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Investigation of Mechanical and Thermal Behaviour of Natural Sandwich Composite Materials for Partition Walls

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ABSTRACT

The need to achieve environmental sustainability has moved the construction sector to show great interest in natural materials that are eco-friendly and possessing high strength to weight ratio, better thermal and mechanical properties, high stiffness and considerable limiting oxygen indexes as well. In response to these requirements, an attempt has been made to study the mechanical and thermal behaviour of natural composite sandwich made of flax reinforcement and coir as core material. The composite sandwiches are fabricated using hand layup technique as per the required dimensions of the specific tests. Experiments were conducted to predict the thermal and mechanical properties, viz. thermal conductivity, limiting oxygen index and tensile strength and the results were discussed. Glass fiber as reinforcement and polyurethane foam as core material was also used to fabricate the composite sandwiches for the purpose of comparison.

Keywords: *Composite sandwich, Flax, Glass, Coir, Polyurethane foam*

I. INTRODUCTION

The increased consumption of fossil fuels has initiated a great effort on the development and exploitation of green energy resources in every sector. The building sector is one among them that consumes a large amount of energy to provide various comfort. A substantial amount of energy is utilized in buildings to provide thermal comfort. The proper selection of materials can prove to reduce this consumption of energy to a large extent.

A significant growth in composite sandwich technology has been induced by the rising demand for lightweight structures in buildings. Composite sandwiches are a combination of two thin face sheets with high strength to weight ratio, separated by a light weight core of considerable thickness. The properties of the sandwich structures depend on the type of material used. The usage of natural materials in these structures for building applications is gaining more attention nowadays and many researches have been focussed on this area. Synthetic fibres like glass and carbon as reinforcement and polyurethane as core material are incorporated in composite sandwiches. The emissions of high level of carbon dioxide and non-biodegradable behaviour of synthetic materials limit its usage in building applications. Therefore, introducing natural materials in these applications prove to provide many benefits to environment because of their good mechanical, thermal and sound absorption properties, biodegradability, availability and cost effectiveness.

During last few years, many researchers have involved in the investigation of incorporating natural fibers as reinforcement in sandwich structures. Flax is one among them, possessing comparable mechanical properties with E-glass fiber. Flax fibers are produced from the stems of the flax plant. On the other hand, coir is a naturally available material obtained from the outer husk of coconut, having remarkable properties like good thermal insulation, better acoustic insulation and excellent damping properties. At present, the use of coir in roofing's and insulation has expanded worldwide due to the development of coir derived materials and its excellent character.

Few researchers have also studied on the thermal and mechanical behaviour of composite sandwiches made of natural materials for partition applications. [1-5] Nadia et.al investigated on the mechanical strength of multi layered sandwich panels made of wood veneer of Aleppo pine as face sheet and cork agglomerate as core material and concluded that the increase in layers of fiber increased the mechanical strength. [6] Sarasini et.al. investigated the response of green sandwich structures to low velocity impacts and they concluded that this combination could be renewable alternative to the traditional glass fiber and synthetic foam because of its peculiar mechanical behaviour. [7] Aidan and Pedram studied the behaviour of sandwich beams made of green materials and concluded an increase in shear behaviour. [8] Kenneth and Amir investigated the behaviour of the flax reinforced sandwich panel exposed to different ambient temperatures and concluded that the failure modes of the sandwich panels were not impacted by the temperatures, rather it is governed by the core density and overall stiffness of flax fiber. [9] Vitale et.al. investigated the thermal behaviour of glass, carbon and jute fiber with polyester resin as skin material and balsa wood and divinycell as core material by using thermal conductivity test and concluded that a material can be considered as an appropriate thermal insulator if its thermal conductivity is 0.15 W/m K or less. [10]

II. EXPERIMENTAL PROCEDURE

A. Materials

The materials used to fabricate sandwich composite were flax fiber (skin reinforcement) and coir (core). Flax fiber in the form of bidirectional woven was obtained from Lineo, France. Coir was obtained from Adhi Annam Coir Comforts Private Limited, India. The density of the coir was 300 kg m^{-3}. The E-glass fibre (skin reinforcement) and polyurethane foam (core) has been used to fabricate composite sandwich for comparison purpose. The E-glass fibers in the form of bidirectional woven were purchased from CovaiSeenu & Company, India. The epoxy resin used was LY556 Grade with a HY951 hardener supplied by CovaiSeenu & Company, India.

B. Composite sandwich fabrication

Composite sandwiches were fabricated using hand layup process, being simple and traditional technique provides better adhesion between fiber layers. Figure 1 shows the hand layup process and the tools used for fabrication. The fiber layers are placed one by one in the mould cavity with the simultaneous application of liquid resin on each layer. The process is repeated until the required thickness is achieved. The coir is then placed on the completed bottom skin. The top skin was stacked up like the bottom skin. After the completion of the layup, the setup is allowed to cure. After 24 hours, the cured composite sandwiches were removed from the mould cavity. Then the samples were cut as per the ASTM standards. The procedure for fabricating the composite sandwich is same for all the combination. Table 1 presents the different combinations of composite sandwiches manufactured and tested.

Fig. 1 Hand layup process

C. Thermal conductivity

Thermal conductivity, being one of the essential properties, is used to quantify different insulation materials. The main requirement of the partition materials in buildings is to restrict the transfer of heat from the surrounding to the inside. Therefore the materials used must possess low thermal conductivity. The thermal conductivity for the fabricated sandwich composites are measured by Heat Flow Meter according to the ASTM standard C518. Figure 2 shows the heat flow meter for measuring thermal conductivity. The samples with dimensions 300 mm × 300 mm × 13 mm are placed between two heated plates of different temperatures, viz one being higher and the other lower. Two heat flux transducers covering a large area on both sides of the specimen are used to measure the heat flowing through the specimen. On the attainment of thermal equilibrium, the outputs of the transducers are measured. The thermal conductivity of the sample (k) is calculated by using equation (1),

$$k = q\, t / \Delta T \qquad (1)$$

where, q is the average heat flux (W/m^2),
t is the thickness of the specimen (m) and
ΔT is the temperature difference (K).

D. Limiting oxygen index

The limiting oxygen index test is used to characterize the flammability properties of the partition materials in buildings. The minimum concentration of oxygen required to sustain flame in the samples is determined as per standard ASTM D-2863. Figure 3 shows the limiting oxygen index tester equipment. The samples with dimensions 50 mm × 50 mm × 13 mm are placed in a heat resistance gas column, subjected to a mixture of nitrogen and oxygen. The sample, after ignition at one end, the percentage of oxygen is reduced and the minimum concentration for a sustainable burning is measured.

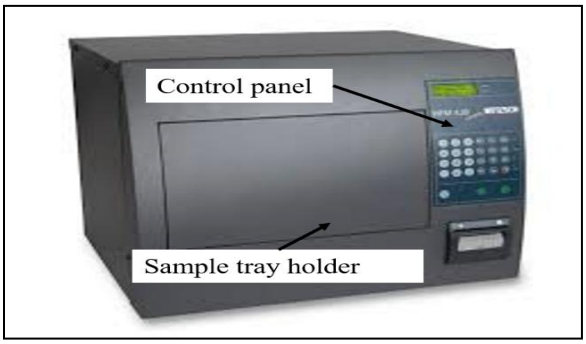


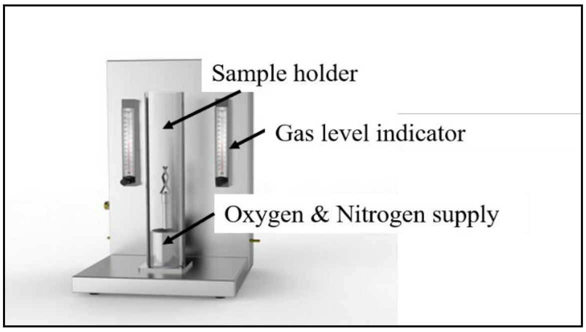
Fig.2 Thermal conductivity tester

Table 1 Different combination of composite sandwiches

S. No.	Sample name*	Sandwich composite		Skin thickness (mm)	Core thickness (mm)	Sandwich thickness (mm)
		Skin	Core			
1	FECR	Flax /Epoxy	Coir	1.5	10	13
2	FEPU	Flax /Epoxy	PU foam	1.5	10	13
3	GECR	Glass/Epoxy	Coir	1.5	10	13
4	GEPU	Glass/Epoxy	PU foam	1.5	10	13

E. Tensile test

The tensile test is essential to characterize the mechanical behaviour of the different materials, so that the materials can be used in appropriate applications. The tensile test for the sandwich composites were performed as per ASTM standard D 3039 in Universal Testing Machine. A 150 mm× 40 mm sample with a thickness of 13 mm was positioned at the centre of the cross heads. A constant speed of 2 mm/min was used. The material properties are expressed in terms of stress and strain. The typical stress vs strain curves for the sandwich composites were generated directly from the machine during the tensile loading of the samples. Figure 4 shows the tensile strength tester.



* F- Flax, E- Epoxy, CR- Coir, PU- Polyurethane foam

Fig.3 Limiting oxygen index tester

III. RESULTS AND DISCUSSION

Experiments were conducted to characterize the thermal and mechanical response of the composite sandwich and the observations are discussed.

A. Analysis of thermal conductivity

The thermal conductivity of composite sandwich panels was measured and their potential as thermal insulators to be used as components for partitions was assessed and compared with the thermal conductivity of the traditionally used synthetic materials. The thermal conductivity of the different composite sandwich samples is shown in Fig. 5. The experimental results show that the composite sandwich with flax as reinforcement and coir as core material has the lower thermal conductivity among the composite sandwiches taken for study.

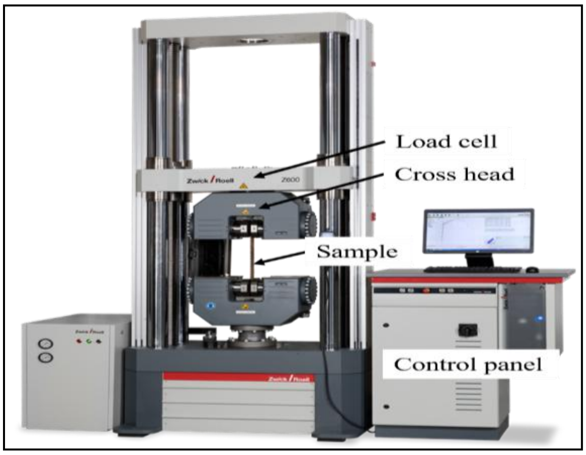


Fig 4 Tensile strength tester

It is observed that flax fiber-reinforced coir composite sandwich (FECR) sample has 15.78%, 38.46%, and 39.62% lower thermal conductivity than flax fiber reinforced foam sandwich (FEPU), glass fiber reinforced coir sandwich (GECR) and glass fiber reinforced foam sandwich (GEPU) respectively.

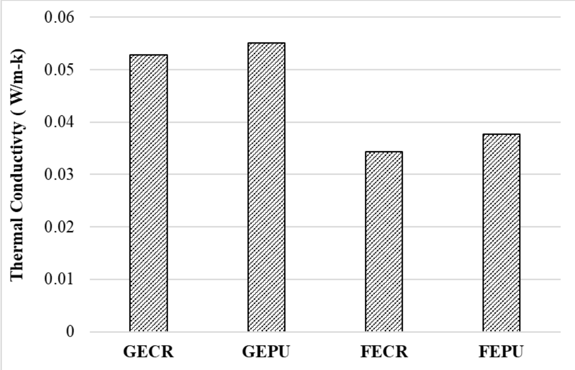


Fig.5 Thermal conductivity of composite sandwiches

The lower thermal conductivity in FECR is achieved due to the factor of density of the fibers and the coir material. The flax fibers offer larger space areas in between the layer of the fibers for the entrapment of air, the result being accounting in a longer time for the travel of air involved from one end to the other. [11] On the other hand, coir, with low density, accounts for the convection to occur, resisting the heat flow, adding to the lower conductivity of the sample. The thermal conductivity in GEPU is comparatively high due to solid nature of glass fiber, helps to conduct more heat. The lower conductivity of the FEPU suits as a best alternate for the traditional partition materials.

B. Analysis of limiting oxygen index

The LOI values for the composite sandwiches was tested and assessed. Figure 6 shows the LOI values for samples. It is observed that the LOI values for the samples were affected by the surrounding temperature. The decrease in LOI value was noted as the surrounding temperature increased. The flax fiber reinforced coir sandwich panel (FECR) possess the higher LOI value, indicating the oxygen concentration required for sustained burning is high. It is observed that, the flax fiber reinforced coir sandwich panel (FECR) has 4%, 8.33% and 4% higher LOI value than glass fiber reinforced coir sandwich panel

(GECR), glass fiber reinforced foam sandwich panel (GEPU) and flax fiber reinforced foam sandwich panel (FEPU). Therefore, FECR can be used as alternate for the partition materials since it possess higher LOI value as of synthetic materials.

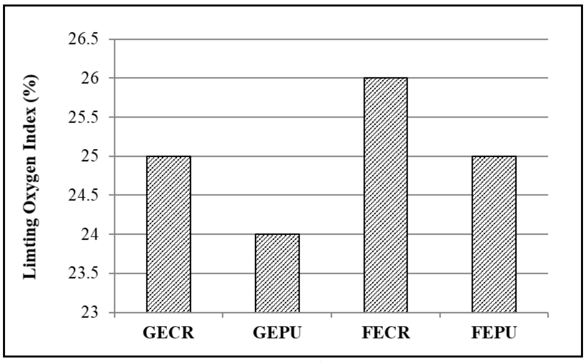


Fig.6 LOI values of the samples

C. Analysis of tensile strength

The tensile behaviour of the composite sandwiches were tested and assessed. Figure 7 shows the tensile strength values of the composite sandwiches. From the experiments, it is observed that the glass fiber reinforced coir sandwich panel (GECR) exhibited higher tensile strength due to the increased tensile strength of the glass fiber. The flax fiber having superior specific properties does not contribute to the strength of the flax fiber. The lack of interfacial bonding between flax and matrix also leads to lower the load carrying capability of FECR and FEPU. This is due to hydrophilic nature of flax fiber and hydrophobic nature of epoxy resin. It is observed that, the glass fiber reinforced coir sandwich panel (GECR) has 46.06 % higher tensile strength than the flax fiber reinforced coir sandwich panel (FECR) and the glass fiber reinforced foam sandwich panel (GEPU) has 44.98% higher strength than the flax fiber reinforced foam sandwich panel (FEPU). The flax fiber reinforced coir sandwich panel (FECR) can be used as alternate for synthetic materials, in applications that does not require load bearing capability.

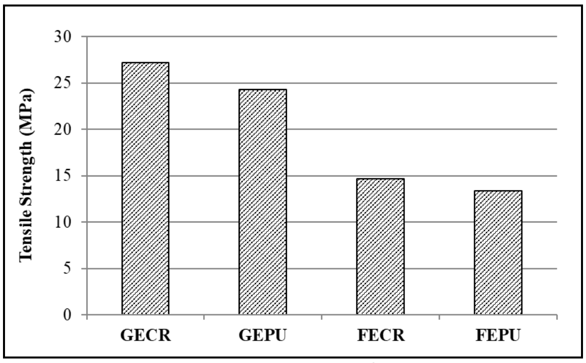


Fig.7 Tensile strength values of the samples

CONCLUSION

The experiments were conducted to reveal the thermal conductivity, flammability, and tensile strength of the samples based on which the performance of the composite sandwich was studied. The performance output expected is lower thermal conductivity, higher limiting oxygen index and higher tensile strength. The results reveal that flax fiber reinforced coir sandwich panel (FECR) exhibited lower thermal conductivity of 0.03 W/m-K, compared to the other samples. On the other hand, the limiting oxygen index values for all the combinations of sandwich panels does not vary much and the FECR exhibited higher LOI value of 26%, as the performance expected. The tensile strength of the glass fiber reinforced coir panel exhibited higher strength of 27.16 MPa in correlation with the flax fiber reinforced panels due to the limitation of the flax fibers, absorbing moisture to a considerable extent. The results obtained from experimental tests reveal that the composite sandwich performance essentially depends on the type of fiber, core, and the resin materials.

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