Investigation of Dielectric Properties of a Novel Hybrid Polymer Composite using Industrial and Bio-waste

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Abstract
Fly ash is an industrial waste which creates environmental problems. Coir dust is a byproduct of coir fiber production. Novel low-cost hybrid polymer composite using coir dust and fly ash particle reinforcement is prepared. Investigation of dielectric behavior of this hybrid polymer composite proves its efficacy as a high-value marketable product. Individual compacts of coir dust, fly ash, coir dust and fly ash are also prepared for comparison with the hybrid polymer composite. Hand lay-up method is adopted for preparation of the compacts. The hybrid composite has lowest porosity, homogeneous surface structure and greater interface bonding when polymer is used as the binder. With increase in frequency of the applied signal, the dielectric constants of the composites decrease due to dielectric relaxation. Dielectric loss of the hybrid composite shows stabilizing trend with increase in frequency of the applied voltage.

Keywords: *polymer composite, dielectric loss, dielectric relaxation, coir dust, fly ash, epoxy resin*

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INTRODUCTION
Fly ash is being considered as waste material, produced as a byproduct from thermal power plants. It is creating severe environmental pollution; so much research is being conducted for more than two decades for its proper utilization as well as to control environmental pollution in the surrounding areas of power plants. Its utilization in industry or in market sector may bring economic and ecological benefits and impart technological developments [1–11]. Coir dust is a spongy, peat like residue from the processing of coconut husk (mesocarp) for coir fiber also known as coco peat. This consists of short fibers (< 2 cm) around 2–13% of the total and cork-like particles ranging in size from granules to fine dust. Coir dust strongly adsorbs liquid and gases. This property is due in part to the honeycomb-like structure of the mesocarp tissue which gives it a high surface area per unit volume [12]. A composite material is a combination of two or more materials (in certain proportions) whose performance characteristics exceed than that of its individual components. Nowadays, polymer composites are of interest; these can provide great strength and stiffness along with resistance to corrosion [13–15]. Natural fiber such as jute, coir, sisal, pineapple, ramie, bamboo, banana, etc., has focussed on the development of natural fiber-reinforced polymer composites primarily to explore value-added application avenues. Such natural fiber-reinforced polymer composites have raised great attention and interest among materials scientists and engineers in recent years due to the considerations of developing an environmental friendly material and partly replacing currently used glass or carbon fibers in fiber-reinforced composites. They are bio-degradable, high specific strength and modulus materials, low priced, recyclable and are easily available. These fiber composites are well suited as wood substitutes in the housing and construction sector [16–22].

Hence, developing low-cost composite material using industrial byproducts and bio-waste materials from local resources is an active field of research [23, 24]. Presently, much research attention is being given to use such materials for capacitor dielectric, insulation, encapsulation, multilayer ceramic chip, printed circuit boards, etc. Fly ash-based composite and bio-fiber-based composite exhibit low dielectric constant and stabilized dielectric loss at high frequencies of applied field, and hence are suitable for electronic applications [25–27].

Development of a hybrid polymer composite retaining both types of characteristics is considered to be an active field of research. This research work aims to develop a hybrid polymer composite material using bio-waste (coir dust) and industrial waste (fly ash) which will retain the advantages of both the fiber-reinforced and particle-reinforced composites and emerges as a viable alternative to the existing polymer composites. The preparation of composites is carried out using hand lay-up method and hence no expensive machinery/equipment is required. Neither large space nor any specific environmental condition such as air conditioning is necessary for this process. Thus, processing cost for developing this hybrid composite is minimal. In this work, hybrid composite samples are prepared with different reinforcement (coir dust and fly ash are the reinforcement in epoxy resin matrix) and further the effect of the reinforcement on the physical and dielectric properties of the hybrid composite are studied through experimental analysis.

MATERIALS AND METHODS

Materials Used

Fly ash was collected from the captive power plant (CPP-II) of Rourkela Steel Plant (RSP). The chemical composition of the fly ash is given in Table 1.

Table 1: *Chemical Composition of Fly Ash.*

Constituents	Percentage (%)
Fe_2O_3	8.1
MgO	1.14
Al_2O_3	24.98
SiO_2	55.85
P_2O_5	0.15
SO_3	1.16
K_2O	0.85
CaO	2.54
Na_2O	0.2
TiO_2	1.75
CO_2	1.56

Epoxy LY 556, chemically belonging to the “epoxide” family is used as the matrix material. Its common name is Bisphenol A Diglycidyl Ether. The hardener with IUPAC name NN'-bis (2-aminoethylethane-1, 2-diamine) used with the epoxy has the designation HY-951. The epoxy resin and the hardener were supplied by Ciba Geigy India Ltd. Coir fiber was collected and processed to form coir dust.

Preparation of Test Samples

Initially, epoxy resin and hardener were mixed in a ratio of 10:1 by weight. Then, both the waste products (50% coir dust and 50% fly ash) were mixed with the epoxy resin by stirring at room temperature, in a glass beaker with the help of suitable glass stirrer. Proper stirring was required for uniform mixing of the reinforcing agent and the polymer matrix and after 10 min of stirring, the material was poured into suitable moulds to obtain plate-shaped and disc-shaped samples (of 12 mm diameter and 2.5 mm thickness). Then compacts of coir dust, fly ash-mixed coir dust and fly ash were prepared for comparison with the hybrid polymer composite. Test specimens of suitable dimensions were cut from the composites. The test samples prepared are shown in Figure 1.

Characterization and Dielectric Measurements

Hardness test is conducted in a Vickers hardness tester, Leitz make. The Vickers Hardness Number (VHN) of the hybrid composite was measured under a load of F = 0.3 kgf and VHN was calculated by using the formula:

$$HV = 0.1889\, F/L^2$$

and

$$L = (X + Y)/2 \qquad (1)$$

where F is the applied load, L is the diagonal of square impression (mm), X is the horizontal length (mm), and Y is the vertical length (mm). The surface morphology of the samples was examined with JEOL T-330 Scanning Electron Microscope. Samples were coated with 60 A° thick platinum in JEOL sputter ion coater for surface conductivity and then observed under SEM, operated at an acceleration voltage of 20.0 kV. For dielectric measurement, the samples were coated with graphite paint on the opposite faces and heated for 5 min (at 100 ^{o}C) in an oven for drying.

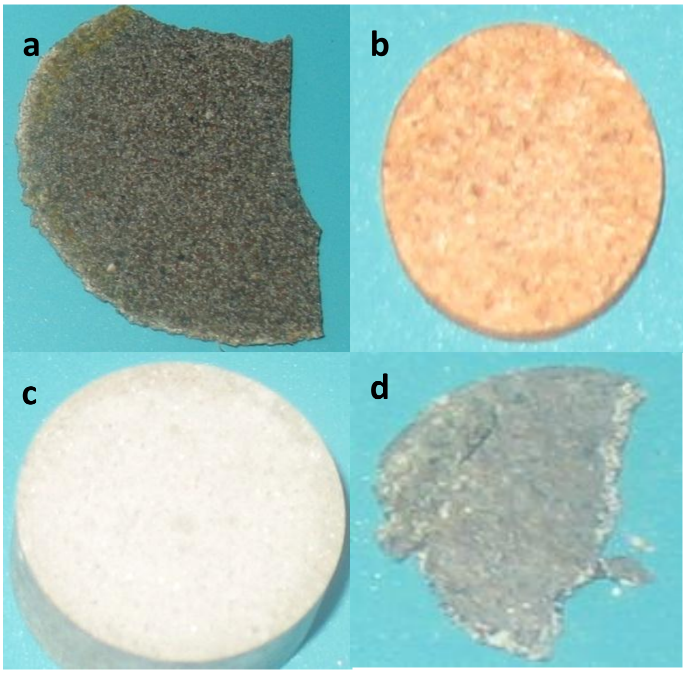

Fig. 1: *(a) Hybrid Polymer Composite of Fly Ash, Coir Dust and Epoxy, (b) Compact of Coir Dust, (c) Compact of Fly Ash, and (d) Compact of Fly Ash and Coir Dust Mixture.*

Dielectric measurements were carried out at a frequency of 10^4 to 10^{14} Hz using HP-4192A LF Impedance Analyzer, connected with a data acquisition system. The temperature was controlled with a programmable oven. In dielectric analysis, each sample is placed between two gold electrodes (parallel plate sensors, TA instruments). A sinusoidal signal was applied, creating an alternating electric field. This electric field produced polarization in the sample, which oscillated at the same frequency as of the applied electric field, but had a phase angle shift d. This phase angle shift was measured by comparing the applied voltage to the measured current, which was separated into capacitive and conductive components. The dielectric constant and dielectric loss were determined as follows:

$$\text{Dielectric constant (k)} = C'/C \quad (2)$$

where, C' (pF) is the measured capacitance and C (pF) is calculated using the equation,

$$C = \varepsilon_0(A/d) \quad (3)$$

where, A is area of the electrode (mm^2) and d is the thickness of the sample (mm).
The dielectric loss is given by,

$$\tan\delta = G(S)/(w\,C'(F)) \quad (4)$$

where, $w = 2\pi f$, f is the measuring frequency and $G = G_0(R-R_0)$ [28].

RESULTS AND DISCUSSIONS

Hardness values of the samples are given in Table 2. From the table, it is seen that the hybrid composite bears higher hardness than that of the coir dust and coir dust + fly ash mixture compact. The increase in hardness of the hybrid composite may be due to the binder used for the composite.

Table 2: *Hardness Value in HV of Different Samples.*

Specimen	Hardness value (HV)
Hybrid composite (Fly ash, coir dust and epoxy)	23.5
Coir dust compacts	18
Coir dust + Fly ash compacts	20
Fly ash compacts	28

The surface morphology of the prepared test samples are given in Figure 2. Figure 2 (a) shows the surface morphology of the compact made from coir dust only. Some amount of inter-particle void spaces is present and the particles are of multifaceted type. Figure 2 (b) indicates the microstructure of the compact made with 50% fly ash and 50% coir dust. This shows more amount of porosity in the compact. Inter-particle bonding of fly ash particles is more prominent than that of the bonding at the interface of coir dust and fly ash, which implies an increased amount of porosity of the compact. Figure 2 (c) demonstrates a compact made with fly ash only. Porous regions are homogeneously distributed and vary from region to region throughout the surface. Figure 2 (d) shows the composite made with blending epoxy resin with coir dust and fly ash in equal percentage (50% +50%). Here some clear globular regions are observed. The interface bonding of coir dust and fly ash particles is found to be superior to that of all other samples. This composite has lowest porosity, homogeneous surface structure and greater interface bonding as compared to other samples.

From Figure 3, it is observed that the dielectric constant (at 10^4 Hz frequency) is maximum for pure fly ash sample and minimum for coir dust. But when coir dust and fly ash are combined together, dielectric constant drops down. For the hybrid composite with epoxy matrix, the dielectric constant value and dielectric loss value initially decreases and attains a steady state with increase in frequency as shown in Figure 4. This may be due to the fact (i) dielectric behavior is dependent on porosity, (ii) material properties and also (iii) interface bonding in case of composite materials. So, in this study the materials used have many diverse physico-mechanical properties. However, it is found that making a composite with these wastes, using a polymer binder is best suited for providing good mechanical strength without sacrificing its dielectric property.

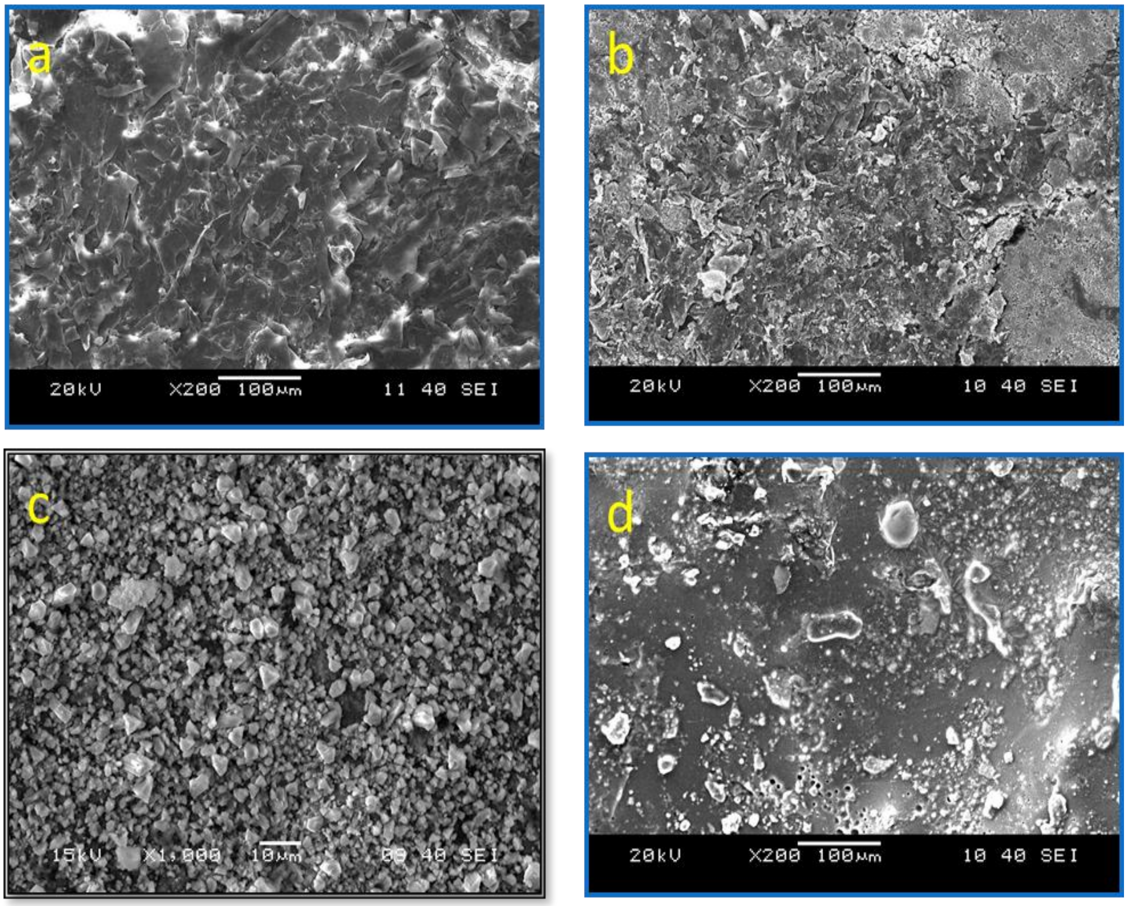

Fig. 2: *SEM Micrographs of (a) Compact of Coir Dust, (b) Compact of Fly Ash and Coir Dust Mixture, (c) Compact of Fly Ash, and (d) Hybrid Polymer Composite of Fly Ash, Coir Dust and Epoxy.*

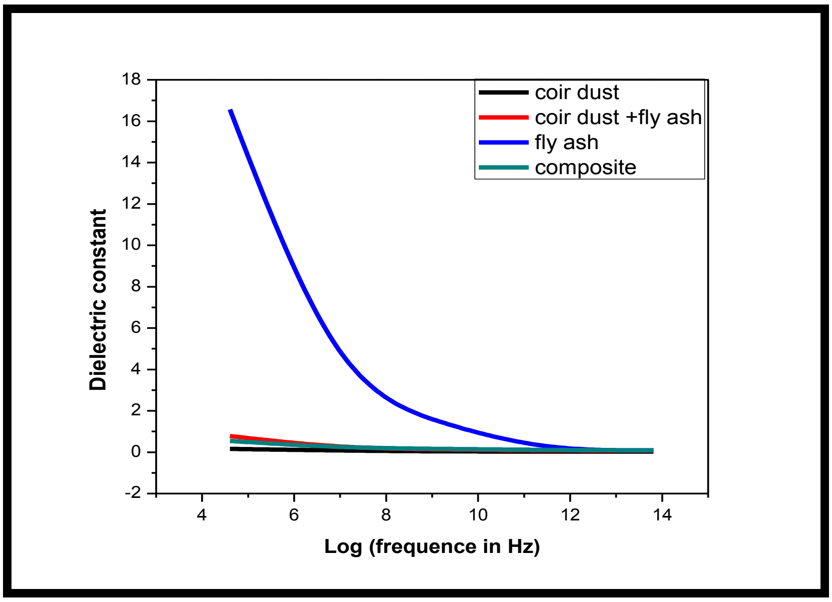

Fig. 3: *Variation of Dielectric Constant with Frequency.*

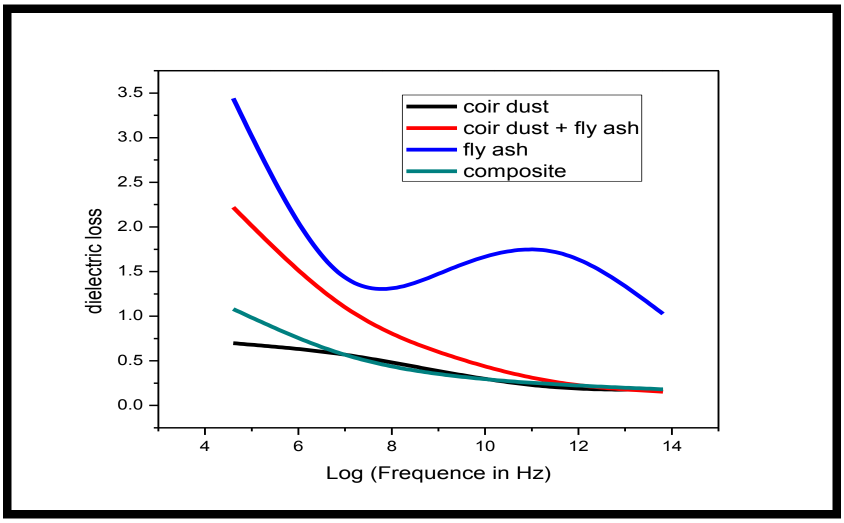

Fig. 4: *Variation of Dielectric Loss with Frequency.*

CONCLUSIONS

The developed hybrid composite results in a performance unattainable by the individual constituents. Polymers have a tendency of moisture absorption. Impregnation of coir dust and fly ash into it helps in the interface bonding and distribution of absorbed moisture in the material which may be one of the reasons for change in dielectric behavior. With increase in frequency, the dielectric constants of the composites decrease due to dielectric relaxation. From theoretical point of view, the dielectric relaxation involves oriental polarization which in turn depends on molecular arrangement of the material. It is known that, at high frequency, the rotational motion of polar molecule is not sufficiently rapid for attainment of equilibrium with applied electric field; hence, dielectric constant decreases, depending on the reinforcement content and types of reinforcement. Dielectric loss of our hybrid composite shows a stabilizing trend with increase in frequency, which appears to be beneficial in electronic industry and that to, can be processed by village artisans also. As the composite is made using industrial byproducts and bio-waste materials from local resources, its cost is less as compared to other polymer composites available today. This can further open up a new frontier for industrialization in the rural sector.

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