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Heat-Absorbing Composite Strength Analysis for Electric Vehicles Battery Pack Cover

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Abstract: One of the key components of Electric Vehicles is the battery pack compartment casing, which needs to be both as light and as strong as possible to cover maximum mileage while withstand vibrations and other mechanical abuse. A layer of thermal protection is also placed to the case because a typical Lithium battery used for an EV is very sensitive to temperature. In this study, a heat-absorbing lightweight composite for the battery pack compartment casing of an electric vehicle is physically constructed and put to the test to determine its mechanical characteristics. The latent ability of organic phase change materials to absorb heat without experiencing thermal rise led to their use as fillers for the resin composite. Depending on what type and how much phase change materials are utilized, the tensile evaluation reveals that the average strength is noticeably compromised. The composite preparation techniques, including the use of carbon fiber as reinforcement material, are also briefly covered in this paper.

Keywords: Battery thermal management system, Electric vehicles, Mechanical properties, Phase Change Materials, Tensile strength

Introduction

Research and development of battery Electric Vehicles (EV) have significantly progressed in recent years due to the worldwide aim to achieve carbon-neutral in 2050 and reduce dependency on fossil fuels. One of the key components in battery EV is the so-called Battery Thermal Management System (BTMS). It is a mandatory feature to protect the battery pack from any kind of thermal abuse. Internal electrochemical reactions in each battery cell during the charging or discharging process often lead to a certain amount of heat dissipating to the surroundings (Gungor et al., 2022; Zhao et al., 2018). Due to its compact nature, an uncontrolled heat dissipation caused some sort of heat entrapment, causing an exponential increase in temperature so-called thermal runaway, which is hazardous (Börger et al., 2019; Feng et al., 2018).

Take an example from a Lithium-based battery, which is currently one of the most popular types of EV known for its high energy density. Its safe operating temperature is generally between 0-40 °C. When heat dissipation causes it to exceed 40 °C, its electrical performance is compensated and its life cycle is also damaged in the long run (Z. Wang et al., 2021). During the EV operation, the surface temperature is significantly affected not only by the environment (Cen et al., 2018; Huda et al., 2020; Talluri et al., 2020), but also by the electrical load (Budiman et al., 2022; Offer et al., 2012). Uneven surface temperature between each battery cell in use leads to different charging or discharging capabilities within a battery module or pack which creating a positive/self-reinforcing feedback to heat dissipation. Severe thermal damage can be initiated from just a single cell failure. As such, a proper thermal management system is required.

A complex vehicle design requires the battery pack to be safely stored and protected not only from thermal abuses but also electrical and mechanical stresses. The complex electrical wiring and connections near the battery pack storage area that become the nature of EV, altogether with constant vibrations when the vehicle is in motion, may affect the batteries' performance and safety. Therefore, a battery pack cover needs to be robust and maintain a certain level of mechanical strength as well as elasticity. Recently, polymer composites have been extensively investigated for their potential substitute for steel or other metal parts in a vehicle (Zhang & Xu, 2022). Such lightweight materials are preferred due to the extreme weight allowed in vehicles, which also contributes to the mileage it could cover from a single battery charge (Arifurrahman et al., 2018; Baser et al., 2022; Sudirja et al., 2020).

Composite materials are formed from at least two different substances, typically with different mechanical or chemical properties, typically with distinct boundaries between them. A simple resin composite can be made by mixing it with a catalyst and letting them cured in a mold for just a couple of hours or days. The composite product usually has unique, standout characteristics, and often is combined with various reinforcement materials. For example, carbon fiber is combined with polymers to form a reinforced plastic with significantly greater mechanical strength than ordinary plastics. Aluminum Tri-Hydroxide (ATH) is added to an Unsaturated Polyester to form a composite with a high level of flame retardancy (Kaleg et al., 2022). Kevlar composite can be found not only in the military but also in the aerospace industry as an engine protection layer. Graphene is mixed with Phase Change Materials (PCM) and recycled plastics as building materials with better indoor thermal conditioning than conventional materials (Acuña-Pizano et al., 2022). PCM composite is also used as a heat absorber in EV to protect the battery pack from overheating. There are many forms of PCM composites reported, such as with graphite (Cabeza et al., 2003; Jiang et al., 2017), metal foam (Hussein et al., 2016; X. Wang et al., 2018), nanopowders (Kochetov et al., 2009), and carbon fibers (Babapoor et al., 2015; Samimi et al., 2016). These previous studies reported a significantly reduced maximum temperature due to an augmented heat transfer from the battery to the composite, despite the PCM itself having a low thermal conductivity.

Besides a simple casting, many complex composite manufacturing methods that often involve reinforcement materials have been developed to date, such as hand lay-up and vacuum infusion methods. As one of the oldest processes, the former is known for its simplicity and is economically feasible. It begins with mixing resin and catalysts, before the mixture is manually applied to the reinforcement fiber in a mold. Another layer of fiber is then put on top of the mixture using a roller to remove air bubbles. These steps are repeated until the desired thickness. Once done, the composite can be removed from the mold, which can be reused. On the other hand, the vacuum infusion process requires a vacuum compressor to infuse the resin mixture along the bundles of reinforcement fibers inside a sealed bag. As a result, the end product typically has better consistency and

properties than the hand lay-up process. However, the vacuum bag cannot be reused, making this process more costly than the hand lay-up.

In this work, a resin composite with PCM is prepared using a simple casting method and evaluated in terms of tensile strength. Brief qualitative comparisons based on still photographs between samples with various compositions are discussed. Two different organic PCM with 20 percent of weight are tested and compared with the base reference. Other specimens are prepared using different composite fabricating methods for comparison. The tensile tests would reveal the suitability of such materials to be used in the EV battery pack case.

Experimental Methods

The base reference composite was made by mixing commercial Ripoxy R-804J resin with MEKP (Methyl Ethyl Ketone Peroxide) as its promoter. Both products were purchased from Justus Kimiaraya, Indonesia. A small amount of Montmorillonite is added to improve its flame retardancy. The mixture is then poured into a 14 cm x 14 cm silicone mold and left cured for at least 24 hours. To study the effect of the vacuum infusion method, another base specimen was prepared. Carbon Fiber HD C524-3K Weave was used as a reinforcement material. The curing process was between 48-72 hours, notably longer duration than the ordinary molding due to the usage of vacuum sealed bag.

Three different organic PCM (Sigma-Aldrich, Singapore) were considered in this study, that is, paraffin C20 mixture, lauric acid, and caprylone. These PCM have unique, different heat absorbing characteristics (Budiman et al., 2021) with their respective peak latent temperature of 53.8 ºC, 44.1 ºC, and 39.4 ºC (NETZSCH DSC 214 Polyma DSC21400A-0710-L). Each PCM was put into a container in a hot water bath until entirely melted before being stirred with the Ripoxy for a minute prior to the catalyst addition. Another sample with graphite powder, known as thermal conductivity augmentation material (Cabeza et al., 2003), was also prepared. After a day, the cured specimens were cut by means of CNC milling and prepared according to the ASTM D638 tensile test requirements.

Results and Discussion

Visual Appearance

Although the minimum duration for the curing process is set as 24 hours, visual observation has been carried out regularly since the mixture was added to the mold. For the base composite, the sample seemed completely dry out and detached from the base just within the first two hours. The other samples took a slightly longer time, but it is expected that the curing is already completed. After 24 hours and the sample is removed from the mold, it is found that the blank specimen (the resin base without any PCM) and the specimen with paraffin has a light brown/grey color, while the lauric and caprylone composites are more yellowish, as depicted in Figure 1. The base sample has a smooth surface, indicating an evenly distributed curing process. On the other hand, the PCM composites are relatively rough, especially in the case of paraffin, which could be a sign that some small amounts of PCM are not fully covered by the resin and are ejected out of the mixture. This could possibly be due to the marginal density difference between the resin and the PCM, which unfortunately could not be simply snubbed, slowly causing the PCM to be separated during the curing duration.

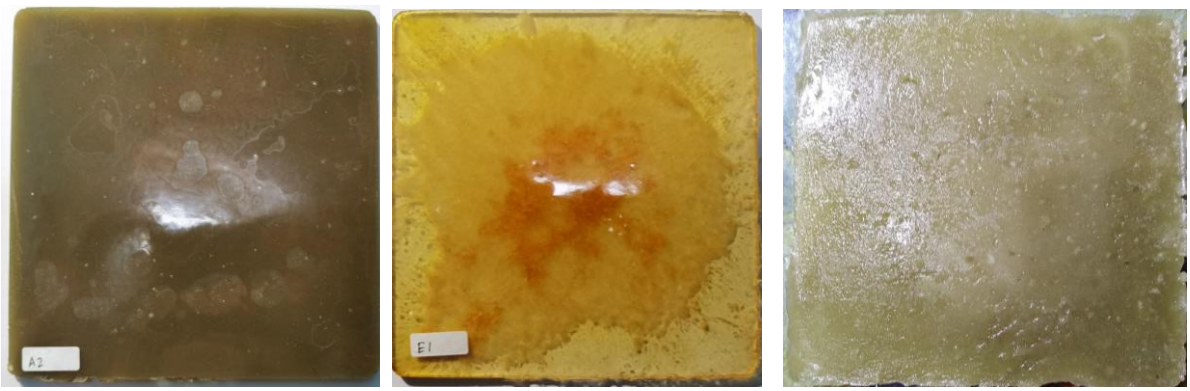

Figure 1. Photographs of the blank, lauric, and paraffin resin composites

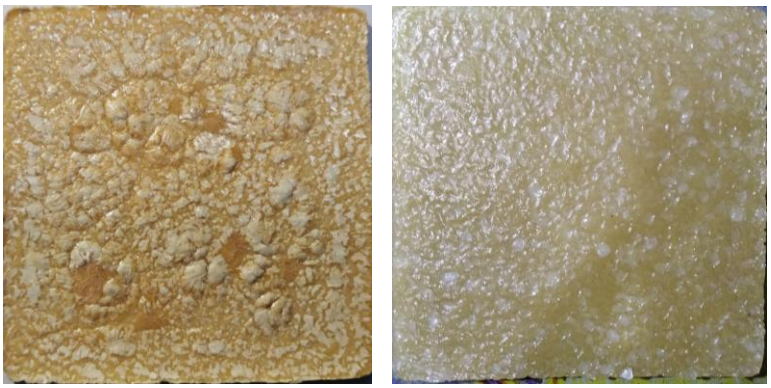

Figure 2. Photographs of the 40% lauric and paraffin composites

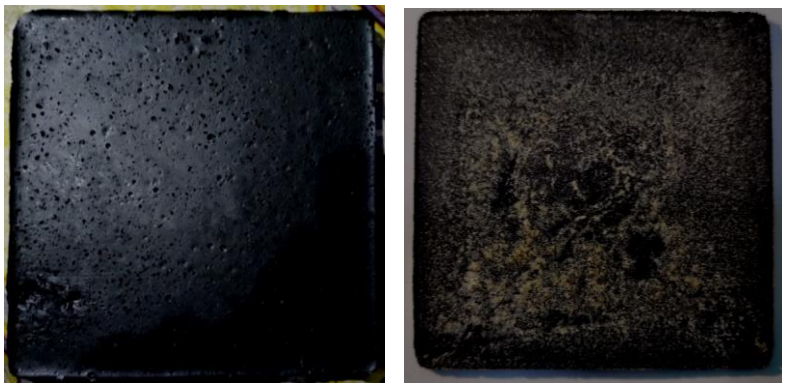

Figure 3. Photographs of the 20% and 40% lauric with graphite

Figure 2 shows the effect of more PCM addition to the mixture. As each of the lauric and paraffin amounts is doubled, unusual PCM lumps could be found especially on the top surface. Those protrusions are rather simple to remove, even with only slight nail movements. Moreover, a notable shrinking process could somehow be found, as the composite side is no longer attached to the side frame. The surface was jagged and a notable amount of fine craters/dimples could be seen. Figure 3 shows a similar result when both lauric samples were also mixed with graphite powder. The yellowish lauric can be spotted well across the sample. Additionally, the lumps are thoroughly melted and separated from the solid specimen when the samples are heated to a temperature above the PCM melting point and subsequently naturally cooled back to room temperature (i.e., one thermal cycle). Our weight composition variations between 5 and 40% PCM suggest that the 20%wt may be the upper limit permitted by this straightforward mold curing process for the PCM to be completely macro-encapsulated within the composite without a weight reduction detected after some thermal cycles.

Mechanical Properties

It is understandable that the presence of PCM might particularly reduce the mechanical strength of the composites, considering its typically brittle appearance. The average tensile results from at least three specimens of composites are tabulated in Table 1, while the stress-strain relation and the force-to-length trend are presented in Figures 4-6 for the base reference case, lauric acid, and paraffin composites, respectively. While the reference sample broke at approximately 1.98 mm in length, the specimen with lauric and paraffin could reach 2.48 and only 1.16 mm, respectively. The presence of lauric acid or paraffin in the resin composite differently reduces the maximum limit of force or stress that can be endured by the material, with the biggest reduction of almost 70% caused by paraffin.

Table 1. Mechanical strength test results of each resin speciments

Specimen	Ultimate Force (N)	Ultimate Stress (MPa)	Modulus (MPa)	Total Elongation (%)
Base	604 ± 16	62.1 ± 0.8	1835 ± 135	3.56 ± 0.02
Lauric ac.	402 ± 16	41.3 ± 5.1	1018 ± 84	3.43 ± 0.96
Paraffin	216 ± 25	22.1 ± 4.9	695 ± 196	2.93 ± 1.61

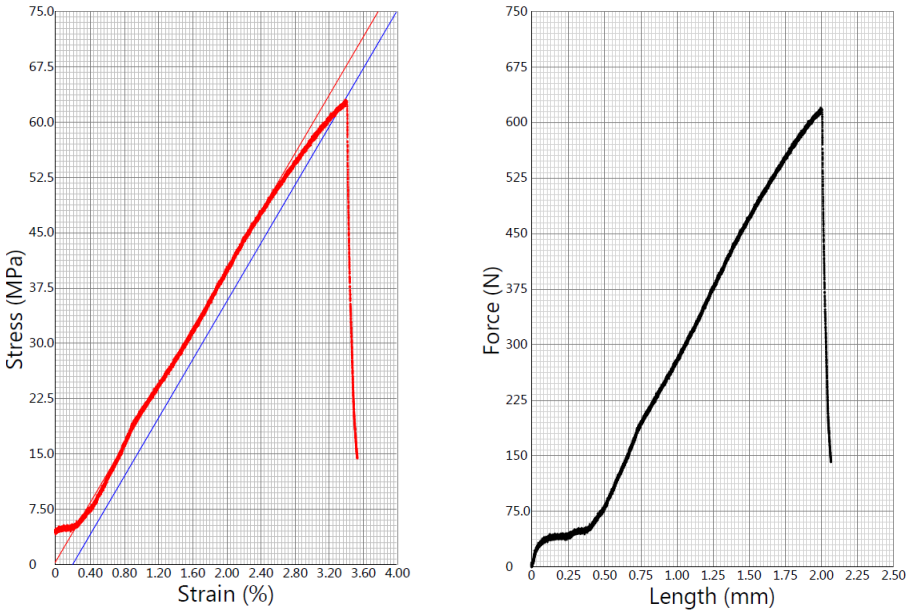

Figure 4. Tensile test results from the base resin

The presence of small dimples or bumps around the surface could also indicate similar situations inside the specimen, that is, the substantial void that weakens the entire structure by potentially allowing crack propagation more easily. Any non-uniform particle distribution so-called agglomeration or volumetric change during PCM phase transition temperature might affect the matrix-filler microscopic structure integrity, hence an increase of potential stress concentration (Kaleg et al., 2022; Luo et al., 2020). Furthermore, the uneven surface roughness could also contribute to the gripping problem of the specimen under the tensile test, resulting in a slightly jagged trend in the middle of the tests, as seen in Figures 5-6.

Unlike PCM, the use of fibers in a composite provides certain stiffness to the resin matrix, leading to protection against cracks or other structural damages. The effect of the vacuum infusion method and carbon fiber reinforcement for the base reference resin specimen can be clearly seen in Table 2. The material could now withstand more than 15 times of force, while the maximum stress could be increased by about five times. The specimen could be stretched by approximately 6.15 mm before it broke. In contrast, the modulus value only increased by about 25%. The more evenly distributed resin mixture inside the fiber weaves leads to a well-spread stress, causing it more difficult to break. Furthermore, the addition of PCM only decreased the ultimate force by 20%, compared to 34% in the previous method.

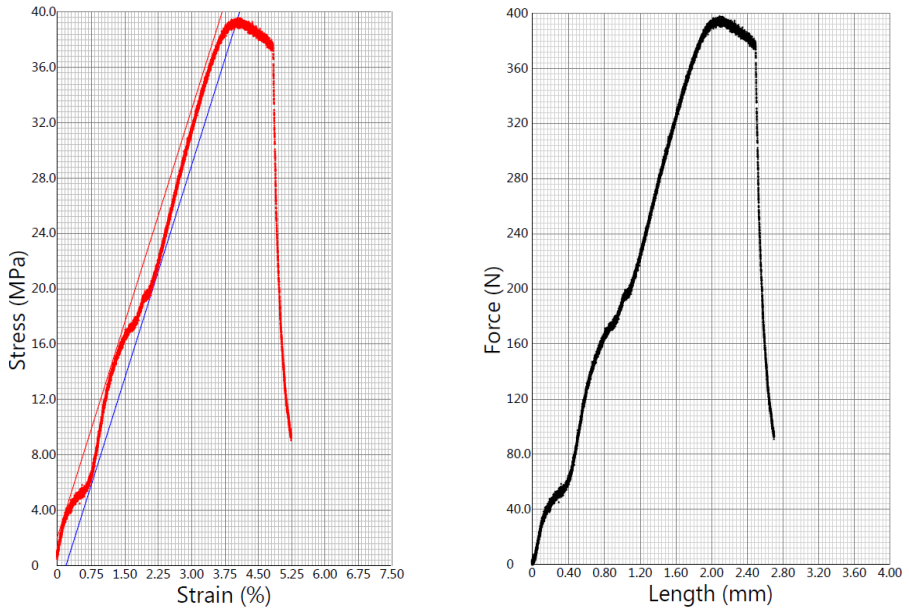

Figure 5. Tensile test results from the resin with lauric acid

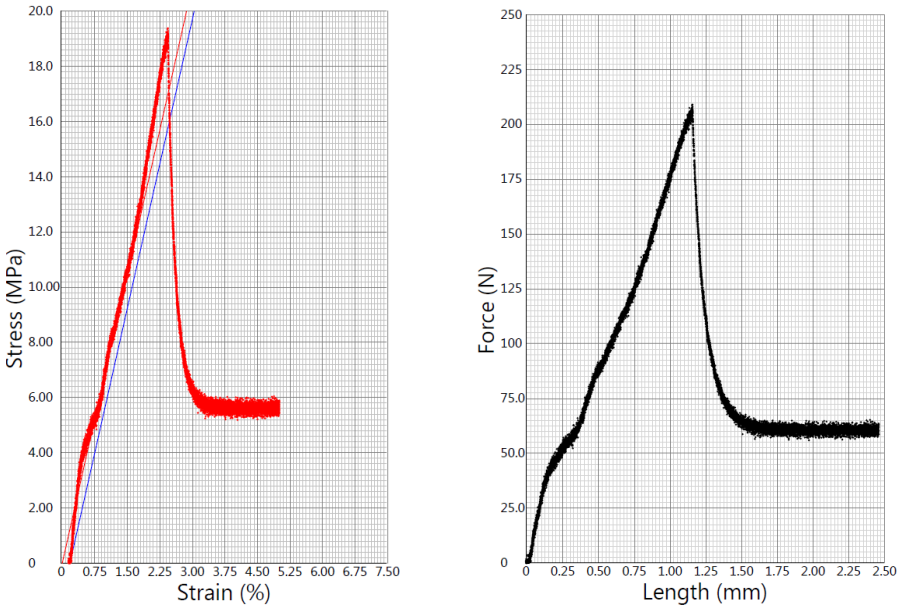

Figure 6. Tensile test results from the paraffin-added resin

Table 2. Mechanical strength of resin speciment with carbon fiber

Specimen	Ultimate Force (N)	Ultimate Stress (MPa)	Modulus (MPa)	Total Elongation (%)
Base	604 ± 16	62.1 ± 0.8	1835 ± 135	3.56 ± 0.02
Reinforced base	10225 ± 175	329.5 ± 6.5	2317 ± 243	11.35 ± 0.85
Lauric	8250 ± 30	220 ± 1.0	2110 ± 245	10.4 ± 0.70
Lauric-graphite	8810 ± 30	271 ± 1.0	2395 ± 245	11.20 ± 0.70

Conclusion

Polymer composites with heat-absorbing material for Electric Vehicles battery pack compartment covers have been manufactured and tested in terms of their mechanical strength. Three different organic Phase Change Materials (PCM) with a similar melting point profile were used and comparatively analyzed. Using a simple casting method, it can be concluded that a maximum of 20%wt PCM can be added to the resin mixture without experiencing extensive agglomeration on the surface. The tensile test was performed to show how much strength reduction was due to the presence of PCM. It can be seen that the lauric acid PCM specimen has a smaller decrease than paraffin. Finally, the presence of carbon-fiber as material reinforcement, coupled with the vacuum infusion method, which leads to a more uniformly distributed mixture within the fiber weave, produces a significant mechanical strength upgrade to the base case.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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