Thermal Conductivity Characterization of Epoxy Based Composites Reinforced with Date Palm Waste Particles

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Abstract Natural additives are largely available and have good environmental properties, therefore it mostly added as reinforcing material in a large number of polymeric materials. The intention of this study is to prepared green composite products to utilize as an insulating material and also in internal components of automobiles and the shipbuilding industry. For that reason, six composites were prepared that using particles from the date palm waste (palm mesh, seed of fruit, and trunk) as reinforcing fillers at (10, 20, and 30) wt.% loading as well as a hybrid of each three fillers in an epoxy matrix. The result included that the variation of thermal properties with the filler volume fraction and also with the type of fillers. At maximum volume fractions (30%), the seed date palm attained the lowest values of thermal properties of 0.138 W/m.K, 720 m²/s, and 0.0201 J/kg.K for the thermal conductivity, specific heat, and thermal diffusivity respectively. Epoxy hybrid composites have the lowest thermal conductivity than other composite materials, making them more suitable for thermal insulation materials.

Keywords: Epoxy composites; date palm fillers, thermal properties, insulating material.

Introduction
Natural or green composites have become more common in recent years as a result of their availability and lower cost. These composites are biodegradable renewable composites that have desirable properties [1]. Worldly environmental interest has also caused a change in awareness toward the use of green filler polymer composites in addition to the rich in natural plant-based fillers has also been a driving force behind research in this field around the world [2].

Plant fillers are primarily obtained from the seed, leaves, and roots, of a wide range of plants, including the date palm tree, banana, jute, flax, kapok, hemp, bamboo, sisal, kenaf, and coir, with cellulose, hemicelluloses, and lignin as the main components of them [3].

The compensation of low-cost natural fillers, which have many advantages over synthetic ones, such as their availability, safe, biodegradable, fewer health risks, low energy required, and environmentally friendly [4,5].

The yearly global production of date palm trees is higher than that of other trees such as coir and sisal/hemp, with an estimated total production of seven million tons of DPF. Other than food-grade date production, a huge proportion of dates are generally wasted. As a consequence, date palm trees
create a greater amount of agricultural waste. The average yearly waste palm date production is estimated to be about two million tons. [6]. Due to these large quantities of its waste, this filler has been widely used by human in every daily life aspects; generally, all part of the date palm is used for a purpose better suited to it. Also, owing to its high bonding, mechanical, physical, chemical, dielectric, thermal, and aging characteristics, epoxy was often used as a multipurpose matrix material for the production of advanced composites used in vital applications [7]. Finding new and advanced methods act to the reduction of energy consumption by reduce heat loss and improve product quality is one of the many difficulties that encounter researchers. In order to design an energy-efficient building, an evaluation of the transformation of heat through the material is very critical. As a result, studying thermal properties, mainly thermal conductivity and thermal diffusivity of material used in construction, is very essential [8, 9]. Several studies have looked at the use of date palm DP in a variety of applications, including mortar reinforcement for building thermal insulation [10, 11]. But on the other hand, there are still limited attempts of studies that look into the use of date palm filler in the production of polymeric composites [12] that making this an intriguing research subject. Joey Yang et al. find that the packing process of natural fillers affects the thermal properties of their composites, as a rule, substrates with heavily packed have a small value of thermal conductivity about 0.05 W/(m · K), while densely packed substrate has slightly higher values of thermal conductivity of 0.07 W/(m · K), because of a smaller amount of cavities [13]. Oushabi et al. showed that the mechanical and thermal properties of the polymer are more improved by the date palm adding, the work shows that the good resulted in thermal conductivity of the prepared composite allows them to be considered successful for the production of reliable, economical, and safe insulating materials [14].

B. Jdayil et.al developed a green polymer composite, as an insulating material, consists of date palm waste at various proportions (10 wt.% - 50 wt.%), they use two types of powder date palm wood (DPW) and date seeds (DS). The properties of prepared composites demonstrated that a durable material with insulation and construction capability can be produced. At maximum filler loading, the thermal conductivity and thermal diffusivity of the composite decreased as filler content increased, reaching a minimum value of 0.0712 W/((m · K) and 0.0358 mm²/s, respectively for 50 wt.% of DS composites [15].

One of the most promising applications of DP fillers in epoxy includes its use in inexpensive insulation building products for composite roofing, ceilings, wall flooring, columns, and beams, as well as some high-performance furniture and household items [16].

At hand study focus on the possibility of using fillers derived from different parts of the date palm tree as a reinforcing additive in the production of polymer composites as a component of an insulating material to reduce the heat loss in buildings. The other driving force that dates palm trees are broadly available in Iraq, a lot of its parts spend without benefit and considered as one of the most agricultural wastes. Therefore the achievement of these green materials will result in a product of more environmental friendly materials, which can aim to substitute several traditionally polymer-based products.

Experimental and Materials

**Epoxy Resin (EP)**

Epoxy resin has been used in this study, is a two-component structure, the first is translucent liquid (resin) with low viscosity which transforms to a solid form after applying the second component (hardener) in a ratio of (3:1) as supplied by Don Construction Produces Ltd. UK and has a density (1.2 g/cm³).

**Fillers preparation**

The date palm has directly associated with human life; in previous, the wood of the date palm is wasted as agricultural residues with no economic benefit. Really, the increase of use of some
reinforced composites made from these agricultural products is a perfect solution for using such waste as a sustainable resource for useful purposes. After the manual separation of the date palm fillers (DPF) were washed in distilled water to eliminate dust, sand, and other impurities joined to its surface then dried by oven at 60°C to reduce the moisture content. By local grinding machine the waste wear ground and the DPF powder with different particles size wear obtained, the required size about 200 μm can be separated using sieving by pass it through a mesh screen, they are displayed in Figure 1.

![Figure 1. Date palm tree powder used in this study.](image)

**Fabrication of Composites**
The hand lay-up technique considers the least expensive and simplest method for molding epoxy, where the mixture of composite materials (particles and epoxy) is placed inside the mould by applying a brush or roller. The mould that was used for thermal conductivity specimens made from glass in dimension diameter of (40 mm) and height (5mm) was shown in Figure 2. The amount of resin and fillers that been required for each group of composites were calculated and mixing via the manual stirring method for 10 minutes to form homogenous blends. 2% hardener was mixed homogeneously with the blend; the mixture was poured into the moulds and left mould for one day. After the composites had completely dried, they were removed from the molds, and the specimens were placed in an oven at (55 °C) for (1 hrs).

![Figure 2. Shows the thermal conductivity specimens.](image)

Three types of date palm waste powders (mesh, seed, and trunk) with mixture of each powder as hybrid were used as natural filler to fabricate DPF/epoxy composites with a total filler loading of (10, 20, 30) wt%, as both composites and hybrid, in addition to a pure resin without filler was prepared to serve as control; their details are listed in Table 1.
**Table 1. Information of prepared specimens**

| Name of samples | Volume fraction of fillers% | Volume fraction of Epoxy% | Mesh | Seed | Trunk |
|-----------------|-----------------------------|---------------------------|------|------|-------|
| E               | 0                           | 100                       | -    | -    | -     |
| M1              | 10                          | 90                        | 10%  | -    | -     |
| M2              | 20                          | 80                        | 20%  | -    | -     |
| M3              | 30                          | 70                        | 30%  | -    | -     |
| S1              | 10                          | 90                        | -    | 10%  | -     |
| S2              | 20                          | 80                        | -    | 20%  | -     |
| S3              | 30                          | 70                        | -    | 30%  | -     |
| T1              | 10                          | 90                        | -    | -    | 10%   |
| T2              | 20                          | 80                        | -    | -    | 20%   |
| T3              | 30                          | 70                        | -    | -    | 30%   |
| MS              | 30                          | 70                        | 15%  | 15%  | -     |
| MT              | 30                          | 70                        | 15%  | -    | 15%   |
| ST              | 30                          | 70                        | -    | 15%  | 15%   |

**Thermal Conductivity Test**

The property that characterizes the ability of a material to transfer heat is the thermal conductivity; this occurs when there is a thermal difference between two regions (high and low temperature regions). Thermal conductivity coefficient has been known as [17]:

\[
Q = -\lambda \frac{dT}{dx} \quad \text{........................ (1)}
\]

Where:
- \( Q \): Thermal flux is heat flow for each unit of time per unit sectional area in the direction of flow (W/m²).
- \( \lambda \): Coefficient of thermal conductivity (W/m.ºC).
- \( \frac{dT}{dx} \): Differences in temperature through the system thickness (ºC/m).

Moreover, both, the specific heat and thermal diffusivity can be calculated. The thermal diffusivity of the composite is another critical parameter that must consider when estimating their ability for use in the insulator construction materials [18]. The calculated thermal diffusivities of a composite are coupled to its thermal conductivity \( \lambda \) by the below equation:

\[
\alpha = \frac{\lambda}{\rho \cdot c_p}
\]

Where \( c_p \) and \( \rho \) are the heat capacity and the density, respectively.

**Results and discussion:**

*Thermal conductivity*

The thermal conductivity of the composites sample is measured by using a hot disk. Values of thermal conductivity and thermal diffusivity for reinforced polymer composites with different volume fractions of fillers are listed in Table 2.
Table 2. Thermal properties of prepared composite.

| Number of Samples | Thermal Conductivity W/m.K | Thermal Diffusivity m²/S | Specific Heat (J/kg.C) |
|-------------------|----------------------------|--------------------------|------------------------|
| E                 | 0.261                      | 0.028                    | 1221                   |
| M1                | 0.24                       | 0.0265                   | 1187                   |
| M2                | 0.221                      | 0.026                    | 1124                   |
| M3                | 0.2                        | 0.025                    | 1113                   |
| S1                | 0.19                       | 0.0244                   | 1120                   |
| S2                | 0.167                      | 0.023                    | 980                    |
| S3                | 0.138                      | 0.0201                   | 720                    |
| T1                | 0.21                       | 0.0265                   | 1132                   |
| T2                | 0.198                      | 0.025                    | 1101                   |
| T3                | 0.174                      | 0.0247                   | 990                    |
| MS                | 0.165                      | 0.024                    | 1108                   |
| MT                | 0.18                       | 0.0264                   | 1170                   |
| ST                | 0.15                       | 0.02                     | 840                    |

From Figure 3 has been found that the thermal conductivity of epoxy resin decreased with adding of date palm fillers, also shown that as the volume fraction increases, the thermal conductivity decreases. This decrease in thermal conductivity can be related to the fact that palm tree fillers have a low thermal conductivity as compared to epoxy resin (the thermal conductivity of date palm is 0.743) [19]. As well as the addition of date palm fillers DPF creates more porosity and air void in the polymer will reduce the density. A similar result has been proved by Chikhi et al. [20] and Ramanaiah et al. [21].

The thermal properties of materials depend upon the constituent’s nature, the volume fraction of their component, the size and shape of reinforcement fillers, and the interface bonding between the matrix and fillers of the composite materials [22].

It should be noticed that date palm fillers serve as an insulator, in slight higher conductivity matrix is epoxy. So the use of date palm fillers in epoxy reduces the thermal conductivity of the material. Composite materials with date palm fillers, at 30% of the volume fraction, are the most insulating composite. The thermal conductivity of composites decreases from 0.261 W/m K for the fiberless sample to 0.138 W/m K for the most insulating content.

The composites reinforced with date palm seeds powder proved higher thermal stability over their other counterparts, this larger thermal conductivity is due to the higher density of these samples (1.3-1.5 g/cm³) [23].

Although prepared composites achieved little drop off in the thermal conductivity, these composites can be replacing 30% of the epoxy, which in this ratio is frequently used in the industry of thermal insulation, with natural filler resulting from waste [24].
Thermal diffusivity

The value of the thermal diffusivity determined using the theoretical equation is shown in Table 2. As clear from results in Figures 5 and 6 that the thermal diffusivity decreases with the use of more amounts of fillers. These results are in agreement with the results of thermal conductivity. The result values of each sample are summarized in figure 4.

As a result, the more date palm fillers in the composites, the less transmission of heat. So, a consequence of this essential result in thermal insulation, an insulator material must not only be poor in thermal conductivity but should also act on delaying the transmission of heat.
Figure 5. Thermal diffusivity of date palm/epoxy composite materials with the volume fraction of fillers.

Figure 6. Thermal diffusivity of date palm/epoxy composite materials with types of hybrid.

Specific heat
Figures (7 and 8) show the values of specific heat for composite specimens. The specific heat of epoxy after adding date palm fillers is 1221 J/kg.K while the minimum value for specific heat is 720 J/kg.K obtained for a composite reinforced with 30% reinforced with seed powder. This is due to the fact that as the weight fraction increases, so does the amount of reinforcement, which has a lower specific heat (Cp) than epoxy resin [21].
Figure 7. Specific heat of date palm/epoxy composite materials with the volume fraction of fillers.

Figure 8. Specific heat of date palm/epoxy composite materials with types of hybrid.

Conclusions
From the procured results, it was concluded the following items:
1. Plant waste fillers can be used as effective natural reinforcement fillers for epoxy resins.
2. The fillers incorporated in polymers change the thermal conductivity of resultant materials depended on fillers amount and properties.
3. The thermal properties of prepared composites had decreased when there is increasing in the volume fraction of the filler. The highest filler volume fraction composites attain the least value of thermal conductivity with seed fillers composites.

4. Since epoxy hybrid composites have a lower thermal conductivity than other composite materials, they can be used in thermal insulation applications in structures buildings.

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