Development of a novel hybrid polymer composite with coir dust and fly ash reinforcements and investigation of its dielectric nature

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Abstract

Fly ash is an industrial waste. Coir dust is a by-product of coir fiber production. A novel low cost hybrid polymer composite, using coir dust and fly ash particle reinforcements is proposed in this paper. Investigation of the dielectric behavior of this hybrid polymer composite proves its potential as a marketable product. Individual compacts of coir dust, fly ash, and a mixture of both were also prepared for comparison with the hybrid polymer composite. Hand lay-up method was adopted for preparation of the compacts. The novel hybrid composite has the lowest porosity, homogeneous surface structure and greatest interface bonding when polymer is used as the binder. Its dielectric properties are studied through experimentation. With an increase in frequency of the applied signal, the dielectric constant of the composite decreases due to dielectric relaxation. Also, dielectric loss of the hybrid composite shows a stabilizing trend with increase in frequency of the applied voltage. The hybrid polymer is found suitable for high frequency electronic applications as a dielectric material.

1. Introduction

The thermal power plants generate significantly large quantities of solid byproducts. Pollution hazards due to the disposal of fly ash, one of the byproducts, into the environment are encountered in various sectors [1]. Its utilization in industrial or market sector may bring economical and ecological benefits, and impart technological developments. Compositionally, fly ash is a mixture of SiO_2, Al_2O_3, $CaSO_4$, and un-burnt carbon. Coir dust, a bio-waste, is a by-product of production of coir fiber, and can be useful for setting up an important industry in most countries where there are plenty of coconuts. Coir dust is a spongy, peat like residue obtained from the processing of coconut husks for coir fiber. It consists of around 2% - 13% of cork like particles ranging in size from granules to fine dust [2].

A composite material is a combination of two or more materials (in certain proportions) whose characteristics differ from that of its individual components. At present, polymer composites are of interest; these can provide great strength and stiffness along with resistance to corrosion [3]. Natural fibers like jute, flax, rice husk, hemp, cotton are used as reinforcements into polymer matrix as an alternative to the commonly used synthetic fibers like carbon and glass because of their low-density, good mechanical properties, abundant availability and bio-degradability [4, 5]. Hence, the development of low cost composite materials using industrial byproducts and bio-wastes from local resources is of great interest to researchers [6, 7]. Further mechanical properties of epoxy based fly ash composites have been studied [8]. Presently, much research attention is given to use such materials for capacitor dielectrics, insulation, encapsulation, multilayer ceramic chip, printed circuit boards etc. [9,10,11]. Fly ash based composite and bio-fiber based composite exhibit a low dielectric constant and stabilized dielectric loss at high frequencies of applied field, and hence are suitable for electronic applications [12, 13,14]. 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 particles reinforced composites and emerge 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/ equipments are required. Hand lay-up is the simplest and oldest open molding method of the composite fabrication processes. Room temperature curing polyesters and epoxies are the most commonly used matrix resins. Curing is initiated by a catalyst in the resin system, which hardens the composite without external heat [15]. Neither large space nor any specific environmental condition such as air conditioning etc. is necessary for this process. Thus, the processing cost for developing this hybrid composite is minimal. In this project, hybrid composite samples are prepared with different reinforcements (coir dust and fly ash are the reinforcements in the epoxy resin matrix) and furthermore, the effect of the reinforcement on the physical and dielectric properties of the hybrid composite is studied through experimental analysis. The new hybrid epoxy based polymer composite material possesses a low dielectric constant, stabilizing trend of dielectric loss at a high frequency of applied electric field, design flexibility, and hence can be a highly valued commercial product.

2. Methodology involved

A low cost polymer composite using simple methodology was developed, and no expensive machinery/equipment is required for processing. Locally available raw materials were utilized in the process. Preparation of hybrid polymer composite involved the following stages:

- The processing of coir dust from coir fiber extracted from coconuts.
- Collection of an industrial pollutant, fly ash from the thermal power plant (CPP-2) of Rourkela Steel Plant.
- The compacts were made applying 5 ton pressure in a Uni-axial Pressing machine.
- Adopting the simple hand lay-up method for making hybrid composites by using the waste materials as reinforcements to an epoxy resin matrix (procedure described below).As binding of particulates of fly ash and coir dust is required to form a bulk mass, Epoxy was used as the binder/matrix material in the fabrication of proposed hybrid composite.
- Preparation of disc shaped samples by cutting, polishing and silver coating for material characterization and testing.
- Measurement of hardness of the hybrid composite using a Micro hardness tester.
- Study and analysis of the surface morphology of the compacts made using coir dust, fly ash, a combination of coir dust and fly ash (50% coir dust and 50% fly ash) and also for the hybrid polymer composite sample using a high precision Scanning Electron Microscope (SEM).
- Observations and analysis of the dielectric properties(dielectric constant and dielectric loss) as a function of frequency of applied electric field (100 Hz - 1MHz) using a PC based dielectric interface equipment.

3. Preparation of the hybrid polymer composite material

3.1 Raw Materials used: Epoxy LY 556 (common name- Bisphenol A Diglycidyl Ether) was used as the matrix material in the fabrication of proposed hybrid composite. The hardener used was HY-951(IUPAC Name- NN0-bis (2-aminoethylethane-1, 2-diamin). Epoxy resin and hardener were mixed in a ratio of 10:1 by weight. Coir fiber was processed it to form coir dust. Fly ash, collected from the nearby steel plant was utilized for the hybrid polymer composite fabrication.

3.2 Procedure followed

The hybrid polymer composite was developed as follows. Both of the waste products (50% coir dust and 50% fly ash) were mixed with the epoxy resin (polymer binder) in a glass beaker with the help of suitable glass stirrer. Proper stirring was done to mix the reinforcing agents with the polymer binder at room temperature. After 10 minutes of constant stirring, polymeric reaction started, which was noticed by a temperature rise. Then the solution was poured into a suitable mould to fabricate a plate-shaped hybrid composite. This process is called casting. After curing for approx. 24 hours at room temperature, the casted slab of hybrid polymer composite was collected from the mould. Disc shaped test samples (12 mm diameter and 2.5 mm thickness) of the composite were prepared by cutting and polishing. The Coir dust compact, fly ash compact, a combined coir dust and fly ash compact were made, for comparison with the hybrid polymer composite, using a Uni-axial Pressing machine with 5 ton applied load. Test specimens of suitable dimensions were prepared from the compacts for testing. The samples of compacts and the hybrid composite prepared are shown below.

Coir dust compact   Fly ash compact   Compact of Coir dust & Fly ash   Hybrid Polymer Composite

4. Investigations done and result analysis

4.1 Hardness measurement test to determine the hardness of the hybrid composite

A Vickers's Micro hardness tester was used for Hardness measurement of the composite sample. In this test, a load F= 0.3 Kgf was considered and Vickers's hardness number was calculated by using the formula. $HV=0.1889\ F/L^2$ and $L=(X+Y)/2$ in mm, where F is the applied load, L is the diagonal of the square impression (mm), X is the horizontal length (mm), and Y is the vertical length (mm). Hardness of the hybrid composite was found to be 19.7 HV, which was more compared to that of the polymer binder alone. The hardness measurement is shown in the Fig. 1 below.

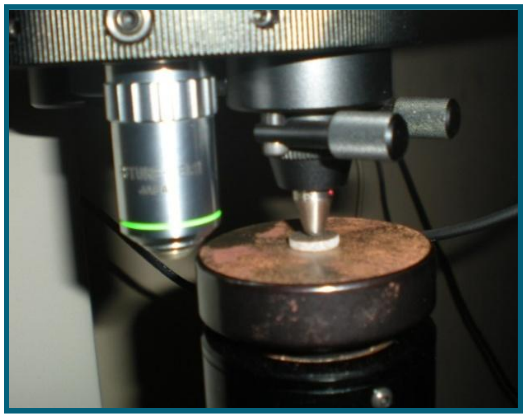

Fig.1.Hardness Measurement

4.2 Surface morphology test

To study the surface morphology of different compacts using coir dust, fly ash, a combination of coir dust & fly ash and the hybrid polymer composite, the following test was carried out. The surface morphology of the composites was examined with JEOL T-330 Scanning Electron Microscope. Samples of the compacts and the hybrid composite were coated with 60 A° thick platinum in JEOL sputter ion coater for surface conductivity and then observed under SEM. Scanning electron micrograph are shown in the following figures.(Fig 2 to Fig 5).

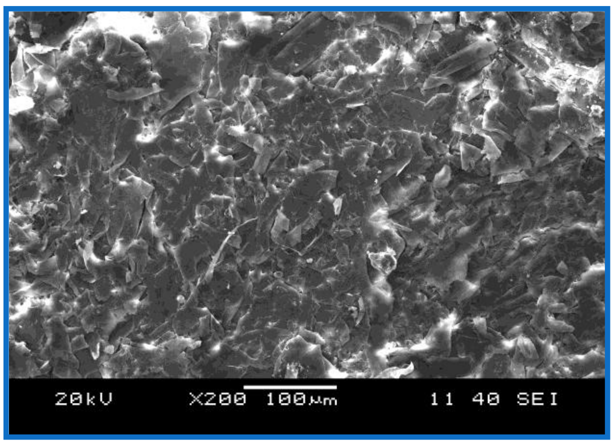

Fig. 2

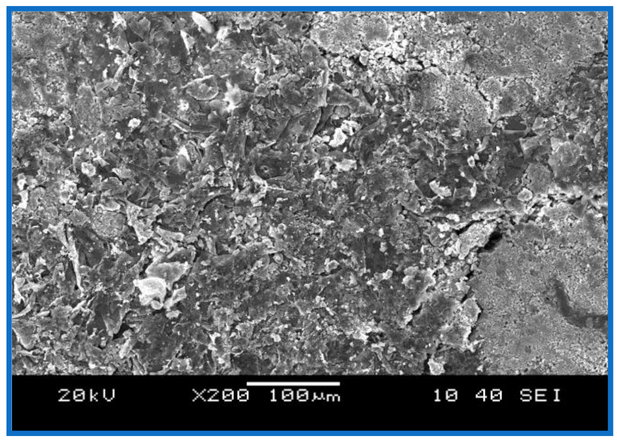

Fig. 3

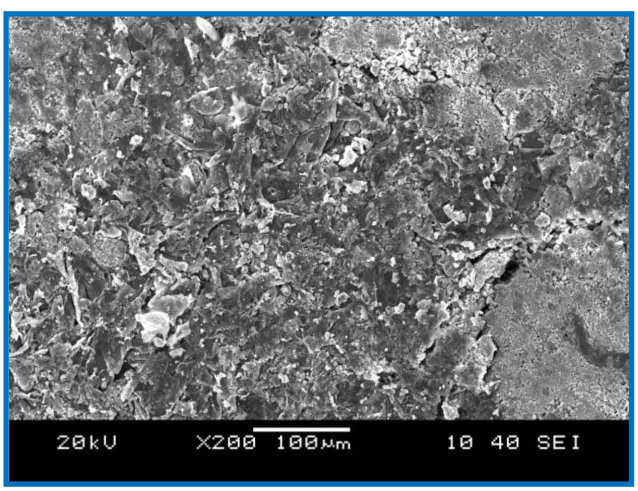

Fig. 4

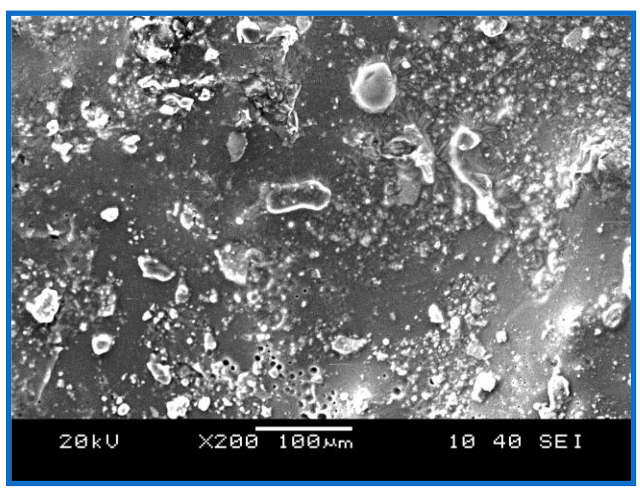

Fig. 5

Figure 2 shows the surface morphology of the compact made from coir dust. Some amount of inter particle void spaces are present and the particles are multifaceted type.

Figure 3 indicates the microstructure of compact made with a combination of 50% fly ash and 50% coir dust. This shows more amount of porosity in the compact. 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 4 demonstrates a compact made with fly ash only. Porous regions are homogeneously distributed and vary from region to region throughout the surface. Poor interface bonding between fly ash and coir dust is evident from the crack propagation along the boundaries of fly ash and coir dust.

Figure 5 shows the composite made with blending epoxy resin with coir dust and fly ash in equal volume percentage. 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 previous cases as there are less interparticle void spaces and crack. This composite has the lowest porosity, most homogeneous surface structure, and greatest interface bonding as compared to previous samples. Formation of cavities is noticed, which may be due to trapping of air bubbles during stirring.

4.3 Dielectric Properties Measurement

A study of the important electrical properties (such as dielectric constant and dielectric loss) of the coir dust, fly ash, mixed (coir dust & fly ash) compacts and hybrid polymer composite as a function of the frequency of an applied electric field was carried out, and is described below.

A dielectric material is an electrical insulator that can be polarized by an applied electric field. The dielectric constant of a material depends upon the degree of polarization of its molecules, which is determined by different contributions such as interfacial, dipole, atomic and electronic polarizations [16]. Interfacial polarization influences the dielectric properties (at very low frequencies) and usually decreases with increasing frequency. Dielectric properties like dielectric constant and dielectric losses were measured with Solartron 1260 Impedance analyzer, connected with PC based data acquisition system as shown in Fig. 8.

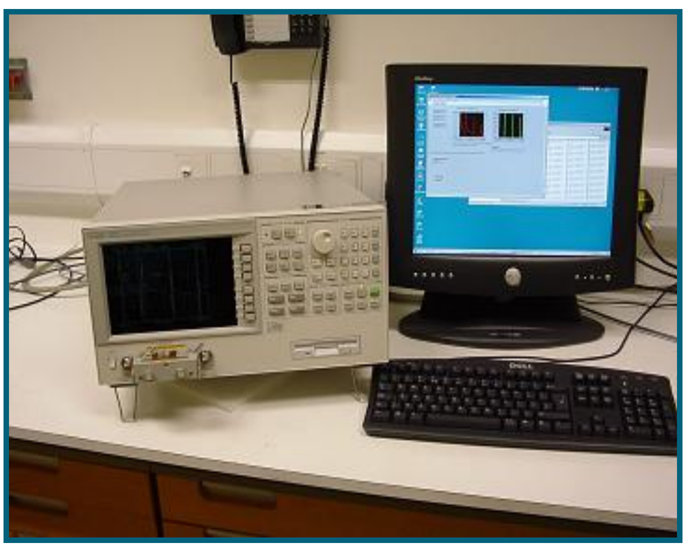

Figure 6: Dielectric interface equipment

The samples of the composites prepared were cut into thin circular shape and their surfaces were polished. Then graphite coating was given on their surfaces to make them conducting and for allowing measurements over a frequency range from 100 Hz to 1MHz. The samples were placed between the two parallel electrodes for measurement. A sinusoidal signal was applied, which creates an alternating electric field. The applied electric field creates a dipole moment as shown schematically in Fig 7. This electric field produces polarization in the sample, which oscillates at the same frequency as of the applied electric field, but has a phase angle shift δ. This phase angle shift was calculated by comparing the applied voltage to the measured current, which is separated into capacitive and conductive components. [12,14,16].The experimental data given in Table 1 and 2 were collected and plotted in Fig 8 and Fig 9 respectively.

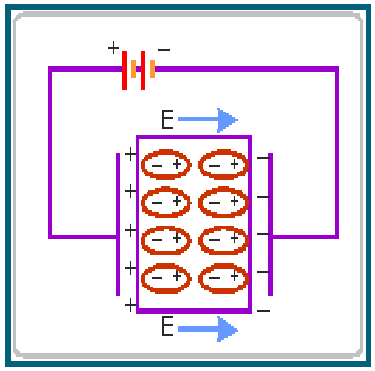

Figure 7: Schematic diagram of the applied electric field for a dielectric

The dielectric constant and dielectric loss are determined as follows:

Dielectric constant (k) = C'/C, where C' (pF) is the measured capacitance and C (pF) is calculated using the equation: $C = \varepsilon_0 . (A/d)$, where A (m.m²) - area of the electrode, d (m. m) - thickness of the sample. The dielectric loss is given by, $\tan \delta = G(S) / (w\ C'\ (F))$, where $w = 2nf$, f is the measuring frequency, and $G=G_0(R\text{-}R_0)$. [12,17]

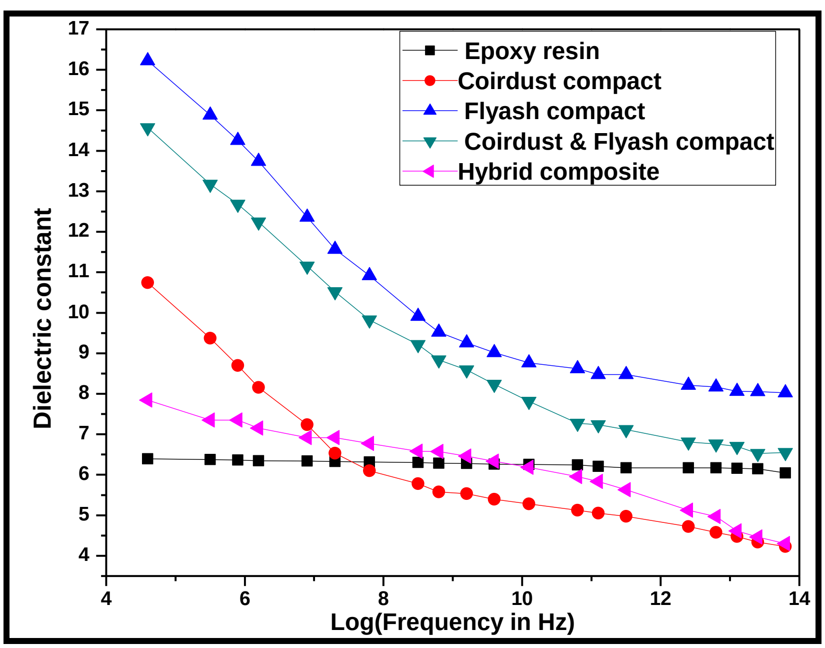

Fig. 8: Variation of dielectric constant with frequency of applied electric field

Data Table -1

Log(frequency in Hz)	Dielectric constant(k)				
	Epoxy resin	Coir dust compact	Fly ash compact	Fly ash & coirdust compact	Hybrid PolymerComposite
4.6	6.39397	10.74533	16.22585	14.56735	7.84125
5.9	6.36111	8.69862	14.2543	12.6826	7.34799
7.3	6.32899	6.53259	11.56553	10.51816	6.91587
8.8	6.28833	5.57744	9.52008	8.83556	6.5717
10.1	6.25322	5.27894	8.76673	7.81453	6.18547
11.5	6.17382	4.97513	8.4761	7.11855	5.62715
12.8	6.17153	4.57553	8.16635	6.75908	4.96558
13.8	6.04649	4.22753	8.02398	6.55258	4.30019

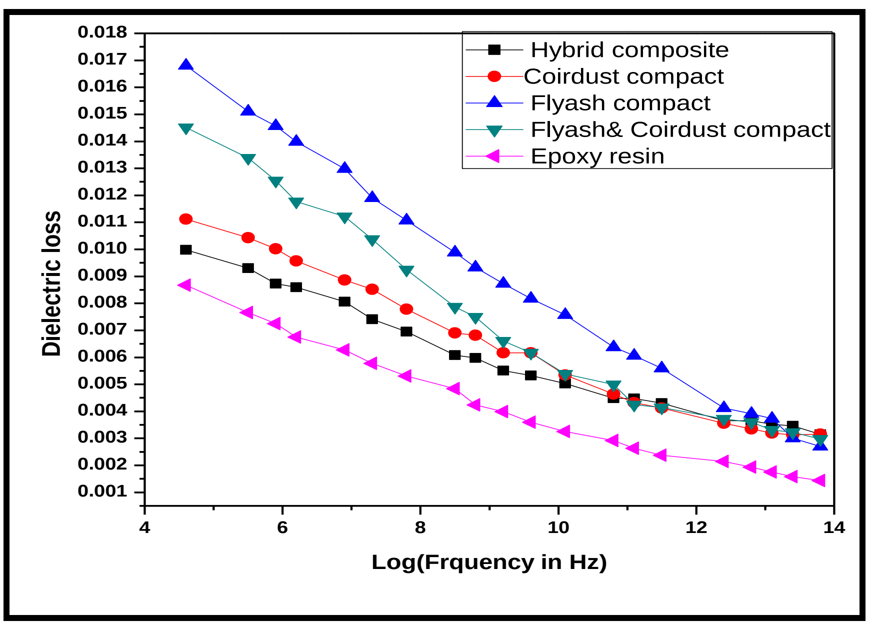

Fig. 9: Variation of dielectric loss with frequency

Data Table -2

Log(frequency in Hz)	Dielectric loss				
	Hybrid Polymer Composite	Coir dust compact	Fly ash compact	Fly ash & coir dust compact	Epoxy resin
4.6	0.00998	0.01112	0.01681	0.01451	0.00867
5.9	0.00873	0.01002	0.01457	0.01254	0.00725
7.3	0.00741	0.00852	0.0119	0.01037	0.00578
8.8	0.00598	0.00682	0.00933	0.0075	0.00424
10.1	0.00503	0.00535	0.00757	0.00538	0.00325
11.5	0.0043	0.00412	0.00559	0.00414	0.00237
12.8	0.00365	0.00335	0.00391	0.0036	0.00193
13.1	0.00352	0.0032	0.00373	0.00331	0.00175
13.8	0.00315	0.00316	0.0027	0.00298	0.00144

It is observed from Fig. 8 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, the 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 Fig. 9. This may be the fact due to; (i) dielectric behavior is dependent on porosity, (ii) material properties and also on (iii) interface bonding in case of composite materials. So in this study the materials used have many diverse physical and mechanical properties. However, it was found that making a composite with these wastes and a polymer binder is best suited for providing good mechanical strength without sacrificing desired dielectric properties.

5. Discussion

The developed hybrid composite results in a performance unattainable by the individual constituents. Polymers have a tendency of moisture absorption. Impregnation of the polymer with coir dust and fly ash 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 increasing frequency, the dielectric constant of the composite decreases due to dielectric relaxation. From theoretical point of view, the dielectric relaxation involves oriental polarization which in turn depends on the molecular arrangement of the material. It is known that at high frequencies, the rotational motion of a polar molecule is not sufficiently rapid for the attainment of equilibrium with an applied electric field, hence, the dielectric constant decreases depending on the reinforcement content and types of reinforcement. Low dielectric constant and stabilizing Dielectric loss of the novel hybrid composite are beneficial in electronics industry [18]. The developed hybrid composite offers advantages of renewability and biodegradability as comparable to synthetic polymer composites in the use of capacitors [12]. As the composite is made using industrial by-products and bio-waste materials from local resources, its cost is less compared to other polymer composites available today[5]. This can further open up a new frontier for industrialization at rural sectors.

6. Future scope of research

Coir dust and fly ash mixed polymer composite can have the potential for use not only in household applications but also for electronic industries. Hence, detail study of mechanical properties, thermal conductivity, chemical resistance etc. need to be carried out in order to explore various applicability of such material. Optimization of the amount of reinforcements (coir dust and fly ash) in the hybrid polymer composite can be attempted to further improve its performance.

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