, glass wool, rock wool, vacuum insulation panels (VIPs), aerogels and polymeric foams are some of the potential candidates for thermal insulation materials

6.1 Water Glass - Graphite Microparticles: XRD analysis of the samples subjected to heating to 400 ° C showed that the material is able to maintain chemical structure unchanged, which confirms its higher thermal stability. The experimentally obtained dependence of the specific heat capacity and thermal conductivity coefficient on temperature showed good thermal insulation properties of the composite material. [44]

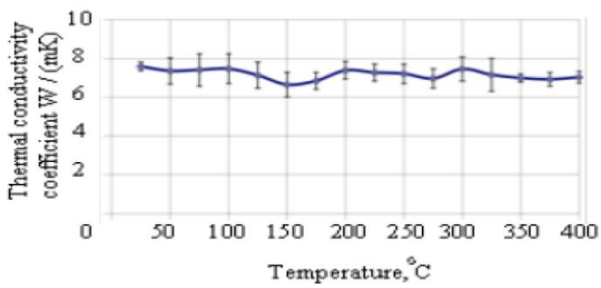
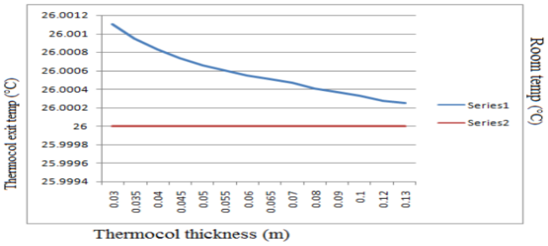


Figure 7. Temperature dependence of thermal conductivity coefficient λ of the CM samples (a) and specific heat ccm in the range of 25°C to 400°C [44]

6.2 Polystyrene composite: The composite materials, considered are concrete (M20) plus Polyurethane foam, concrete plus Polystyrene (thermocol), G.I. Sheet with Polyurethane foam and G.I. sheet with

Polystyrene. This composite material sandwich between reflective coating, water proofing compound layer and are further analysed for techno-economical feasibility.[45]



Graph.11. Thermocol exit temperature (°C) Vs thickness of thermocol (m2)

Figure 8. Thermocol exit Temperature (°C) Vs thermal transmittance (W/ m2- K)[45]

6.3 Ultralight materials: Ultralight materials are solids with a density of less than 10 mg/cm3, including silica aerogels, carbon nanotube aerogels, aerographite, metallic foams, polymeric foams, and metallic microlattices. The density of air is about 1.275 mg/cm3, which means that the air in the pores contributes significantly to the density of these materials in atmospheric conditions. They can be classified by production method as aerogels, stochastic foams, and structured cellular materials.[wiki]

7.Integrated Sandwich Composite Material: The concept of "Integrated Sandwich Composite Material" is a novel approach to constructing composite materials with enhanced structural properties and Thermal insulation properties

Conclusion:

The concept of "Integrated Sandwich Composite Material" presents a compelling approach to developing materials that exhibit remarkable strength, lightweight characteristics, and additional functionalities. By combining a core material with face sheets and securely bonding them together, this concept offers enhanced structural properties and opens up new possibilities for various industries.

Future Scope:

The concept of integrated sandwich composite materials holds significant potential for further development and innovation. Here are a few areas of future scope:

1. Material Advancements: Continued research in material science can lead to the discovery of new lightweight and high-strength materials that can be integrated into sandwich composites. Advances in nanotechnology and the development of novel materials with superior mechanical properties could revolutionize the field.
2. Manufacturing Techniques: Further advancements in manufacturing techniques will improve the efficiency and scalability of producing integrated sandwich composite materials. Automation, additive manufacturing, and scalability of producing integrated sandwich composite materials. Automation, additive manufacturing, and other innovative production methods could reduce costs and enable the fabrication of complex geometries.
3. Functional Integration: The integration of additional functionalities within sandwich composites can be expanded further. This includes the development of smart materials that can actively respond to environmental changes, self-healing capabilities, and enhanced sensing and actuation functionalities.

4. Sustainability: Incorporating sustainable and eco-friendly materials into integrated sandwich composites is an important avenue for future development. The focus on recyclability, biodegradability, and reduced carbon footprint will align with the growing need for environmentally friendly solutions

5. Performance Characteristics: Experiments, Numerical Solution, Optimization Technique, Analysis and validation.

Purpose of Study:

The purpose of studying the concept of "Integrated Sandwich Composite Material" is to expand our knowledge and understanding of this innovative material approach, uncover its benefits and applications, and pave the way for future advancements that can revolutionize industries, improve performance, and drive innovation.

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