

EXPERIMENTAL INVESTIGATION ON THERMAL PROPERTIES OF COMPOSITE PHASE CHANGE MATERIAL

Submitted in partial fulfilment of the requirements for the award of

Bachelor of Engineering Degree in

Mechanical Engineering

By

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DEPARTMENT OF MECHANICAL ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with grade "A" by NAAC |12B Status by UGC| Approved by AICTE

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI-600119

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BONAFIDE CERTIFICATE

This is to certify that this project report is the bonafide work of Dhanasekaran.J (Reg.no.37150053), Balaji.K (Reg.no.37150025) who carried out the project entitled **“EXPERIMENTAL INVESTIGATION ON THERMAL PROPERTIES OF COMPOSITE PHASE CHANGE MATERIAL”** under supervision from December 2020 to March 2021

Internal Guide

External Guide

Submitted for viva voce examination held on _____

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DECLARATION

We Dhanasekaran.J (Reg.no.37150053), Balaji.K (37150025) hereby declare that the project that the Project Report entitled “**EXPERIMENTAL INVESTIGAATION ON THERMAL PROPERTIES OF COMPOSITE PHASE CHANGE MATERIAL**” done by me under the guidance of **Mr.V.SRIRAM M.E (PHD)** ,Assistant professor, faculty of mechanical engineering, Sathyabama institute of science and technology is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Mechanical Engineering

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ABSTRACT

In this paper, a composite phase change material supported paraffin and carbon foam derived from starch was ready. The paraffin was encapsulated within the carbon foam that was ready by employing a foaming and steaming methodology at completely different carbonization temperatures. Carbon foams comprised amorphous carbon and were impregnated with paraffin to get the paraffin/carbon foam composites (PCCs). Once change state at 1100 °C, the loading proportion of the carbon foam enabled to succeed in most 72.79%. Paraffin encapsulation failed to lead to any new structure or chemical bonds concerned or modification within the geometry. The latent heats of the sample were 174.3 J/g at the melting temperature (47.9 °C), and 151.4 J/g at the phase change temperature (52.8 °C). Thermal conductivity of PCCs reached up to one.93 times than that of paraffin. The composite natural process material fabrication was cost-effective, atmosphere friendly, with chemicals stable, and appropriate for energy-efficient building applications to possess broad application prospects and worth

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CHAPTER-1

1. INTRODUCTION

Energy may be a crucial material foundation for economic development. This energy model is based on an energy consumption structure dominated by nonrenewable fossil fuels, and in world, the unbalanced supply and demand of heat energy in time and space is problematic and causes significant waste [1]. Thermal energy are often stored by sensible or heat of transformation (phase change heat) of matter, which can be an efficient and reliable method to require care of the balance between heat supply and demand, as compared with the unreliability of other energy storage methods [2–4]. Phase change materials (PCMs) are a kind of energy material that change their state with temperature to end heat storage and release, and this process is cyclically reversible, such PCMs are often reused [5–9]. In recent years, PCMs are widely utilized in air conditioning storage systems, solar energy and building envelopes.

1.1 Technical details and natural resources

Over the past 50 years, differing types of materials, including hydrated salts, paraffin, fatty acids, eutectics of organic and non–organic compounds, and polymers are identified as potential PCMs and are extensively studied and used. Paraffin has many advantages as a sort of commonly used organic solid–liquid phase change material (PCM). It inexpensive, nontoxic, chemically stable, features an appropriate melting point, and massive heat of transformation. Moreover, it's resistant to decomposing at temperatures below 140 °C, which is within the quality working temperature range. However, because of its low thermal conductivity, the applications of paraffin are limited. Hence, plenty of researches has focused on improving the thermal conductivity of paraffin.

Adding high thermal conductivity materials to form PCMs could also be a standard research direction. Although this may improve the thermal conductivity of paraffin, it creates more cost for the PCM application field. Additionally, the use of matrix materials with good thermal conductivity can also effectively improve the thermal conductivity of a PCM while at the same time ensuring that the fabric has an enthalpy of phase transition just like the pure PCM. The matrix materials most often utilized in experiments are high thermal conductivity porous materials. Because of their rich porous structure and massive specific area, porous materials have good adsorption properties. When a PCM encapsulated within the pore structure is converted from solid to liquid, the PCM are often adsorbed inside the pores without leakage. Metal foam [28] used as a supporting material may end in high thermal conductivity and excellent morphological stability, but the metal readily corrodes, and thus the value is

high, and thus the method is complicated, which seriously restricts the appliance development.

1.2 phase change materials

A phase change material (PCM) could also be a substance which releases/absorbs sufficient energy at phase transition to provide useful heat/cooling. Generally the transition are getting to be from one of the first two fundamental states of matter - solid and liquid - to the other. The phase transition also can be between non-classical states of matter, just like the conformity of crystals, where the material goes from conforming to a minimum of one crystalline structure to conforming to a special, which may be a far better or lower energy state.

The energy released/absorbed by phase transition from solid to liquid, or the opposite way around, the heat of fusion is typically much above the sensible heat. Ice, as an example, requires 333.55 J/g to melt, on the opposite hand water will rise one degree further with the addition of just 4.18 J/g. Water/ice is therefore a very useful phase change material and has been used to store winter cold to relax buildings in summer since a minimum of the time of the Achaemenid Empire.

By melting and solidifying at the phase transition temperature (PCT), a PCM is capable of storing and releasing large amounts of energy compared to sensible heat storage. Heat is absorbed or released when the material changes from solid to liquid and therefore the other way around or when the inside structure of the material changes; PCMs are accordingly mentioned as heat of transformation storage (LHS) materials.

There are two principal classes of phase transition material: organic (carbon-containing) materials derived either from petroleum, from plants or from animals; and salt hydrates, which generally either use natural salts from the ocean or from mineral deposits or are by-products of other processes. A third class is solid to solid phase transition.

PCMs are utilized in many different commercial applications where energy storage and/or stable temperatures are required, including, and among others, heating pads, cooling for telephone switching boxes, and clothing.

By far the foremost important potential market is for building heating and cooling. PCMs are currently attracting plenty of attention for this application because of the progressive reduction within the value of renewable electricity, including limited hours of availability, resulting in a misfit between peak demand and availability of supply. In North America, China, Japan, Australia, Southern Europe and other developed countries with hot summers peak supply is at

midday while peak demand is from around 17:00 to 20:00. This creates plenty of demand for storage media.

Solid-liquid phase change materials are usually encapsulated for installation within the top application, to contain within the liquid state. In some applications, especially when incorporation to textiles is required, phase transition materials are micro-encapsulated. Micro-encapsulation allows the material to remain solid, within the type of small bubbles, when the PCM core has melted.

1.2.1 Characteristics and classification of PCM

Latent heat storage square measure usually achieved through changes inside the State of matter from liquid→solid, solid→liquid, solid→gas and liquid→gas. However, solely and liquid→solid section changes square measure sensible for PCMs. though liquid→gas transitions have a far higher heat of transformation than solid→liquid transitions, liquid→gas section changes square measure impractical for thermal storage as a result of massive volumes or high pressures square measure needed to store the materials in their gas section. Solid→solid section changes square measure usually terribly slow and have a relatively low heat of transformation.

Initially, solid→liquid PCMs behave like wise heat storage (SHS) materials; their temperature rises as they absorb heat. In contrast to standard SHS materials, however, once PCMs reach their natural process temperature (their melting point) they absorb massive amounts of heat at a virtually constant temperature till all the material is liquefied. Once the close temperature around a liquid material falls, the PCM solidifies, cathartic its hold on heat of transformation.

A large variety of PCMs square measure out there in any needed temperature vary from -5 up to a hundred ninety $^{\circ}\text{C}$. inside the human comfort vary between twenty and thirty $^{\circ}\text{C}$, some PCMs square measure terribly effective, storing over two hundred kJ/kg of warmth of transformation, as against a specific heat capability of around one kJ/(kg $^{\circ}\text{C}$) for masonry. The storage density will thus be twenty times larger than masonry per metric weight unit if AN temperature swing of ten $^{\circ}\text{C}$ is allowed.[2] but, since the mass of the masonry is far higher than that of PCM this specific (per mass) heat capability is somewhat offset. A masonry wall might have a mass of two hundred kg/m², thus to double the heat capability one would need extra ten kg/m² of PCM.

1.2.2 Organic PCMs

Hydrocarbons, primarily paraffin's (C_nH_{2n+2}) and lipids however conjointly sugar alcohols.

Advantages

- Freeze while not a lot of super cooling
- Ability to soften congruently
- Self-nucleating properties
- Compatibility with standard material of construction
- No segregation
- With chemicals stable
- Safe and non-reactive

Disadvantages

- Low thermal conduction in their solid state. High heat transfer rates square measure needed throughout the phase transition cycle. Nano composites were found to yield AN economical thermal conduction increase up to 216%. [7][8]
- Volumetrically heat of transformation storage capability square measure usually low
- Ignitable. This can be partly relieved by specialized containment.

1.2.3 Inorganic PCMS

Salt hydrates ($M_xN_yH_2O$) [9]

Advantages

- High volumetrically heat of transformation storage capability
- Handiness and low price
- Sharp temperature
- High thermal conduction
- High heat of fusion
- Non-flammable

Disadvantages

- Tough to prevent inharmonious melting and section separation upon athletics, which can cause an enormous loss in heat of transformation H.
- Corrosive to several different materials, like metals. this might be overcome by encapsulation in little quantities in non-reactive plastic.
- Amendment of volume is extraordinarily high in some mixtures

- Super cooling square measure usually a retardant in solid–liquid transition, necessitating the employment of nucleating agents which can become defunct once continual

1.2.4 Absorbent materials

Many natural building materials square measure absorbent , that is they are going to soak up (water condenses) and unleash water (water evaporates). The strategy is thus:

- Condensation (gas to liquid) ΔH_0 ; H will increase (endothermic process) absorbs heat (or cools).
- While this method liberates a little amount of energy, massive surfaces space permits important (1–2 °C) heating or cooling in buildings. The corresponding materials square measure wool insulation and earth/clay render finishes.

1.2.5 Solid-solid PCMs

A specialized cluster of PCMs that bear a solid/solid state change with the associated absorption and unleash of large amounts of heat . These materials amendment their crystalline structure from one lattice configuration to a special at a tricky and quick and well-defined temperature, and so the transformation will involve latent heats a bit like the foremost effective solid/liquid PCMs. Such materials square measure helpful as a result of, in contrast to solid/liquid PCMs, they are doing not need nucleation to forestall super cooling. in addition, as a result of it's a solid/solid state change , there's no visible amendment inside the appearance of the PCM, and there are no issues related to handling liquids, e.g. containment, potential outpouring, etc. presently the temperature vary of solid-solid PCM solutions spans from -50 °C (-58 °F) up to +175 °C (347 °F).

1.2.6 Technology, development of PCM

The most ordinarily used PCMs square measure salt hydrates, fatty acids and esters, and varied paraffin's (such as octadecane). Recently conjointly ionic liquids were investigated as novel PCMs.

As most of the organic solutions square measure water-free, they are going to be exposed to air, however all salt based mostly PCM solutions should be encapsulated to forestall water evaporation or uptake. Each sorts supply sure blessings and drawbacks and if they are properly applied sort of the disadvantages becomes and for certain applications.

They have been used since the late nineteenth century as a medium for thermal storage applications. They have been used in such various applications as cold transportation for rail and road applications and their physical properties square measure, therefore, documented.

Unlike the ice storage system, however, the PCM systems square measure usually used with any standard water hair-raiser each for a replacement or instead retrofit application. The positive temperature state change permits centrifugal and absorption hair-raisers conjointly as a result of the standard reciprocal and screw chiller systems or maybe lower close conditions utilizing a cooling system or dry cooler for charging the TES system.

The temperature vary offered by the PCM technology provides a replacement horizon for the building services and refrigeration engineers relating to medium and heat energy storage applications. The scope of this thermal energy application is wide-ranging of star heating, hot water, heating rejection (i.e., cooling tower), and dry cooler electronic equipment thermal energy storage applications.

Since PCMs rework between solid–liquid in thermal athletics, encapsulation naturally became the apparent storage alternative.

1.2.7 Encapsulation of PCMs

- Macro-encapsulation: Early development of macro-encapsulation with giant volume containment failing because of the poor thermal physical phenomenon of most PCMs. PCMs tend to solidify at the sides of the containers preventing effective heat transfer.
- Micro-encapsulation: Micro-encapsulation on the opposite hand showed no such downside. It permits the PCMs to be incorporated into construction materials, like concrete, simply and economically. Micro-encapsulated PCMs additionally offer a conveyable heat storage system. By coating a microscopic sized PCM with a protecting coating, the particles may be suspended at intervals a continual section like water. This technique may be thought-about a natural action suspension (PCS).
- Molecular-encapsulation is another technology, American state eloped by DuPont de Nemours that permits an awfully high concentration of PCM at intervals a compound. It permits storage capability up to five15 kJ/m² for a 5 metric linear unit board (103 MJ/m³). Molecular-encapsulation permits drilling and cutting through the fabric with none PCM escape.

As natural action materials perform best in little containers, thus they're sometimes divided in cells. The cells are shallow to cut back static head – supported the principle of shallow instrumentality pure mathematics. The

packaging material ought to conduct heat well; and it ought to be sturdy enough to face up to frequent changes within the storage material's volume as section changes occur. It ought to additionally prohibit the passage of water through the walls, therefore the materials won't dry out (or water-out, if the fabric is hygroscopic). Packaging should additionally resist escape and corrosion. Common packaging materials showing chemical compatibility with temperature PCMs embrace stainless-steel, plastic and polyolefin

1.2.8 Thermal composites

Thermal composites may be a term given to mixtures of natural action materials (PCMs) and alternative (usually solid) structures. An easy example may be a copper mesh immersed in paraffin. The copper mesh at intervals paraffin may be thought-about a material, dubbed a thermal composite. Such hybrid materials are created to attain specific overall or bulk properties.

Thermal physical phenomenon may be a common property targeted for maximization by making thermal composites. During this case, the essential plan is to extend thermal physical phenomenon by adding an extremely conducting solid (such because the copper mesh) into the comparatively low-conducting PCM, therefore increasing overall or bulk (thermal) physical phenomenon. If the PCM is needed to flow, the solid should be porous, like a mesh.

Solid composites like fibreglass or Kevlar prepreg for the region business sometimes visit a fiber (the Kevlar or the glass) and a matrix (the glue, that solidifies to carry fibers and supply compressive strength). A thermal composite isn't thus clearly outlined however might equally visit a matrix (solid) and therefore the PCM that is after all sometimes liquid and/or solid reckoning on conditions. They're additionally meant to get minor parts within the earth.

1.2.9 Application of PCMS

Applications of natural action materials embrace, however don't seem to be restricted to:

- Thermal energy storage
- Solar change of state
- Cold Energy Battery
- Conditioning of buildings, like 'ice-storage'
- Cooling of warmth and electrical engines
- Cooling: food, beverages, coffee, wine, milk merchandise, inexperienced homes
- Delaying ice and frost formation on surfaces

- Medical applications: transportation of blood, in operation tables, hot-cold therapies, treatment of birth physiological condition
- Human body cooling below large covering or costumes.
- Waste heat recovery
- Off-peak power utilization: Heating quandary and Cooling
- Heat pump systems
- Passive storage in climatology building/architecture (HDPE, paraffin)
- Smoothing exothermic temperature peaks in chemical reactions
- Solar power plants
- Spacecraft thermal systems
- Thermal comfort in vehicles
- Thermal protection of electronic devices
- Thermal protection of food: transport, building trade, ice-cream, etc.
- Textiles utilized in covering
- Computer cooling
- Turbine body of water chilling with thermal energy storage
- Telecom shelters in tropical regions. They defend the high-value instrumentation within the shelter by keeping the indoor air temperature below the utmost permissible by interesting heat generated by power-hungry instrumentation like a Base Station system. Just in case of an influence failure to traditional cooling systems, PCMs minimize use of diesel generators, and this will translate into monumental savings across thousands of medium sites in tropical

1.2.10 Hearth and issues of safety

Some natural action materials are suspended in water, and are comparatively nontoxic. Others are hydrocarbons or alternative combustible materials, or are virulent. As such, PCMs should be selected and applied terribly fastidiously, in accordance with hearth and building codes and sound engineering practices. as a result of the inflated hearth risk, flame unfold, smoke, potential for explosion once command in containers, and liability, it should be wise to not use combustible PCMs at intervals residential or alternative often occupied buildings. Natural action materials are being employed in thermal regulation of natural philosophy.

1.3 Paraffin wax

Paraffin wax (or oil wax) may be a soft colorless solid derived from oil, coal or shale that consists of a combination of organic compound molecules containing between twenty and forty carbon atoms. it's solid at temperature and begins to soften on top of around thirty seven °C (99 °F), and its boiling purpose is on top of 370 °C (698 °F). Common applications for wax embody lubrication, electrical insulation, and candles; artificial wax are often created into crayons. It's distinct from lamp oil and different oil merchandise that area unit generally known as paraffin.

Un-dyed, unscented paraffin candles area unit inodorous and bluish-white. wax was initial created by Carl Reichenbach in European country in 1830 and marked a serious advancement in candle creating technology, because it burned a lot of cleanly and faithfully than animal oil candles and was cheaper to supply.

In chemistry, paraffin is employed synonymously with alkane series, indicating hydrocarbons with the final formula C_nH_{2n+2} . The name springs from Latin parum ("barely") + affinis, which means "lacking affinity" or "lacking reactivity", touching on paraffin's unreactive nature.

1.3.1 Properties of wax

wax is usually found as a white, odorless, tasteless, waxy solid, with a typical temperature between concerning forty six and sixty eight °C (115 and 154 °F) and a density of around 900 kg/m³. It's insoluble in water, however soluble in ether, benzene, and bound esters. Paraffin is unaffected by commonest chemical reagents however burns without delay. Its heat of combustion is forty two MJ/kg.

The organic compound $C_{31}H_{64}$ may be a typical element of wax. Wax is a wonderful electrical stuff, with an impedance of between 10¹³ and 10¹⁷ ohm meter. This can be higher than nearly all different materials except some plastics (notably Teflon). It an efficient nucleon moderator and was employed in James Chadwick's 1932 experiments to spot the nucleon.

Wax is a wonderful material for storing heat, with a selected heat capability of two.14–2.9 J g⁻¹ K⁻¹ (joules per gram kelvin) and a heat of fusion of 200–220 J g⁻¹. Wax phase-change cooling including retractile radiators was wont to cool the natural philosophy of the satellite Roving Vehicle throughout the manned missions to the Moon within the early Nineteen Seventies. Wax expands significantly once it melts and this enables its use in wax component thermostats for industrial, domestic and, notably, automobile functions.

1.3.2 Producing of wax

The feedstock for paraffin is slack wax that may be a mixture of oil and wax, a byproduct from the purification of grease.

The primary step in creating wax is to get rid of the oil (de-oiling or de-waxing) from the slack wax. The oil is separated by crystallization. Most typically, the slack wax is heated, mixed with one or a lot of solvents like an organic compound so cooled. Because it cools, wax crystallizes out of the answer, departure solely oil. This mixture is filtered into 2 streams: solid (wax and some solvent) and liquid (oil and solvent). Once the solvent is recovered by distillation, the ensuing merchandise area unit known as "product wax" (or "press wax") and "foots oil". The lower the share of oil within the wax, the lot of Refined it's thought of (semi-refined versus absolutely refined). The merchandise wax could also be any processed to get rid of colors and odors. The wax might finally be alloyed along to provide bound desired properties like soften purpose and penetration. Wax is sold-out in either liquid or solid type.

1.3.3 Applications of wax

In industrial applications, it's usually helpful to switch the crystal properties of the wax, usually by adding branching to the present carbon backbone chain. The modification is typically through with additives, like EVA copolymers, crystalline wax, or sorts of polythene. The branched properties lead to a changed paraffin with a better body, smaller crystalline structure, and changed useful properties. Pure wax isn't used for carving original models for casting metal and different materials within the lost wax method, because it is comparatively brittle at temperature and presents the risks of breakage and breakage once worked. Soft and pliable waxes, like beeswax, could also be most popular for such sculpture, however "investment casting waxes," usually paraffin-based, area unit expressly developed for the aim.

During a microscopic anatomy or pathology laboratory, wax is employed to impregnate tissue before sectioning skinny samples of tissue. Water is far from the tissue through ascending strengths of alcohol (75% to absolute) and also the tissue is cleared in associate degree organic solvent like solvent. The tissue is then placed in wax for variety of hours so set during a mildew with wax to chill and solidify; sections area unit then cut on a scientific instrument.



Fig.1. paraffin wax

1.4 Carbon foam

Carbon foam could be a porous carbon material with a special three-dimensional network ligament structure, and has excellent properties like denseness, low thermal resistance, hot temperature resistance, corrosion resistance, and sensible electrical conduction. Therefore, carbon foam has nice application prospects in varied fields, together with energy storage and conversion, sorption and separation, and contact action moreover as catalyst carriers. We tend to ready carbon foam by thermal foaming technique of yeast fermentation, however they centered on the preparation method and therefore the properties of the carbon foam itself. No application of carbon foam ready by foaming technique as an activity matrix material was investigated.

1.4.1 Preparation of carbon foams

The process of atomic number 6 foam takes 3 main steps: foaming, carbonization, and a graphitization heat treatment. The foaming method of carbon foams were meted out in an exceedingly pressure vessel by heating the foaming precursors at the required heating rate to five hundred five hundred in an exceedingly N atmosphere and pressure up to 5-9 MPa, soaking for 2 hours, so cooling to temperature by natural cooling. Following the foaming method, every sample was change state in an environment of N at a heating rate of zero.2°C/min to 1000°C. the ultimate process step was graphitization, that occurred at 3000°C in an environment of argonon

1.4.2 Properties of carbon foam

Thermal conduction could be a property accustomed describe its ability to transfer steady state conditions. The thermal conduction of carbon foam is usually calculated by measurement the thermal diffusivity and density of the sample. The thermal conduction of CF1-6, and is 153 W/ (m•K), 179 W/ (m•K), 201 W/ (m•K), 171 W/ (m•K), 169 W/ (m•K), 151 W/ (m•K), severally. It's clear that the thermal diffusivity

of CF1 (3.91 cm²/s) and CF2 (3.78cm²/s) foaming from precursor A is more than CF4 (3.65cm²/s) and CF5 (3.24 cm²/s) foaming from precursor B, and CF4-5 is more than CF6 (2.72cm²/s) foaming from precursor C. The sanative rule of specific thermal conduction of samples is that the same with their thermal diffusivity. The high thermal conduction according for mesophase primarily based carbon foams primarily results from the powerfully familiarized mesophase layers inside the bubble walls. One method for making ready mesophase foams is confined carbonization, wherever the discharge of the volatile product within the transformation method creates the open cell network of the froth. The thermal diffusivity of the atomic number 6 material was associated with the atomic number 6 ligaments, crystal parameters, the bridge of micro-graphite structures, and therefore the arrangement of micro-graphite structures. The thermal diffusivity and bulk density of carbon foam powerfully influences the ensuing thermal conduction. The thermal conduction of CF3 is more than CF2, and CF2 is more than CF1. Usually, thermal conduction will increase with increasing density for the samples foaming from same precursor. There could also be some micro-cracks with the take a look at sample of CF5 for the rationale of lower thermal conduction than CF4. The precursor is a very important issue that determined the properties of carbon foams. The results showed that lower density and better thermal conduction were achieved for the carbon foams victimization the 2 varieties of pitches A and B with higher volatile parts. Summarizes the compressive strength of carbon foam derived from the assorted precursors. The compressive strength of the carbon foams ranges from one.6 to 3.4 MPa. The compressive strength will increase with increasing density for the samples foaming from identical precursor. Like CF1-3 foaming from precursor A, its density is zero.54 g/cm³, 0.66 g/cm³, 0.83 g/cm³, and compressive strength is one.60 MPa, 2.48 MPa, 3.40 MPa, severally. The mechanical property of cellular materials is sophisticated, that rely on each the sort of precursor and therefore the material's microstructural arrangement. The mechanical strength of carbon foam trusted the length and amount of cracks in samples, basing on the brittle materials fracture rule.

Table 1

Density (g/cm ²)	Thermal diffusivity (cm ² /s)	Thermal Conductivity (w/(m.k))	Specific conductivity (w/(m.k))/g/cm ³)	Thermal strength (Mpa)	compressive
0.54	3.91	153	283	1.60	

1.4.3 Application of carbon foam

Carbon foam prepared from mesophase pitch under pressure (bulk density of 0.25-0.65g/mL, thermal conductivity of 0.3-180 W/m.K) was tested as a heat sink material for cooling of power electronics, because of its lightweight, high thermal conductivity and efficient contact with coolants, gas or liquid. Cooling efficiency of the carbon foam by using two kinds of coolant, air and water, was studied to evaluate heat transfer coefficient. Very high coefficient of ca. 2600 W/m²K was obtained for the carbon foam by using water coolant, being ten times higher in comparison with ca. 250 W/m²K for conventional Al-foam heat sink. The response time for the carbon foam was much shorter than Al-foam.

Electromagnetic response of the carbon foam, which was prepared from a mesophase pitch at 450 oC under 2.0 MPa and had the cell size of 400-600 μ m, was studied. Microwave reflectivity for carbon foam is shown in Fig. 33 as a function of carbonization temperature. The carbon foam carbonized at 700 oC shows excellent microwave absorption performance, reflection loss reaching more than -10 dB (90% absorption) at around 7 GHz. The cells of carbon foam are supposed to act as a darkroom for microwaves. Also on RVC foam, microwave absorption performance was confirmed. Carbon foams prepared via template carbonization using PU had smaller dielectric constants but several times larger dielectric loss in comparison with their corresponding pulverized powders. Moreover, carbon foams showed magnetic

loss, although it could not be observed on their corresponding pulverized powders. Carbon foams prepared from mesophase pitch showed anisotropic microwave absorption along the gravitational force during foam preparation.

1.5 COMPOSITES

A stuff (also known as a composition material or shortened to composite that is that the common name) could be a material that is made from 2 or a lot of constituent materials. These constituent materials have notably dissimilar chemical or physical properties and are united to form a fabric with properties not like the individual components. Among the finished structure, the individual components stay separate and distinct, characteristic composites from mixtures and solid solutions.

Typical designed composite materials include:

- Reinforced concrete and masonry
- Composite wood like ply board
- Reinforced plastics, like fiber-reinforced chemical compound or covering material
- Ceramic matrix composites (composite ceramic and metal matrices)
- Metal matrix composites
- And alternative advanced composite materials

There are varied reasons wherever new material are often favored. Typical examples embody materials that are less costly, lighter or stronger once associated with common materials.

More recently researchers have additionally begun to actively embody sensing, actuation, computation and communication into composites that are referred to as Robotic Materials.

Composite materials are typically used for buildings, bridges, and structures like boat hulls, pool panels, race car bodies, shower stalls, bathtubs, storage tanks, imitation granite and cultivated marble sinks and countertops.

The most advanced examples perform habitually on orbiter and craft in hard-to-please environments.

1.5.1 Samples of composite materials

Concrete is that the commonest artificial stuff of all and generally consists of loose stones (aggregate) command with a matrix of cement. Concrete is a cheap material, and cannot compress or shatter even underneath quite a massive compressive force. However, concrete cannot survive tensile loading (i.e., if stretched it'll quickly break apart). Therefore, to relinquish concrete the power to resist being stretched, steel bars, which may resist high stretching forces, are usually superimposed to concrete to make ferroconcrete.

Fiber-reinforced chemical compounds embody carbon fiber strengthened polymer and glass-reinforced plastic. If classified by matrix then there are thermoplastic composites, short fiber thermoplastics, long fiber thermoplastics or long fiber-reinforced thermoplastics. There are various thermosetting composites, as well as paper composite panels. Several advanced thermosetting chemical compound matrix systems typically incorporate aramid fiber associate degreed carbon fiber in an epoxy matrix.

Form memory chemical compound composites are superior composites, developed mistreatment fiber or material reinforcement and form memory chemical compound organic compound because the matrix. Since a form memory chemical compound organic compound is employed because the matrix, these composites have the power

to be simply manipulated into varied configurations after they are heated higher than their activation temperatures and can exhibit high strength and stiffness at lower temperatures. They'll even be cooked-over and reshaped repeatedly while not losing their material properties. These composites are ideal for applications like light-weight, rigid, deployable structures; fast manufacturing; and dynamic reinforcement.

High strain composites are another form of superior composites that are designed to perform in a very high deformation setting and are usually employed in deployable systems wherever structural flexing is advantageous. Though high strain composites exhibit several similarities to form memory polymers, their performance is usually enthusiastic about the fiber layout as opposition the organic compound content of the matrix.

Composites may use metal fibres reinforcing alternative metals, as in metal matrix composites (MMC) or ceramic matrix composites (CMC), which incorporates bone (hydroxyapatite strengthened with albuminoidal fibres), cermet (ceramic and metal) and concrete. Ceramic matrix composites are unit engineered primarily for fracture toughness, not for strength. Another category of composite materials involve plain-woven cloth composite consisting of longitudinal and crosswise laced yarns. Plain-woven cloth composites are unit versatile as they're in kind of cloth.

Organic matrix/ceramic combination composites embrace asphalt concrete, compound concrete, mastic asphalt, mastic roller hybrid, dental composite, grammar foam and mother of pearl. Chobham armour could be a special variety of composite armour utilized in military applications.

to boot, thermoplastic composite materials will be developed with specific metal powders leading to materials with a density vary from two g/cm³ to eleven g/cm³ (same density as lead). The foremost common name for this kind of fabric is "high gravity compound" (HGC), though "lead replacement" is additionally used.

These materials will be utilized in place of ancient materials like Al, stainless-steel, brass, bronze, copper, lead, and even metal in weight, reconciliation (for example, modifying the middle of gravity of a lawn tennis racquet), vibration damping, and radiation shielding applications. High density composites are a unit Associate in Nursing economically viable possibility once sure materials are unit deemed venturesome and are unit prohibited (such as lead) or once secondary operations prices (such as machining, finishing, or coating) are unit an element.

A sandwich-structured composite could be a special category of material that's fancied by attaching 2 skinny however stiff skins to a light-weight however thick core. The core material is generally low strength material, however its higher thickness provides the sandwich composite with high bending stiffness with overall tenuity.

Wood could be a present composite comprising polysaccharide fibres in an exceedingly polymer and hemicellulose matrix. designed wood includes a large sort of totally different product like wood fibre board, plywood, familiarized strand board, wood plastic composite (recycled wood fibre in synthetic resin matrix), Pykrete (sawdust in ice matrix), Plastic-impregnated or laminated paper or textiles, Arborite, Formica (plastic) and Micarta. Alternative designed laminate composites, like Mallite, use a central core of finish grain wood, warranted to surface skins of sunshine alloy or GRP. These generate low-weight, high rigidity materials.

Particulate composites have particle as filler material spread in matrix, which can be nonmetal, like glass, epoxy. Tire is Associate in nursing example of particulate composite.

Advanced diamond-like carbon (DLC) coated compound composites are according wherever the coating will increase the surface property, hardness and wear resistance.

1.5.2 Cores in composites

Many lay-up styles of composite additionally involve a co-curing or post-curing of the prepreg with several alternative media, like foam or honeycomb. Generally, this is often called a sandwich structure. This is often a a lot of general lay-up for the assembly of cowlings, doors, radomes or non-structural components.

Open- and closed-cell-structured foams like polyvinylchloride, polyurethane, synthetic resin or phenyl ethylene foams, balsa wood, grammar foams, and honeycombs area unit usually used core materials. Open- and closed-cell metal foam may be used as core materials. Recently, 3D graphene structures (additionally referred to as graphene foam) have additionally been used as core structures. A recent review by have provided the outline of the progressive techniques for fabrication of the 3D structure of printed symbol, and also the samples of the utilization of those foam like structures as a core for his or her various compound composites.

1.5.3 Ways of fabrication

Normally, the fabrication of composite includes wetting, combination or saturating the reinforcement with the matrix. The matrix is then iatrogenic to bind along (with heat or a chemical reaction) into a rigid structure. Usually, the operation is finished in AN open or closed forming mould. However, the order and ways that of introducing the constituents alters significantly. Composites fabrication is achieved by a large type of ways, as well as advanced fibre placement (Automated fibre placement), covering material spray lay-up method, filament winding, and lanxide method, tailored fibre placement, tufting and z-pinning.

1.5.4 Different fabrication ways

Different kinds of fabrication embody casting, centrifugal casting, braid (onto a former), continuous casting, filament winding, press moulding, transfer moulding, pultrusion moulding and slip forming.

There are forming capabilities as well as CNC filament winding, vacuum infusion, wet lay-up, compression moulding, and thermoplastic moulding, to call a number of. The observes of solidification ovens and paint booths is additionally needed for a few comes.

1.5.5 Physical properties of composite

The composite's physical properties aren't identical (independent of the direction of applied force) in nature. However they're generally allotropic (different reckoning on the direction of the applied force or load). As an example, the composite panel's stiffness can sometimes rely on the orientation of the applied forces and/or moments. The composite's strength is finite by 2 loading conditions.

1.5.6 Mechanical Properties of Composites

In general, particle reinforcement is strengthening the composites but fiber reinforcement. It's wont to enhance the stiffness of the composites whereas increasing the strength and also the toughness. Due to their mechanical properties, they're employed in applications during which wear resistance is needed. For instance, hardness of cement are often raised by reinforcing gravel particles, drastically. Particle reinforcement an extremely advantageous methodology of standardization mechanical properties of materials since it's terribly straightforward implement whereas being low value.

1.5.7 Testing of composite

Composites are tested before and when construction to help in predicting and preventing failures. Pre-construction testing might adopt finite part analysis (FEA) for ply-by-ply analysis of sinusoidal surfaces and predicting wrinkling, crimping and dimpling of composites. Materials could also be tested throughout producing and when construction by numerous non-destructive ways as well as supersonic, diagnostic procedure, shearography and X-ray radiography, and optical device bond scrutiny for NDT of relative bond strength integrity during a localized space.

CHAPTER-2

LITERATURE REVIEW

TOPIC: Experimental investigation of the flame retardant and form-stable Composite phase change materials for a power battery thermal Management system

AUTHORS: Jiangyun Zhang a, b, Xinxu Li a, Guoqing Zhang a, Hongwei Wu b, Zhonghao Rao c, Jianwei Guo d, Dequan Zhou a

DATE: 2017

DESCRIPTION:

An efficient battery thermal management system (BTMS) will undoubtedly promote the performance and lifespan of battery packs. In this study, a novel flame-retarded composite PCMs composed by paraffin (PA), expanded graphite (EG), ammonium polyphosphate (APP), red phosphorus (RP) and epoxy resin (ER) has been proposed for battery module. The thermo physical and flame retardant properties are investigated at both macro and micro levels. The results show that the proposed composite PCMs with an APP/RP ratio of 23/10 exhibit the optimum flame retardant performance. Besides, the APP/RP-based composite PCMs for 18,650 ternary battery module has also been researched comparing with air cooled and PCM with pure PA modes. The experimental results indicated that the fire retardant PCMs shown significant cooling and temperature balancing advantages for battery module, leading to a 44.7% and 30.1% reduction rate of the peak temperature and the maintenance of the maximum temperature difference within 1.36 °C at a 3 C discharge rate for 25 °C. Even at 45 °C, the uniformity can still be controlled within 5 °C. Thus,

this research indicates the composite PCM had good flame retardant and form stable properties, it would be utilized in BTMS, energy storage and other fields.

TOPIC: Thermal reliability test of some fatty acids as PCMs used for solar thermal latent heat storage applications.

AUTHORS: Ahmet Sari

YEAR: 2002

DESCRIPTIONS:

The purpose of this study is to determine the thermal reliability of stearic acid, palmitic acid, myristic acid and lauric acid as latent heat energy storage materials with respect to various numbers of thermal cycles. The fatty acids, as phase change materials (PCMs), of industrial grade (purity between 90% and 97%) were subjected to accelerated thermal cycle tests. The differential scanning calorimetric (DSC) analysis technique was applied to the PCMs after 0, 120, 560, 850 and 1200 melt/freeze cycles in order to measure the melting temperatures and the latent heats of fusion of the PCMs. The DSC results indicated that the change in melting temperature for the PCMs was in the range of 0.07–7.87 C, and the change in latent heat of fusion was)1.0% to)27.7%, except for stearic acid between 560 and 1200 melt/freeze cycles. However, the decrease in the latent heats of fusion for all the PCMs was not regular with increasing thermal cycles. The experimental results also show that the investigated fatty acids as latent heat energy storage materials have a good thermal reliability in view of the latent heat of fusion and melting temperature with respect to thermal cycling for thermal energy storage applications in the long term.

TOPIC: PREPARATION, CHARACTERIZATION AND THERMAL PROPERTIES OF MICROENCAPSULATED PHASE CHANGE MATERIALS THERMAL ENERGY STORAGE.

AUTHORS: Cemil Alkan a, AhmetSarı a, AliKaraipekli a, OrhanUzun

YEAR: 2008

This study is focused on the preparation, characterization, and determination of thermal properties of Microencapsulated docosane with polymethyl methacrylate (PMMA) as phase change material for thermal energy storage. Microencapsulation of docosane has been carried out by emulsion polymerization. The microencapsulated phase change material (MEPCM) was characterized using Scanning electron microscopy (SEM) and Fourier transform infrared (FTIR) spectroscopy. Thermal properties and thermal stability of MEPCM were measured by differential scanning calorimetric (DSC) and thermal gravimetric analysis (TGA). DSC analysis indicated that the docosane in the microcapsules melts at 41.01°C and crystallizes at 40.61°C. It has latent heats of 54.6 and 48.7 J/g for melting and crystallization, respectively. TGA showed that the MEPCM degraded in three distinguishable steps and had good chemical stability. Accelerated thermal cycling tests also indicated that the MEPCM had good thermal reliability. Based on all these results, it can be concluded that the micro encapsulated docosane as MEPCMs have good potential for thermal energy storage purposes such as solar space heating applications.

TOPIC: Preparation of paraffin/expanded vermiculite with enhanced thermal conductivity by implanting network carbon in vermiculite layers

AUTHORS: Wei-min Guan, Jin-Hong Li*, Ting-ting Qian, Xiang Wang, Yong Deng

YEAR: 2015

DESCRIPTION:

Paraffin/expanded vermiculite with modified porous carbon layer was prepared in the study. In the composite phase change materials (PCM), expanded vermiculite was impregnated with sucrose in the layer and then carbonated in situ in order to enhance thermal conductivity and improve the adsorption capacity of expanded vermiculite, which acted as a carrier material in the preparation of the form-stable PCM. SEM

images showed the morphology of expanded vermiculite had been changed after carbonation. A series of micro-pores had been formed among the layers of expanded vermiculite with the diameter ranging from several microns to 120 μm . Thermal properties of the composite PCM were determined by differential scanning calorimeter (DSC) analysis. According to DSC analysis results, when the paraffin adsorption reached 53.2 wt.%, latent heats of the composite PCM were respectively 101.14 J/g at the freezing temperature of 48.85 $^{\circ}\text{C}$ and 103 J/g at the melting temperature of 53.1 $^{\circ}\text{C}$. TGA results showed that the form-stable composite PCM presented good thermal stability. Due to the formation of carbon structure in the layer of expanded vermiculite, the thermal conductivity of the supporting materials was improved, thus slightly decreasing the extrapolated onset melting temperature of pure paraffin. Furthermore, the results of FT-IR analysis and thermal cycling tests showed that the form-stable composite PCM had good chemical stability and thermal reliability after 200 melting/freezing cycles. The form-stable composite PCM with good thermal properties, thermal reliability, and chemical stability is the promising PCM for the low-temperature thermal energy storage applications.

TOPIC: Solar Energy Storage Methods

AUTHORS: Yu Hou, Ruxandra Vidu, and Pieter Stroeve

YEAR: 2011

DESCRIPTION:

Solar energy can provide an abundant source of renewable energy (electrical and thermal). However, because of its unsteady nature, the storage of solar energy will become critical when a significant portion of the total energy will be provided by solar energy. In this paper, current solar energy storage technologies are reviewed. Storage methods can be classified into categories according to capacity and discharge time. New developments in solar energy storage require advances in chemical engineering and materials science. Life cycle assessment (LCA) is an important tool to evaluate energy consumption and environmental impact of renewable energy processes. LCAs

of some of the storage methods are reviewed. It is important to note that, while using renewable energy sources such as solar power, storage methods based on no recyclable materials or methods that consume significant amounts of energy may undermine the effort to reduce energy consumption.

TOPIC: Preparation of polyethylene paraffin compound as a form-stable solid-liquid phase change material

AUTHORS: Ye Hong, Ge Xin-shi

YEAR: 2000

DESCRIPTION:

In this paper, the preparation of a form-stable phase change material (form-stable PCM) polyethylene paraffin compound (PPC) is described. This kind of form-stable PCM is a compound which consists of a paraffin as a dispersed phase change material and a high density polyethylene (HDPE) as a supporting material. Several kinds of HDPEs and paraffin's are evaluated as candidate materials for PPC as a form-stable PCM. The structure of the prepared PPC is analyzed by using scanning electronic microscope (SEM) and its latent heat is given by DSC method.

TOPIC: Use of Nano- α -Al₂O₃ to improve binary eutectic hydrated salt as phase Change material

AUTHORS: Yushi Liua, b, Yingzi Yanga

YEAR: 2017

DESCRIPTION:

In this paper, a novel Na₂SO₄·10H₂O-Na₂HPO₄·12H₂O eutectic hydrated salt (EHS) with melting temperature of 31.2 °C/no phase separation was firstly prepared for thermal energy storage applications at heating solar greenhouses and active solar heating systems in buildings. In order to inhibit super cooling and enhance thermal

conductivity of EHS, Nano- α -Al₂O₃ at different weight proportions was loaded into EHS. The multi-factors orthogonal test method has been employed to evaluate the nucleation effects of Nano- α -Al₂O₃. Besides, various characterization techniques such as DSC, OM, SEM and FT-IR were adopted to investigate the thermal properties, microstructure and chemical stability. The results showed that Nano- α -Al₂O₃ was a highly effective nucleating agent and excellent thermal conductive filler. The super cooling degree was reduced from 7.8 °C to 1.6 °C and the thermal conductivities were improved by up to 61.3% when adding 4.5 wt% Nano- α -Al₂O₃ and 1.0 wt % borax. Moreover, the latent heat of 4.5 wt% Nano- α -Al₂O₃ modified EHS decreased by only about 8% and its melting point maintained constant as that of pure EHS. In addition, the modified EHS had good thermal and chemical stability after 200 thermal cycles.

TOPIC: Thermal conductivity improvement of phase change materials/graphite foam composites.

AUTHORS: Mahmoud Moeini Sedeh, J.M. Khodadadi

YEAR: 2013

DESCRIPTION:

Effective thermal conductivity of composites of graphite foam infiltrated with phase change materials (PCM) was investigated numerically and experimentally. Graphite foam, as a highly-conductive, highly-porous structure, is an excellent candidate for infiltrating PCM into its pores and forming thermal energy storage composites with improved effective thermal conductivity. For numerical simulation, the graphite structure was modeled as a three-dimensional body-centered cube arrangement of uniform spherical pores, saturated with PCM thus forming a cubic representative elementary volume (REV). Thermal analysis of the developed REV was conducted for unidirectional heat transfer and the total heat flux was determined, which leads to the effective thermal conductivity evaluation. For experimental verification, a sample

of graphite foam was infiltrated with PCM. The effective thermal conductivity was evaluated using the direct method of measuring temperature within the sample under fixed heat flux in unidirectional heat transfer. The results indicate a noticeable improvement in the effective thermal conductivity of composites compared to the PCM. Our numerical and experimental results are in agreement and are also consistent with reported experimental results on graphite foam. Moreover, the role of natural convection within the pores is found to be negligible.

TOPIC: Fabrication and properties of carbon/carbon-carbon foam composites

AUTHORS: Bin Wang, Bugao Xu and Hejun Li

YEAR: 2019

DESCRIPTION:

This paper was focused on the development of a new composite for high thermal insulation applications with carbon/carbon (C/C) composites, carbon foams and an interlayer of phenolic-based carbon. The microstructure, mechanical properties, fracture mechanism and thermal insulation performance of the composite was investigated. The experiment results showed that the bonding strength of the C/C-carbon foam composite was 4.31 MPa, and that the fracture occurred and propagated near the interface of the carbon foam and the phenolic-based carbon interlayer due to the relatively weak bonding. The shear load-displacement curves were characterized by alternated linear slopes and serrated plateaus before a final failure. The experiment revealed that the thermal conductivity of the C/C-carbon foam composite was 1.55 W.m⁻¹.K⁻¹ in 800.C, which was 95.8% lower than that of C/C composites, proving that the thermal insulation of the new foam composite was greatly enhanced by the carbon foam with its porous hollow microstructure.

TOPIC: Preparation and thermal properties of polyethylene glycol/expanded

Graphite as novel form-stable phase change material for indoor energy saving.

AUTHORS: Yingni Yang, Yao Pang, Yi Liu, Hongwu Guo

YEAR: 2018

DESCRIPTION:

Phase change material (PCM) is a new kind of material for energy storage; its thermal properties are key factors in determining the application areas and the actual effect. The polyethylene glycol (PEG)/expanded graphite (EG) composite was prepared as a novel form-stable PCM by vacuum impregnation in this study. Nitrogen adsorption test indicated that EG belonged to materials in mesoporous scale with developed porous structure and prodigious adorability. The PEG/EG PCM owned excellent sealing performance and remarkable thermal storage capacity. The phase change temperatures and latent heats of the PEG/EG PCM were in range of 18.89–25.93 TGA and thermal performance manifested that the PEG/EG PCM presented good thermal stability and EG performed favorable conductivity and improved the thermal storage efficiency. The obtained PCMs were suitable for indoor energy saving and thermal comfort improvement.

TOPIC: Preparation and thermal properties of phase change materials based on paraffin with expanded graphite and carbon foams prepared from sucrose

AUTHORS: ao yu Yina, Zhaohui Huang^{*}, Ruilong Wena, Xiaoguang Zhanga, Bo Tana, Yan'gai Liua, Xiaowen Wua, and Minghao Fanga,

YEAR: 2016

DESCRIPTION:

Carbon foam/ expanded graphite composite (CEC) was prepared from sucrose-expandable graphite resin by thermal foaming method. This CEC was impregnated with paraffin through the pores to obtain paraffin/carbon foam/expanded graphite composite (PCEC). In case of CECs, when the amount of added expandable graphite reached 10 wt.% to 15 wt.%, the microstructure of the CEC was damaged due to expansion in volume of the expandable graphite. Fourier transform infra-red

spectroscopy (FTIR) and X-ray diffraction (XRD) analysis of PCECs showed that there was no chemical interaction between the paraffin and CECs. With an increase in the amount of expandable graphite in CECs, the adsorption capacity of paraffin and the latent heats first showed an increase and then decreased. The heat-transfer capability of the paraffin was truly improved by the CECs. The processes for the preparation of the CECs and PCECs were environmental friendly, convenient, and inexpensive. The PCECs, with good thermal properties and chemical stabilities, are suitable for the low temperature (40-50°C) thermal energy storage applications.

CHAPTER-3

AIM AND SCOPE

3.1 AIM OF THE PROJECT

In this paper we tend to we aim to investigate the thermal properties of a phase change material by adding a composite materials therefore we've got taken paraffin as phase change material and carbon foam as composite material we tend to prepare carbon foam we are victimization starch as raw materials we do this project in impregnation methodology and investigate the whether or not the thermal properties are increasing.

3.2 scope of the project

Energy is a crucial material foundation for economic development. This energy model relies on AN energy consumption structure dominated by unrenewable fossil fuels, and in world, the unbalanced provide and demand of warmth energy in time and area is problematic and causes vital waste [1]. Thermal energy is keep by wise or heat (phase modification heat) of matter, which may be a good and reliable methodology to keep up the balance between heat provide and demand, as compared with the dependableness of different energy storage ways [2–4]. {Phase modification phase transition state change physical change natural process natural action activity} materials (PCMs) area unit a form of energy material that change their state with temperature to finish heat storage and unharness, and this method is cyclically reversible, such PCMs is reused [5–9]. In recent years, PCMs are wide utilized in air-con storage systems, alternative energy and building envelopes

CHAPTER-4

4. MATERIALS AND EXPERIMENTAL METHOD

4.1 METHODOLOGY

During this paper, cheap and without delay obtained starch is employed as a material, and traditional foaming and steaming methodology are adopted to create carbon foam. Considering the shortcomings of paraffin, the porous carbon foam support material with three-dimensional penetration is ready by carbothermal reduction. The high heat of transformation solid– liquid part material paraffin is encapsulated within the inherent pore structure of the carbon foam by a vacuum impregnation method to arrange a formed composite PCM. Through the extremely thermally physical phenomenon carbon foam, the inexpedient of low thermal conductivity of paraffin is improved. The results of this paper square measure expected to supply a technique to arrange composite PCMs that square measure cheap, environmentally friendly, and high performance, so facultative PCMs to own broad application prospects and price.

4.2 MATERIALS USED

The materials employed in the method is starch and yeast for preparation of carbon foam and that they are purchased. And the the} paraffin was also purchased .all water employed in the method to dissolve dry yeast and blend with starch was deionized water

4.3 Preparation of carbon foam

The flow chart for preparing carbon foam is shown in Fig. 1. during a typical method, 6 g of dry yeast powder was added to 150 ml of deionized water, and also the mixture was stirred ceaselessly for 15 min till the dry yeast powder was fully dissolved; the answer was then poured into a dough mixer, within which 300 g of starch had been placed ahead. Once fifteen min of slow mixture with the dough mixer, the starch lumped along. The paste foamed for concerning 60 min at 40 40 to make the porous structure. Also, the paste of pure starch while not yeast was ready for comparison. The most element of yeast powder, sodium hydrogen carbonate, was rotten by heat treatment to supply carbon dioxide, whereby the overflow of CO₂ created a loose porous structure. The paste was turn over regular cuboid samples then steamed for half an hour. After that, the sample was placed in an air oven to dry at two hundred two hundred for three h. Finally, the dried sample was placed during a muffle chamber to carbonize at totally different temperatures (500 °C, 700 °C, 900 °C, and 1100 °C) within the atmosphere of buried coke, and also the samples were selected as C500, C700, C900, and C1100, severally. The samples of pure starch with totally different carbonization temperature were selected as S500, S700, S900, and S1100, severally. The heating rate was set to ten 1000/min below 1000 1000 and 5 °C/min higher than 1000 °C, and also the holding time was set to three h. Finally, the sample was cooled to temperature during a buried coke atmosphere.

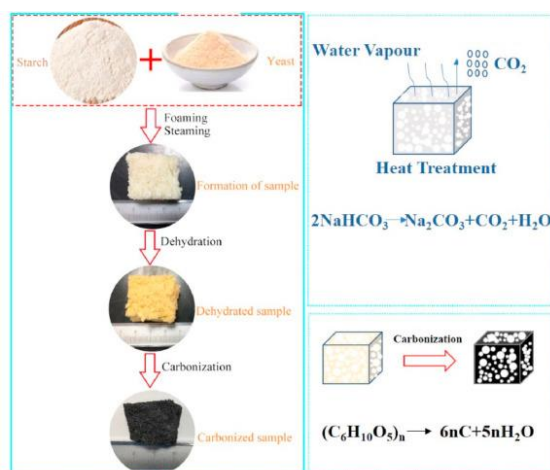


Fig. 2. Flowchart for preparing carbon foam.

4.4 Preparation of composites

The PCCs and paraffin/carbon foam (prepared from pure starch) composites (PPSs) were prepared by employing a vacuum impregnation methodology, as shown in Fig. 2. Solid paraffin and carbon foam were placed in a glass beaker that was placed in a vacuum oven. The vacuum pump was turned on, and therefore the air within the vacuum oven was extracted till the pressure within the vacuum oven was but 0.01 MPa. At identical time, the vacuum oven was heated to 80 °C to soften the solid paraffin. After 1h, the pores of carbon foam were impregnated with paraffin, and therefore the intermediate composites were obtained. The intermediate composites samples were later on placed on paper, that was set in an kitchen appliance at 80 °C to get rid of the liquid paraffin. The paper was replaced continuously till there was no paraffin leaking onto the paper. The composites obtained were then selected as PCC500, PCC700, PCC900, and PCC1100, admire C500, C700, C900, and C1100, and PPS500, PPS700, PPS900, and PPS1100, admire S500, S700, S900, and S1100, severally. The lots of the composite samples were recorded before and when impregnation.

4.5 Characterization

The thermal properties of the paraffin and PCCs were investigated via differential scanning calorimeter. Paraffin and PCCs were heated from zero 0 to 100 a hundred, at a heating rate of 10 °C/min, followed by cooling to zero 0. The thermal stability of the PCCs was measured by thermo–gravimetric analysis (Instruments Q50) of 0°C-600 °C, at a heating rate of 10 °C/ min. The thermal diffusivity was measured by employing a thermal conductivity tester.

CHAPTER-5

RESULTS AND DISCUSSION

5.1 Characterization of carbon foam

Yeast and water contend vital a significant} important role throughout the formation of the pore structure. Once water was more, the starch was gelatinized. At constant time, once the yeast was distributed into the paste, CO₂ was created and free to make pores. Also, once samples were dried and turn, they created and free CO₂ and water vapour to make pores throughout drying and carbonizing steps. The microstructure of the carbon foam turn at completely different temperatures bestowed in Fig. 3 and Fig. 4. As shown in Fig. 3, the pores of carbon foam ready from pure starch with completely different carbonization temperature were irregular. The pore size of samples C500, C700, decreases with increasing carbonization temperature, and therefore the average size of the pores distributed within the cell walls ranges from 1 to 50µm, excluding those having some hundred micrometer dimension that are visible on the macro. Moreover, it are often seen from Fig. four that the cell walls have a definite thickness and cross-link with one another that contributes to thermal diffusion. For carbonization distributed at five hundred five hundred (Fig. 4(a)), most of the pores are open, the pore size ranges from ten to 50 50, and therefore the cells walls are comparatively complete. Whereas at 700 °C and 900 °C, the thickness of cell walls will increase, and little pores are virtually invisible. At 1100 °C, the pore size within the cell walls ranges from one to twenty one, and therefore the variety of pores will increase, that results in a a lot of uniform pore distribution. The formation of pores is caused by the evaporation of physically absorbable water and free water within the low temperature zone; within the middle temperature zone, it's principally the fracture dehydration and decomposition of organic polymer chains in starch, releasing liquids like fuel and natural resin and gaseous merchandise like co₂ and CO. within the extreme temperature zone (generally on top of 700 °C), the network shrinkage and

structural reforming of the carbon material principally happens, forming a basic carbon skeleton, and because the temperature will increase, the pores become smaller. The results indicate that the porousness of the matrix material improved with the rise within the carbonization temperature, and therefore the corresponding giant specific area contributes to the loading and storage of PCM. As shown in Fig. 5, the mercury intrusion methodology was applied to live the porousness and therefore the pore diameter distributions of the matrix materials with different totally completely different carbonization temperature beneath different pressures. Fig. five (a) shows the parameters of the matrix materials, like porousness and pore diameter distribution, and therefore the porousness of the matrix materials was seventy three.59%, 70.66%, 71.94%, and 71.02%, severally. The rationale why the porousness of C500 is over the opposite 3 samples is that C500 has a lot of macropores. Moreover, it are often seen that the contribution of pore size diameter on the cumulative pore space, indicating that the cumulative pore space of the matrix materials principally originates from macropores, that proves that the matrix materials have a decent potential because the PCM supporting materials. The XRD patterns of the carbon foam created with completely different carbonization temperatures area unit shown in Fig. 6. It are often seen that the broad peak at around 23° indicates the presence of amorphous carbon that was also proof of some degree of graphitization of the carbon foams [15, 29]. The broad peak at roughly approximately [15, 30, 31], whose intensity will increase step by step with the rise of carbonization temperature, additionally indicates the presence of amorphous carbon. Also, TGA was used to investigate the thermal stability of the ready matrix materials, as shown in Fig. 7. The mass loss of the matrix materials before 100 one hundred were the water absorbed within the pores of the matrix materials. It are often seen that the matrix material turn at 500 500 has the biggest mass loss rate, probably as a result of the matrix material has not been fully turn at this temperature, therefore once heated to 600°C in an exceedingly N surroundings, the carbohydrates within the matrix material rotten with a lot of mass losing. It can even be seen that the mass loss rate of matrix materials became lower

and lower with carbonization temperature increasing. once turn at 1100 °C, the mass loss was less than zero.5%, indicating that the carbohydrates within the matrix material at this carbonization temperature virtually fully rotten.

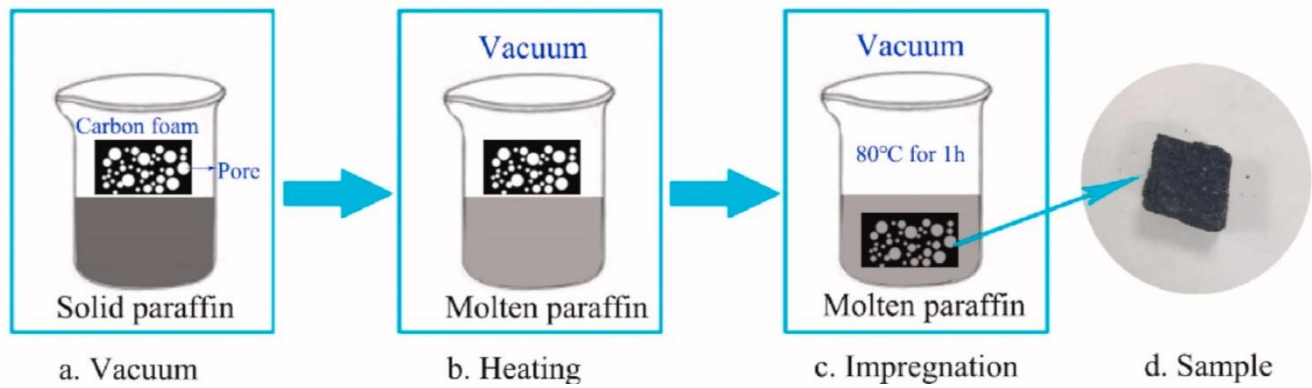


Fig. 3. Schematic diagram of vacuum impregnation treatment for preparing composites

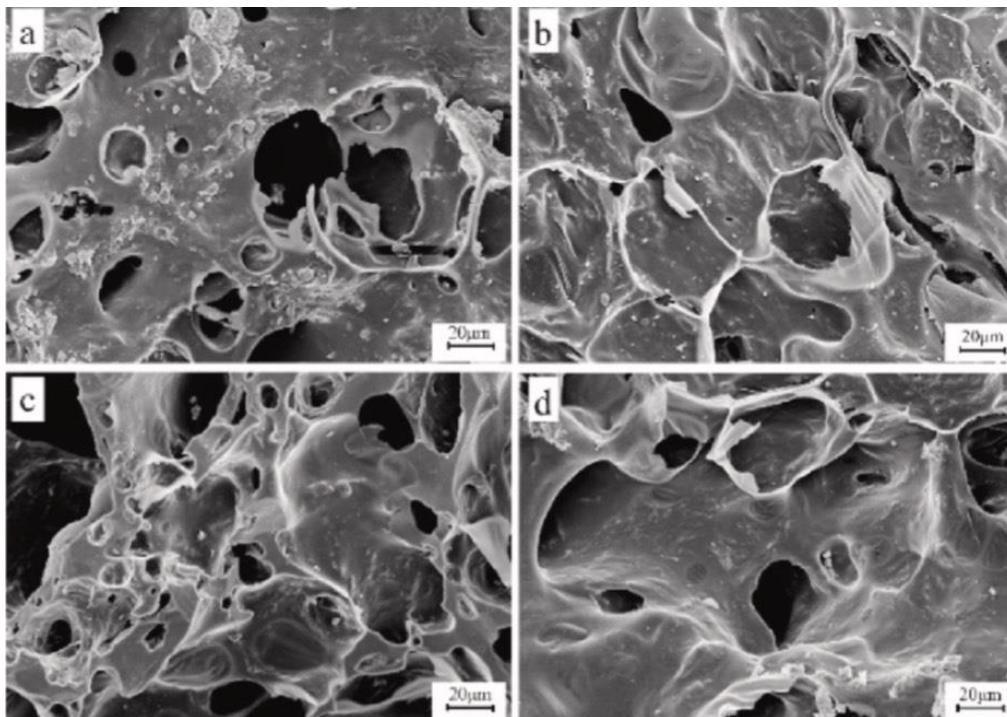


Fig. 4. SEM micrograph of (a) S500, (b) S700, (c) S900, (d) S1100.

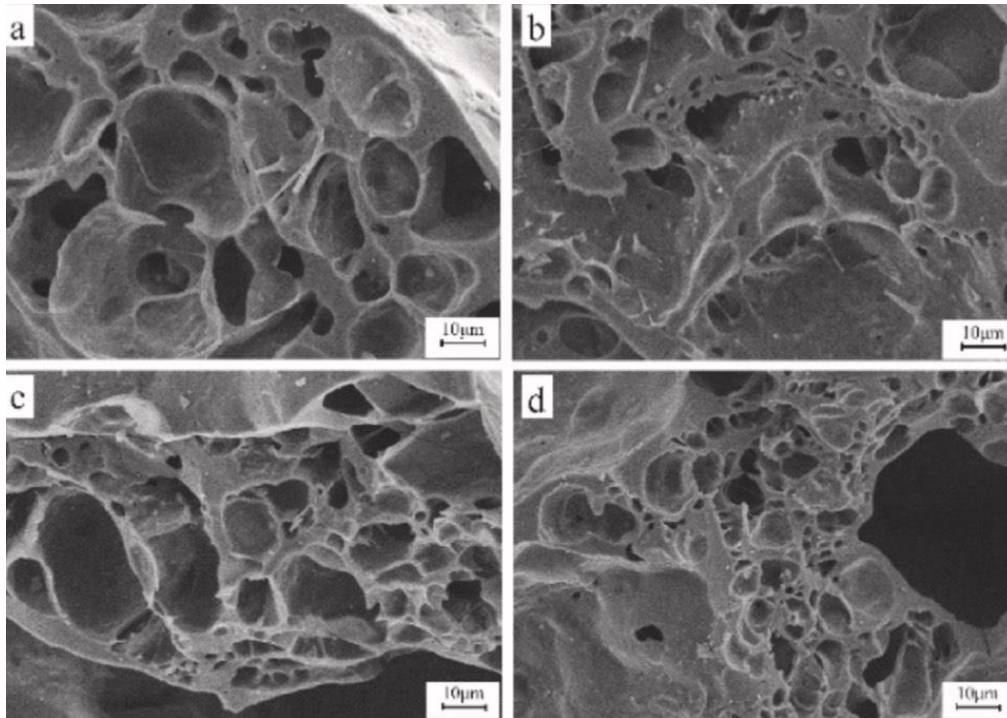


Fig. 5. SEM micrograph of (a) C500, (b) C700, (c) C900, (d) C1100.

5.2 Characterization of the PCCs

The hierarchic pores of the porous carbon were loaded with liquid paraffin in a very combination of capillarity and physical adsorption. Fig. 8 shows the microstructure of the PCCs once vacuum impregnation range of pores is clearly reduced, doubtless thanks to the paraffin loading. It may be seen clearly in Fig. 8 that almost all of the massive pores don't seem to be loaded with paraffin, whereas smaller pores area unit crammed with paraffin as a result of capillarity.

The percentage of loaded paraffin was calculated per equivalent weight.

$$H = \frac{m_P - m}{m_P} \times 100 \text{ percent} \quad \dots(1)$$

Wherever m_P and m area unit the lots of the carbon foams before and once vacuum impregnation treatment, severally, the loading share per sample area unit conferred in Table one, Table 2, and Fig. 9. All knowledge were averaged from 5 measured values. The uncertainty of loading share As shown in Fig. 9, the carbon foams ready

with the yeast powder has higher load rate and narrower error variation than the one ready from pure starch below an equivalent preparation method, this illustrates the previous has priority for energy utilization materials. Moreover, among the PCC series composites, the common loading rate of PCC1100 has the tiniest variance to different three cluster composites. As a a lot of economical and stable composite, subsequent properties of PCC1100 once thermal cycles (including SEM, FT-IR and XRD etc.) ought to be any analyzed to exhibit its recyclability, aside from initial properties like DSC, TGA, and thermal conduction etc.. XRD patterns of the PCCs and paraffin area unit shown in Fig. 10. There are two clear diffraction peaks at 2θ values of 21° and 23° , and there are not any different distinct peaks. once comparison the XRD spectra of the PCCs thereupon of the carbon matrix in Fig. half dozen and above all with the XRD pattern

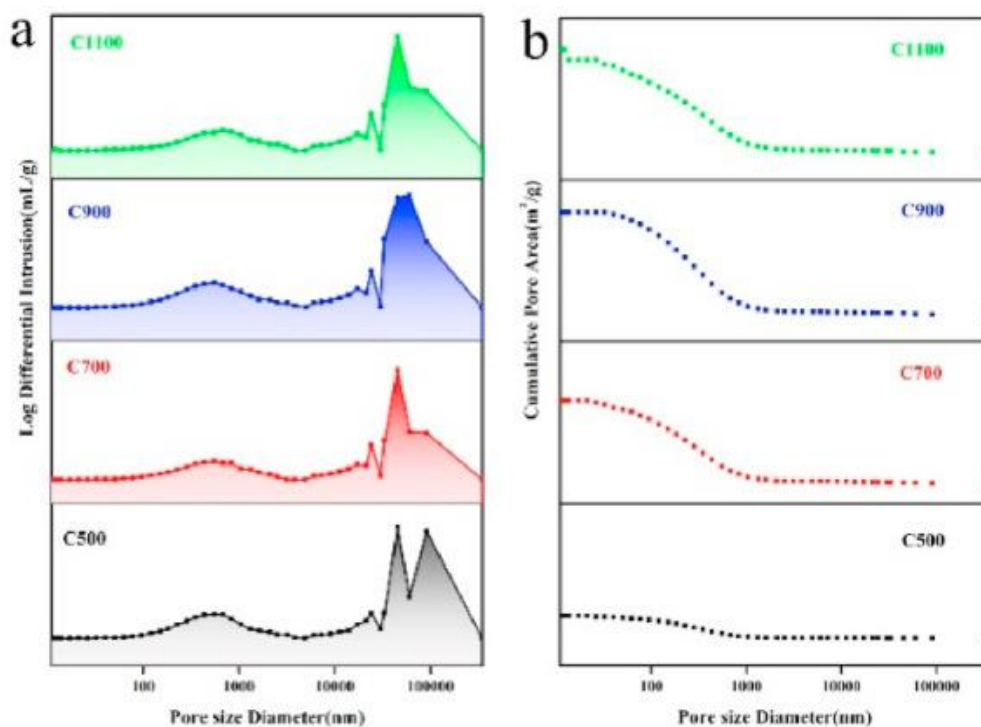


Fig. 6. (a) Aperture distribution curves, (b) Accumulated pore area distribution curves.

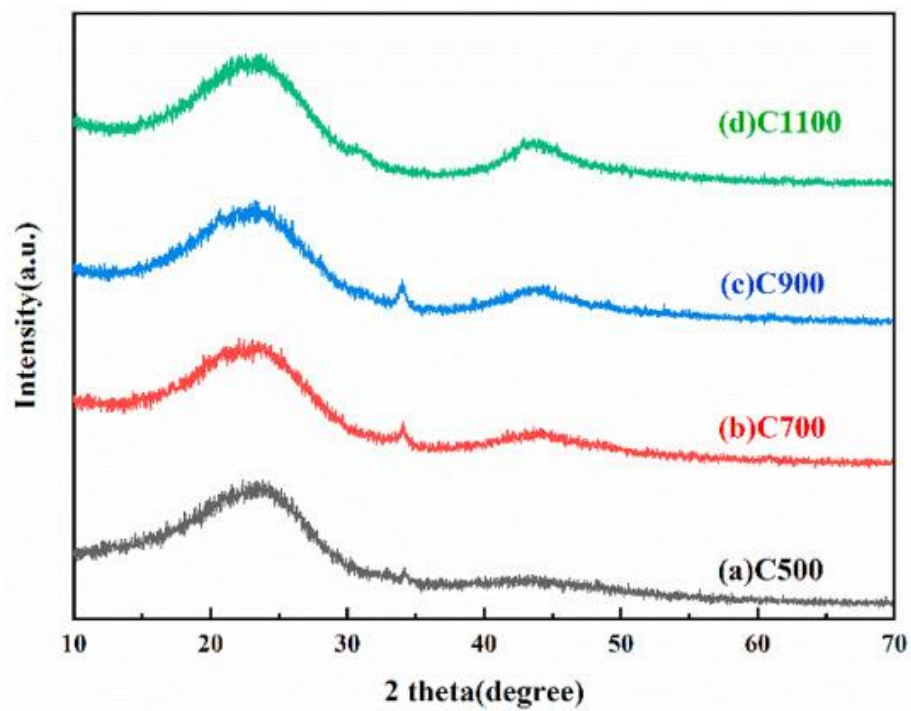


Fig. 7. XRD patterns of (a) C500, (b) C700, (c) C900, (d) C1100.

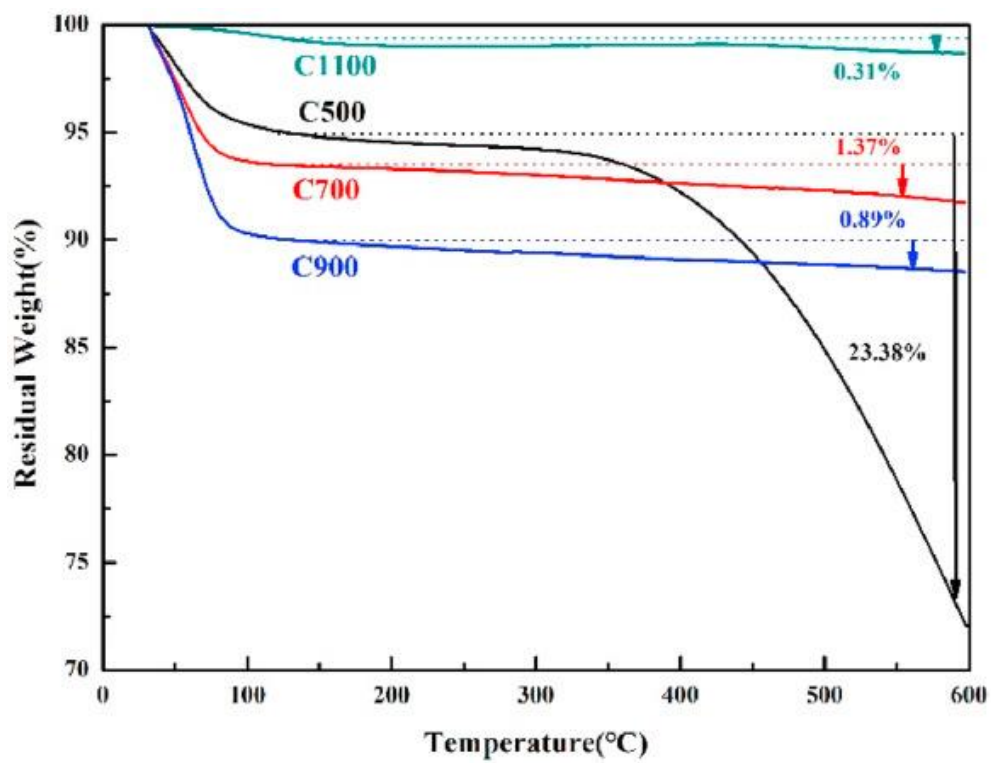


Fig. 8. The TGA curves of C500, C700, C900, and C1100.

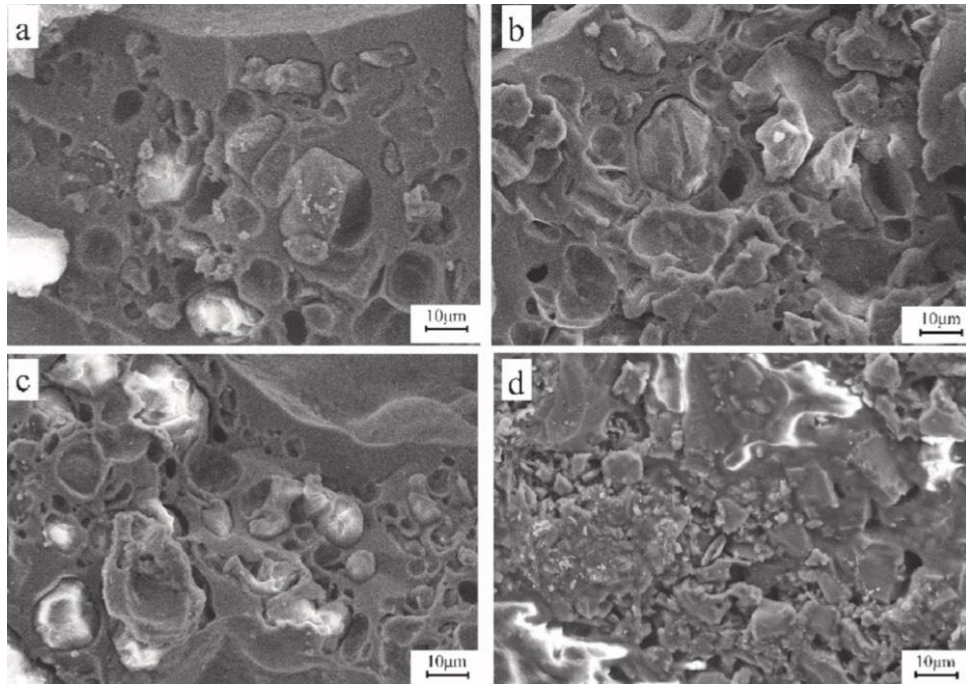


Fig. 9. SEM images of (a) PCC500, (b) PCC700, (c) PCC900, (d) PCC1100.

Table 2

Mass composition of the prepared PSSs

Serial number	PSS500		PSS700		PSS900		PSS1100	
	Before	After	Before	After	Before	After	Before	after
The quality of samples before & after impregnation (g)	0.49	1.11	0.57	1.32	0.32	0.71	0.75	1.81
	0.77	1.71	0.55	1.27	0.35	0.84	0.52	1.32
	0.53	1.24	0.49	1.21	0.45	1.12	0.45	1.11
	0.61	1.41	0.61	1.41	0.37	0.88	0.32	0.82
	0.56	1.27	0.69	1.51	0.56	1.41	0.77	1.85
Average load rate (%)	56.15		56.81		58.26		59.60	
Standard deviation (%)	0.88		1.84		2.11		1.17	

Table 3

Mass composition of the prepared PCCs.

Serial number	PCC500		PCC700		PCC900		PCC1100	
	Before	After	Before	After	Before	After	Before	After
The quality of samples before & after impregnation (g)	0.55	1.53	0.34	1.09	0.55	1.94	0.85	3.13
	0.43	1.23	0.47	1.5	0.37	1.33	0.48	1.76
	0.77	2.12	0.43	1.45	0.44	1.67	0.36	1.32
	0.88	2.41	0.54	1.66	0.75	2.52	0.42	1.53
	0.93	2.66	0.59	2.04	0.58	2.17	0.57	2.12
Average load rate (%)	64.26		69.27		71.76		72.79	
Standard deviation (%)	0.74		1.44		1.36		0.21	

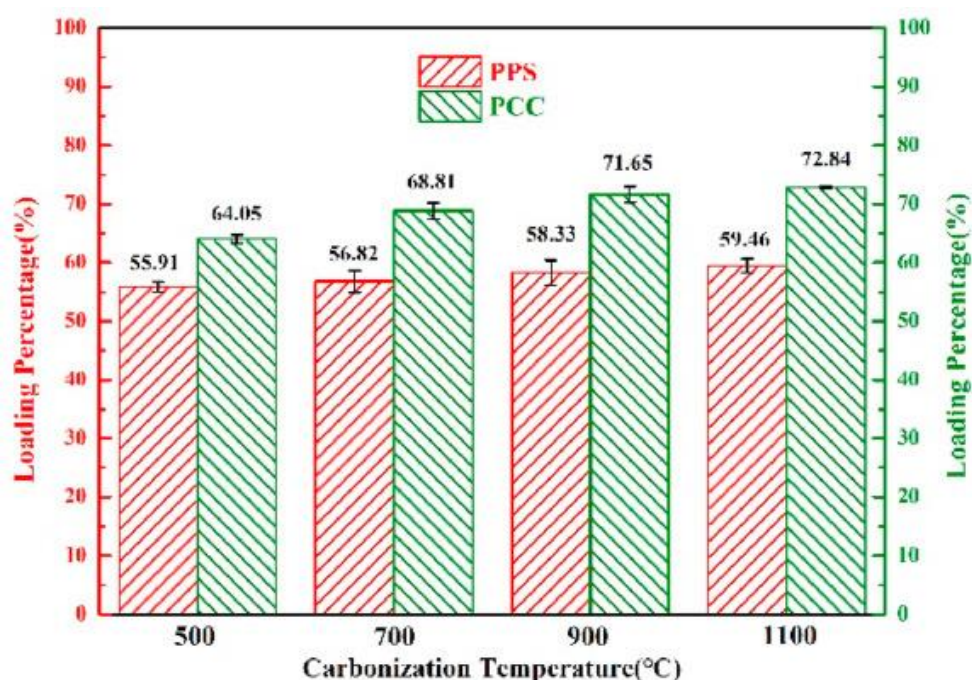


Fig. 10. Mass composition of representative PPSs and PCCs. Closest to the respective average.

5.3 Thermal properties of PCCs

Thermal properties are unit necessary indicators for PCM applications. The phase change temperature and total heat of paraffin and PCCs were determined by DSC, as shown in Fig. 12. The down arrow represents the endothermic method whereas the up arrow represents the energy-releasing method. Because the temperature rises and falls, the sample undergoes a suction–discharge–exothermic cycle. The thermal properties of paraffin and PCCs are given in Table 3, where t_m are the melting temperature and H_m are the heat energy of the melting and chilling processes, severally. It may be seen that there are 2 phase change peaks within the DSC curves of paraffin. The primary method happens and corresponds to the solid–solid phase change of the solid paraffin throughout the heating process. The second peak seems at 49.8 °C, indicating a solid–liquid phase transition within the paraffin. Whether or not it's a heating or cooling method, there are a unit 2 section transitions. In each the pure paraffin and PCCs samples, the melting and solidification occur at around the same temperature. As shown in Table 3, the t_m and T_f of paraffin were 49.8 8 and 52.9 °C, respectively. The t_m and T_f of PCCs samples PCC500, PCC700, PCC900, and PCC1100 were forty nine.6 half-dozen and fifty three.1 °C, 48.7 seven and fifty two.8 °C, 48.5 five and five2.4 °C, and 47.9 nine and fifty two.8 °C, severally. The results indicate that the modification phase transition state change physical change natural process natural action temperature of the PCCs didn't change very much like compared thereto of paraffin. The heat energy of the phase transition throughout melting and activity were obtained by group action the realm of the peaks. The heat energy of paraffin throughout melting method and activity were 208.4 J/g and 198.2 J/g, severally. within the process, the heat energy of PCCs was closely associated with the mass fraction of paraffin within the PCCs, as solely paraffin will store heat energy. Therefore, it may be terminated from Table three and Fig. nine that the modification rule of heat energy of PCCs which of weight share of paraffin within the PCCs were slightly completely different, however the distinction wasn't giant, and therefore the heat energy of PCCs was under paraffin. Thermal stability is a vital

property for the appliance of PCMs, therefore TGA and DTG were used to investigate the thermal stability of the ready PCCs, as shown in Fig. 13. The mass loss of the paraffin and PCCs occurred in one step. The TGA and DTG curves of paraffin and PCCs beneath element indicate that the PCCs gift an honest thermal stability within the operating temperature range; PCMs area unit usually employed in buildings to stay heat in throughout the winter and heat out throughout the summer, having work temperature is usually below one hundred one hundred. Within the TGA curves, the entire mass loss of paraffin, PCC500, PCC700, PCC900, and PCC1100 is ninety nine.98%, 68.14%, 68, 08%, 69.51%, and 70.43%, severally. The mass loss attributed to the decomposition of carbohydrates within the matrix materials and paraffin. decreasing the partial mass loss from sugar decomposition as shown in Fig. 7, the residual mass loss of the opposite samples is in sensible agreement with the paraffin loading percentages, and therefore the rate of mass loss is under the corresponding loading share, this can be caused by the physical interaction between paraffin and therefore the matrix material, like capillary and physical phenomenon forces, that not solely will limit the quantity of paraffin within the matrix material, however may improve the thermal stability of PCCs. The DTG curves were conjointly proof, because the curves of the PCCs were not sleek, as compared with the curve of paraffin. Thermal athletics was administered to gauge the thermal irresponsibleness of the PCMs by fast the method of melting and chilling, continuance cycles two hundred times. Sample PCC1100 was placed on paper, heated to eighty, so cooled to temperature. Hence, an entire thermal cycle was completed together with melting and chilling. Fig. fourteen shows that the form of PCC1100 sample didn't modification, and there was no leak onto the paper. Also, Fig. fifteen shows the SEM pictures of PCCs once two hundred times thermal athletics. Compared with Fig. 8, the paraffin was firmly absorbed within the skeleton structure of carbon foam, and there was no overall read. On the full, no structural harm and obvious loss of paraffin were determined within the composite PCM that indirectly proves that the composite PCM has structural stability throughout thermal athletics. The DSC curves were measured once more once the thermal

athletics, as shown in Fig. 16 (a). There have been solely slight changes within the curves that was proof of the wonderful thermal responsibleness of sample PCC1100. In Fig. 16 (b), the FT-IR spectra correspond to sample PCC1100 before and once two hundred thermal cycles, and therefore the peaks endure no obvious changes, which suggests that no chemical action occurred once two hundred thermal cycles. Thus, proving the wonderful thermal stability of the PCCs. Thermal physical phenomenon and thermal diffusivity area unit key parameters for PCM applications. The thermal physical phenomenon and thermal diffusivity of paraffin and PCCs measured at temperature area unit shown in Table four, Table five and Fig. 17, all knowledge is averaged from five times measurements, indicating that the thermal physical phenomenon and thermal diffusivity of the samples improved with the increasing carbonization temperature. The thermal physical phenomenon of sample PCC1100 was zero.339 W/ (m·K), that was one.93 times on top of that (0.176 W/(m·K)) of paraffin. Moreover, the thermal diffusivity of sample PCC1100 was sixty seven.4 cm²/s, that was five.86 times on top of that (11.5 cm²/s) of paraffin. Hence, the warmth transfer capability of paraffin was improved by incorporating it into carbon foam

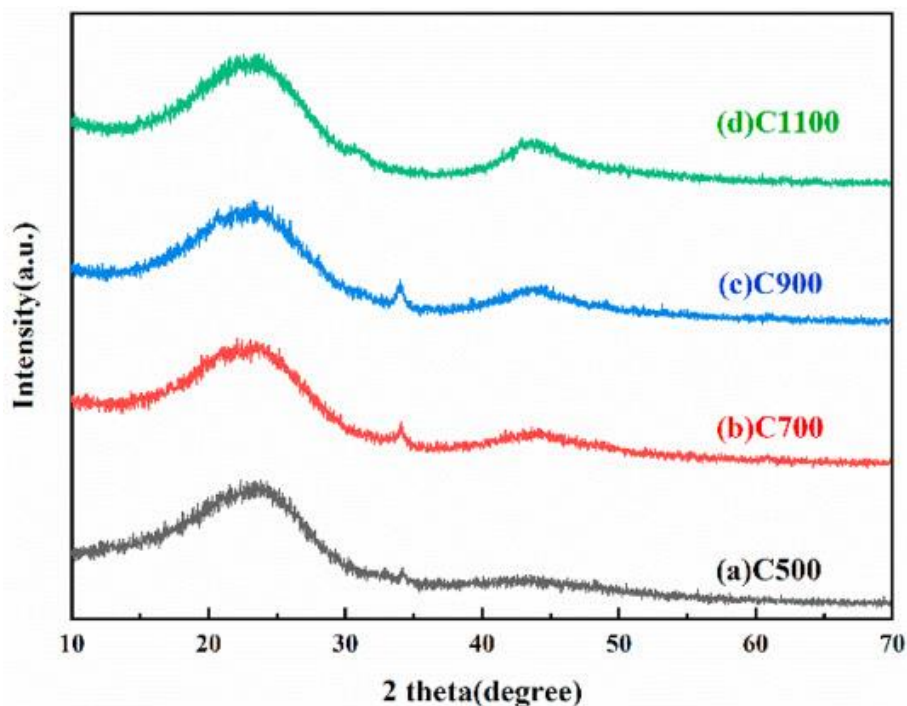


Fig. 11. XRD patterns of Paraffin and PCCs.

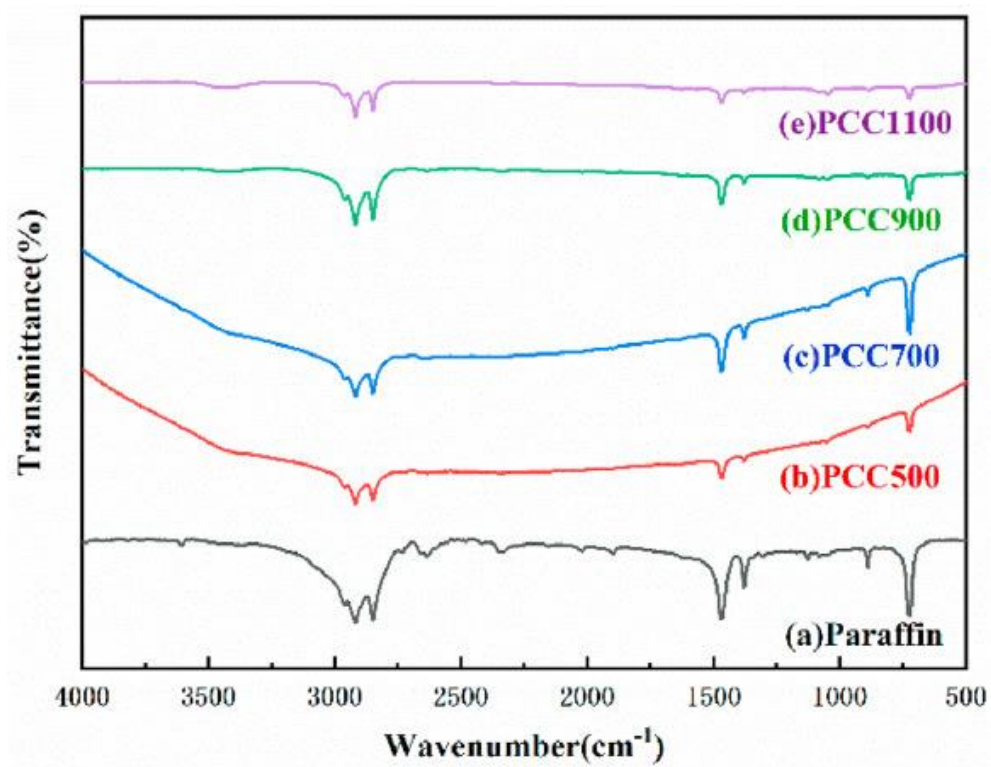


Fig. 12. FT-IR spectra of Paraffin and PCCs.

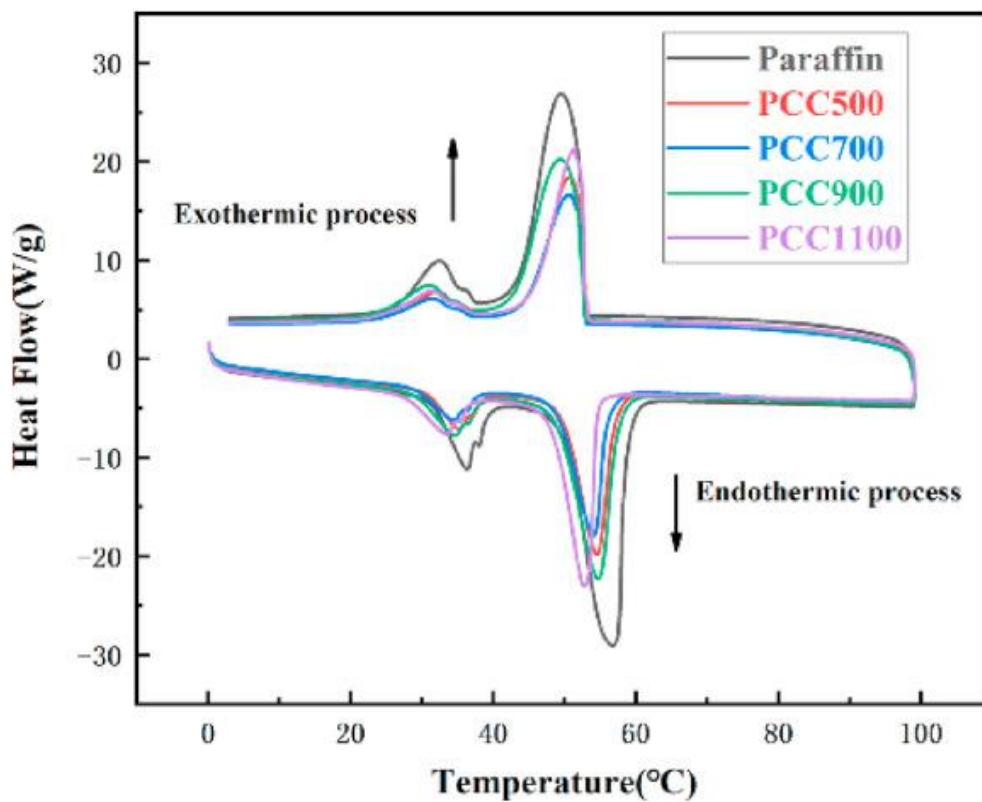


Fig. 13. DSC curves of paraffin and PCCs.

5.4 Final results

Table 4

Melting temperature of paraffin and pccs

Serial number	Paraffin	PCC500	PCC700	PCC900	PCC1100
Melting temperature T _m (°C)	68.2	68.3	68.4	68.3	68.4

Table 5***Latent heat of paraffin and pccs***

Serial number	Paraffin	PCC500	PCC700	PCC900	PCC1100
Latent heat Hm (J/g)	190	126.87	118.44	112.56	108

Table 6***Thermal conductivity of paraffin and PCCs***

Serial number	Paraffin	PCC500	PCC700	PCC900	PCC110
Thermal conductivity (w/mk)	0.3712	1.61	1.992	2.283	2.418

Table 7***Thermal diffusivity of paraffin and pccs***

Serial number	Paraffin	PCC500	PCC700	PCC900	PCC1100
Thermal diffusivity (cm ² /s)	1.42×10^{-7}	9.16×10^{-7}	1.02×10^{-6}	1.22×10^{-6}	1.32×10^{-7}

Table 8***Specific heat of paraffin and pccs***

Serial number	Paraffin	PCC500	PCC700	PCC900	PCC1100
Specific heat (KJ/Kg K)	2.14	1.92	1.88	2.1	2.26

CHAPTER -6

6.1 CONCLUSION

In this study, carbon foam was prepared by simple normal foaming and steaming method at different carbonization temperatures. Also, the PCCs were prepared by vacuum impregnation to investigate the effect carbonization temperature had on the thermal properties. The morphology of the carbon foams showed that the carbon foams with hierarchical pores prevented paraffin from leaking, which can be attributed to the combined action of the capillary forces and physical absorption of the pore structure. XRD patterns of the matrix materials showed the presence of amorphous carbon and a certain degree of graphitization. By increasing the carbonization temperature, the percentage of paraffin loading increased, and when the carbonization temperature was 1100 °C, the percentage of loaded paraffin maximized at 72.79% without leakage. The XRD patterns and the FT–IR spectra of the paraffin and PCCs indicated that the interaction between the carbon foam and paraffin was physical loading without chemical interaction. The DSC curves showed the latent heat of sample PCC1100 was 174.3 J/g at the melting temperature of 47.9 °C and 151.4 J/g at the freezing temperature of 52.8 °C. TGA and thermal cycling test showed that the PCCs had good chemical and thermal stability and reliability in a typical working temperature range. Finally, the thermal conductivity of sample PCC1100 was 0.339 W/ (m·K), which was 1.93 times higher than that (0.176 W/ (m·K)) of paraffin. The entire carbon foam and PCCs fabrication process was environmentally friendly and inexpensive. Therefore, the developed PCCs are acceptable for low-temperature thermal energy storage applications.

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