Effect of fillers (Bentonite - Zirconium) on the thermal behaviour of PVC polymer

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Abstract. Thermal conductivity is one of the basic physical phenomena that can affect matter in heat quantities and explain what happens during the heat transfer process. The work indicates to the importance of investigate for effect of filler material Bentonite and ZrO₂ on the thermal properties of polyvinyl chloride as a binder material with ratio of 3% compared with the ratio of Zirconium Oxide which was in the limits (0%, 5%, 10%, 15%) besides Bentonite, the burn process was carried out at various temperatures 800, 900, 1000, 1100 and 1200 °C. The results showed a decrease in the values of thermal conductivity from (0.5-0.3 W/m.K) when adding zirconium oxide, while increasing the percentage of the Bentonite with increasing and the burning temperature led to the increment of thermal conductivity for the prepared samples.

Keywords: Thermal conductivity, polyvinyl chloride, zirconium oxide, polymer composite

1. Introduction

Polymeric materials are among the important materials in the industry for many reasons, the most important of which is ease of manufacture and cheap price, light weight, good chemical specifications that are not present in ceramic and metallic materials, but after technological development, especially in the field of space industries and the manufacture of cars, airplanes and boats, the need increased to manufacture materials with specifications In particular, attention has turned to the manufacture of composite materials, including polymeric composites. Most of the polymeric composite materials were the reinforcement material with ceramic or glass materials in the form of fibers or powder, where many previous studies were conducted to learn about changing the thermal properties of the composites of polymeric materials with changing the type and quantity of the reinforcement material added [1].

The aim of this study is to study the thermal conductivity of polymeric material and the effect of temperature on the thermal conductivity of matter, as the thermal conductivity is one of the basic physical phenomena through which it can be studied and how a substance is affected by heat.

2. Experimental details

2.1 Theoretical part
Thermal conductivity is a phenomenon of thermal transfer, in which energy is transferred from one location to another due to irritation of the atoms or molecules of the material due to a change in the temperature of the medium, but the conductivity mechanism in the solid materials differs from it in the liquid and from it in gases as well as differs in the conductive materials from the insulating materials. The thermal conductivity of the insulating materials has been measured on the principle of the thermal conductivity of the samples in the form of a large diameter disk relative to thickness. When there is a thermal gradient ($dT/dX$) during a physical medium in the direction ($x$) the average of thermal conductivity resulting from the difference in temperature across the vertical cross-sectional area of the heat flow is given by:[2]

\[
\frac{dQ}{dt} = -KA \frac{dT}{dX} \quad \ldots \ldots (1)
\]

Since ($K$) represents the constant of proportionality and is called thermal conductivity and is a measure of the process of thermal selection across the material, negative sign means that the flow of heat towards the lower temperature, and the addition of negative sign in the equation is useful in making $K$ a positive quantity, and other forms of the equation above the formula The following

\[
Q = K \frac{T_1 - T_2}{X} \quad \ldots \ldots (2)
\]

It represents the basic equation for thermal conductivity, which is known as the Fourier equation, and from equation (1) the thermal conductivity is defined as the amount of heat that passes through the unit area of the material per unit of time where the thermal conductivity is proportional to the difference between the temperatures of the external surfaces of the material and is inversely proportional to the thickness, so The average of heat flow is not dependent on the absolute temperature, but on the difference in the temperature of the two sides.

One of the practical methods used to calculate the value of the thermal conductivity of the insulating solid $l$ is to expose one of the sides of the samples to a heat source and calculate the temperature at the opposite side, as the sample is placed in a thermal gradient so that the flow of heat that reaches the other side is balanced. Thus, the thermal properties are calculated by calculating the influencing factors and from the methods used in measuring the thermal conductivity is the stacked disk system, or the technique of heat flow in a cylinder, and since the temperature passing through the sample is the average amount of heat passing through the disk and thus the formula will be:[3]

\[
K \left[ \frac{T_2 - T_1}{d_s} \right] = E \left[ T_1 + \frac{2}{r} (d_1 + \frac{1}{4} d_s) T_1 + \frac{1}{2r} d_s T_2 \right] \ldots \ldots \ldots \ldots \ldots (3)
\]

Where
- $d_s$: thickness of the disc
- $r$: disk radius
- $k$: the thermal conductivity of the disk $S$
- $T_1$: face temperature A
- $T_2$: face temperature B
- $T_3$: face temperature C

The value of $E$ can also be calculated from the power supplied to the heating coil ($H$), so it is:

\[
H = IV = \pi r^2 E(T_1 + T_2) + 2\pi r E \left[ d_1 T_1 + \frac{1}{2} d_s (T_1 + T_2) + d_2 T_2 + d_3 T_3 \right] \ldots \ldots (4)
\]

Since $V$ is the difference in voltage passing through the coil (Volt) and the current $I$ (Amp).

After calculating the value of $E$, it is substituted in equation (3). Thus, we obtain the thermal conductivity value ($K$) for the sample to be examined in units ($W/m.K$).

2.2 Materials used in research

2.2.1 Bentonite

Bentonite is an impure clay composed mainly of montmorillonite or calcium silicate oxide and is found in the form of powder in a gray color does not smell it.

The Bentonite or volcanic mud is a commercial name for a special type of clay consists mainly of mineral smectite. Bentonite are plenty of minerals including calcium, magnesium, silica, sodium,
copper, iron and potassium, the result is the processes of transformation of volcanic glass and mainly of hydrolytic silicate [4].

2.2.2 Zirconium Oxide

Zirconium Oxide is a single crystalline substance that transform to a tetra material increase of temperature and characteristics depend on the degree of stability and the amount of stability and quality of raw materials included in its composition and a zirconia used in this research prepared by (fluka chemie AG-CH 9770 Buchs) And its purity 99.9% [5-6].

2.2.3 Polyvinyl chloride

It is a widely used plastic material and The designation is abbreviated as PVC and it is used in a lot of applications and has been used in many industries as insulating material for electric wires, floor coverings, bottling industry, auto industry and it has distinctive characteristics in terms of high electrical insulation, strong abrasion resistance, low moisture absorption and good flexibility[7-8] .

2.3 The method of work

The basic material used in this work is bentonite powder with a granular size 75µm, and zirconium of Indian origin was added with a granular size of 100µm≥ for the purpose of improving the properties of the composite with weight ratios (5,10,15 wt%) to the bentonite powder as shown in Table(1)[9-10].

The materials were prepared and weighed with a sensitive scale and the granular size was measured by using special sieves for this purpose in the laboratory, the samples were also mixed using a mechanical mixer for two hours, and then the PVC binder was added in a percentage of (3%) and the samples were formed by Semi-dry pressing method and using a hydraulic press with a diameter of (40 mm) under a pressure of (25 MPa ) and a period of time of (2 min), the sintering process was carried out using an electric furnace at normal atmospheric pressure and temperatures (800,900,1000,1100,1200)°C for a period of two hours .

For the purpose of measuring the thermal conductivity of the samples, a Lee’s disk was used to calculate the thermal conductivity of the insulation materials using the device manufactured by (Griffen and George). The thermal conductivity was calculated using the equation (1) as explained in figures (1-6) that show the effect of added zirconium oxide on the thermal conductivity of the samples prepared from the compound at different temperatures.

| material Matrix (Bentonite) | Add Material (ZrO₂) | Symbol |
|-----------------------------|--------------------|--------|
| 100                         | 0                  | A      |
| 95                          | 5                  | B      |
| 90                          | 10                 | C      |
| 85                          | 15                 | D      |

3. Results and Discussion

It's noted from Figures 1-5, that the addition of zirconium oxide led to a decrease in thermal conductivity of the materials and continues to decrease with the increase of the added ratio and the thermal conductivity is also increased by increasing the Bentonite content from (4-12)% .Where the thermal conductivity of the samples prepared was measured by the law of the thermal conductivity of the equation (3) of the figures, which shows the conductivity decrease due to the defect of the supported and added material with granules of the base material to obtain a homogeneous distribution and thus its spread easily among them and which led to obstruction the heat transfer and thus reducing
the amount thermal conductivity increases the values of weight fractures, as the presence of interfaces leads to impeding the movement of waves and the transfer of energy becomes a difficult process due to the discontinuity of the structure and the loss of part of its energy during the transition from the base material to the strengthening as shown in Table 1 [11-13].

Figures 6, 7 and 8 indicated that conductivity increased with increasing temperature and gave higher values as the insulating materials are affected at high temperatures by phonons, which represent the vibrations of the crystal lattice and are responsible for the transfer of heat in solid insulating materials, so the phonon collision process with another is considered an important process at those degrees at which the number of phonons participating in the collision process increases and this means that the thermal conductivity in this case depends entirely on the average of the free path of the phonons (the average distance traveled by two phonons for each successive collision) Whereas, phonons are the single transmitters of energy and it has a major role in the conduction process and all kinds of solid materials at high temperatures [14-15].

Figure 1. Thermal conductivity for Zirconia at 800 °C

Figure 2. Thermal conductivity for Zirconia at 900 °C

Figure 3. Thermal conductivity for Zirconia at 1000 °C

Figure 4. Thermal conductivity for Zirconia at 1100 °C

Figure 5. Thermal conductivity for Zirconia at 1200 °C

Figure 6. Thermal conductivity for Zirconia for burn degree at ratio 12%
4. Conclusions

1- The rate of addition of zirconium oxide granules resulted in a decrease in the thermal conductivity values of the polymeric compounds from (0.65 W/m.K) to (0.34 W/m.K).

2- The thermal conductivity values increase with increasing the content of Bentonite from (0.34 W/m.K) to (0.68 W/m.K).

3- The increase in the burning temperature led to an increase in the conductivity of all the samples, and they became of high density and low porosity, which resulted from the participation of phonons in the thermal conductivity at high temperatures.

4- The ratio of the strengthening material and the interfaces between the phases of the composite material are the reason for the low conductivity values of the polymeric compounds.

5- In the thermal conductivity test, the polymeric composite gave the highest values of thermal conductivity by increasing the burning temperature due to its influence with phonons, crystal grid vibrations, and the free path rate of the phonon.

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