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A study of the effect of volume fraction of Alumina Oxide on the thermal conductivity values of polyester resin particulate composites

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ABSTRACT

This study aims to calculate the thermal conductivity of unsaturated polyester resin when adding aluminum oxide Al_2O_3 as a filler in different quantities of 10%, 20%, and 30% to the resin and to study the effect of these additives on the thermal conductivity (K) of this resin material. The behavior was changed based on Fourier's thermal conductivity law when calculating the resin's K value before and after adding aluminum oxide. The results showed an increase in thermal insulation with an increase in the percentage of aluminum oxide in the resin with a decrease in the thermal conductivity value. The lowest value obtained was 0.23 W/m.c when the percentage of alumina oxide was 30% at the highest applied temperature of 50 °C. This was illustrated through the graphs that summarize the relationship between thermal conductivity and temperature based on different percentages of aluminum oxide.

Keywords: Unsaturated polyester resin, Alumina Oxide, Thermal insulation, Thermal conductivity

1. Introduction

With the increasing importance of energy and its widespread use, using thermal insulation materials has become necessary in buildings to reduce energy use, whether in cooling, heating, or other processes. Thermal insulation is a material or a group of overlapping materials that retard the rate of heat flow by conduction, convection, and radiation when applied correctly. Thermal insulators are defined as materials that reduce or resist heat transfer from outside to inside and vice versa. Reducing the need to use air conditioners, and its use is beneficial in all seasons; it works to maintain the temperature of the building in summer and winter and protects it from heat loss in the winter, so it remains warm and from gaining heat in the summer, so it remains cool or moderate (Wessel, 2001). Thermal insulating materials are classified into three main materials, which are as follows (Bakatovich & Gaspar, 2019): Fibrous insulation materials, such as silica materials, glass, and rock wool, and fiberglass and mineral wool are among the most widely used types. Cellular insulations, such as polystyrene and polyurethane. Granular insulations, examples of which are Calcium silicate, cellulose and expanded polystyrene of heat insulating materials are many, among which are the following: (ASTM, 2013) Glass mineral wool: Mineral glass wool is used as a thermal insulator in steam pipes, hot water lines, and industrial applications, as well as in the aircraft industry. These materials are characterized by their appropriate cost and ability to be used in high-temperature insulation. Calcium silicate is a non-combustible material with a compressive strength of 600 kN/m^2 and is used in steam pipelines and hot water lines, and added as insulators in ships, furnaces, and boilers. Rock mineral wool is widely used in thermal insulation applications. Also, it is used in the industrial and commercial sectors as a fire prevention material in installations and equipment.

One of the characteristics of thermal insulation materials is the ability of the material to be thermally insulated, and the thermal conductivity coefficient usually measures it. The lower the conduction coefficient is, the more the material’s resistance to heat transfer. The thermal resistance is inversely proportional to the coefficient of thermal conductivity through the insulating material, which is usually done by all the different means of transmission (conduction, convection, and radiation) (Yousefi & Tariku, 2021).

Any insulation material's thermal characteristics must be examined since they have a significant impact on how heat is transferred within building envelopes. Thermal conductivity, specific heat, thermal diffusivity, thermal expansion, and mass loss are the primary factors that determine thermal characteristics (Yousefi & Tariku, 2021). The primary indicator of a material's capacity to transfer or restrict heat flows through building insulation materials is its thermal conductivity coefficient. Three primary parameters influence thermal conductivity at the macroscopic level: density, moisture content, and operating temperature (Ukponmwan, 1993).

Although traditional building materials are commonly utilized, alternative materials that come from natural sources also have comparable heating performance requirements. Condensation within the sample causes the thermal conductivity to decrease with increasing density, according to a study on hemp fiber insulation materials (Zach et al., 2016). Conversely, when density increases by 2/3, hemp fibers based on concrete notice an approximate 54% increase in thermal conductivity (Collet & Pretot, 2014). In a sheep wool test, it was found that when the apparent density increases from 20 to 40 kg/ m^3, a 50% increase in temperature might result in a 21% drop in heat conductivity (Zach et al., 2012). However, in his cellulose fiber experiment, Sekino found the reverse pattern (Sekino, 2016). From 20 to 110 kg/m^3, the density increases, and the λ values rise by roughly 5%. From 20 to 110 kg/m^3, there is a minor rise in the λ values of around 5%. An indicator of how density influences λ values was developed, known as "apparent thermal conductivity," to help explain this discovery. Thermal conductivity rises as a result of an increase in the number of thermal bridges made by cellulose fibers in the material as its density increases. In an experimental study utilizing three biomaterials, shemp concrete, flax concrete, and rape straw concrete, the impact of moisture on thermal conductivity at various concentrations was found to have the same effect. Research revealed that the dry density might be used to represent the dry thermal conductivity as a linear function of the latter. An additional investigation conducted by G. Balčiőnas et al. (Balčiūnas et al., 2016) proved that the relationship represented by a multiple regression equation and 97% of density determine the thermal conductivity of hemp shives composites. Additionally, because of the low density of the sapropel binder additive, this specimen showed low thermal conductivity, ranging from 0.055 to 0.076 W/(m.K) within the range of 210 to 410 kg/m^3. Coconut fiber is one of the various natural fiber varieties that has been considered as a lightweight option for composite reinforcement. Three different coconut sample types were studied, and the results showed that as density increased from 30 to 120 kg/m^3, thermal conductivity dropped from 0.052 to 0.024 W/ (m.K) (Bui et al., 2020).

2. Materials and methods

2. 1. Composite materials

A composite material consists of two materials combined with different mechanical and physical properties. The purpose of this combination is to derive new properties that were not available in the original materials. In nature, there are many examples of composite materials, including cellulose fibers with wood material. In industry, reinforcing resins with synthetic fibers is the most common (Mallick, 2007). For the manufacture of a composite material, two materials must be available:

- **Base materials (Matrix Material).**

They are either metallic, ceramic, or resinous materials, which are most widely used for their good mechanical and thermal properties. Resins include phenolic, epoxy, and polyester resin.

- **Reinforcement material.**

There are several methods of reinforcing, including particle strengthening, dispersion strengthening, and fiber strengthening. Examples of the types of fibers used are glass fibers, Kevlar fibers, and glass fibers. Reinforcing by fibers is the most common reinforcement material due to its great strength compared to resin materials (Zach et al., 2013).

2. 2. Unsaturated polyester resin

Unsaturated polyester resin belongs to the group of thermosetting resins, where these resins are not able to be reformed by heat after turning into a solid material as a result of forming long polymeric chains intertwined with each other, which is called cross-linking. It is prepared from a reaction with a dibasic unsaturated acid, and it is required that one or both of the monomers have a double bond in their composition (Malik et al., 2000).

Polyester resin has good thermal properties as it withstands high temperatures (for resins) up to 260° C. Still, it suffers spontaneous disintegration at a temperature of about 300° C, even in the absence of oxygen. It is also characterized by excellent electrical and chemical resistance to solvents, acids, salts, wear, and environmental influences. It is also low in cost but also characterized by weakness and fragility (Mallick, 2007; Malmström & Hult, 1997). Polyester is added to fiberglass for the manufacture of mold structures, aircraft and automobile fuselage components, and other industries.

2. 3. Fillings

Fillings can be defined as metallic materials added to resin materials in different proportions to change their properties to obtain new properties, and one of the properties that require changing and as needed is resistance, stiffness, bladder, thermal, and electrical resistance (Teh et al., 2008). Fillers are added to polyester resin for two purposes: the first one is to reduce cost due to its low cost, and the second one is to strengthen the resin and have high resistance properties. Ceramic materials are considered one of the most important fillers added to the resin and kneaded for high hardness, resistance to wear, and poor conduction of heat. They are widely used in thermal insulators. Among the materials used are silicon oxide (silica), magnesium oxide, alumina, and others (Silva et al., 2012).

3. Experimental work

The following materials were used in this research:

1- Unsaturated polyester resin obtained from Tajoura Plastics Research Center.

2- Alumina, used alumina or aluminum oxide AL_2O_3 - with particle size and purity (95.5% µm10%).

3. 1. Sample preparation

Models are 25 mm in diameter and 4 mm thick. The preparation is done by mixing a quantity of resin after it hardens by adding 2% methyl ethyl ketone peroxide to the precipitate. After that, aluminum oxide is added in different proportions of 10%, 20% and 30% by weight

3. 2. Thermal conductivity measurement:

The Fourier Law can be used to calculate the thermal conductivity coefficient (k):

$$Q = -k \times A \times \left(\frac{\Delta T}{\Delta X}\right)$$

Where:

Q: The amount of heat that passes per unit of time and is measured in (W).

k: Coefficient of thermal conductivity, measured in (W/m.c).

A: Heat flow cross-sectional area, measured in (m^2).

$\left(\frac{\Delta T}{\Delta X}\right)$: temperature gradient relative to distance, measured in (°C/m) .

Figure 1. Thermal conductivity

The curve shown in Figure 2 shows how to calculate the value of the temperature gradient ($\Delta T/\Delta X$) applied in the Fourier equation. (X_1, X_3) represent the distance between the thermometers on both sides of the model, and X_2 represents the thickness of the model (Bergman et al., 2011).

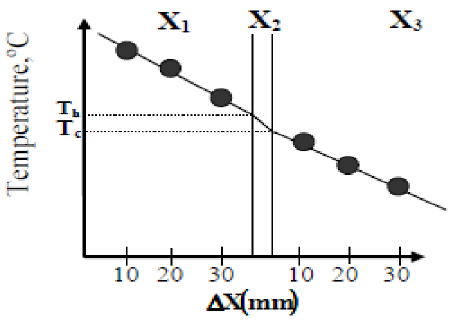

Figure 2. Temperature gradient

4. Results and discussions

Thermal conductivity increases with the increase in temperature, and the reason for this is the vibrations in the internal structure of the resin, which increase with the increase in temperature (Bogomolov et al., 2003). These vibrations begin to decrease when fillings are added to the resin, which works to impede the vibration and thus reduce the value of the thermal conductivity.

Figure 4 represents the thermal conductivity of polyester resin plus (10%) Alumina oxide as the percentage of thermal insulation increases as a result of obstruction. The internal structural vibration of the oxide, in addition to the alumina, is a poor conductor of heat due to its being of ceramic oxides (Zhou et al., 2007).

The thermal insulation value and the percentage of retardation of vibrations increase with the increase in the percentage of added alumina, as shown in Figure 5, which represents the thermal conductivity of the polyester resin in addition to (20%) of the alumina oxide, as the obstacles to heat transfer increase with the increase in alumina oxide minutes (Teh et al., 2008). This behavior continues with the increase in the proportion of alumina oxide, as shown in Figure 6, which represents the thermal conductivity of polyester resin in addition to (30%) of alumina oxide.

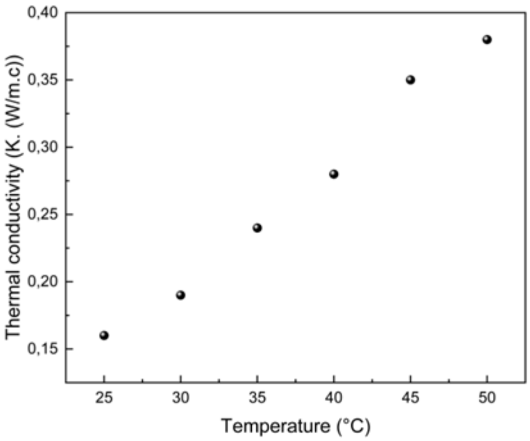

Figure 3. Polyester resin

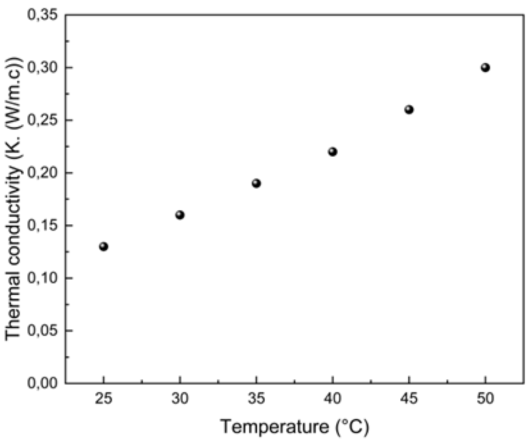

Figure 4. Polyester+10% Al_2O_3

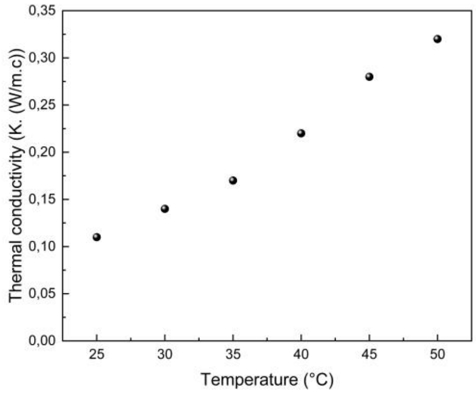

Figure 5. Polyester resin+20% Al_2O_3

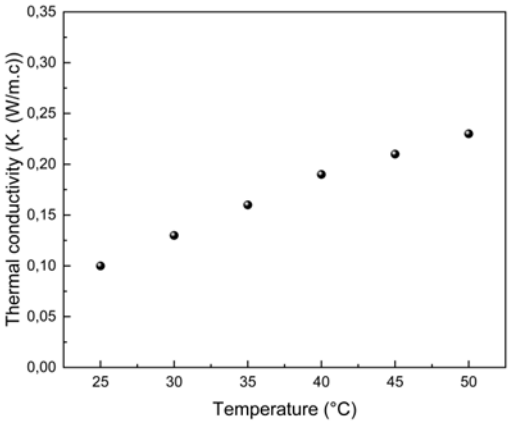

Figure 6. Polyester resin+30% Al_2O_3

5. Conclusion

Through the results obtained from the thermal conductivity test of polyester resin before adding alumina and after adding certain percentages of alumina oxide, a number of conclusions were reached:

1- The thermal conductivity value of polyester resin increases with increasing temperature, and this is attributed to the nature of the resin that can transfer heat.

2- When adding different percentages of alumina oxide, a decrease in the thermal conductivity coefficient of polyester resin was observed, as its value decreased at a rate of 30% more than 20% with the same change in temperature remaining constant.

3- Some other materials can be added, whether natural materials such as palm fibers, wool, thermal images, etc., to the polyester resin material and used as materials for either thermal insulation or heat conduction after studying the experiments and testing the thermal conductivity.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Data Availability

No data was used for the research described in the article.

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