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Effect of ferrite on electrical and optical properties of fly ash enriched nanohybrids

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For a variety of applications in the production of sustainable composite materials, fly ash (FA)-enriched ferrite nanohybrids (NHs) have emerged as an effective and trending technology in the field of nanohybrids. For the purposes of the current research, NHs were fabricated, characterized and examined for electrical conductivity (σDC) in a wide range of physical conditions. Development and stability of NHs was confirmed by UV spectroscopy. Surface morphology of NHs was ascertained through scanning electron microscopy. The effect of temperature on σDC of NHs was evaluated over the range of 25^0C to 115 (±2^{o}C). I-V characteristics of all the specimens were recorded in the voltage range of 5 to 45 V at RT.

Keywords: FA, BF, DC conductivity, SEM, NHs.

INTRODUCTION

FA is a byproduct of coal combustion in thermal power plants, and black ferrite (BF) is a type of ceramic material composed of iron oxide (Fe_2O_3) and other metal oxides [5]. The chemical composition of the FA particles consists of Al_2O_3 (24.80%), SiO_2 (50.50%), Fe_2O_3 (12.68%), MgO (1.61%), CaO (1.02%), SO_3 (1.02%) and other elements (10.21%), as reported by different sources [4]. Combining FA with BF creates a composite material that can have several useful properties depending on the intended application. Because of its dominant-negative surface charge, FA is a promising adsorbent. Numerous uses for wastewater treatment have been documented [12]. The combination of FA and BF can be utilized to develop magnetic composites with potential applications in various fields, such as electronics, energy storage, and environmental remediation [10].

BF is known for its magnetic properties, making it suitable for applications in magnetic data storage, magnetic sensors, and electromagnetic devices. The most thermodynamically stable iron oxide phase in the family is hematite (Fe_2O_3), and it has a number of benefits, including natural availability, biocompatibility, and low cost [11].

By incorporating FA into the BF matrix, it is possible to create magnetic composites with tailored properties. The combination of FA and BF can result in materials with enhanced electromagnetic interference shielding properties. Such composites can be used to protect electronic devices and sensitive equipment from unwanted electromagnetic radiation [13].

Composite materials of FA and BF might exhibit catalytic properties, enabling them to accelerate certain chemical reactions [14]. This could find applications in environmental cleanup and industrial processes. Depending on the composite's mechanical properties, it may have applications in structural engineering and construction [8]. The FA could provide a lightweight filler or reinforcement within the BF matrix. It's important to note that the properties of the composite heavily depend on the specific composition, manufacturing process, and ratio of FA to BF. Extensive research and experimentation would be required to optimize the material for specific applications [16].

According to a global survey, around 780 MT of FA are generated annually worldwide, of which 226.13 are produced domestically. The type of coal, burning circumstances, combustion rate, and cooling control all affect the composition of FA produced from various resources [17]. FA can be used as a filler for high-performance PCs because of its high bulk density, porosity, particle size, and surface area. Due to their improved electrical, mechanical, thermal, and electrochemical properties, FAs have been incorporated as reinforcement in BF-based polymers over the years [1].

The addition of BF to FA can significantly affect its electrical conductivity. FA is typically a non-

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conductive material, as it mainly consists of silicon dioxide (SiO_2) and other non-metallic components [7]. On the other hand, BF is a ceramic material composed of iron oxide (Fe_2O_3) and other metal oxides and is known to be a semi-conductor or insulator depending on its composition and doping. When BF is added to FA, it can introduce certain changes to the electrical properties of the composite material. Depending on the concentration and type of BF used, the addition of BF to FA can increase the electrical conductivity of the NHs [2]. BF particles may act as conductive pathways within the non-conductive FA matrix, allowing for the movement of electrons. In this case, the electrical conductivity of the composite material would lie between that of a conductor and an insulator. The conductivity can be modulated by adjusting the BF content [3]. In some cases, the addition of BF may not significantly alter the electrical conductivity of FA, especially if the BF content is relatively low, or if the specific type of BF used is more insulating in nature. The conductivity of NHs may also be temperature-dependent, as both BF and FA can show variations in their electrical properties with temperature changes. The specific electrical behavior of the NHs will depend on factors like the percentage of BF in the mixture, the type of BF used (e.g., magnetite, hematite, etc.), the distribution and size of the BF particles within the FA matrix, and any additional processing or treatment applied during composite fabrication. These variations in electrical conductivity can have practical applications [4]. For example, if a certain level of electrical conductivity is desired in a composite material for specific electronic or electromagnetic applications, the proper selection and incorporation of BF can help achieve that objective.

It's worth noting that experimental research and testing would be necessary to determine the exact electrical conductivity characteristics of a specific FA composite with BF, as there can be a wide range of possible outcomes based on the mentioned factors. Incorporating BF into FA can lead to magnetic composites suitable for applications in data storage, magnetic sensors, or electromagnetic devices. Additionally, the combination may also offer benefits in terms of waste management, environmental remediation, and structural engineering [6].

EXPERIMENTAL

Materials

FA was collected from pulp and paper industry situated nearby area of the University. FA was finely ground into 0.80 mm mesh size, stored at 50 ± 1^0C and used for preparation of NHs. All the chemicals and solvents (purity >99.55) were locally arranged and used without further purification. Commercially available ferrite was procured from Research-Lab Fine Chem Industries, Mumbai, India. The moisture content of FA was deduced according to a procedure reported earlier [9]. The disk-shaped specimens (diameter 1 cm) of FA, ferrites and NHs for electrical conductivity measurements were fabricated in 2.20±0.01 mm thickness through mixing a series of compositions of ferrite with FA under hydraulic press at 100 kg/cm^2 for 5 minutes.

Characterization

Scanning electron microscopy (SEM) measurements were performed on a JSM 6610 (LV) at 0.2 KX (1 mm) and 15 kV. UV-vis absorbance experiments were carried out at room temperature with UV-vis Specord-200 using quartz cuvettes. The energy band gap of specimens was estimated from Tauc plot. Electrical conductivity measurements were performed on a Keithley nanovoltmeter (2182A) equipped with current source (6221) and a temperature-controlled four-probe arrangement. The activation energy (Ea) was deduced through Arrhenius equation: $\sigma = \sigma_o exp(-Ea/kT)$, where σ is electrical conductivity of the specimen at temperature (T, K), σ_o is pre-exponential factor, and k is Boltzmann constant.

RESULTS AND DISCUSSION

Electrical behavior of FA, BF and NHs

Electrical conductivity of FA, BF and NHs containing pellets was examined at different experimental conditions to estimate the working performance and durability of developed NHs.

Electrical conductivity at variable voltages

In order to ascertain the relative electrical behavior of FA, BF and NHS their σDC (mS/cm) were examined in the voltages ranging 1 to 100 V at 25±1°C (Fig. 1). Results indicate that at 1 V and 10 V for all pellets, σDC values were comparatively low. Maximum σDC were obtained at 100 V with maximum value of 1.03 for BF-derived pellets. The conductivity response of BF was found to be higher over FA and NHs at all voltages.

Effect of temperature

In order to determine the relative electrical behavior of FA, BF and NHs, their σDC (mS/cm) were examined at variable temperatures ranging from 25 to 115°C (Fig. 2). Plot of FA, BF and NHs-derived pellets shows a linear increase in σDC with temperature. Ea was also calculated for BF, FA and

NHs and it was found to be 7.08 $Jmol^{-1}$, 0.61 $Jmol^{-1}$ and 2.24 $Jmol^{-1}$ for BF, FA and NHs, respectively.

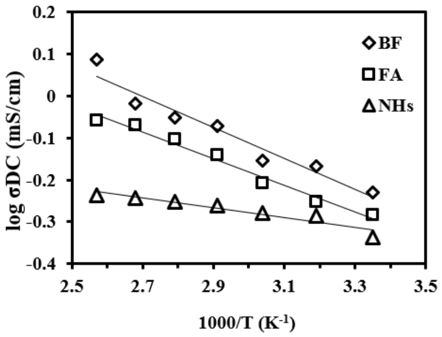

Fig. 1. Effect of voltage variation on σDC

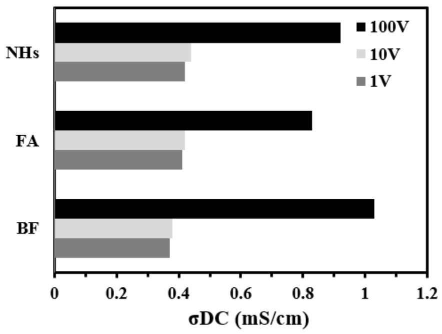

Fig. 2. Effect of temperature on σDC

I-V characteristics of FA, BF and NHs

I-V characteristics of pellets were recorded in the voltage range of 5 to 45 V at RT. Electrical characteristics examinations reflect those conductivities of BF-derived pellets was higher over FA and NHs-based pellets. Fig. 3 demonstrates the I-V plot of FA, BF and NHs derived showing a linear increase in current with voltage at room temperature that implies Ohmic conductive behavior of pellets.

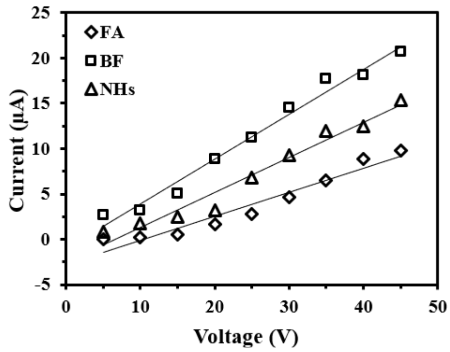

Fig. 3. I-V characteristics of FA, BF and NHs

Moisture content analysis of FA

Percent moisture content of FA was analyzed by loss on drying method and average moisture content was found to be 0.0175% [18].

Surface morphology of FA, BF and NHs

In order to have comparable results FA and NHs were imaged at a common scale of 1 mm and 25 kx. FA is primarily composed of compact or hollow spheres with a consistent smooth texture, as shown in the figure. The presence of solid deposits or small crystals, such as soluble alkaline sulfates, iron mineral dendrites, mullite crystals, etc., could frequently be seen on the surface of spheres. Small spherical particles with some agglomerated particles in the FA pores can be seen. Additionally, some quartz flakes, unburned coal residue, or even vitreous unformed pieces could be noticeable. It was determined that the ferrosphere in the figure is of the dendritic type. High levels of iron oxide are seen in the ferrosphere, and this type of particle structure rarely occurs in FA. The images show that the development of NHs is significantly influenced by the ferrosphere [20]. In the case of NHs, no such agglomerated particles are observed, a smooth surface indicating that ferrite is completely distributed into the pores of FA, leading to formation of more stable NHs.

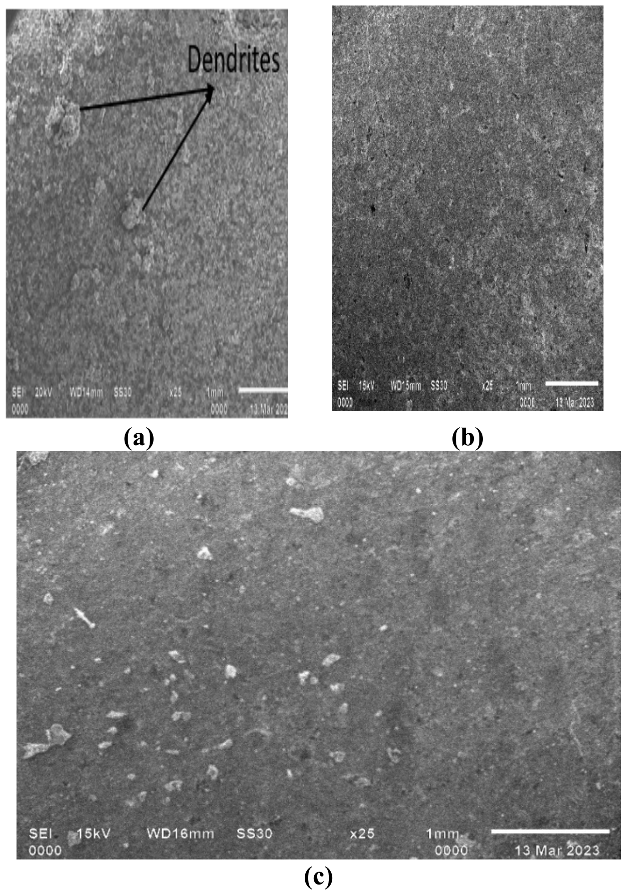

Fig. 4. SEM images of a) FA b) NHs (c) BF

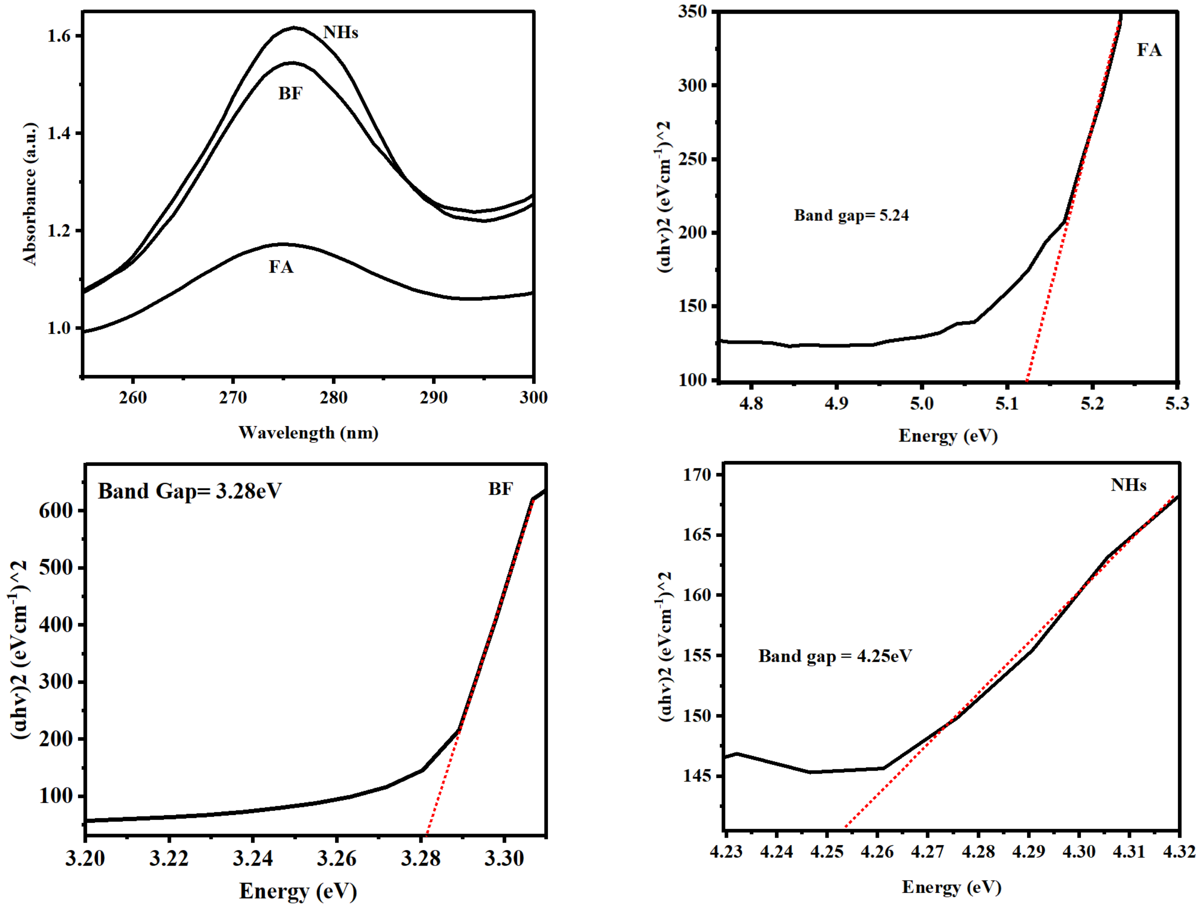

Fig. 5. UV-Vis spectra of a) FA, BF and NHs; b) band gap energy graph of FA; c) band gap energy graph of BF; d) band gap energy graph of NHs.

Optical spectroscopy

The absorption spectra of FA, BF and NHs are shown in Fig. 5. In our present study FA exhibited a maximum absorption spectral peak at 274 nm and most of the peaks were observed in the region of 270 nm-280 nm but were absent in the region of 600-900 nm. In the case of BF the maximum absorption peak is observed at 275 nm which is in close resemblance with the maximum absorption peak of NHs at 276 nm. Band gap energy was also calculated with the help of Tauc plot for FA, BF and NHs (Table 1) [19].

Table 1. Band gap energy for FA, BF and NHs

Samples	Band gap energy (eV)	λ_{max} (nm)
FA	5.24	274
BF	3.28	275
NHs	4.25	276

CONCLUSION

Pellets of FA, BF and NHs were fabricated using a hydraulic press. Surface morphology of FA and NHs was investigated by FESEM analysis revealing that BF-based pellets showed maximum σDC (mS/cm) of 1.03±0.20 at 100 V and ambient temperature. I-V plot of FA, BF and NHs-derived pellets shows a linear increase in current with voltage at room temperature that implies Ohmic conductive behavior of the pellets, The moisture content was also evaluated for FA and it was found to be 0.0175%. The band gap energy obtained from UV reflectance spectra analysis was 5.24, 3.28, and 4.25 eV for FA, BF and NHs, respectively. Synergic compatibility of FA with BF plays an important role in electron channeling that results in optimization of conductivity over time in harsh environments that make NHs an interesting choice of electrically conducting material to use in microelectronics, microwave absorption and batteries.

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