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Preparing of polymeric composites for thermal insulation applications

Prepared By: Shadan Abdul Karim.

SUPERVISOR: A. Lecturer Nawar Bakly

بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

وقل ربي زدني علما

صدق الله العظيم

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Dedication

To my family

To my friends

To my distinguished teachers

To all those who have trusted and documented our abilities and ambitions since childhood

Thank you from the bottom of my heart.

ABSTRACT

Current trends of decreasing electronic device sizes and increasing energy density need searching for alternate thermal management materials. Reinforcing polymers with thermally conductive metallic materials is considered as one of the feasible solutions to overcome the thermal management issues for modern electronic devices. The thermal characteristics of composite materials comprised of polypropylene (PP) with copper (Cu) particles in various weight percentages are reported in this work; 0%wt Cu, 10% wt Cu, 20% wt Cu and 30% wt Cu. As well as increasing the thermal conductivity coefficient after adding different percentages of copper to it, as we notice an increase in the thermal conductivity coefficient seven times from 0.2 to 1.5, and this is suitable for dispersing the heat that must be dispersed in electronic devices with polymeric covers. Results show that the effective thermal conductivity of the polymer matrix increases slightly with the addition of Cu particles. This effect can be attributed to the higher thermal conductivity of the metal particles compared to the polymer as well as the effective reinforcement in the polymer matrix. In addition, there was an increase in the density of composite 30% Cu70% PP by 27%.These preliminary experiments are intended to deliberate on the influences of metal particles in polymers to enhance their thermal properties without affecting their durability and mechanical properties. Such composites will be essential components in electronic packaging to spread thermal energy efficiently.

خلاصة

الاتجاهات الحالية لتقليل حجم الأجهزة الإلكترونية مصحوبة بزيادة كثافة طاقتها تدل على البحث عن مواد إدارة حرارية بديلة. يعتبر تقوية البوليمرات بالمواد المعدنية الموصلة حرارياً أحد الحلول الممكنة للتغلب على مشكلات الإدارة الحرارية للأجهزة الإلكترونية الحديثة. في هذا العمل ، قمنا بالإبلاغ عن الخصائص الحرارية للمواد المركبة المصنوعة من مادة البولي بروبيلين (PP) مع جزيئات النحاس (Cu) بنسب وزن مختلفة ؛ 0٪ ، 10٪ ، 20٪ و 30٪. فضلا عن زيادة معامل التوصيل الحراري بعد اضافة نسب مختلفة من النحاس اليها حيث نلاحظ زيادة في معامل التوصيل الحراري سبع مرات من 0.2 الى 1.5 وهذا مناسب لتشتيت الحرارة التي يجب ان تشتت في الاجهزة الا لكترونية مع أغطية بوليمرية . أظهرت النتائج أن الموصلية الحرارية الفعالة لمصفوفة البوليمر تزداد مع إضافة جزيئات النحاس. يمكن أن يُعزى هذا التأثير إلى الموصلية الحرارية العالية للجسيمات المعدنية مقارنة بالبوليمر بالإضافة إلى التعزيز الفعال في مصفوفة البوليمر . بالإضافة إلى ذلك ، كانت هناك زيادة في كثافة بنسبة 27٪ للمركب 30٪ Cu70 ٪ PP ، وتهدف هذه التجارب الأولية إلى مناقشة تأثيرات جزيئات المعادن في البوليمرات لتعزيز خواصها الحرارية دون التأثير على متانتها وخصائصها الميكانيكية. ستكون هذه المركبات مكونات أساسية في العبوة الإلكترونية لنشر الطاقة الحرارية بكفاءة .

Aim of this study:

Improving the thermal properties of polymers such as polypropylene (PP) with thermally conductive metallic materials such as (Cu) is considered as one of the feasible solutions to improve thermal conductivity of polymer to overcome the thermal management issues for modern electronic devices.

NOMENCLATURE

A area, m^2

Cu copper

FTIR Fourier infrared spectrometer

K effective thermal conductivity, W/m.K

PP polypropylene

Q heat rate, W

T temperature, K

CHAPTER ONE

1.1 Introduction

Polymeric composites have become a popular choice for thermal insulation applications due to their lightweight, low thermal conductivity, and excellent insulation properties. The preparation of polymeric composites for thermal insulation applications involves the combination of various materials and processing techniques to achieve the desired properties. One common method for preparing polymeric composites for thermal insulation is by incorporating fillers such as nanoparticles, fibers, or aerogels into a polymeric matrix. These fillers act as insulating barriers that hinder heat transfer, thereby reducing the thermal conductivity of the composite material. Additionally, the matrix material can be modified to enhance its insulating properties, such as by adding foaming agents or using polymers with low thermal conductivity. Another approach is to use a layer-by-layer (LBL) assembly technique to prepare multilayered polymeric composites with alternating layers of insulating and conductive materials. The insulating layers provide the thermal insulation while the conductive layers act as pathways for heat dissipation, resulting in improved thermal insulation performance [1]. Polymers and polymer-based composites have been employed in numerous electronic devices owing to their light-weight, ease of production, versatility, and low cost compared to metals. Polymers are used as insulating materials, protective materials, and components for structures. Polyolefin-based materials, such as polyethylene (PE) and polypropylene (PP), are utilized extensively owing to the ease of processing and flexibility in manufacturing different artifacts, excellent transparency, and strong mechanical characteristics [2]–[4]. Nevertheless, most of the polyolefin's are insulating in nature; the thermal conductivity is needed to be improved to enhance the thermal management in electronic packaging. One of the classical methods to increase the thermal conductivity of polymers is to reinforce them with conductive fillers, such as metallic particles, carbon nanotube, and graphite particles [5]–[10]. The effective thermal conductivity of polymers mixed with conductive particles depend largely on filler's concentration, size, geometry, thermal conductivity, and interaction with the polymer chains [11]–[14].

CHAPTER TWO

2.1 Introduction

Polymer composites reinforced with metal particles have been the subject of extensive research due to their unique properties such as improved mechanical strength, thermal conductivity, and electrical conductivity. Among the various polymer matrices used for such composites, polypropylene (PP) has received significant attention due to its low cost, easy process ability, and good mechanical properties.

One of the commonly used metal reinforcements for PP composites is copper (Cu) due to its excellent thermal and electrical conductivity. The incorporation of Cu particles into a PP matrix can improve the thermal and electrical conductivity of the composite while maintaining the low density and ease of processing of the polymer matrix.

The preparation of PP-Cu composites involves various techniques such as melt mixing, in-situ polymerization, and electro spinning. The properties of the resulting composites depend on factors such as the size and distribution of the Cu particles, the content of the Cu particles, and the processing conditions [15].

2.2 Application of thermal conductivity of composite polymer

The thermal conductivity of composite polymers has many important applications, especially in industries such as aerospace, electronics, and building materials. The thermal conductivity of composite polymers plays a crucial role in determining their thermal insulation properties, which are essential for maintaining the stability and reliability of various devices and structures.

One significant application of composite polymers with high thermal conductivity is in electronic devices, where heat dissipation is critical to prevent device failure. By incorporating fillers such as graphite, carbon nanotubes, or metallic particles into the polymer matrix, the thermal conductivity of the composite can be significantly improved, thereby enhancing its heat dissipation properties.

Another important application of composite polymers with high thermal conductivity is in the construction industry. Composite polymers with low thermal conductivity can be used as insulating materials to reduce heat transfer through building envelopes, resulting in improved energy efficiency and reduced heating and cooling costs [16].

2.3 Polypropylene (PP)

Polypropylene (PP) is a thermoplastic polymer that is widely used in a variety of applications due to its excellent mechanical properties, chemical resistance, and low cost. PP is a type of polyolefin, which is a class of polymers that are produced from simple olefin monomers such as ethylene and propylene. Figure (1) Show Molecular Structure of PP.

PP can be processed using various techniques such as injection molding, extrusion, and blow molding, making it a versatile material for the manufacture of a wide range of products such as packaging materials, automotive components, and household appliances.

PP has a high melting point, which makes it suitable for applications where high-temperature resistance is required. Additionally, PP has good dimensional stability and low moisture absorption, which makes it suitable for use in outdoor applications. One of the significant drawbacks of PP is its poor impact resistance at low temperatures, which can lead to brittleness and cracking. However, this can be improved by incorporating additives such as elastomers or fillers into the PP matrix [17].

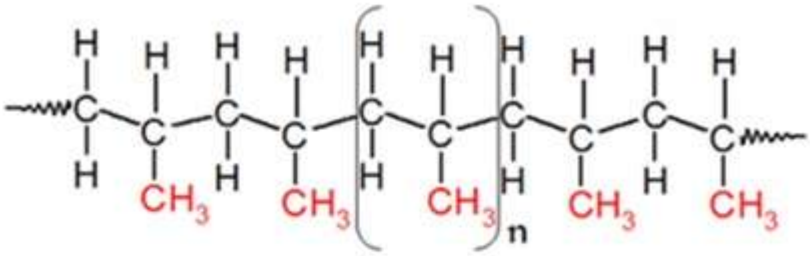

Figure (1): Molecular Structure of PP.

2.3.1 Chemical properties of Polypropylene (PP)

Polypropylene (PP) is a polymer that has a unique set of chemical properties, which makes it suitable for use in various industrial and commercial applications. Some of the key chemical properties of PP are discussed below:

1- **Chemical resistance**: PP is highly resistant to a wide range of chemicals, including acids, bases, and solvents. This property makes PP ideal for use in applications where exposure to chemicals is common, such as in the chemical processing and automotive industries.

2- **Hydrophobicity**: PP is hydrophobic, meaning it repels water. This property makes PP suitable for use in outdoor applications and in products that are exposed to moisture or high humidity.

3- **Thermal stability**: PP is thermally stable, meaning it can withstand high temperatures without degrading. This property makes PP suitable for use in applications where high-temperature resistance is required, such as in automotive components and household appliances. As well as the thermal conductivity of the Polypropylene (PP) is 0.2 W/ (m·K)

4- **Oxidation resistance**: PP is highly resistant to oxidation, which makes it suitable for use in outdoor applications and products that are exposed to UV radiation [18].

2.3.2 Physical properties of Polypropylene (PP)

Polypropylene (PP) is a thermoplastic polymer that possesses a unique set of physical properties, which make it suitable for use in a wide range of industrial and commercial applications. Some of the key physical properties of PP are discussed below:

1-**Density**: PP has a relatively low density, which makes it lightweight and easy to handle. The density of PP typically ranges from 0.90 to 0.91 g/cm3.

2 -**Melting point**: PP has a high melting point, which makes it suitable for use in high-temperature applications. The melting point of PP typically ranges from 160 to 170°C.

3 -**Flexibility**: PP has good flexibility, which makes it suitable for use in products that require bending or shaping. PP also has good fatigue resistance, which makes it suitable for use in products that undergo repeated bending or flexing.

4- **Tensile strength:** PP has good tensile strength, which makes it suitable for use in products that require high strength and stiffness. The tensile strength of PP typically ranges from 30 to 40 MPa.

5 -**Transparency:** PP can be made transparent, making it suitable for use in products that require optical clarity [19].

2.4 Copper (Cu)

Copper (Cu) is a chemical element with the symbol Cu and atomic number 29. It is a soft, malleable, and ductile metal with excellent electrical and thermal conductivity, as well as good corrosion resistance .Figure (2) show structure of Copper.

Copper is widely used in various industrial and commercial applications, including electrical wiring, plumbing, roofing, and industrial machinery. It is also used in the production of coins, jewelry, and decorative objects.

Copper is an essential trace element for human health, playing a role in the formation of red blood cells, maintaining a healthy immune system, and aiding in the absorption of iron. However, excessive exposure to copper can be toxic, leading to gastrointestinal distress, liver damage, and other health problems.

Copper has been extensively studied in various fields of research, including materials science, physics, chemistry, and biology. Its unique properties make it a versatile material with many potential applications [20].

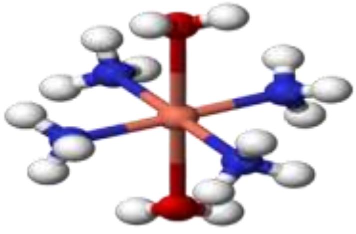

Figure (2) : show structure of Copper.

2.4.1 Chemical properties of Copper

Copper (Cu) is a chemical element with unique chemical properties that make it useful for a wide range of applications. Some of the key chemical properties of copper are discussed below:

1-**Reactivity**: Copper is a relatively reactive metal, reacting with oxygen in the air to form a layer of copper oxide on its surface. This layer provides protection against further corrosion.

2- **Acidity**: Copper is not a very acidic metal, and does not readily react with acids.

3**- Redox activity**: Copper can readily undergo oxidation and reduction reactions, making it useful in electrochemical applications such as batteries and electroplating.

4- **Solubility**: Copper is sparingly soluble in water and most organic solvents, but can dissolve in strong acids and ammonia solutions.

5- **Catalytic activity**: Copper is a good catalyst for a variety of reactions, including hydrogenation and oxidation.

2.4.2 Physical Properties Copper

Copper (Cu) is a metallic element that has a unique set of physical properties that make it suitable for a wide range of industrial and commercial applications. Some of the key physical properties of copper are discussed below:

1-**Density**: Copper has a relatively high density of 8.96 g/cm^3, making it a heavy metal.

2-C**onductivity**: Copper is an excellent conductor of both electricity and heat, making it ideal for use in electrical wiring and heat transfer applications. 401 W/(m·K)

3- **Ductility**: Copper is highly ductile and can be easily drawn into wires or other shapes without breaking.

4- **Malleability**: Copper is also highly malleable, meaning it can be easily shaped into various forms without cracking or breaking.

5- **Corrosion resistance**: Copper has good corrosion resistance and can resist the effects of exposure to air and water.

CHAPTER THREE

3. Experimental Part

3.1 Thermal Conductivity

Thermal conductivity is the ability of a given material to conduct or transfer heat. It is generally denoted by the symbol (K). The reciprocal of this physical quantity is referred to as thermal resistivity. Materials with high thermal conductivity are used in heat sinks, on the other hand, materials with low values of (K) used as thermal conductivity. Learn the thermal conductivity formula here.

3.2 Thermal Conductivity Formula

Fourier's law of thermal conduction also known as the law of heat conduction is very relevant for heat transfer computation. This principle is applicable for heat transfer between two isothermal planes.

$$\mathbf{Q = K \times A \times (T_{HOT} - T_{COLD}) / dX}$$

It states that the rate at which heat is transferred through a given material is proportional to the negative value of the temperature gradient. And it is also proportional to the area through which the heat flows, but inversely proportional to the distance between the two isothermal planes.

The Formula for Thermal Conductivity (K)

Every substance has its own capacity for conducting and transferring the heat. The thermal conductivity of a material is explained by the following formula:

$$\mathbf{K = -Q\, dx / A\, \Delta T}$$

3.3 Steps of work:

1. Material preparation: The raw materials, including PP polypropylene pellets as shown in figure 3-B and Cu powder as shown in figure 3-A,that have been prepared. And after making sure that the materials are clean, dry and free from contaminants.

2- Weight and material mixing Material mixing: The materials were mixed by weight using the electronic scale, where the percentages of the composite materials where

a) A ratio of 10% Cu to 90% PP

b) 20% Cu to 80% PP

c) 30% Cu to 70% PP

d) 100% pure PP

After that, acetone was added to the mixture as shown in figure 3-c, and it was stirred well to ensure good mixing and adhesion of copper with polypropylene.

A B C

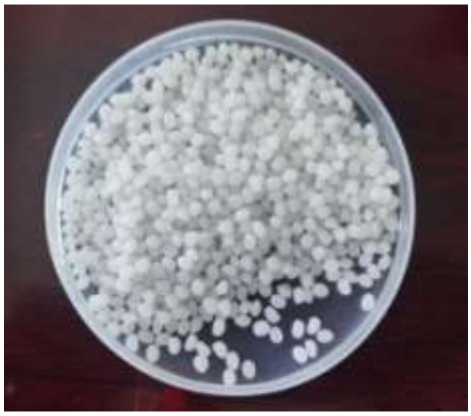

Figure 3-A shows copper powder Figure 3–B show polypropylene. Figure 3 -C Acetone

3. Extruder Feeding: The twin extruder is set up with a feeding system which can handle both PP granules and copper particles. This usually involves separate hoppers or feeders for each material, which will be combined into the extruder.

4. Extruder setting: Configure the double extruder according to the specific requirements of the materials and the required mixing ratio. This includes setting temperature zones, screw speed, and other parameters. Figure (4) shows the twin-screw extruder.

5. Preheating: The extruder has been preheated to the appropriate temperature range for both PP and copper. The temperature will vary based on the specific grades of the materials used. In general, PP requires temperatures from 160 °C, while copper may require higher temperatures to ensure proper melting and mixing.

6. Feeding and Melting: Start the extruder and feed the PP granules and copper particles into their respective hoppers. The materials will be conveyed by individual screws inside the extruder cylinder and melt gradually due to the heat generated by the extruder.

7. Mixing zone: Inside the extruder, there will be a specific mixing zone where the molten PP comes into contact with the copper. This section is designed to promote the fine mixing and dispersion of copper particles within the PP matrix. Typically screws and barrel geometry are optimized for efficient mixing.

8. Cooling and solidification: After the mixing area, the molten PP with copper dispersion is cooled using a cooling system, air cooling. This helps to solidify the material and maintain the desired properties.

Figure (4): show Twin screw extruder device.

9. Quality control: Throughout the process, it is important to monitor and control parameters such as temperature, screw speed and mixing efficiency to ensure consistent and homogeneous mixing of PP and copper.

11. Rolling: Placing the sample inside a 3 mm thick roll after leaving the extruder to obtain the thickness of the sample required for examination. Figure (6) Shown samples inside the insulator after the test.

12. Cutting: The samples are cut in the form of circles that fit the circular thermal insulator as shown in Figure (5-A), through which the samples are examined with a diameter of 48 mm.

A

B

Figure(5-A) Circular PP/Cu Samples

Figure(5-B) Thermal insulator

13) Thermal conductivity device: Figure 8 This device consists of two disks, top metal disk and lower metal disk, and heated at the top of the top metal disk as shown in figure 7.

The temperature of the upper disk is raised by the heater to 100 ^{o}C, then the heat is transferred by conduction in one direction to the sample and the insulator, after which the heat is transmitted to the lower disk by the sample. Notes the circular samples as shown in figure (5-A) is placed inside a circular thermal insulator as shown in figure (5-B). The temperature of the upper disk, the sample, and the lower disk are calculated. As shown in figure 7 & 8.

Figure 6: Shown samples inside the insulator after the test.

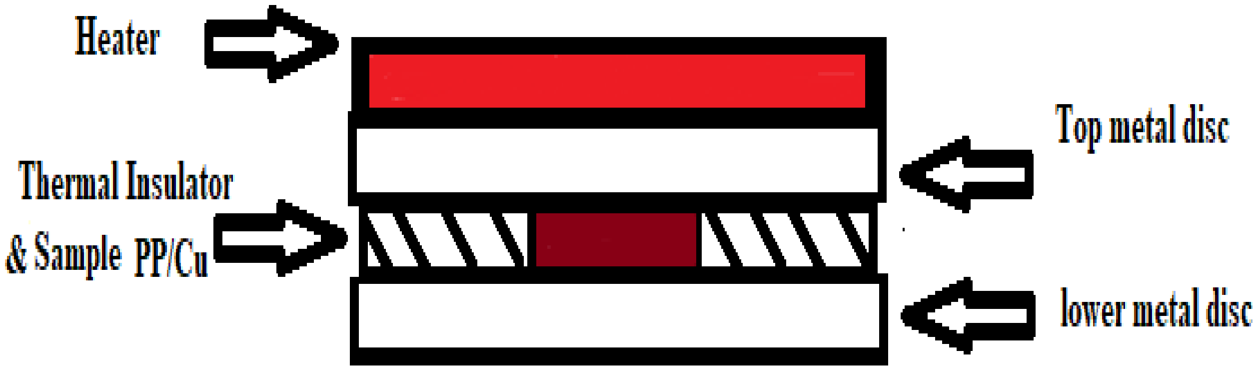

Figure 7 An illustrative diagram showing the mechanism of heat transfer between top metal disk and lower top metal disk and the sample

Figure 8, Thermal conductivity device

14) Examination device: It is a device through which the temperature of the upper surface of the sample is raised to 100 degrees Celsius. The sample is taken out immediately and the temperature difference for the upper and lower surfaces is measured. And obtain the temperature difference for the two sides of the sample, dT. As well as measuring the voltage and current of the heater used. As shown in Figure 7& 8.

15) Theoretical laws: using (Fourier's Law) and with the presence of the sample thickness and sample area that we find from the sample diameter. The temperature difference calculated from the **Thermal Conductivity** is calculated. After calculating the value of Q from voltage by the current

3.4 Results and Discussion

The table (1) show the thermal conductivity values function of the applied voltage by current to get power Q. It is possible to calculate the thermal conductivity using the Fourier's Law suitable for different composite ratio of 10% Cu to 90% PP, 20% Cu to 80% PP, 30% Cu to 70% PP, 100% pure PP and from figure 9 , notice a significant increase in the value of the thermal conductivity coefficient with a higher amount of copper in the samples.

Table (1) show the thermal conductivity values

	Cu/PP composites	Thermal Conductivity (W/m.K)
1.	100%pp	0.2
2.	90% pp+10% Cu	0.395
3.	80% pp+20% Cu	0.893
4.	70% pp+ 30% Cu	1.58

Typical values of k for pure PP in this work. It is within the previously reported values for which between 0.12 W/mK [10] and 0.24 W/mK [12], [14]. thus,This agreement serves as a benchmark thermal conductivity for this work.

Effective thermal conductivity of Cu/PP samples increases slightly with the percentage of copper particles in sample. For example, at 10% Cu, k rises to 0.395 W/mK at 11 V and. Also, when a copper loading was increased to 30 wt%, which are the maximum values k is an increase of 1.58 W/m K. addition It enhances the highly conductive copper particles of PP composites. The effective thermal conductivity is in agreement with the former Reports [11], [12], [26].

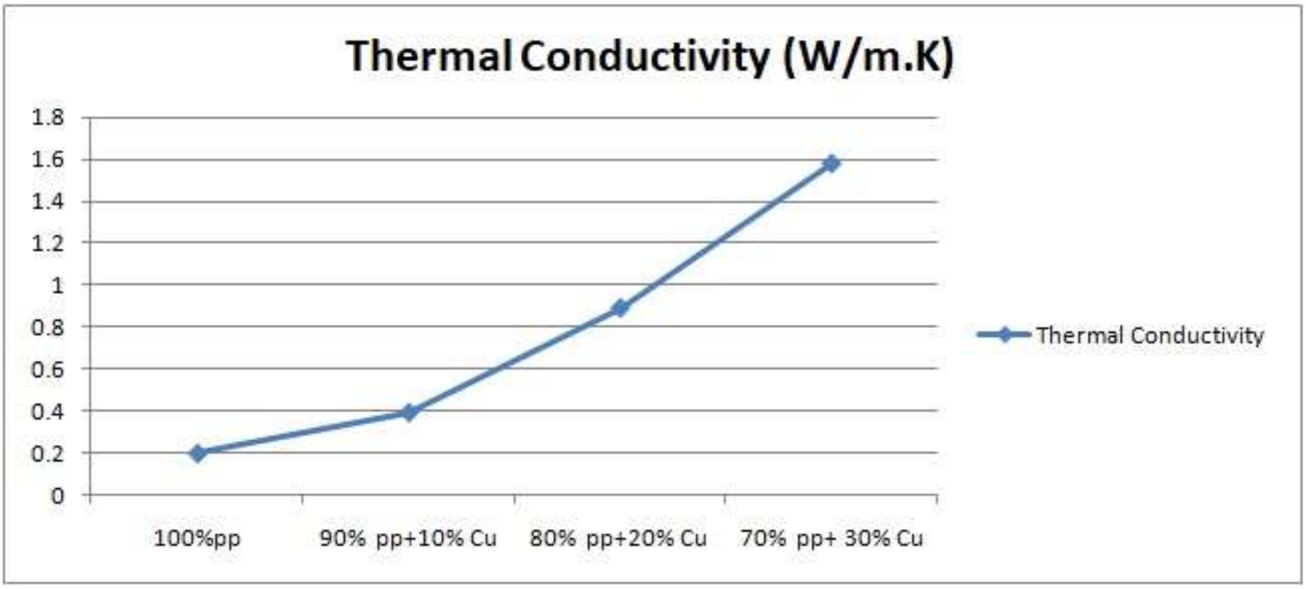

Figure 9 Diagram showing the increase in thermal conductivity values

Also note that the density value will increase with the increase in the amount of copper inside the samples. Where its value is 900 kg/m^{3}at pure polypropylene then its value increases to 1144 kg/m^3 at 70% PP - 30% Cu as shown in figure 10 Diagram showing the increase in density values.

Table 2 density of Cu/PP composites

	Cu/PP composites	density kg/m^3
1.	100% PP	900
2.	90% PP- 10% Cu	939.5
3.	80% PP- 20% Cu	977.6
4.	70% PP- 30% Cu	1144

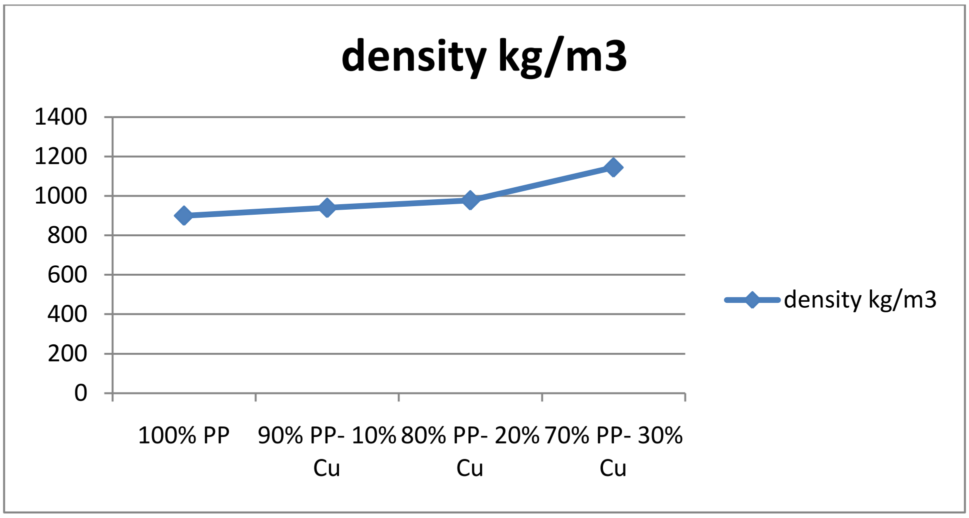

Figure 10, Diagram showing the increase in density values

3.5 Conclusions

The effects of the addition of Cu particles to the PP matrix are characterized by various techniques to prepare conductive polymer composites for thermal management in electronic devices. The thermal properties of Cu/PP composites were measured with different weight percentages of Cu particles. Furthermore, the effective thermal conductivity of the polymer matrix increases slightly with the addition of Cu particles. This effect can be attributed to the higher thermal conductivity of the metal particles compared to the polymer as well as the effective reinforcement in the polymer matrix.

These results clarify the influences of the Cu metal particles in polypropylene polymers to enhance their thermal properties. Such composites will be essential components in existing and future electronic packaging to spread thermal energy efficiently.

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