Study of Thermal Conductivity and Hardness Test of Carbon Black / Polymer Micro Composite

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Abstract. In this research studied of Thermal Conductivity and Hardness Test of Carbon Black / Polymer Micro Composite at different weights ratios were studied. Five samples were prepared for Carbon black with epoxy resin, where the percentages of carbon black ranged between 2%, 4%, 6%, 8% and 10%. The mechanical properties of hardness test that the values of hardness for Carbon black decreasing with increased ratios of additive compared to the case of pure epoxy. For thermal conductivity coefficient (K), the results that values for Carbon black increased by increasing the ratios additive compared to pure epoxy.

1. Introduction

1.1 Polymers
The word polymer is originally a Greek word consisting of two sections: the first poly means "many" and the second mer means "part" which represent the (many – parts) [1]. Polymers are substances consisting of many molecules or elements that lead to long chains. These large molecules usually referred to as macromolecules [2]. Polymers consist of the interconnection of a large or small number of repeated units of molecules called monomers. Monomers are organic molecules or repeated units responsible for the production of polymers [3].

1.2 Structure and properties of polymers
The polymer structure is strongly affected by several properties such as molecular weight, molecular weight division, and the degree of branching polymer. Polymers are subject to strain and depend on the applied stress after this stress is removed. Some of these polymers may not always return to their normal state, which means a certain amount of permanent deformation. The polymer molecules can slip on top of each other under the influence of stress. Therefore, the influencing factors that determine the size of polymeric properties can be divided into three aspects:

1 - The polymer chain's geometry and size, such as the molecular weight factor and the chain branch in polymers.
2 - Regularity and repetition units and the nature of the series determined by the polymerization mechanism.
3 - The forces within the polymer chains and how these forces affected the arrangement of molecules in the polymer chains [4].

1.3 Epoxy resins
Epoxy resins include two or more epoxy groups that produce a large class of compounds. Epoxy groups interact with a various resin containing active hydrogens such as amines and anhydrides; these Resins associated with amine hardeners are widely used as Structural adhesives because they are good thermal
and mechanical properties [5]. The term "epoxy resin" is applied to both pre-polymers and healing Resins. The first contains reactive epoxy groups. In healing resins, all reactive groups may be reacted, so that although they no longer hold epoxy groups are still called cured Epoxy resins [6]. Epoxy has many properties including high strength, high adhesive, low shrinkage and conductive electrical and thermal properties. Therefore, it is the most common matrix material for high-performance compounds and adhesives [7].

1.4 Carbon black (CB)
Carbon black (CB) is pure elemental Carbon created by imperfect combustion or thermal decomposition of gaseous or liquid hydrocarbons. Current worldwide production about 6.8 million tons per year approximately 90% from CB used in rubber applications, 9% as a pigment, and the remaining 1% as a fundamental component in various applications. Carbon black is used widely as a reinforcing agent in rubber products to improve physical and mechanical properties. Carbon black is one of the more stable chemical products. In the general sense, carbon black is a Nanomaterial most commonly used on a large scale. The overall dimension ranges from tens of nanometers to a few hundred nanometers [8].

Carbon black is a fine particle that is not crystalline structure. It classified as a conventional particle assembled with a dimension (1-100 nm) and high electrical conductivity but low aspect ratio. Carbon black is one of the nanoparticles produced in commercial quantities (tons). Depending on the production method, the average primary particle diameters in many commercially produced blacks range from 10 to 500 nm, while the initial primary diameter ranges from 100-800 nm. Carbon black was one of the long-term nanotechnology applications and nanomaterials used to modify mechanical, electrical, and other polymers' physical properties [9]. Generally, Carbon black used a powder commercial form carbon, a lot like graphite [10].

Many kinds of research have been made to improve the epoxy by adding Carbon black, which will enhance the mechanical properties and thermal conductivity. A. Hameed et al. [11] enhanced the tensile strength, tensile modulus of elasticity, flexural strength and impact strength are improved by (24.02%, 7.93%, 17.3% and 6%) respectively at 2wt%. The compressive strength and hardness are improved by (44.4%, 12%) at 4wt%. Abdul Khalil et al. [12] enhanced the flexural, impact properties and thermal stability of epoxy filled by three types of Carbon black. Still, he did not study the other critical mechanical properties. A. Verma et al. [13] at 5 wt% of Carbon black in epoxy resin exhibited the best mechanical properties (High tensile strength and hardness).

2. Theory

2.1 Hardness test
Hardness is a mechanical property representing material resistance to penetration and scratching, measured by the indentation distance and recovery when the indenter is compressed into the surface under continuous load. There are several ways to express hardness. There are four types of hardness tests used to measure material resistance, shore hardness, diamond hardness pyramid, and Brinell hardness and Rockwell hardness. Epoxy resins are tested for penetration resistance through shore rigidity (Shore Durometer). The Durometer hardness tester consists of a pressure foot, an indenter, and an indicating device. Two types of Durometers that are most commonly used are Type A and Type D. The primary difference between the two types is in the indenter's shape and dimension. A-type Durometer used soft material, while D-type Durometer used slightly harder material [14].

2.2 Thermal conductivity of polymers
Thermal conductivity of polymers is essential properties for both polymer applications and processing. Most materials have a good conductivity such as metals, while others have very little connectivity, such as polymers [15]. Thermosets is a compound that has thermal conductivity due to its easy moulding capability and high thermal resistance. However, some epoxy resins are amorphous resin and have low heat conductivity ranged from 0.15-0.25 W/m².K [16]. Polymers and plastics are naturally low in
thermal conductivity. Polymers are lightweight, high strength/weight ratio and easy moldability, etc. [17].

Lee’s disc apparatus performed the measurements of the thermal conductivity (k) using the following equation [18]:

\[
I.V = \pi r^2 h \left( T_1 + T_2 \right) + 2 \pi r h \left[ d_1 T_1 + d_2 T_2 + d_3 T_3 \right] \ldots \ldots (1.1)
\]

Calculate the amount of thermal energy (h) passing through the disc through the following equation:

\[
K \frac{T_2 - T_1}{d} = h \left[ T_1 + \frac{2}{r} \left( d_1 + d/2 \right) T_1 + \frac{1}{r} d T_2 \right] \ldots \ldots (1.2)
\]

Where:
- K = Thermal conductivity coefficient (w/m².k)
- I = Electric current (A).
- V = voltage (volt).
- r = Radius of disk (mm).
- h = amount of thermal energy.
- d = Thickness of disk (mm).
- d_1, d_2, d_3 = Thickness of spacemen (mm).
- T_1, T_2, T_3 = temperature in kelvin.

3. Experimental Work

3.1 Materials
The Table 1 shows the mechanical properties of epoxy and carbon black. For epoxy Resin, it shows the values of Density at 20°C, Viscosity at 20°C, Flexural Strength, Modules of Elasticity and Color either Carbon black it shows the values of Particle size, Purity of Carbon, Average Roughness and also Appearance, Morphology.

Tables 1 show the properties of epoxy resin and carbon black materials.

**Epoxy Resin:**

| Density at 20°C | Viscosity at 20°C | Flexural Strength | Modules of Elasticity | Color |
|-----------------|-------------------|------------------|----------------------|-------|
| 1.05 gm/cm³     | 300               | 63 Mpa           | 2800 Mpa             | colorless |

**Carbon Black:**

| Appearance       | Particle size | Purity of Carbon | Morphology  | Average Roughness |
|------------------|---------------|------------------|-------------|-------------------|
| Black Micro powder | 370.51 µm     | 99.99%           | Spherical   | 1.68 nm           |

3.2 Preparation for Carbon black Micro composite

Five samples were prepared for each test. The weight of carbon black calculated according to the required weight fraction (2, 4, 6, 8, and 10 %wt.) ratios of epoxy resin. Each percentage of Carbon black, epoxy and hardener was weighted separately using a sensitive balance. Then, the micro Carbon black manually mixed with epoxy resin for about 10 minutes at room temperature continuously and slowly to avoid bubbling during mixing until a mixture's homogeneous state. Adding hardener to the mixture and intermingling the mixture by electric mixer for 8 minutes to prevent heat generated during mixing. This
will effect on the properties of epoxy resin and disperse the micro particles homogeneously. Then placed the mixture in the desiccator to remove the bubbles and then the mixture was poured from one corner into the mould (to avoid bubble formation which causes cast damage). The uniform pouring is continued until the mould is filled to the required level. The mixture was left in the mould for (24) hours at room temperature to solidify. The plastic moulds made of Teflon in circular form for thermal tests (dimensions 40*3 mm) and then extract the samples from the moulds and softened and work for thermal properties tests shown in Figure 1.

![Figure 1. Specimens prepared in this work according to stander specification](image)

4. Results and Discussions

4.1 Thermal Conductivity for Carbon black (Microstructure)

Heat is a form of energy, associated with the movement of atoms or particles or any particle involved in the composition of matter. Where heat is transmitted through the conductivity method from high-energy molecules into least energy molecules.

In the epoxy, thermal conductivity is due to the phonons and considers Carbon black are promising materials for thermal conductivity. When adding percentage of Carbon black to the epoxy as shown in the table 2 and Figure 2 thermal conductivity coefficient (K) increased as shown in the previous tables the reasons of epoxy into the following: When mixing the epoxy with the Carbon black will spread the particles of Carbon black in parts mixture at a randomly, depending on the process of manufacturing and the presence of these grains will play an important role in the process of thermal conductivity. When applied heat energy into the surface module, this energy will transfer from the upper heat to the lowest heat. The heat transfer mechanism depends on two phenomena: First, the heat transfer by the phonons (generated by vibration of the polymer chains). Second: the free electrons (carbon black). When the amount of heat to the polymer chains vibrate, these chains and molecules form a group of phonons that transmit heat and free electrons move through the molecules, causing heat to pass through the materials, and that the results are consistent with the finding of the researcher (Abdul Khalil et.al.) [10].
Table 2. Ratios weight Fraction and value of Thermal conductivity coefficient (K) (watt/m².kelivn), of Carbon black and Pure Epoxy.

| Weight Fraction (W %) OF C.B | Thermal conductivity coefficient (K) (watt/m².kelivn) |
|-----------------------------|------------------------------------------------------|
| Pure Epoxy                  | 0.294                                                |
| 2%                          | 0.676                                                |
| 4%                          | 0.979                                                |
| 6%                          | 1.165                                                |
| 8%                          | 1.167                                                |
| 10%                         | 1.173                                                |

Figure 2 values of Thermal Conductivity for Carbon black.

4.2 Hardness test for Carbon black (C.B) (Microstructure):

The results show that the values of hardness decreased by increasing Carbon black ratios, as shown in the Table (3). The reason for this is attributed into the accumulation of the micro-materials that were added to the epoxy during the mixing process in a specific region more than the other areas in the samples, this, in turn, causes the interconnection of these regions and decreases in the cross-liked of epoxy and weakness in the forces of the polymer chain of the prepared models as shown in Figures 3.
Tables 3. The ratios weight Fraction and values of hardness, Carbon black and Pure Epoxy.

| Weight Fraction (W %) OF C.B | Hardness |
|-----------------------------|----------|
| Pure Epoxy                  | 74       |
| 2%                          | 75       |
| 4%                          | 75.15    |
| 6%                          | 77.6     |
| 8%                          | 74.2     |
| 10%                         | 73.5     |

Figure 3. The value of hardness for Carbon black.

5. Conclusions
From the research, the values of hardness for Carbon black decreasing with increased ratios of additive. When increased the weight fraction of Carbon black, will increase the thermal conductivity coefficient (K).
References

[1] D. Teegarden, "Polymer chemistry", National science teachers Association, Virginia, p. 13, (2004).
[2] A. Osswald and G. Menges, "Material Science of polymers for Engineers", 3rd Edition, Carl Hanser Verlag, Germany, p.3, (2010).
[3] M. Chanda, "Introduction to Polymer Science and Chemistry: A Problem-Solving Approach", 2nd Edition, Taylor & Francis Group, New York, p.1, (2013).
[4] N. Subramanian, "Basics of Polymers Fabrication and processing Technology", Momentum press Engineering, New York, p. 18, (2015).
[5] N. Abdul Razack and A. Varghese, "The Effect of Various Hardeners on the Mechanical and Thermal Properties of Epoxy Resin", International Journal of Engineering Research & Technology (IJERT), Vol. 3, No. 1, pp. 2662-2665, (2014).
[6] B. Ellis, "Chemistry and Technology of Epoxy Resins", Springer Science and Business Media Dordrecht, p.1, (1993).
[7] C. Campbell, "Structural Composite Materials", Advanced Semiconductor Materials International (ASM), USA, p. 67, (2010).
[8] W. Zhang, S. Blackburn and A. Dhegihan-Sani, "Effect of carbon black concentration on electrical conductivity of epoxy resin–carbon black–silica nanocomposites", Journal of materials science, Vol. 42, No. 18, pp. 7861–7865, (2007).
[9] H. Majeed, S. Hamza and R. Kareem, "Effect of Adding Nano carbon black on the mechanical properties of epoxy", Diyala Journal of Engineering Sciences, Vol. 7, No. 1, pp. 94-108, (2014).
[10] A. Nassir, "Studying the effect of Nano carbon black on mechanical properties of Unsaturated polyester resin", The Iraqi Journal For Mechanical And Material Engineering, Vol. 13, No. 4, pp. 784-798, (2013).
[11] A. Hameed, S. Hamza and R. Kareem, "Effect Of Adding Nano Carbon black On The Mechanical Properties Of Epoxy", Diyala Journal of Engineering Sciences, Vol. 07, No. 01, pp. 94-108, (2014).
[12] H. Abdul Khalil, P. Firoozian, I. Bakare, H. Akil and A. Noor., "Exploring Biomass Based Carbon Black as Filler in Epoxy Composites: Flexural and Thermal Properties", Mat. Des, No.31, p. 3419–3425, (2010).
[13] A. Verma and K. Baurai, "Mechanical, microstructural, and thermal characterization insights of pyrolyzed carbon black from waste tires reinforced epoxy nanocomposites for coating application", Polymer Composites, Vol. 41, No.1, PP. 338-49, (2020).
[14] E. Aziz, "A Study on the effect of Hardener on the Mechanical Properties of Epoxy Resin", M.Sc thesis, University of Technology, College of Engineering, pp. 16-18, (2010).
[15] L. Chung and S. Lin, "Thermal conductivity of epoxy resin composites filled with combustion synthesized h-BN particles", Journal of Molecules, Vol. 21, No. 5, pp. 670, (2016).
[16] A. Hashim, "Smart Nanoparticles Technology", Publisher in Tech open science/ open minds, Croatia, p. 520, 529, (2012).
[17] C. Shiu and J. Tsai, "the Characterizing thermal and mechanical properties of Graphene /epoxy Nano composite", Composites Part B: Engineering, Vol. 56, pp. 691-697, (2014).
[18] M. Lee, T. Wang and J. Tsai, "mechanical properties of Nano composite with Functionalized Graphene", Journal of Composite Materials, Vol. 50, No. 27, pp. 3779-3789, (2016).