Investigation of Flexural Properties and Thermal Conductivity for Wood Dust Filled Epoxy.

Ban M. Al-Shabander
Department of Physics, College of Science, University of Baghdad, Baghdad-Iraq.
E-mail: ban.m.alshabander@gmail.com.

Abstract

This paper presents the flexural properties and thermal conductivity of composites made from wood dust filler particles and epoxy resin. The flexural tests of composites, based on wood dust filler particles at different filler contents viz. (0, 1, 3, 5, 7 and 10) Wt%, were carried out using an Instron universal testing machine according to ASTM D790 and their results were presented. Experimental results showed that the flexural strength of the composites decreased with the increase of the filler particle content. Concerning the relation between the Young's modulus and percentage of filler for flexural tests, it was found to be directly proportional at low concentrations of wood dust, at concentrations of 7 Wt% and 10 Wt% wood dust, the Young's modules decreases with increasing wood dust, with values of (1.870) and (1.824) GPa respectively.

Thermal tests were done using Lee's disk to determine the coefficient of thermal conductivity. The results obtained showed that the increasing weight percentage of wood dust in the composite leads to decreasing the thermal conductivity.

Keywords: Polymer composite, thermal conductivity of epoxy, flexural strength.

Introduction

Particulate composite materials are widely used in industrial applications. To make efficient use of such materials the variation of physical properties with the type and concentration of filler materials should be studied. One important property of particulate composites is the thermal conductivity. In many applications, knowledge of the thermal conductivity of a composite is required to calculate the rate of thermal dissipation. Some applications related to modern integrated circuit systems even require tailor able thermal conductivity [1]. Reinforcing fillers are added to improve certain mechanical properties such as Young's modulus or tensile strength, reducing the shrinkage and increasing the hardness.

Epoxy resins (ER) are one of the most important classes of thermosetting polymers which are widely used as matrices for filler reinforced composite materials and as structural adhesives [2, 3]. These resins are amorphous, highly cross-linked polymers and this structure results in these materials possessing various desirable properties such as high tensile strength and modulus, uncomplicated processing, good thermal and chemical resistance, and dimensional stability [3]. However, it also leads to low toughness and poor crack resistance, which should be upgraded before they can be considered for many end-use applications [1]. Using natural fillers to reinforce the composite materials offers the following benefits in comparison with mineral fillers [4, 5]: strong and rigid, light weight, environmental friendly, economical, and renewable and abundant resource.

Various works on the application of natural fillers and fibers in composites like pineapple, sisal, coconut coir, jute, palm, cotton, rice husk, bamboo, and wood as the reinforcements in composites have been reported in the literature. Nayak et al. [6], investigated numerically and experimentally the thermal conductivity of epoxy matrix composites filled with pine wood dust (PWD), with addition of 35.9% vol. of PWD, the thermal conductivity drops about 57.3% in neat epoxy is achieved. Sapuan et al. [7], studied the tensile and flexural properties of epoxy composites based on coconut shell filler particles. Abdul Razak et al. [8], studied electrical and thermal properties of epoxy-carbon black composites. They found that the epoxy/ carbon black composites have better thermal properties than the neat epoxy. Hathal et al. [9], prepared a hybrid composite material contains a matrix which is Epoxy resin (EP) natural and fabricated fibers (Kevler fiber + Woven and short glass fiber + Palm fiber + Metal fiber), the results obtained showed good improvement of thermal conductivity values of the composite material consists of metal wires as result of improve the thermal conductivity. Fuad et al. [10], investigated the new type wood-based filler derived from oil palm wood flour (OPWF) for bio-based thermoplastics composites by thermo gravimetric analysis and the results are very promising. A. Jadah [11], prepared sheets or block woods from sawdust and UPE/chopped reeds composites having good mechanical properties and resistance for environment effects like rain and water.

The first objective of this paper involves preparation of epoxy/ wood dust composites with varying content of wood dust. The second objective is to characterize these composites for flexural properties and thermal conductivity.

Theory

Flexural properties:

The flexural strength is defined as a material's ability to resist deformation under load. It represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress, here given the symbol *S* [12, 13]. When an object is bent, Fig.(1), it experiences a range of stresses across its depth.

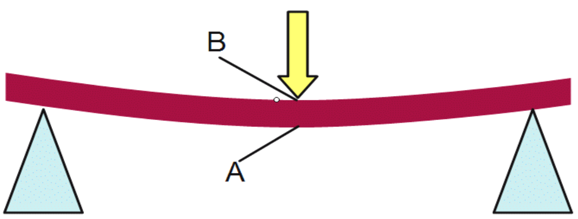

Fig.(1) Beam of material under bending. Extreme fibers at B (compression) and A (tension).

For a rectangular sample under a load in a three-point bending setup is shown in Fig.(2),

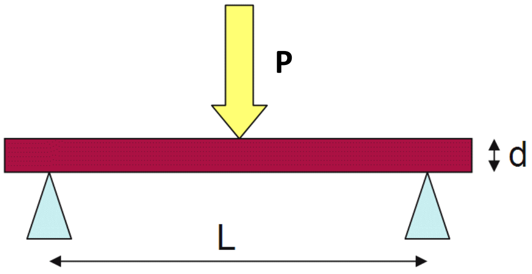

Fig.(2) Beam under 3 point bending.

P : is the load (force) at the fracture point, L is the length of the support span, b *and* d are the width and thickness of the beam respectively.

$$S = \frac{3PL}{2bd^2} \quad \text{.....(1)}$$

The flexural modulus *E* is a measure of the stiffness during the first initial part of the bending process.

$$E = \frac{L^3}{4bd^3} \cdot \frac{P}{D} \quad \text{.....(2)}$$

where *I* is the second moment of initial of the cross-section with respect to the neutral axis and *P/D* refers to the slope of tangent of the steepest initial straight-line portion of load-deflection curve [14, 15].

Thermal conductivity:

The thermal conductivity under steady conditions is the quantity of heat flow in unit time through a unite area of substance caused by a unit thermal gradient [16]. The heat transfer process depends upon structure and state of the thermal substance and temperature difference between any two points. Mainly there are two mechanisms for heat transfer through a solid substance [17, 18]. In solid conductor the free electron and lattice vibration are the dominant mechanism of heat transfer. The phonons are the unique mechanism in solid insulator substance. According to the first clear statement proposed by Fourier, the heat flows through a substance is proportional to the temperature gradient, as the following relation [16]:

$$J = -k\frac{dT}{dx} \quad \text{...(3)}$$

where J is the flux of thermal energy transmitted across a unit area per unit time, k is thermal conductivity coefficient, and dT/dx is the temperature gradient. Thermal conduction is most conveniently described in terms of the scattering phonons, by others phonons, or by electrons or grain boundary or impurities.

Experimental:

Material:

The polymer used in this work is epoxy which is commercial adhesive grade at room temperature curable araldite Euxit50 resin K (Epoxy) supplied by the Egyptian swiss chemical industrials Co., with formulated amine hardener in ratio 3:1 for curing. The epoxy resin is a liquid with low viscosity and transparent in color, the specific gravity of it at 20 °C is 1.05 g/cm^3. The filler component was wood dust with apparent density 0.55 g/cm^3.

Processing of composite:

To prepare the composite samples, a mould of size 150×150×4 mm^3 was made from glass. Glass silicon was used for joining frames, then plastic sheet was placed in the bottom of the mould. The composites were prepared with hand lay-up technique. The epoxy/wood dust composites were prepared with 1, 3, 5, 7, and 10 wt. % filler content. Initially epoxy resin and hardener were mixed together based on the weight ratio (3:1) to form a matrix. Then some of the weighted filler were added to epoxy resin with continuous mixing. This process was continued until weighted materials were finished. The mixture was poured into the mould. Then it was covered by plastic sheet. The curing time was around 24 hr at room temperature 23°C. The composite was taken out of the mould in the form of a plate and was cut and machined to produce samples conforming to the ASTM standards (D-790) for bending test, each sample was in 60 mm support span, 25 mm width and 3mm thickness. The thermal conductivity test samples were cut in shape like disc with 85mm of diameter and 3-4mm of thickness. All these tests were carried out for pure epoxy and epoxy/wood dust composites.

Three-point bending test

Bending tests were carried out by using an Instron universal testing machine of (5kN) full scale load capacity, according to ASTM standard (D-790) [19]. The load was applied on the specimen at the middle of support span, the test was with cross head speed of 1mm/min for bending test, the flexural stress can be determined using equation 1 to draw the flexural stress deflection curve and, also it was possible to determine the Young's modulus for different composites using equation 2.

Thermal test:

The thermal conductivity measured in this work using Lee's disc apparatus [20]. Fig.(3) shows the arrangement of this apparatus. This apparatus is working under the principle that when heat is transferred by conduction through unit cross-sectional area of material then a temperature gradient is generated perpendicular to the area which will results in a steady state after some time. At steady state heat conducted through the sample (epoxy/wood dust composite) is equal to the heat radiated from the Lee's disc.

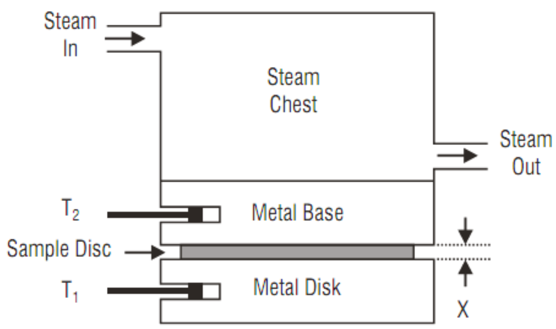

Fig.(3) Lee's disc apparatus.

The thermal conductivity of the sample (k) can be calculated using the relation,

$$k = \frac{H\,x}{A(T_2 - T_1)} \quad \text{...(4)}$$

Where (H) is the rate of heat transfer by conduction, A is the cross sectional area and $T_2 - T_1$ is the temperature difference across the sample of thickness x.

Result and Dissection

Flexural stress of epoxy:

According to the results, Fig.(4) shows the flexural stress vs. deflection curve for epoxy resin, the curve almost consist of two regions, linear (elastic) and nonlinear (plastic) regions. The linear region of the curve, shows that the applied stress on the specimen is distributed on the backbone of the polymer, because of the epoxy has cross-linking between the backbone chain restricts the movement of these chains under bending stresses. On the nonlinear region the specimen is deformed, this can be explained because of the concentration of the stresses at the lower region of the specimen (the convex side) where the specimen is extended, the stress will be constricted at the ends of crazes, which is grown to form the micro cracks, these micro cracks will be accumulated together to form the main crack, which pass through the specimen until the fracture occurs, this results agree with other previous researchers [22, 23].

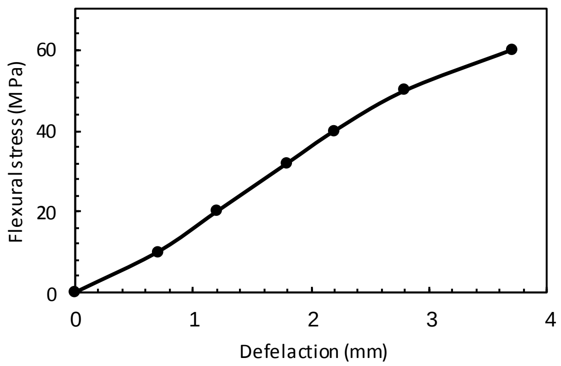

Fig.(4) Flexural stress-deflection curve for EP.

Flexural stress of composites:

The addition of wood dust particles to epoxy resin acts to decrease the flexural strength of composites as shown in Fig.(5).

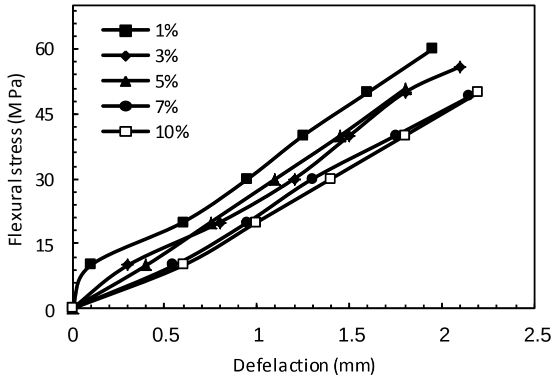

Fig.(5) Flexural stress-deflection curve for EP/WD composite.

The obtained results may be attributed to the poor adhesion at the filler/ matrix interface. In addition, the interface between particle and matrix is stressed, so many micro cracks will increase, so that the crack will spread and fracture occur. Accordingly, the additions of wood dust to the polymer matrix lead to decrease in stress similar result have been reported by other workers [22]. At low concentrations of wood dust the Young's modulus of epoxy filled with wood dust composite was gradually increased with increasing wood dust content as shown in Table (1).

Table (1)
Flexure stress, Young's Modulus for bending test for EP/WD composite.

Wt %	*S_{max}(MPa)*	*E (GPa)*
0	60	1.362
1	60	2.035
3	56	2.133
5	50.8	2.265
7	49	1.870
10	50	1.824

At concentrations of 7 wt% and 10 wt% wood dust, the Young's modules are decreased with increasing wood dust content, this is due to the random orientation of the particle, and low adhesion between matrix and wood dust particles, which makes degrades their mechanical properties, These observations are in very good agreement with the [24].

Thermal Conductivity :

The thermal conductivity results are graphically plotted in Fig.(6).

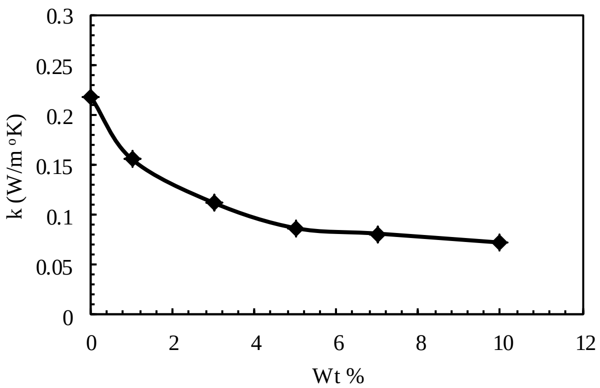

Fig.(6) Thermal conductivity of EP/WD composites.

Inspection of this curves reveals that the thermal conductivity of epoxy resin decreased after mixing with wood dust this decreasing attributed to, air voids created during preparation of composite, and the thermal conductivity of wood dust is less than thermal conductivity of epoxy resin therefore increasing the percentage of wood dust decreasing the thermal conductivity. The shape of wood dust is assumed to be spherical, while in actual practice they are irregular shaped. Although the distribution of wood dust in the matrix body is assumed to be in an arranged manner, it is actually dispersed in the resin almost randomly. The incorporation of wood dust results in reduction of thermal conductivity of the composite. The addition of 10%wt of wood dust reduces the thermal conductivity by about 67.1% in compared with the neat epoxy, as indicated by other workers [6].

Conclusions

This experimental investigation on flexural properties and thermal conductivity of wood dust filled epoxy composites has led to the following conclusions :

a. The addition of wood dust filler decreases the flexural strength for epoxy/wood dust composite with the increase of the filler weight percentage.

b. Incorporation of wood dust results in reduction of thermal conductivity of epoxy resin.

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الخلاصة

يعنى هذا البحث بدراسة خواص الالتواء والتوصيلية الحرارية لمتراكبات مكونه من جسيمات غبار الخشب والايبوكسي. وقد قمنا بأختبار متراكبات تحوي نسب مختلفه من جسيمات غبار الخشب و قدرها (0, 1, 3, 5, 7, 10) Wt% وذلك بأجراء اختبارات عالمية طبقا لتوصيف محدد ASTM D 790. وقد اظهرت هذه الاختبارات ان متانة الانحناء تتناقص مع زياده نسبة الجسيمات الممزوجة. اما بخصوص العلاقه بين معامل يونك والنسبة المئوية للمادة الممزوجة فأنها تزداد بزيادة نسبه جسيمات الخشب عند التراكيز الواطئة اما عند التراكيز العالية (7) Wt% و (10) Wt%فأن معامل يونك يتناقص مع زيادة نسبه جسيمات الخشب وتساوي (1.870) و (1.824) GPa على الترتيب. اجريت اختبارات حرارية تضمنت استخدام قرص لي لحساب معامل التوصيل الحراري واظهرت النتائج المستحصلة انخفاض التوصيلية الحرارية مع زيادة نسبة جسيمات الخشب.