

# Multi-Functional Composites for Encapsulation of Phase Change Materials in Thermal Energy Storage systems

Selvakumar.P<sup>1</sup>, Selva Prabhu.S<sup>2</sup>, Heric.J.S<sup>3</sup>, Beniyel.M<sup>4</sup>, Suresh.K<sup>5</sup>, Jude.S.A.A<sup>6</sup>

*<sup>1</sup>Professor, Dept. of Mechanical Engineering, PSN College of Engineering and Technology, Tamilnadu, India*

*<sup>2,3,4,5,6</sup>Research Scholar, PSN College of Engineering and Technology, Tirunelveli, Tamilnadu, India*

\*\*\*

**Abstract** - In this work preparation and characterization of composite materials for phase change material encapsulation in thermal energy storage (TES) was focused. The structure was produced by combining epoxy resin with paraffinic phase change material (PCM) mixed with thermal conductive fillers which is reinforced with carbon fibre. The thermal response was conserved after various thermal heating and cooling cycles. Due to the thermal conductivity fillers present inside the composite laminates increases the thermal conductivity of the material. Carbonaceous particle was mixed with the epoxy resin with 1% weight ratio, thermal conductivity is enhanced approximately 33% and 21% was found for graphene nanoplatelets and expanded graphite mixtures respectively. Infrared emission sensor is used for monitoring the laminates cooling rate. Thermal analysis was carried out for different ratios of thermal conductivity fillers, carbon nanotubes in epoxy resin and the potential material with higher thermal properties was found by using various analysis and structure properties were studied by using SEM analysis

**Key Words:** PCM - Phase Change Material, TES - Thermal Energy Storage, SEM - Scanning Electron Microscopy.

## 1. INTRODUCTION

Thermal energy can be stored as latent heat and sensible heat. Thermal energy storage is the temporary storage which is used for storing excess heat. Among sensible and latent heat storage, The latent heat system consist of phase change material can store and release large amount of energy this system consist of large phase change enthalpy. Pcm can function in a specific temperature with small volume deviation. Paraffin waxes, ethylene glycol and fatty acids are the common PCM's. Though paraffin wax has enormous advantages it has very low thermal conductivity and leakage problem is encountered in the molten state. Leakage can be overcome by micro or nano encapsulation of pcm by shells are by polymer confinement. Thermal conductivity also the main factor considered for phase change material in order to increase the thermal conductivity, conductive materials such as nano fillers are added. Metals are used extensively due to their excellent thermal properties and mechanical strength. Although metals having some demerits such as chemical compatibility and issues regarding fouling. The advantages of polymer or plastic components are they are reduced in weight, low cost, compatible with corrosive fluids and coefficient of thermal expansion is low. The major barrier is Thermal conductivity of polymer material is low. When the

thermal conductivity increases it can be used in various fields. PCM's are used in building industry and also employed in electronic device cooling applications. Weight and volume are also main parameters considered in TES System. Polymer composites with good mechanical properties and light weight with structural and non-structural functions. Shape-stabilizing agent (carbon-based, organic, ceramic or metallic), up to rapidly little has been done to mean and delineate polymer-matrix structural composites with TES capacity.

The aim of the work to produce epoxy /carbon structural laminates having the capacity to store and release large amount of thermal energy in a certain temperature range. Epoxy resin is combined with carbon fibers and paraffin wax shape stabilized and also with alumina and graphite. In this paper the thermal properties of the laminates were investigated extensively.

### 1.1.PHASE CHANGE MATERIAL

When a material melts or vaporizes, it absorbs heat; when it changes to a solid (crystallizes) or to a liquid (condenses), it releases this heat. This phase change is used for storing thermal energy in PCMs. Also, the PCM has been subjected to accelerated life cycling equivalent to 12 years of performance with no loss of capacity. With the physical equilibrium of the PCM established after the first few cycles, the phase change appears to be stable and the TES capacity constant indefinitely, or at least as long as the life of chiller equipment used to freeze the PCM. Latent TES in the temperature range 0–120 °C is of interest for a variety of low-temperature applications, such as space heating, domestic hot water production, heat-pump-assisted space heating, and greenhouse heating and solar cooling. The melting and freezing characteristics of PCMs, and their ability to undergo thermal cycling, and their compatibility with construction materials is essential for assessing the short and long-term performance of a latent TES. Using two different measurement techniques (e.g., differential scanning calorimetry and thermal analysis), the melting and freezing behavior of PCMs can be determined. Thermal cycling and corrosion behavior are also of importance in the appropriate choice of materials as they affect the life of a latent heat storage.

## 2. EXPERIMENTAL WORK

The Polymer Thermal conductive barrier made by Epoxy/Carbon Fibers. The reinforcement material carbon fiber is 3k plain weave type used to fabricate the thermal conductive material. Carbon fiber plain weave has good mechanical formability and strength than 6k, 12k and twill weave. Carbon fiber 3k tow (3000 filaments per fiber) and is a commonly selected fabric style for aerodynamic parts. It delivers uniform strength in both longitudinal and latitudinal directions. A high-performance resin system with curing agent has been pre-impregnated into the fabric for an ideal 35% strength-to-weight ratio, and repeatable high-quality results.

The Thermal Conductive Fillers (TCFs) we have to use Aluminium and Copper. Those metal has desirable thermal conductive properties. It's can be used as a filler to improve the thermal carrying properties of epoxy/carbon fiber reinforced polymer composite. Lamellar structures will make by the lamellar die pattern die. Interlamellar Cavities filled by the PCM materials and fully concealed by thermal conductive reinforcement materials.

The most significant difference between polymer and metal materials is the thermal conductivity. The thermal Conductivities of most polymers listed are lower than 1W/mK, which are around 100 times lower than those of most metals. Because of this, it might appear futile to pursue polymers for heat transfer application. However, if we consider the application of heat exchangers with corrosive fluids, seawater in particular, the only possible metals will be Cu-Ni alloy and Titanium. Cu-Ni alloys offer good resistance to corrosion, polluted water, and deposit attack, but can be expensive. Recent advances in manufacturing technologies now permit the use of titanium, which is highly resistant to corrosion and provides more flexibility in the design of heat exchangers due to its low density and high strength.

### 2.1. Composite sheet Fabrication

The composite sheets were manufactured through lamination of carbon fiber fabric and epoxy resin with nano aluminium and expanded graphite. The curing agent (Hy 991) had a gel time of approximately 1 hour. Two types of carbon fiber fabric were used, as shown in Table 1.

**Table 1 - Types of carbon fiber fabric used.**

Fabric Type	Areal weight	Direction of the fibers
RC 200 P	200 g m <sup>-2</sup>	Bidirectional plain weave in a 0/90o orientation
RC 200 T	200 g m <sup>-2</sup>	Bidirectional twill weave in a 0/90o orientation

The epoxy resin and the curing agent are weighed, mixed and placed in a desiccator to remove dissolved air using a

vacuum pump for 10 minutes. Three layers of carbon fiber fabric are placed one by one on the positive mold and the resin is evenly spread over each layer with a brush. Carefully bubbles get rid from in between layers. The fabrics are laid on the mold in the sequence presented. Release film and peel ply are used to facilitate the removal of excess resin and to give the desired finishing to the surfaces of the laminates. Finally, the bubbles completely rid by heat gun. The assembly is placed in an environment protect to control the resin curing temperature at 30°C - 50 ° C for at least 10 hours.

After curing, the polymer films are removed resulting in different finishes on the positive (outer) and negative (inner) surfaces of each plate. While a glossier texture is achieved on the former, the inner surface is rougher to facilitate bonding of two identical plates with epoxy resin to form the perfect laminated polymer. Each part is weighed to determine the ratio of carbon fiber fabric to epoxy resin, which is approximately 50% wt. Table 2 presents the main material characteristics of the laminates. The selection of the carbonaceous particle fillers will be discussed in Section 2.2.

**Table - 2: Main material characteristics of the heat exchangers**

Type	Matrix	Carbon fiber fabric	Carbonaceous Fillers
1	Epoxy (50%)	3 layers (50%)	None
2	Epoxy (45%)	3 layers (50%)	Expanded graphite (5%)
3	Epoxy (40%)	3 layers (50%)	Aluminium Particles (10%)

### 2.2. Epoxy Resin Thermal Conductivity Enhancement

In order to improve the thermal performance of the polymer composite, the following thermally conductive carbonaceous particles and Aluminium fillers were selected as potential candidates to increase the thermal conductivity of the epoxy resin: Clear, carbon fiber 3k, expanded graphite (HC 30). Mixing was performed manually using a scoop. The load was limited to 1% wt., since larger loads were observed to greatly increase the viscosity of the epoxy resin (making it harder to mix), thus impairing the lamination of the plates.

The thermal conductivity of the epoxy resin/particle (filler) composite was measured using an IRX-63 Infrared Thermal Laser sensing meter. Specimens were manufactured using a silicone rubber mold to comply with the dimensions specified by the meter manufacturer. Initially, pure epoxy resin specimens were fabricated with and without the application of vacuum to the resin. Air bubble entrainment was inevitable during the resin-curing agent mixing process and this was observed to cause a significant reduction of the

specimen thermal conductivity. During the vacuum process, the resin with the carbonaceous particles showed a more vigorous degassing (resulting from heterogeneous nucleation of gas bubbles on the particles). The pure epoxy resin specimen prepared under vacuum had a consistently higher thermal conductivity in comparison with the others. The epoxy resin specimens mixed with graphene Nanoplatelets and expanded graphite presented the highest values of thermal conductivity.

### 3. RESULTS AND DISCUSSIONS

#### 3.1 Heat transfer Enhancement and thermal conductivity measurement

The effective thermal conductivities of the composite warmness exchanger plates (epoxy resin and carbon fiber cloth composite) had been measured the usage of an IR thermal conductivity meter. Despite its higher size uncertainty in comparison with the Laser comp meter (five% as opposed to 3%, as declared by using their respective manufacturers), the device changed into applied due to its higher flexibility with appreciate to the specified thickness and form of the specimen. Also, for the reason that IR Thermal conductivity meter is primarily based on a brief measurement technique in response to a warmth pulse on the floor, it's miles capable of estimating the "local" powerful thermal conductivity of the vicinity adjacent to the sensor. On this manner, measurements could be accomplished on each sides of the plate (i.e., positive and bad surfaces) to offer an idea approximately the uniformity of the powerful thermal conductivity within the direction perpendicular to the orientation of the fibers. Determine 6 shows the powerful thermal conductivity consequences for the pure epoxy resin and for both facets of the composite plates. The effects for the composite plates are considerably higher. However, there is also a large difference between the effective thermal conductivities measured on the positive side and on the negative side of each plate. This discrepancy is possibly related to the highly anisotropic nature of the composite material due to the carbon fiber fabric layers. The different values of fiber density and orientation give rise to different heat conduction properties in each direction. The different thicknesses of the epoxy resin layer and fiber weavings on each side (positive and negative, see Table 1) may also contribute to the different values of effective thermal conductivity in the direction normal to the fibers on each side. Another aspect is related to the thermal conductivity meter itself, which does not recognize the anisotropy of the different composite layers in its embedded temperature thermal conductivity effusivity correlation. Therefore, as the presence of a carbon fiber fabric layer closer to the negative surface contributes to a more effective heat diffusion through the composite material, a higher apparent thermal conductivity is measured in the direction perpendicular to the orientation of the fibers. A somewhat unexpected result was the consistently higher effective thermal conductivity of the unloaded plate (without

particles) compared to the other plates with carbonaceous particles. To find an explanation for the behaviour of the thermal conductivity, samples of the three composite heat exchanger plates were evaluated in a Hitachi TM3030 scanning electron microscope (SEM).

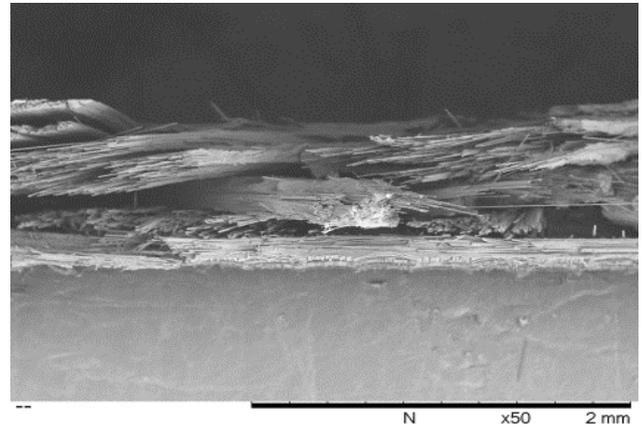


Figure – 1: Sem image of epoxy resin without particle

Fig 1 and 2 with a magnification of 40 times. The samples with carbonaceous particles exhibit the carbon fiber fabric layers further away from each other than in the sample without them. This is an indication that the delamination was more severe in samples with particle loading due to the greater number of voids. The sample with expanded graphite exhibited the greatest delamination.

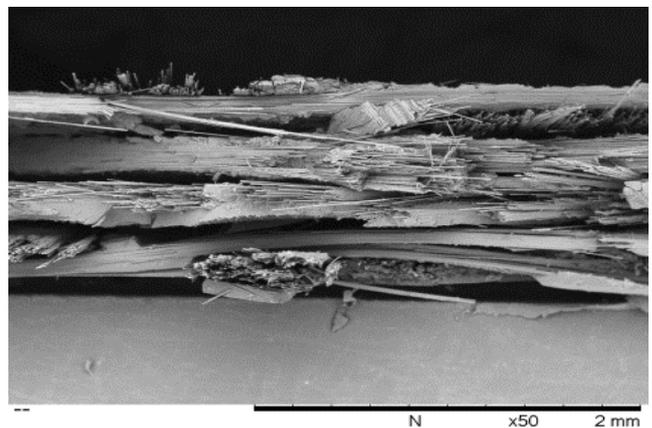


Figure – 2: Sem image of epoxy with expanded graphite particle

### 3. CONCLUSION

From the obtained results it was found that epoxy resin in addition of carbon nanotubes, carbon nanofillers and expanded graphite. An enhancement of approximately 33% and 21% in the thermal conductivity of the epoxy resin was achieved with the addition of 1% wt. graphene nanoplatelets and expanded graphite particles, respectively, And effective thermal conductivity in the range of 5.1 to 5.4 Wm<sup>-1</sup> K<sup>-1</sup> have been found

## REFERENCES

- [1] Hawlader MNA, Uddin MS, Zhu HJ. Encapsulated phase change materials for thermal energy storage: experiments and simulation. *Int J Energy Res* 2002.
- [2] Zaheed-Maheswaran, Process Intensification: Cross-corrugated Polymer Film Compact Heat Exchanger (PFCHE), Ph.D. thesis, University of Newcastle Upon Tyne, 2003.
- [3] Robynne Murray, Louis Desgrosseilliers, Jeremy Stewart, Nick Osbourne, Gina Marin, Alex Safatli, Domyenic Grouix, Mary Anne White. "Design Of Latent Heat Energy Storage System Coupled With A Domestic Hot Water Solar Thermal System". World Renewable Energy Congress 2011 Sweden 8-13 May 2011.
- [4] Regin AF, Solanki SC, Saini JS. Latent heat thermal storage using cylindrical capsule: numerical and experimental investigations. *Renew Energy* 2006.
- [5] M. Wang, Q. Kang, N. Pan, Thermal conductivity enhancement of carbon fiber composites, *Appl. Therm. Eng.* 29 (2009) 418-421.
- [6] S. Wang, J. Qiu, Enhancing thermal conductivity of glass fiber/polymer composites through carbon nanotubes incorporation. *Composites Part B* 41 (2010) 533-536.
- [7] D. Kada, A. Koubaa, G. Tabak, S. Migneault, B. Garnier, A. Boudenne, Tensile properties, thermal conductivity, and thermal stability of short carbon fiber reinforced polypropylene composites, *Polymer Composites* (2016) DOI 10.1002/pc.24093
- [8] Lee, J., Lee, M., Jeon, S. A study of plastic evaporator for domestic freezer/refrigerator. In: *Proceedings of the 23rd International Congress of Refrigeration*. Prague, Czech Republic; 2011, p. Paper 163.
- [9] M. Raudensky, I. Astrouski, M. Dohnal, Intensification of heat transfer of polymeric hollow fiber heat exchangers by chaotisation, *Appl. Therm. Eng.* 113 (2017) 632-638.
- [10] J. Zhuang, C. Huang, G. Zhou, Z. Liu, H. Xu, D. Wu, Y. Fan, Y. Zhang, Influence of factors on heat dissipation performance of composite metal-polymer heat exchanger with rectangular microstructure, *Appl. Therm. Eng.* 102 (2016) 1473-1480.
- [11] T. Malik, C. W. Bullard. Suitability of polymer heat exchangers for air conditioning applications. Air Conditioning and Refrigeration Center (ACRC) Technical Report 237, University of Illinois at Urbana-Champaign (2005).
- [12] T.B. Scheffler, A.J. Leao, Fabrication of polymer film heat transfer elements for energy efficient multi-effect distillation, *Desalination* 222 (2008) 696-710.
- [13] O. Abdelaziz, Development of Multi-Scale, Multi-Physics, Analysis Capability and its Application to Novel Heat Exchanger Design and Optimization, Ph.D. thesis, University of Maryland, 2009
- [14] M.T. Tamura, J.R. Barbosa Jr., Circuitry design of polymer plate heat exchangers based on entropy generation minimization, *International Journal of Mechanical Engineering* over the years, i eir o reto, SP, Brazil.
- [15] J. Cevallos, A. Bar-Cohen, D.C. Deisenroth, Thermal performance of a polymer composite webbed-tube heat exchanger, *Int. J. Heat Mass Transfer* 98 (2016) 845-856.
- [16] Lasercomp Fox 5 User' manual, 2004, Available from [tainsstruments.com](http://tainsstruments.com).
- [17] S.T. Viana, Fabrication and experimental thermal analysis of hybrid composite heat exchangers, D.Eng. thesis (in Portuguese), Federal University of Santa Catarina, 2016.
- [18] ASHRAE Standard 51, Laboratory Methods of Testing Fans for Rating. Atlanta, GA, USA, 1999.
- [19] Coleman, H., Steele, W., Experimentation, Validation, and Uncertainty Analysis for Engineers. 3rd ed., John Wiley & Sons, Inc., 2009.
- [20] C-Therm TCi Thermal Conductivity Analyzer User Manual, X130041 Rev. C, [www.mathisinstruments.com](http://www.mathisinstruments.com).
- [21] T.L. Bergman, F.P. Incropera, D.P. DeWitt, A.S. Lavine, *Fundamentals of Heat and Mass Transfer*. 7th Ed. Wiley, 2011.
- [22] V. Gnielinski, Ein neues Berechnungsverfahren für die Wärmeübertragung im Übergangsbereich zwischen laminarer und turbulenter Rohrströmung. *Forschung im Ingenieurwesen*, v. 61, n. 9, p. 240-248, 1995.
- [23] Chen, Y-M; Ting, J-M. Ultra high thermal conductivity polymer composites, *Carbon* 40, 359-362, 2002.