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Characterization of Epoxy Resin Composite with Fire Kaolin at Different Temperatures

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ABSTRACT

This pioneering study investigates epoxy resin's mechanical properties and thermal conductivity, specifically exploring the effects of kaolin powder fired at (550 ºC and 925 ºC). Epoxy resin composite was formed by blending epoxy with (5, 10, 15, 5, 20) wt—% of kaolin powder to create a range of specimens. Fourier transform infrared (FTIR) spectroscopy analyses were performed to understand the interaction between kaolin powder and matrix material. Parameters such as flexural strength, impact strength, shore D hardness, and thermal conductivity were measured on the prepared samples. The results demonstrate that including kaolin powder in the polymer produces a progressive enhancement in flexural strength, impact strength, shore D hardness, and thermal conductivity.

Keywords: Epoxy, composites, ceramic, metal particle, modulus elasticity, FT-IR spectroscopy

INTRODUCTION

Polymers are materials made of repeating and long chains of molecules connected by chemical bonds. So the word polymer was found from poly, which means "many," and MERS, which means "part." It can be converted into final products like pure form [1].

When combined with hardeners or curing agents, epoxy resins, a type of polymer, form a robust, long-lasting substance that finds extensive use in various industries, including electronic packaging, automotive, and aerospace. Epoxy resin possesses chemical properties that result in minimal or no volatile substances during treatment, making it amenable to temperature control. In the past, numerous attempts were made to enhance the mechanical properties of polymers by incorporating ceramic granules. However, the high filler content often led to porosity and defects in the composite due to the resulting material's inherent low flexibility and strength [2].

One method of reinforcing an epoxy resin system is using inorganic fillers, which improve its properties (mechanical, thermal, and electrical). Several studies were conducted to determine the loaded composite materials and what kind of inorganic fillers must be used to achieve better properties [3].

The structure of clay minerals as layered structures, either two, three, or four sheets of tetrahedral silica $[SiO_4]^{4-}$ or octahedral alumina $[AlO_3(OH)_3]$. The chemical formula of Kaolin is $Al_2Si_2O_5(OH)_4$, a layered and electronically neutral (uncharged) material. It is found mainly in Ethiopia's Bombowha and Kombolcha areas and is usually a byproduct of granite and pegmatite [4].

One of the best fillers is Kaolin clay. Many reasons make us use this filler, including the following: we can find it easily, it has the best price, it is thermally stable, it is non-toxic, it improves the mechanical properties and water absorption, and it has gel strength [5, 6].

The treatment process is essential; the degree of porosity or distribution of filler affects the dielectric performance of the final composite. On the other side, a Sufficient amount of fillers 30 % in volume is significant for the permittivity of the composite; we can notice that the ceramic phase affects the thermal properties [7,8].

There are many methods for surface analysis. The first one is infrared spectroscopy, and the other is FTIR spectroscopy. This method helps us to know everything about the chemical composition of the fiber surface. Fourier transform infrared spectroscopy (FTIR) is a primarily used technique to identify macroscopic or microscopic samples (gas, liquid, and solid) by using a beam of infrared radiation [9,10]

METHODS AND MATERIAL

The base material used is epoxy, a viscous liquid at a room temperature range of 18-30 ºC. It turns into a solid state after adding the solid material to the epoxy in a ratio of 0f (1:2). To strengthen the epoxy, kaolin was added and fired at temperatures of 550 ºC and 925 ºC.

Kaolin is a soft white clay essential in the manufacture of china and porcelain. It is also widely used in producing paper, rubber, paint, and many other products.

The met kaolin was obtained by calcinating kaolin at high temperatures (550 and 925 °C) for 5 hours. Calcination causes dehydroxylation and destruction of the kaolinite's initial crystalline structure.

Burnt kaolin was added to the epoxy in different weights (5, 10, 15, 20) wt. % and manual molding was used to prepare the samples. The average particle size of kaolin powder is 75µm. Kaolin powder was gradually applied to the epoxy with continuous mixing by a glass rod, adding a tiny percentage of silica foam to prevent sedimentation and distribute the powder homogeneously from the epoxy.

The mixture of epoxy-kaolin powder composite was poured continuously into a prepared mold until it was filled; after the casting, they were left in the molds for (1 day) for the solidification process and bonded between the epoxy and kaolin powder. The casting was extracted from the molds and heated in an electric oven at (50 ºC) for 1 hour.

Samples were manufactured according to ASTM D790 for the three-point flexural test and based on the ASTM standard (ISO 179) for the impact test [11].

The specimen for Shore D's hardness test was circular, with a diameter (50mm) and thickness (10mm) [12].

RESULTS AND DISCUSSION

Adding varying weight fractions of firing kaolin powder augments the mechanical properties of epoxy resin composite. Flexural strength has increased with the addition of firing kaolin powder to the epoxy matrix, according to flexural strength test results. Based on the results obtained, flexural strength increased for all the specimens of the manufactured composite.

When addition (5, 10, 15, 5, 20) wt. % of kaolin powder after firing at (550 and 925) ºC, the flexural strength of the composites grew gradually. It can be seen in Figure (1) that the Flexural strength increased from (21.67 MPa) to (45.47 MPa) when the epoxy resin was reinforced with kaolin powder and fired at (550 ºC) (metakaolin). At the same time, the Flexural strength of the composite was improved from (32.146 MPa) to (75.47 MPa) when kaolin was fired at (925 ºC).

Firing kaolin powder at 925 ºC filled resins improved flexural strength properties by 57%, while met kaolin improved flexural strength by 52%. The dispersion of reinforcement powder for kaolin powder, which calcinated at 925 ºC, also improved flexural strength[10].

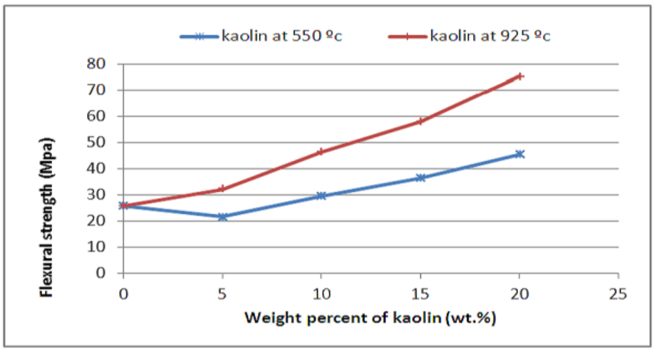


Fig. 1. Flexural strength of epoxy-kaolin powder composite in difference weight fraction.

Adding firing kaolin powder to the resin yields the best results for impact strength.

Figure (2) illustrates how the impact strength values change with the weight percent of kaolin powder in epoxy resin. When the kaolin powder percentage was increased in the epoxy resin from 5 wt.% to 20 wt. %, this improved the impact strength from 5.82 MPa to 7.41MPa for kaolin heating at 550 ºC. This behavior refers to filling the void spaces between the polymer chain and enhancing the reinforcement and matrix. At the same time, the impact strength was increased from 6.33MPa to 9.75MPa when the kaolin powder was fired at 925 ºC from 5 wt. % to 20 wt. %.

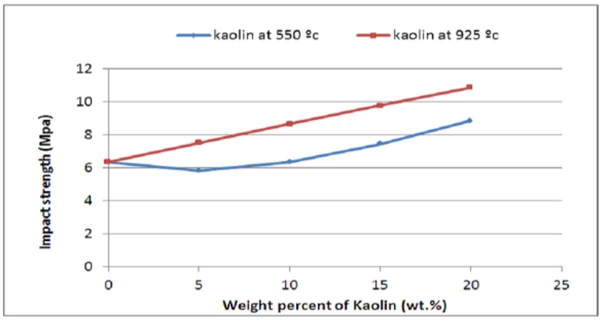


Fig. 2. IMPact strength of epoxy-kaolin powder composite in difference weight fraction.

The hardness was an important property of the epoxy-kaolin composite. It resisted an indentation with which a force was applied, thus reflecting good compatibility between the filler and the injected resin. In Figure 3, the results show the hardness property of the specimens increased after adding kaolin powder to it due to the increase in the hardness of the kaolin powder, which increases the resistance of the materials to deformation under the applied force after incorporation of kaolin powder with epoxy resin. It can be observed in Figure(3) that the hardness increased from (11.5) without kaolin powder to (20.8) with 20 wt.% kaolin powder calcination at 550 ºC and from (11.5) without kaolin powder to (27.73) with 20 wt.% kaolin powder calcination at 925 ºC.

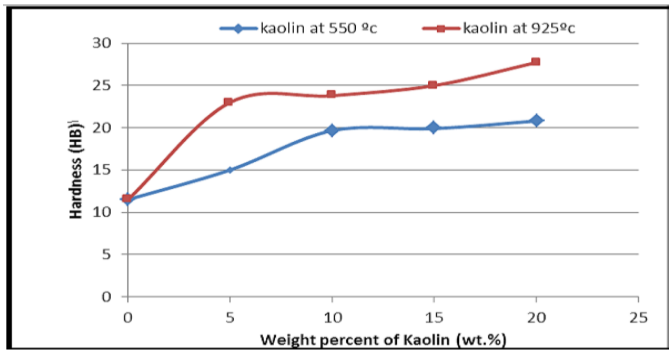


Fig. 3. Hardness of epoxy-kaolin powder composite in difference weight fraction.

When adding kaolin powder, the surface temperature of specimens displays a much faster increase than that of pure epoxy. Moreover, specimens with different percentages of kaolin powder present a slightly faster increase in temperature rising speed compared with an increase in weight percent of powder because the kaolin particles have an excellent heat transfer ability. Figure 4 shows thermal conductivity is confirmed to be 0.672 w/m.k at 5 wt. % to o.799 w/m. k at 20 wt. % with temperature 550 ºC, while at 925 ºC, thermal conductivity increased from 0.688 w/m.k at 5 wt. % to 0.954 w/m.k at 20 wt. % [13].

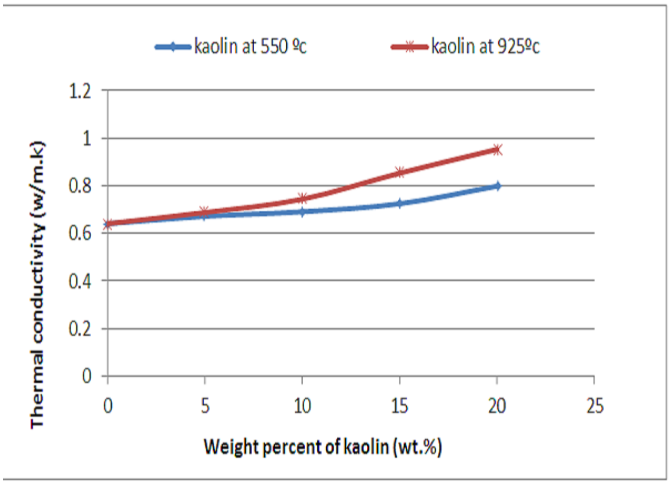
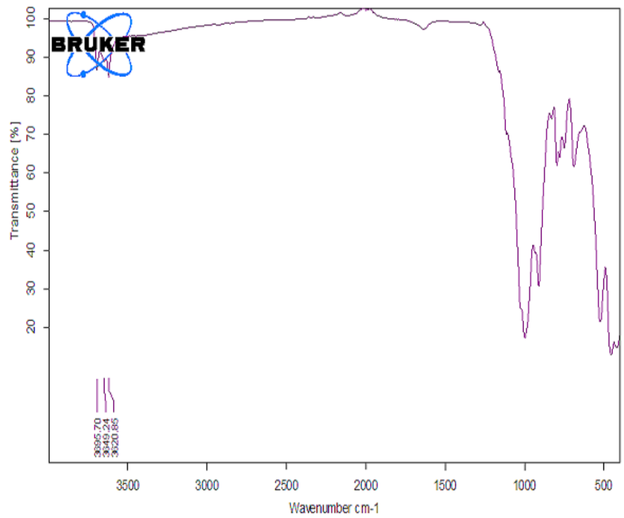
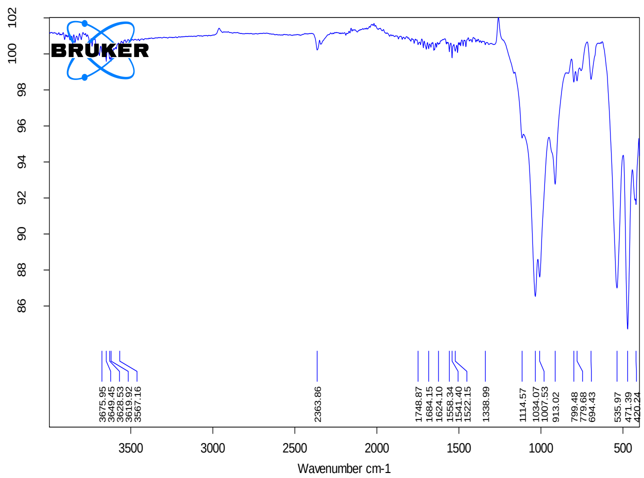


Fig. 4. Thermal conductivity of epoxy-kaolin powder composite in difference weight fraction.



a



b

Fig. 5.a ,b: The effect thermal treatment to kaolin - epoxy on FTIR spectrum

FT-IR analysis of kaolin-epoxy after exposure to heating shows about the same spectrum as before heating with a shift in peak positions. These results indicate that the heating irradiation didn't result in structural changes in kaolin-epoxy chains, which matches E. Erasmus and R. DEJU [14, 15].

Table 1 The types of vibrations corresponding to the chemical bonds in kaolin-epoxy were obtained by FT-IR analysis.

bands	**No heat**	**550c**	**925 ºC**
C-H out phase bend (625-970)cm-1	455.66 523.54 690.34 750.16 778.97 796.71 829.60 910.28	420.24 471.39 535.97 694.43 779.68 799.48 913.02	454.11 693.65 778.46 797.26
C-O stretch (1015-1300)cm-1	-----	1034.07 1114.57	1054.96
CH2 bending (1300-1380)cm-1	------	1338.99	1339.07
C=O stretch (1550-1780)cm-1	1634.94	1558.34 1624.10 1684.15 1748.87	1623.70 1652.62 1698.41 1748.81

By comparing the firing behavior of kaolin powder, some peaks appeared at 550 and 925°C, such as C-O. The effect of the thermal treatment of kaolin-epoxy on the FTIR spectrum is shown in Figure (5), and these bands are listed in Table (1) for different thermally treated (550 ºC and 925 ºC).

Without heating, a peak at (455.66 - 910.28) cm-1 indicates C-H out phase bend, and the peak at

(420.24- 913.02) cm-1 at heating (550 ºC) and the peak at (454.11-797.26) cm-1 at heating (925 ºC).

The figure indicates that the C-O stretch disappeared without heating, and peaks (1034.07-1114.57) cm-1 appeared at 550 ºC and 1054.96 cm-1 at 925 ºC.

This also indicates that CH2 bending disappeared when no heating was applied, and peaks (1338.99) cm-1 appeared at 550 ºC and 1339.07 cm-1 at 925 ºC.

At the same time, the C=O stretch appeared without heating with a peak (1634.94) cm-1 but the peak (1558.34-1748.87) cm-1 for (550 ºC), and the peak (1623.70-1748.81) cm-1 at heating (925 ºC).

CONCLUSION

The current work can be concluded as follows:

1. The flexural strength of kaolin powder fired at 550 ºC –epoxy matrix composites gradually improved from 21.67 MPa at 5 wt.% to 45.47 MPa at 20 wt.%, while 32,15 MPa to 75.47 MPa for kaolin powder fired at 925 ºC.
2. The impact strength of kaolin powder-reinforced epoxy matrix composites was found to increase with the increase in reinforcement (5 to 20 wt. %) in the epoxy matrix composites for kaolin fired at 550 ºC and 925 ºC.
3. Hardness enhancement with added kaolin powder (5 to 20 wt. %) content at two firing temperatures of kaolin (550 and 925 ºC).
4. The incorporation of kaolin powder increases the thermal conductivity of epoxy resin composites. When adding the weight ratio (5 to 20) of kaolin powder, the thermal conductivity of epoxy–kaolin composites improves in relation to pure epoxy resin.

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