Materials International
Open Access Journal (ISSN: 2668-5728)

Article
Volume 6, Issue 1, 2024, 9
https://doi.org/10.33263/Materials61.009

Preparation, Characterization, and Performance of Ethylene Propylene Diene Monomer for Thermal Energy Storage

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Scopus Author ID 15073269400
Received: 3.08.2022; Accepted: 3.10.2022; Published: 19.02.2024

Abstract: Solar energy is widely used globally due to its abundance and high frequency. Thermal energy storage is a crucial device that converts sunlight into energy. This research aimed to determine the effect of the paraffin: graphite ratio on the phase change material's thermal resistance (PCM). In combination with the paraffin-compatible Ethylene Propylene Diene Monomer (EPDM), PCM was used as a base polymer to prepare paraffin graphite composites. The samples were prepared by heating at 180 °C for 20 minutes with mass ratios of PCM70: EPDM30, PCM80: EPDM20, and PCM90: EPDM10. Tensile strength testing, thermal stability analysis, and SEM results were analyzed. The maximum tensile strength is obtained at an 80:20 mass ratio of 9.34 MPa. The material has a thermal stability of 307.04°C at the onset and 399.50°C at the end. The results of the SEM morphology test indicate that the best interaction occurs between polymers with a mass ratio of 70%:30% at a ratio of 9:1, resulting in a very well-mixed surface that is smooth and free of lumps.

Keywords: EPDM; graphite; paraffin; phase change material; polymers; thermal resistance.

1. Introduction

Solar energy is used worldwide because it is abundant and has a high frequency. It is critical to collect sunlight, transport solar energy, and store it as heat energy in a solar thermal system. The solar thermal collector's heat transfer fluid or device is critical for collecting sunlight and converting it to thermal energy [1]. By utilizing heat flow directly to absorb and store thermal energy, we can avoid heat loss from the collector into the environment and dissipate energy between the meeting surface and the heat flow, resulting in increased storage capacity and improved reception efficiency. In this scenario, the heat transfer must be highly photothermal, have high thermal conductivity, and have a large thermal storage capacity, as PCM has a high enthalpy and thermal conductivity, which can boost photothermal energy [2]. Thermal energy storage is one of the most efficient methods of storing thermal energy. Heat energy is transferred when a solid transforms into a liquid or a liquid into a solid [3]. A shape or phase change occurs as a result of this. This occurs initially in solid-liquid iPCM in situations similar to conventional storage shifts, where energy is released in proportion to the amount of

heat received. Unlike other forms of energy storage, PCM can absorb and release heat at nearly constant temperatures. Compared to traditional icon energy storage materials such as water or stone, PCM can release heat up to 4-5 times its volume [4]. To meet the growing demand for national electrical energy consumption, which is a result of increased electrical energy usage or electrification, as well as changes in the Indonesian people's lifestyle. According to figures released by the Ministry of Energy and Mineral Resources in 2019, electricity consumption in Indonesia reached 1,064 kWh/capita in 2018, an increase of 5.4 percent over the previous year. The government anticipates that public power consumption will increase to 1,129 kWh/capita this year [5].

A phase change material (PCM) is a material that undergoes physical transformations during the heating and cooling processes to store and release heat energy. PCM can be classified as solid-solid, solid-liquid, gas-solid, or liquid-gas [5,6]. Solid-liquid PCM is the most frequently used PCM class due to its high latent heat and low volumetric change during the phase transition. Organic PCM (paraffin and fatty acids) and inorganic PCM (paraffin and fatty acids) are examples of solid-liquid PCM (such as hydrated salts). Phase change materials (PCM), also referred to as materials that can store latent heat, can release a large amount of heat energy over an extended period of time without changing their temperature [7-10]. Paraffin is a phase transition material capable of storing heat energy. The availability of abundant paraffin at a low cost is easy to obtain, is non-toxic, and has a relatively high latent heat of 200-250 kJ/kg with a melting temperature of 24, making it ideal for use in conjunction with metal materials and non-corrosive, resulting in extremely high heat transmission [11]. Even though polymers and paraffin have the same desirable properties as PCM, they have a lower thermal value of 0.2 W.m.K. As a result, adding exposed graphite increases their thermal conductivity while compensating for their low heat transfer rate. By incorporating a small amount of expanded graphite into the mixture, the thermal conductivity of PCM can be increased [10-12]. EPDM is composed of low-melting-point alkanes that react readily with paraffin to form compounds with lower melting points. Using an ethylene-propylene-diene polymer can improve the structure of phase-changer materials [13]. The material's ethylene propylene-diene polymer can be modified. A phase changer in a small area can improve mechanical properties, and a suitable ethylene-propylene-diene copolymer ratio can improve expanded graphite dispersion and increase heat conductivity [14,15]. PCM is frequently adsorbed into phase change composites via porous materials such as expanded graffiti, 0 CNT Array, and 3D graffiti. The phase change composition has a higher thermal conductivity, which significantly increases the thermal energy charge/discharge rate in the thermal system. Additionally, because carbon-based materials dominate the composite phase change, the phase change of the photothermal composite may be significantly enhanced, allowing the composite to absorb solar energy directly and transmit it to air or other hot liquids. Carbon-based phase transition composites have been described previously as optical and thermal acceptors [16-18].

This study aims to determine the effect of the paraffin: graphite ratio on the thermal resistance of the Phase Change Material (PCM) by heating it at 180oC for 20 minutes in several mass ratios of PCM and EPDM. The Phase Changing Material is miscible with other polymers, including Ethylene Propylene Diene Monomer (EPDM), which is compatible with paraffin. PCM with excellent mechanical properties and a good EPDM mixture are used as the base polymer to prepare paraffin graphite composites. The resulting PCM would have a high tensile strength, a high thermal conductivity, and a significant amount of latent heat.

2. Materials and Methods

2.1. Ingredients and EPDM PCM preparation.

The technical grade of paraffin (OP70, T m from ~ 65°C). Expanded graphite (EG). Ethylene propylene diene monomer rubber (EPDM). All chemicals were used as received without further purification in cations. Prepare the paraffin, graphite, and EPDM materials by mixing them with a fixed ratio of EPDM gel using a DSM Xplore co-rotating extruder at a melting temperature of 1800 °C and a screw speed of 100 rpm. PCM EPDM polymers with various 9:1 and 8:2 fillers were mixed in a ratio of 70%:30% (PCM70-EPDM30), where each total mixture weighed 20 grams to ensure full filling of the extruder. Also, prepare 80%:20% and 90%:10% polymers with filler variations of 9:1 and 8:2 from the total mixture weight as a comparison sample. Next, the PCM (Paraffin: Graphite) + EPDM polymer mixture was coated with aluminum foil into the ASTM 638 DType I standard specimen mold. Then, compaction (compressing) with a hot press tool at a temperature of 180 degrees for 20 minutes under atmospheric pressure.

2.2. Characteristics of PCM

The material that has been formed is left at room temperature until it solidifies completely. Test the mechanical properties of tensile strength with the UTM Exceed Model E43. It uses SEM JSM-6510 LA, Thermal Stability, and Morphological Analysis of the New Material PCM + EPDM. The material that has been formed is allowed to stand at room temperature until it is completely solidified.

3. Results and Discussion

3.1. Thermo gravimetric analysis (TGA) characterization.

The manufacture of these composites requires mixing the filler and the matrix at high temperatures to calculate the degradation effect on the properties of the filler-containing material. Research has analyzed the thermal stability studies of PCM EPDM composites through TGA. The direct evidence of the perfect interaction is the increase in heat resistance through TGA (Thermal Gravimetric Analysis) testing, namely, the onset temperature from 200^0C for pure PCM increases to 399.50^{o}C for EPDM-based PCM. Figure 1 depicts a plot of mass decrease on the y-axis and ratio growth on the x-axis. Because the onset and endset occurred only once, all PCM EPDM samples had a single breakdown, as the graph shows. In this investigation, the EPDM PCM degradation temperature ranged from 250^{o}C to 4000^{o}C. According to Figure 1, pure PCM begins to lose mass at a temperature of 200 [17,19]. PCM with the addition of 20% and 30% EPDM at a ratio of 9:1 and 8:2 began to deteriorate at temperatures of 307.04^{o}C, 293.85^{o}C, 303.29^{o}C, and 293.09^{o}C, respectively.

These results indicate that, compared to pure PCM without mixing, the EPDM addition to the paraffin graphite polymer improves heat stability. The material's thermal stability, which is indicated by a rise in the degradation temperature, improves with increasing filler concentration. The increase in degradation temperature is caused by the bond between the polymer and filler, which is fused more strongly so that it is difficult to break, and the decomposition of the material becomes slower. The study with the maximum degradation temperature was conducted by PCM with the addition of 20% EPDM at 307.04^{o}C.

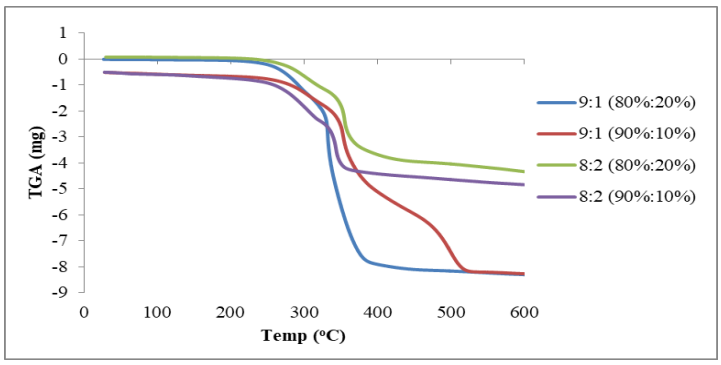

Figure 1. TGA analysis chart on sample 9:1 (80%:20%, Sample 9:1(90%:10%), Sample 8:2 (80%:20%), and Sample 8:2 (90%: 10%) Against Temperature.

At the same time, the PCM study with the addition of 10% EPDM is the lowest, with a degradation temperature of 293.09°C. The effect of the paraffin: graphite ratio on increasing thermal stability is that the more paraffin, the thermal stability decreases because when the temperature rises to 200, paraffin will decompose completely, while EPDM polymer does not decompose below 250 and completely decomposes up to 300. Because graphite decomposes at a considerably higher temperature, graphite is what remains after the TGA test. It has been demonstrated that the most recent matrix and filler developments, paraffin and graphite, may be mixed with EPDM with a ratio of 9:1 and a mass ratio of 80:20% to enhance the thermal properties of PCM materials.

3.2. Tensile test results with universal tensile test machine (UTM).

At this stage, a tensile strength test (Tensile Strength) will be carried out on the PCM EPDM sample, which aims to determine the effect of the mass ratio of paraffin: graphite into EPDM on the mechanical characteristics of the tensile strength (Tensile Strength) of the material. The observational data on the tensile strength test results are shown in Table 1.

Table 1. Tensile strength test results data table with universal tensile text machine (UTM) tool.

Comparison Paraffin: Graphite	Mass Ratio (Paraffin: Graphite) : EPDM	Tensile Strength Test (Mpa)
9:1	70 % : 30% 80% : 20% 90% : 10%	3.4 3.9 3.2
8:2	70 % : 30% 80% : 20% 90% : 10%	2.8 3 2.2

From Table 1, it is known that the tensile strength of the EPDM PCM obtained ranges from 2.5 to 3.9 MPa. Figure 2 shows the relationship between comparative variations (paraffin: graphite): EPDM vs. tensile strength values measured in % with tensile strength values (Tensile Strength) in MPa units on PCM EPDM. From the graph above, it can be seen that the sample with 80%:20% PCM EPDM at a ratio of 9:1 has a better tensile strength to the polymer when compared to other polymers. However, the addition of filler has a threshold. When it exceeds the acceptable threshold for a polymer, what happens is that the polymer becomes brittle and weak, so an ideal filler composition is needed. The tensile strength values of the six samples vary from 2.5 to 3.9 MPa, whereas the PCM EPDM value has a maximum tensile strength of 3.4 MPa at a ratio of 9:1 with a variance of 70% to 30%. The graph above shows that the tensile

strength of the EPDM PCM sample at a ratio of 9:1 with a variation of 80%:20% is the highest tensile test value compared to other samples, which is 3.9 MPa, in the PCM EPDM sample with a mass ratio of 80%:20% at a ratio of 8:20% The tensile strength reaches 3.2 MPa. Meanwhile, PCM EPDM, with the addition of 30% EPDM, has the lowest tensile strength value. This also occurs in PCM polymers at a ratio of 8:2, adding 10%, 20%, and 30% EPDM filler, which are 2.8, 3.2, and 2.2 MPa. This figure also has the lowest tensile strength value of the six composites formed. The decrease in the tensile strength value is due to the composition of the EPDM filler having exceeded the threshold level, namely because the mass ratio is 8:2, which shows that the mechanical properties of tensile strength and stiffness in PCM can be increased by adding 10%–30% EPDM into the polymer. It will effectively improve mechanical properties. In addition, if the sample is left in the melting device for too long, the crosslink bond in the polymer is reduced by the high temperature, which has an adverse effect on the tensile strength, which should rise if it surpasses 10% to 30%.

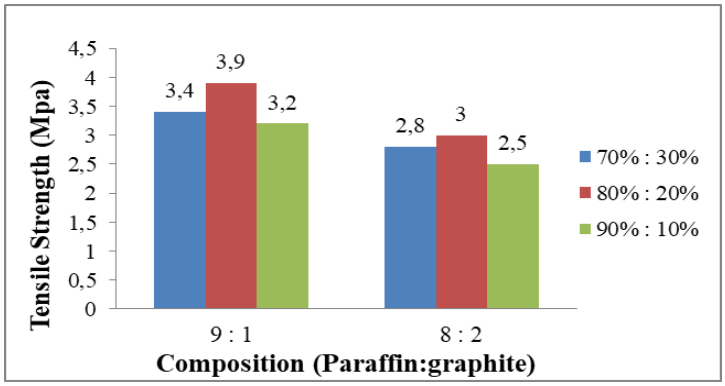

Figure 2. Comparative variation graph (paraffin: graphite): EPDM VS strong value tensile strength (MPa) on the EPDM PCM.

3.3. Morphological structure test results with SEM.

SEM is a morphological examination tool that can detect the surface of a material with more resolution than ordinary optical microscopes. This approach allows researchers to see what is happening in and around the interface, matter, and oxide layer in great detail. The shape of the EPDM PCM microstructure was looked at with a scanning electron microscope (SEM), as shown in the SEM photos in Figure 3. Magnification of x100 shows that the six structures have very large differences namely, the PCM sample with a ratio of 9:1 at a mass ratio of 80%:20% has a smoother surface and forms a good interfacial bond between the matrix and filler compared to the PCM matrix with a ratio of 9:1 at a mass ratio of 90%:10%, which indicates some form of agglomerate and large pores, as well as a rough surface. This happens because, based on the study's research [20], the surface of the EPDM PCM sample turns rough with the increase in the mass fraction of the EPDM PCM. PCM EPDM has a structure where PCM EPDM has a large tensile strength with a larger mass fraction than pure PCM. EPDM can provide a continuous composite structure, so the sample has a large elongation at break with a large EPDM mass fraction [21]. Suppose it is associated with the tensile test and thermal degradation test. In that case, the results of this SEM test are also correlated, where the surface structure of the PCM composite with a ratio of 9:1 at a mass ratio of 80%:20% is the best because it produces good tensile strength and thermal stability [22].

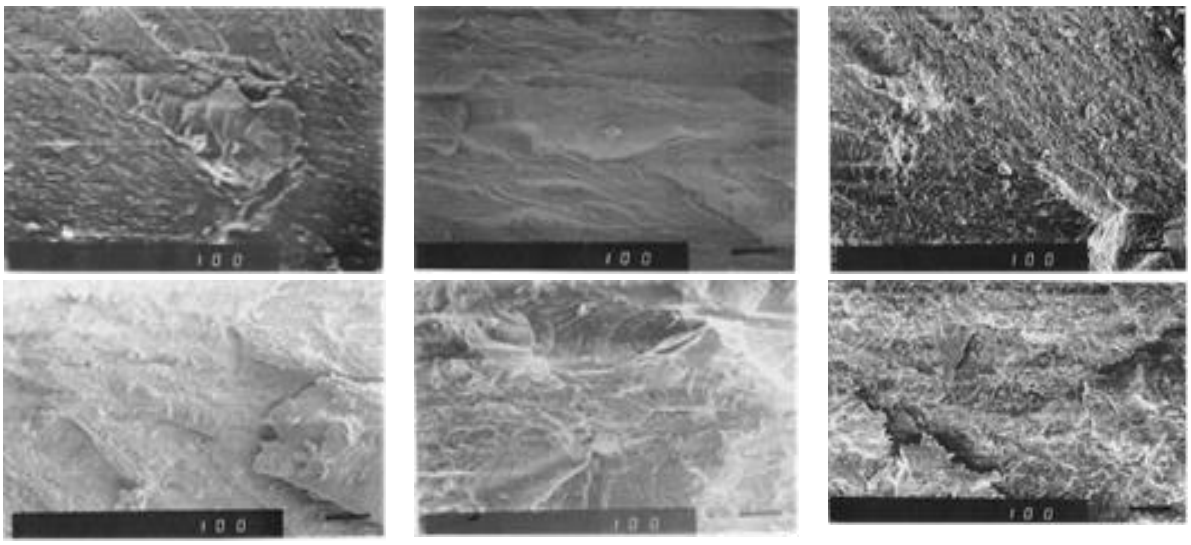

Figure 3. SEM test results.

4. Conclusions

PCM with excellent mechanical properties and a good EPDM mixture are used as the base polymer to prepare paraffin graphite composites. The effect of the paraffin: graphite ratio on the increase in thermal stability is that the more paraffin, the thermal stability decreases, and the higher the concentration of filler added, the better the thermal stability of the material, at a ratio of 9:1 with a mass ratio of 80%:20%, 307.04ºC onsite and ends at 399.50 ºC. The higher the tensile strength value, the better the polymer, but the addition of filler has a threshold accepted by the polymer. Based on the results of the tensile test, it is shown that the PCM composite at a mass ratio of 9:1 with a mass ratio of 80%:20% is the optimal filler composition for PCM composites with a tensile strength value of 3.9 MPa. While the results of the surface morphology test using SEM show that the surface turns rough with increasing PCM EPDM fraction, the best interaction between composites was achieved with a mass ratio of 80%:20% at a ratio of 9:1, with a very well-mixed surface, smooth with no lumps formed. EPDM can provide a continuous composite structure, so the sample has a large elongation at break with a large EPDM mass fraction.

Funding

This research was funded by the Education, Culture, Research, and Technology Ministry of the Republic of Indonesia for financial support through grant Number 185/E4.1/AK.04.PT/2021.

Acknowledgments

The authors express their gratitude to the Education, Culture, Research, and Technology Ministry of the Republic of Indonesia for the financial support through grant Nomor: 185/E4.1/AK.04.PT/2021.

Conflicts of Interest

All authors confirmed there is no conflict of interest.

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