

Research Article

Study on the Properties of Epoxy Composites Using Fly Ash as an Additive in the Presence of Nanoclay: Mechanical Properties, Flame Retardants, and Dielectric Properties

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Received 3 September 2020; Revised 23 November 2020; Accepted 28 November 2020; Published 8 December 2020

Academic Editor: Marinos Pitsikalis

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Small and light fly ash is a by-product of thermal power plants, in which oxides mainly present in fly ash are suitable to reinforce composite materials. Its content accounts for 10, 20, 30, 40, and 50% of those materials. However, due to the smooth surface, it cannot stick completely in plastics. Therefore, in this work, it was studied to combine nanoclay additive (I.30 E) with 1, 3, and 5% by weight to synergize to improve mechanical strength, fire retardation, and electrical properties. Mechanical properties and flame retardant properties have improved markedly. At the combined ratio of 40% by weight of fly ash and 3% nanoclay, nanocomposites have tensile strength values of 64.12 MPa, flexural strength of 89.27 MPa, compressive strength of 215.23 MPa, and impact resistance of Izod 14.45 kJ/m², oxygen index limited to 26.8% of fire retardant material. In terms of dielectric strength, the electric strength of pure epoxy is 17.5 kV/mm, higher than that before adding nanoclay (12.7 kV/mm). The presence of nanoclays in the material creates a tortuous electric path, slowing the propagation of the power plant, which is the main factor that improves the breaking strength of the nanocomposite.

1. Introduction

The amounts of fly ash releasing from thermal power plants are increasing and affects both the economy and environment. Therefore, they are recommended to use in different fields such as chemistry, agriculture, concrete, construction, and polymer industry. Using fly ash in producing polymer products can improve their mechanical features such as tensile and impact strength [1]. In addition, epoxy is the top insulating material used in electric power and electronic industries [2]. Thus, combining these materials in manufacturing composite products is a way of reusing sewage and reducing cost in treatments [3]. In addition to epoxy resins, some constructions have also used fly ash as reinforcement for composites on different plastic substrates such as: polyethylene and nylon 6 [4–6]. Furthermore, they are essentials in insulating systems and electrical equipments such as cast resin dry transformers, generators, and breaker

switches [4–6]. In process, not only electricity influences on those machines but also temperature and mechanics, so it is needed to prevent them from fire and explosion [7, 8].

The use of fly ash and nanoclay in creating nanopolymer has been well known recently [9, 10]. If the amount of fly ash added in production accounts for 40% of total ingredients, mechanical strengths, as well as dielectric one such as bulk and surface resistivities, decrease slightly. Some works have found ways to modify the surface of fly ash to improve compatibility with base materials to increase mechanical and dielectric properties and flame retardant properties [11]. In addition, other works show that the study at the levels of 5, 10, and 20 parts of fly ash denatured by inorganic and organic substances brings a significant improvement in mechanical properties and fire retardant. Moreover, this method attracts lots of people because of low cost, high heat resistance, and being ecofriendly [12, 13].

This research is about the effect of adding commercial nanoclays in combination with fly ash to improve

mechanical properties, flame retardant properties, and dielectric properties. Scanning electron microscopes are used to investigate the structural morphology of materials, compatibility, and low wetness, as well as nanoclay dispersion capabilities in combination with the XRD method.

2. Materials and Methods

2.1. Materials. The epoxy Epikote 240 (EP240) was provided by Shell Chemicals (USA). EP240 is a low-viscosity, based on a blend of bisphenol A resin and bisphenol B resin, contented epoxy group of 24.6%, molecular weight (Mw) of 5100–5400 mmol/kg, density of 1.12 g/ml, and viscosity at 25°C of 0.7–1.1 Pa s. Diethylenetriamine (DETA) received from Dow Chemical (USA) has a density of 0.95 g/ml, boiling point of 207°C, and Mw of 103 mmol/kg and used directly without any further purification. Nanoclay I.30 E (Nanacor, USA) is a surface-changing montmorillonite (MMT) mineral that will disperse into nanoparticles in epoxy resin systems. Dispersion creates a mixture close to the molecule often called nanocomposite. This new composite model shows enhanced strength, heat, and barrier properties. I.30 E is provided in the form of a white powder dispersed into thin particles that are almost transparent in the plastic matrix. Fly ash taken from the ash waste of the Pha Lai Power Station was collected in Song Da Joint Stock Company 12, Cao Cuong, Vietnam. Before investigation, fly ash was washed by acetone to remove impurities.

2.2. Methods

2.2.1. Sample Preparation. The fly ash was prepared according to Table 1. Fly ash (20, 30 and 40 wt%) and nanoclay I.30 E (1, 3 and 5 wt%) were dispersed in epoxy Epikote 240 resin and stirred at 3000 rpm for 8 h (HS-100T, WiseStir, Korea). In order to break up the nanoclay bundles and disperse the additives, it was sonicated using an ultrasonic bath (Elmasonic S300 H, 37 kHz, Germany) for 6 h, 65°C. After the mixtures were homogeneously mixed, the curing agent DETA (amount of curing agent was calculated by epoxy content of epoxy resin, stirred for 15 min at 200 rpm/min) was added and the mixtures were moulded for curing. The mould was coated with a uniform thin film of silicone, a releasing agent for easy removal of cured specimen. The samples were cured at room temperature for about 24 h and further cured at 80°C in the laboratory oven for 3 h. Then, the samples were removed from the mould, and after 7 days, the mixture was analyzed and mechanical properties were measured. We followed the methods of Nguyen et al. [14].

2.2.2. Characterizations

- (i) Limiting Oxygen Index (LOI) according to ASTM D2863-12 and JIS K720 standard (Japan): the sample bars used for the test were $150 \times 6.5 \times 3 \text{ mm}^3$.

TABLE 1: Taguchi orthogonal array of designed experiments based on the coded levels.

Trial	Fly ash (wt. %)	Nanoclay content (wt. %)	Sample code
1	20	1	NP01
2	30	1	NP02
3	40	1	NP05
4	20	3	NP06
5	30	3	NP07
6	40	3	NP08
7	20	5	NP09
8	30	5	NP10
9	40	5	NP11

- (ii) The Horizontal Burning tests (UL-94HB): standard bar specimens are to be $125 \pm 5 \text{ mm}$ long by $13.0 \pm 0.5 \text{ mm}$ wide and provided in the minimum thickness and $3.0 (-0.0 + 0.2) \text{ mm}$ [15].
- (iii) Combustion resistance: the apparatus is specifically designed for combustion and incandescence resistance of thermoplastics, thermosetting, rigids, and laminates designed and built to meet the following standard: ASTM D 757; specimen's dimensions $3.17 \times 12.7 \times 121 \text{ mm}^3$ and maximum temperature 950°C.
- (iv) The combustion rate was measured by COMBUSTION RESISTANCE COD 6145000 according to the ASTM D757-77 standard. Specimen's dimensions: $3.17 \times 12.7 \times 121 \text{ mm}^3$.
- (v) Flexural strength was determined according to the ISO 178–1993 standard in INSTRON (USA) equipment with crosshead speed 2 mm/min, temperature 25°C, and humidity 75%. The specimen size according to the ISO is $100 \times 15 \times 4 \text{ mm}^3$.
- (vi) Compressive properties were determined by using three-point bending test specimens with dimensions of $15 \times 10 \times 10 \text{ mm}^3$ according to ISO 178–1993.
- (vii) Izod Impact Strength was determined according to the ASTM D265 standard in Tinius Olsen (USA). Specimen size: the standard specimen according to the ASTM is $64 \times 12.7 \times 3.2 \text{ mm}^3$ ($2\frac{1}{2} \times \frac{1}{2} \times 1\frac{1}{8}$ inch). Izod Sample Geometry: 2 mm.
- (viii) Tensile properties were determined by using three-point bending test specimens according to ISO 178. The specimen size according to the ISO is $10 \times 4 \times 80 \text{ mm}^3$.
- (ix) The morphology of the samples was carried out by using a scanning electron microscope (SEM, Evacseq error codes, S-4800, Japan). Structural characterizations were studied by X-ray diffraction (XRD, D8-Advance, Bruker, Germany).
- (x) Surface resistivity relies on humidity, temperature, and electric field strength. Mass resistivity and surface resistivity are measured under the ASTM D257-66 which uses three-electrode measuring system, Japanese direct current measuring

instruments-TR 8401 from TAKEDA brand, and DC voltage 1000 V.

- (xi) Electrical strength is the resistance of insulating materials when the applied voltage is not destroyed. It is featured by electric field strength at the puncture point (puncture intensity). It is identified under the ASTM D149-64 on the equipment of TL A70 No. 417 from Russia with alternating current, frequency of 50 Hz, and voltage rate of 1 kVS. The samples were measured at room temperature, humidity of 60%, and with thickness of 2 mm (See Figure 1).

3. Results and Discussion

3.1. Study on Mechanical, Fireproof, and Dielectric Properties of Composite Materials Based on Matrix Epikote 240 Epoxy Reinforced with Fly Ash

3.1.1. Mechanical Properties and Fire Retardant. To gain the best effect, the fly ash needs to be mixed with basic plastic in suitable ratios. Therefore, it is necessary to find how much fly ash is needed. A range of samples were produced with the changeable proportion in weight of fly ash, from 10 to 50%. The impact of this change on the mechanical properties of composites is shown in Table 2.

The tensile strength of the materials' peaks at 57.81 MPa, increases 3.41% when using 20% of the fly ash, and then, it tends to decline with higher proportion of the fly ash. The compressive strength tends to increase with every proportion and peaks at 198.81 MPa and increase 27.37% with 40% of the fly ash. However, the more the amount of the fly ash, the lower the impact strengths and tensile strengths.

In general, the introduction of fly ash into epoxy resin-based composite materials has improved some of the material's mechanical properties such as tensile strength, flexural strength, and compressive strength. In particular, the strength value increases when the fly ash content increases and reaches the maximum value at 40% of fly ash weight and higher than other published work such as that of Bachtrong et al. [1].

Table 3 shows that the fire retardant features of the materials are significantly improved. The fabricated materials are good and stable, especially when the percentage of the fly ash is 40%, the minimum oxygen is 24.6%, the fire rate is 18.19 mm/min tested under the UL 94 HB method, and the flame retardant velocity is 20.12. Moreover, these materials meet the standards of fire retardant products with 40% used fly ash.

Fly ash is fire retardant and ecofriendly for the polymer epoxy production process taking place physically. The fly ash escapes on the surface of the material, making the ash layer even more heat stable and increasing the ability to prevent thermal contact (physical fireproof mechanism in solid phase), and the ash layer prevents gas release.

3.1.2. Electrical Properties. The results in Table 4 show that the resistivity of epoxy/fly ash composite materials is about 1013 (Ω cm), and when there is fly ash, the resistivity value of

the material decreases compared to the blank sample. However, great value is still achieved within the permissible limits for use as an insulating material (106–1015 Ω cm). The result of Table 3 also shows that, at the content of 20 parts of fly ash, the surface resistivity of the material increases, but when the fly ash continues to be added, the resistivity value now tends to decrease until constant at a mass fraction of 50 parts. But most composites achieve values above 1012 (Ω cm), which is suitable for insulating materials.

In this work, all the mixed composites were measured at room temperature, humidity of 60%, an alternating voltage of 100 V, frequency of 50 Hz, and with thickness of 2 mm to examine their electric strength. From Table 3, it can be seen that the electrical strength value of composite materials decreases as the amount of fly ash is higher and is lower than that of epoxy materials matrix. The fly ashes on the surface of the materials are hygroscopic, so they can make the breakdown voltage of the materials decrease if they are added more.

The dielectric strength measurement (disruptive voltage test) was performed, and the results can be seen in Table 4 where the dielectric strength of epoxy resin is lower than that of epoxy with fly ash. The electrical properties, as well as dielectric strength, of the materials in which fly ashes are added in production are down when giving extra fly ash due to the influence of the oxide elements and polar groups in fly ashes. However, the dielectric strength is still at a stable level.

3.1.3. Structural Morphology of Composite Material Based on Matrix Epikote 240 Epoxy Reinforced with Fly Ash. From Figure 2, it is found that the fly ash particles are fairly evenly dispersed and well moistened, no holes appear, they adhere well to epoxy, and the broken surface of the material is smooth. Hence, the fire retardant features of those materials are improved, and the mechanical strength is still stable at the high level. These results are matched with the results of determining the mechanical properties and fire retardation stated above.

In this study, the size of fly ash particles is small, ranging from 10 μ m to 35 μ m, compared to that in the work of Sim et al. As Sim et al. concluded, the smaller the fly ash particle size is, the more improved the mechanical properties will be [8].

3.2. Study on the Effect of Nanoclay Content (I.30 E) on Mechanical Properties, Ability of Fire Retardant, and Electrical Properties of Epoxy Nanocomposite Materials

3.2.1. Mechanical Properties and Fire Retardant

Investigation of the morphological structure and X-ray diffraction of epoxy nanocomposite materials

Nanoclay I.30 E (with 1, 3, and 5% mass) is dispersed into epoxy resin by the mechanical stirring method at 3000 rpm at 80°C for 8 hours and, then, through ultrasonic stirring for 60 minutes, with a value of 50% power and vibration ultrasonic at 65°C.

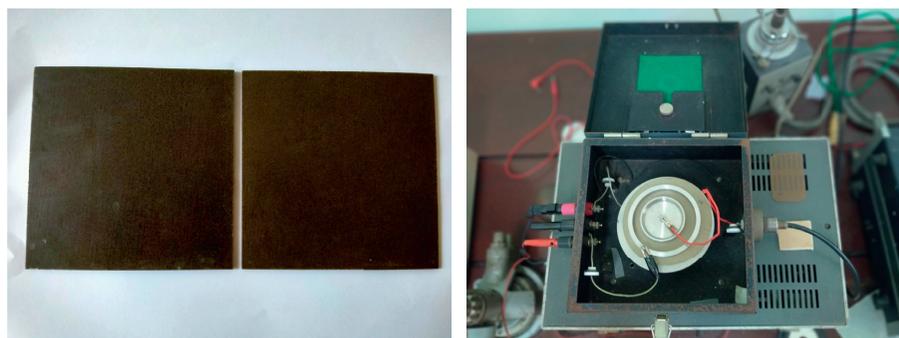


FIGURE 1: Specimen and puncture intensity measuring device.

TABLE 2: Effects of epoxidized linseed oil to mechanical strength of materials.

Fly ash (parts volume)	Tensile strength (MPa)	Flexural strength (MPa)	Compressive strength (MPa)	Impact strength (KJ/m) ²
Neat epoxy	55.90	86.75	156.08	7.11
10	47.79	87.35	169.27	7.02
20	57.81	86.67	175.39	6.96
30	40.39	83.25	179.67	6.17
40	36.64	79.89	198.81	6.05
50	34.92	78.55	191.78	5.79

TABLE 3: Results for flammability tests (reaction to small flame) oxygen index (OI) and UL 94 for nanocomposites.

Trial	Fly ash (parts volume)	LOI (vol% O ₂ ± 2σ)	Combustion rate (mm/min)	UL94 HB (mm/min)
1	Neat epoxy resin	20.6	28.41	Not rated (NR)
2	10	21.9	23.27	23.75 (HB)
3	20	22.1	22.05	22.08 (HB)
4	30	23.2	20.47	21.48 (HB)
5	40	24.6	18.19	20.12 (HB)
6	50	24.1	18.35	20.45 (HB)

TABLE 4: Dielectric properties, reliability strengths, and surface resistivity of epoxy and its composites.

Fly ash (parts volume)	Volume resistivity (Ω cm)	Surface resistivity (Ω)	Electric reliability (kV/mm)
0	45.4 × 10 ³	5.6 × 10 ²	12.7
10	23.8 × 10 ³	7.5 × 10 ²	13.8
20	19.7 × 10 ³	8.5 × 10 ²	13.2
30	15.5 × 10 ³	7.9 × 10 ²	13.8
40	7.5 × 10 ³	5.9 × 10 ²	13.1
50	6.9 × 10 ³	4.7 × 10 ²	12.8

X-ray diffraction diagram of nanocomposite epoxy/nanoclay materials is shown in Figure 3. Figure 3 shows the XRD diagram of nanoclay I30 E appearing at an angle $2\theta = 40^\circ$ corresponding to the basic distance $d = 22.128 \text{ \AA} = 2.2128 \text{ nm}$ which does not appear on that of nanocomposite samples with 1, 3, and 5% of nanoclay mass. It is demonstrated that the strong macromolecules of the epoxy inserted into the space between the nanoclay layers increased the distance d , resulting in the nanoclay structure being altered, particularly peeling.

Structural morphology of epoxy nanocomposite material

From Figure 4, it can be seen that the broken surface of the material becomes coarser than that of the epoxy resin (Figure 2(f)) with different nanoclay contents. Thus, the cracks which touch nanoclay layers can change their directions or may be interrupted. Therefore, the materials need more power to deform, and then, their mechanical strength can increase.

Many cracks are visible and tend to be bent with 3% nanoclay content. However, if the nanoclay content exceeds the threshold (4% by weight) leading to a decrease in compatibility with epoxy resin and the accumulation of nanoclay particles (Figure 4(c)), the excess nanoclay creates holes within the main material.

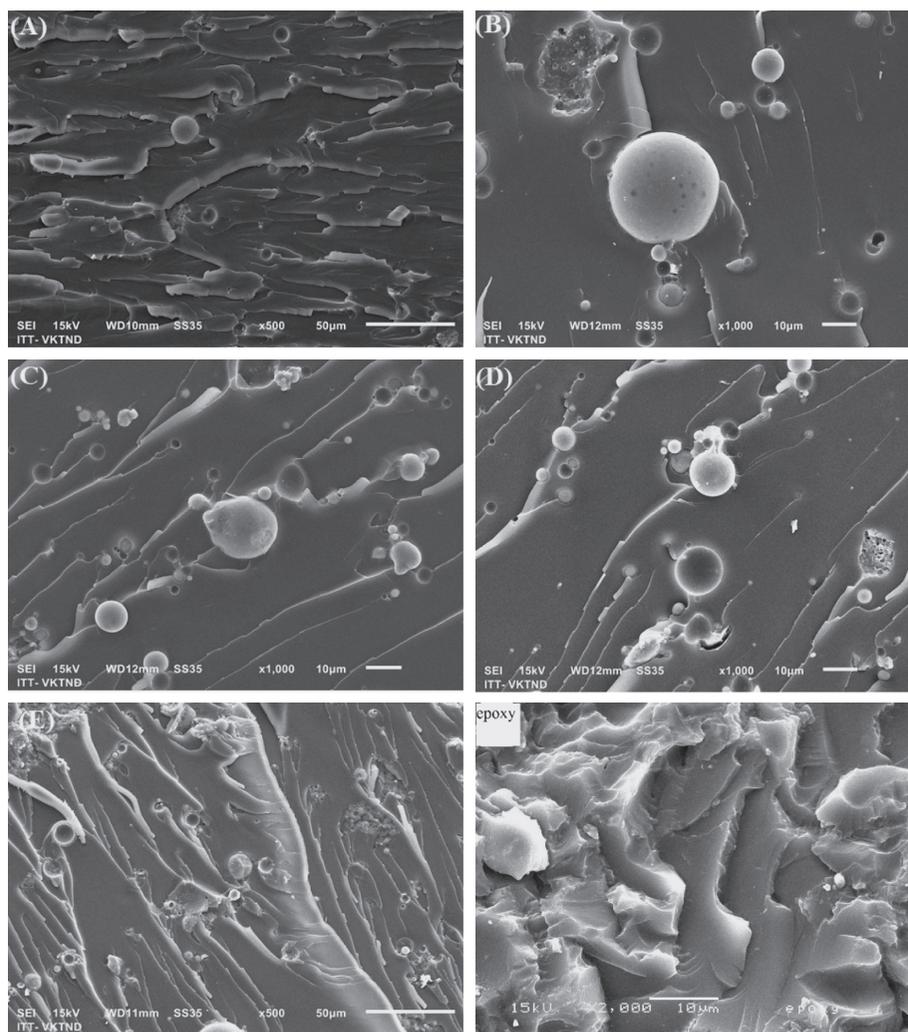


FIGURE 2: SEM images of epoxy/fly ash composites: (a) 10 phr FA, (b) 20 phr FA, (c) 30 phr FA, (d) 40 phr FA, (e) 50 phr FA, and (f) (epoxy) neat epoxy.

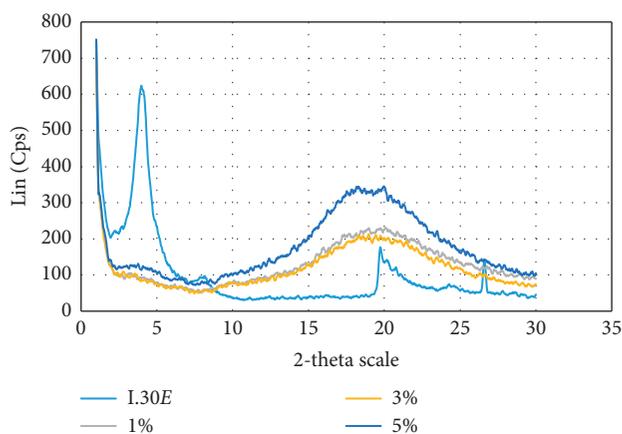


FIGURE 3: XRD diagram of materials I.30 E; nanocomposite: 1 wt.%, 3 wt%, and 5 wt.% nanoclay.

These factors are a reason for the reduction of mechanical strength compared to a 3% nanoclay mass sample. Thus, only 3% of nanoclay I.30 E is needed

compared to epoxy resin in nanocomposite materials, and nanostructures and the mechanical strength are significantly improved.

Mechanical properties

From Table 5, it can be seen that, at 3% of nanoclay mass, mechanical properties are significantly improved. In detail, tensile, flexural, compressive, and impact Izod strengths reach 61.37 MPa (increase 9.7%), 100.15 MPa (increase 15.44%), 170.78 MPa (increase 9.41%), and 14.79 KJ/m² (increase 79.88%), respectively.

From Figure 4, it can be seen that the roughness of the fractured surface increases and the cracks' paths change because of the presence of nanoclay in epoxy. Thus, the propagation of cracks is more difficult, avoiding stress concentration and, then, contributing to the reduction of cracks in epoxy resins. With a 3% nanoclay content, many cracks were visible and tended to be bent (Figure 4(b)).

However, when the nanoclay rate is added up to 5%, a range of nanoclay particles appear on the interface of nanoclay-epoxy (there exist residual nanoclay particles,

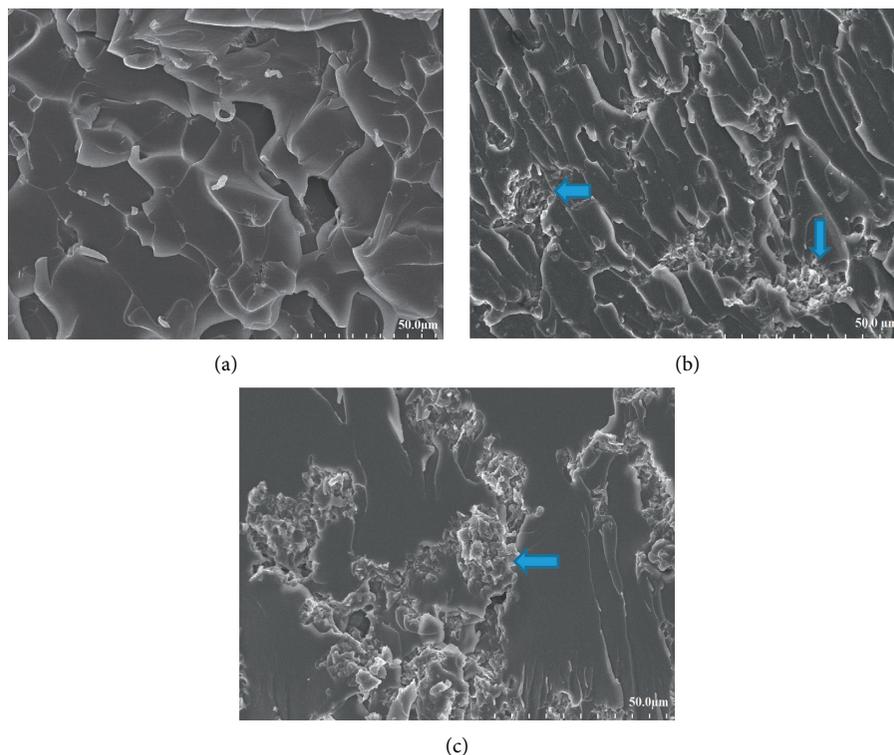


FIGURE 4: FE-SEM image of epoxy Epikote 240/nanoclay I.30 E nanocomposite materials: (a) 1% wt nanoclay, (b) 3% wt nanoclay, and (c) 5% wt nanoclay.

TABLE 5: Mechanical strength of nanocomposite epoxy Epikote 240/nanoclay I.30 E material with different nanoclay I.30 E contents.

Sample code	wt. % nanoclay I.30 E	Tensile strength (MPa)	Flexural strength (MPa)	Compressive strength (MPa)	Impact strength (kJ/m ²)
Neat epoxy	0	55.90	86.75	156.08	7.11
TA 1*	1	59.45	88.45	160.09	8.69
TA 3	3	61.37	100.15	170.78	12.79
TA 5	5	51.89	75.23	167.55	10.35

*TA 1: nanocomposite epoxy/nanoclay I.30 E material with nanoclay I.30 E 1 wt. %.

forming a separate phase that breaks down homogeneous the structure) and cracks are increased and will go to those weaknesses and result from stress concentration resulting in a decrease in mechanical properties. In nanocomposite samples with 1% nanoclay, the fractured surface hardly shows much nanoclay because of the small content.

From Table 6, the nanoclay dispersion in epoxy affects the fire resistance of nanocomposite materials. A barrier-like layer of nanoclay elements, which are heat-resistant and heat-retaining, slows down the diffusion of oxygen and prevents flammable volatiles and transferring heat from going in the materials, then reduces combustion sustain time. Thus, 3% of nanoclay mass is the ideal content for nanocomposite materials based on the epoxy resin matrix to balance mechanical strength and fire resistance. The results

of mechanical strength and fire retardation have shown that they are affected by the dispersion of the nanoclay in epoxy.

3.2.2. Electrical Properties. From Table 7, it can be seen that the more the amount of nanoclay added is, the more the value of the electric durability gets, from 15.2 to 17.5 Kv.mm⁻¹. The number at 3% of nanoclay content is at 17.5 kV mm⁻¹, which increases 38.4% compared to that in nonnanoclay materials. The nanoclay elements act as a barrier and also direct the current in meandering orbits that delays the conductivity [16].

From Table 7, it can be seen that the value of mass and surface resistivity of nanocomposite materials tends to increase when adding more nanoclay at different content. However, the dielectric properties tend to decrease with 5% of nanoclay. This is because of the heterogeneity that there are defects existing in

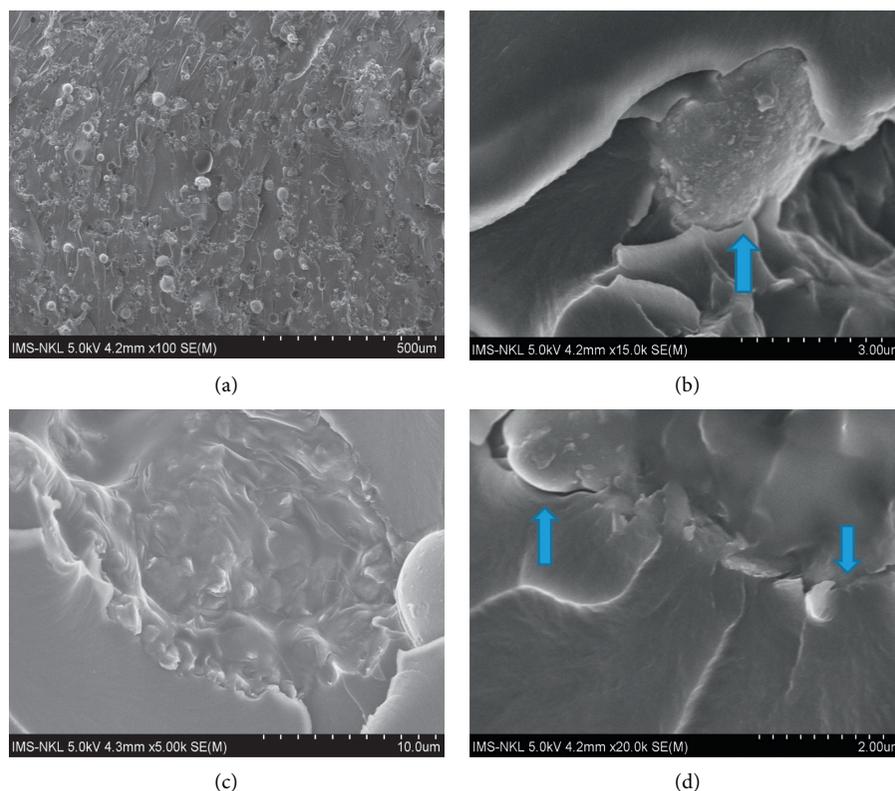


FIGURE 5: SEM image of the broken surface of the nanocomposite: 40 parts by weight of bat ash and 3% by weight of nanoclay.

TABLE 6: Results for flammability tests (reaction to small flame) oxygen index (OI) and UL 94 for nanocomposites.

Sample code	wt. % nanoclay I.30 E	LOI (vol% O ₂ ± 2σ)	Combustion rate (mm/min)	UL94 HB (mm/min)
Neat epoxy	0	20,6	28.41	—
TA 1	1	21.5	25.67	26.38
TA 3	3	23.7	21.75	21.40
TA 5	5	23.2	22.07	23.76

TABLE 7: Dielectric properties, reliability strengths, and surface resistivity of epoxy and its nanocomposites.

Fly ash (parts volume)	Volume resistivity (Ω. cm)	Surface resistivity (Ω)	Electric reliability (kV/mm)
0	45.4×101^3	5.6×101^2	12.7
1	45.0×101^3	9.5×101^2	15.2
3	46.3×101^3	12.5×101^2	17.5
5	50.5×101^3	10.2×101^2	15.8

the materials such as empty holes and bubbles or the agglomeration of nanoclay particles in the epoxy matrix [16].

From Table 7, it can be seen that the value of the dielectric strength plotted increases as the amount of fly ash in epoxy increases. Maximum dielectric strength is reached in 3% mass fraction nanoclay, with value $17.5 \text{ (kV mm}^{-1}\text{)}$. This result is higher than that published by Guevara-Morales and Taylor [10].

3.3. Study on Mechanical, Fireproof, and Dielectric Properties of Composite Materials Based on Matrix Epikote 240 Epoxy Reinforced with Fly Ash and Nanoclay

3.3.1. Mechanical Properties and Fire Retardant Properties. From Table 8, it can be seen that the mechanical strength of the samples has been improved and is the highest when the

TABLE 8: Optimum mechanical properties of epoxy/fly ash/nanoclay nanocomposites from fine-tuning experiments.

Trial	Sample code	Fly ash content (wt. %)	Nanoclay content (wt. %)	Tensile strength (MPa)	Flexural strength (MPa)	Compressive strength (MPa)	Impact strength (kJ/m ²)
1	Neat epoxy	0.00	0.00	55.90 ± 0.3	86.75 ± 0.3	156.08 ± 0.3	7.11 ± 0.3
2	NP01	20	1	54.15 ± 0.3	88.02 ± 0.2	175.00 ± 0.3	6.90 ± 0.3
3	NP02	30	1	52.05 ± 0.2	82.12 ± 0.3	173.25 ± 0.3	7.80 ± 0.3
4	NP05	40	1	51.45 ± 0.3	78.35 ± 0.3	178.05 ± 0.2	8.50 ± 0.3
5	NP06	20	3	60.23 ± 0.2	89.34 ± 0.2	189.81 ± 0.3	10.44 ± 0.3
6	NP07	30	3	59.45 ± 0.3	87.14 ± 0.2	201.02 ± 0.2	13.69 ± 0.3
7	NP08	40	3	64.12 ± 0.3	89.27 ± 0.2	215.23 ± 0.3	14.45 ± 0.3
8	NP09	20	5	58.35 ± 0.2	87.89 ± 0.3	197.76 ± 0.2	14.81 ± 0.3
9	NP10	30	5	57.19 ± 0.2	88.76 ± 0.3	203.28 ± 0.3	13.07 ± 0.3
10	NP11	40	5	60.64 ± 0.3	85.25 ± 0.2	209.81 ± 0.3	13.01 ± 0.2

TABLE 9: Results for flammability tests (reaction to small flame) oxygen index (OI) and UL 94 for fly ash/nanoclay/epoxy nanocomposites.

Trial	Material	Fly ash content (wt%)	Nanoclay content (wt%)	LOI (vol% O ₂ ± 2σ)	Combustion rate (mm/min)	UL94 HB (mm/min)
1	Neat epoxy	0.00	0.00	20.6 ± 0.3	28.41	Not rated (NR)
2	NP01	20	1	23.2 ± 0.3	24.39	20.87 (HB)
3	NP02	30	1	23.7 ± 0.3	22.37	19.07 (HB)
4	NP05	40	1	24.1 ± 0.4	22.45	18.34 (HB)
5	NP06	20	3	25.4 ± 0.3	19.15	17.44 (HB)
6	NP07	30	3	26.3 ± 0.3	17.08	15.07 (HB)
7	NP08	40	3	26.8 ± 0.3	15.79	14.01 (HB)
8	NP09	20	5	25.9 ± 0.3	16.35	16.77 (HB)
9	NP10	30	5	26.3 ± 0.4	16.07	16.09 (HB)
10	NP11	40	5	25.9 ± 0.3	20.56	18.23 (HB)

ratio in content of nanoclay and the fly ash is 3% and 40%, respectively.

The material achieves the best compatibility and the phase structure of the material so the mechanical properties remain high. Moreover, it remains high even with other ratios because the products are matched with the phase structure of the best ones. Hence, the mechanical properties of added nanoclay materials are higher than those of only added fly ash ones.

When nanoclay was added in epoxy, the mechanical strength changed significantly and it makes up for the negative effects by the fly ash.

From Table 9, it can be seen that the fire retardant rate was improved when having nanoclay, especially when the ratio in the content of nanoclay and the fly ash is 3% and 40%, respectively. The epoxy resins are easy to burn by oxidizing agents. When nanoclay is present, the burning will be delayed because nanoclay has formed a thin film covering the material.

Although thin, it is interwoven quite complicatedly by nanoclay. This makes it difficult for the oxidizing agents to penetrate and helps the material's fire resistance, especially when the protective coal layer is formed in nanoclay due to being dispersed evenly in epoxy.

Due to the material burns, the nanoclay forms layers of coal evenly and fairly on the surface of the material separated from the oxygen in the environment, thus preventing the development of the flame. An evenly spread layer of coal

(ash) kept the sample free of dripping and improved the flame resistance of epoxy. The combination of fire protection mechanisms has improved the fire resistance of the materials [14].

From Figures 5(b) and 5(c), it can be seen that the fly ash particles get on well with epoxy. Additionally, wet ability is very high so the interface surface between fly ash and resin does not have any cracks.

Under the effect of stress, cracks in epoxy material will appear in the most critical areas and cracks will grow, when fly ash is dispersed evenly with nanometer size in epoxy, cracks can be effectively prevented, and cracks change direction as they pass through the surface of the fly ash (Figure 5(d)); the arrow shows the developing crack is prevented by fly ash) but have difficulties to spread out. Thus, the combination of epoxy and the fly ash can prevent the materials from cracking.

From Figure 6, it can be seen that fly ash and nanoclay fairly dispersed in the epoxy resin matrix in good wet ability compatibility, especially at a mixing ratio of 40 percent fly ash and 3 percent nanoclay by weight. Evidence shows that, after the material is broken, the fly ash particles remain on the broken surface and the epoxy surrounds the particle (there is no gap around the grain). In it, the nanoclay is also distributed evenly and crept into the area of flame retardant additives (the position of the arrows), and there is no phenomenon of clustering and agglomeration, showing the good compatibility of the combination: nanoclay-fly ash-epoxy.

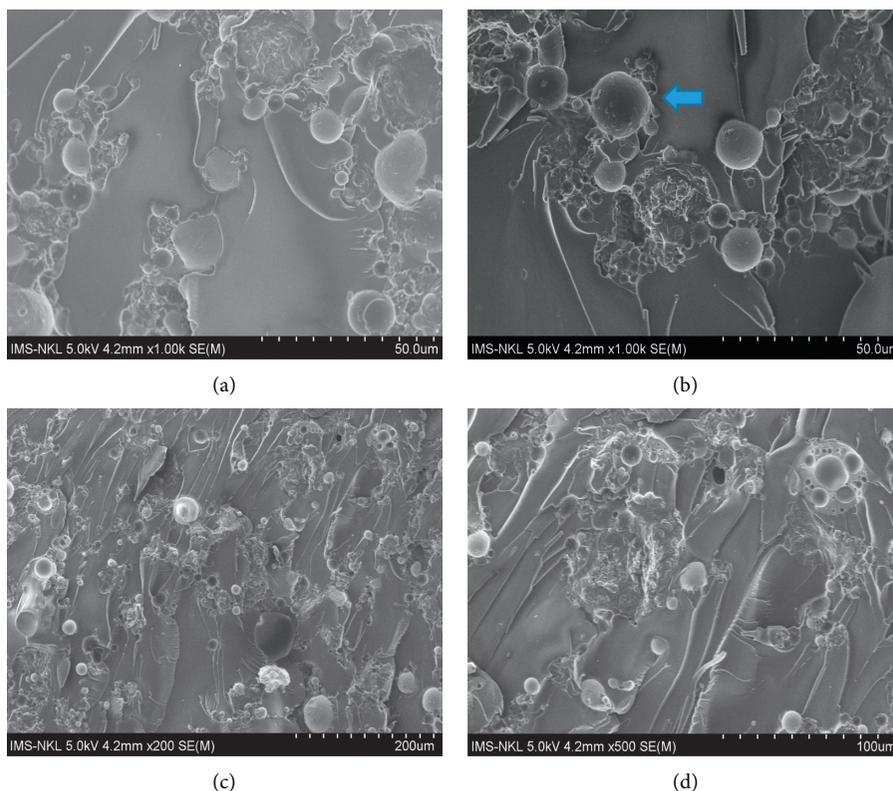


FIGURE 6: SEM image of the nanocomposite: (a) 20% fly ash, 3% nanoclay; (b) 30% fly ash, 3% nanoclay; (c) 40% fly ash, 3% nanoclay; and (d) 40% fly ash, 2% nanoclay.

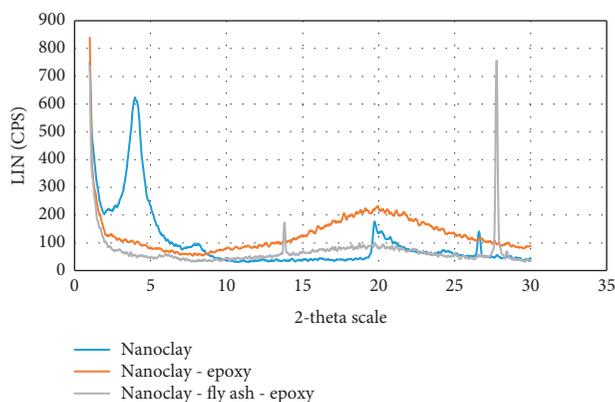


FIGURE 7: XRD of materials: nanoclay (I.30 E), epoxy/nanoclay, and epoxy/nanoclay/fly ash (NP08).

TABLE 10: Dielectric properties, and reliability strengths, and surface resistivity of epoxy nanocomposites.

No	Material	Fly ash content (wt%)	Nanoclay content (wt%)	Volume resistivity (Ω cm)	Surface resistivity (Ω)	Electric reliability (kV/mm)
1	Neat epoxy	0.00	0.00	45.4×101^3	5.6×101^2	12.7
2	NP01	20	1	44.3×101^3	7.6×101^2	13.5
3	NP02	30	1	45.7×101^3	10.4×101^2	13.1
4	NP05	40	1	44.8×101^3	9.8×101^2	13.8
5	NP06	20	3	46.5×101^3	6.6×101^2	14.8
6	NP07	30	3	46.9×101^3	9.0×101^2	15.7
7	NP08	40	3	47.1×101^3	11.7×101^2	16.8
8	NP09	20	5	48.5×101^3	10.1×101^2	15.2
9	NP10	30	5	45.1×101^3	5.5×101^2	14.5
10	NP11	40	5	44.2×101^3	9.2×101^2	14.2

From Figure 7, it can be seen that the nanoclay dispersed in epoxy. For materials having fly ash, some peaks are shown in the XRD diagram because the fly ash also includes other substances such as metal oxides Fe_2O_3 and Al_2O_3 .

3.3.2. Electrical Properties. From Table 10, it can be seen that the electrical properties of nanocomposite materials reduced due to the influence of the oxide components and polar groups in the fly ash. Moreover, the insulating feature of them reduces as the fly ash content is higher but still fits under standards of insulating material.

The nanocomposites which consist of nanoclay and the fly ash have improvements in insulation properties. Especially, a mixing ratio of 40 percent fly ash and 3 percent nanoclay by weight is the best choice for both mechanical strength, fire resistance, and electrical insulation of the material.

Fly ash and nanoclay fairly dispersed in the epoxy resin matrix in good wettability and compatibility. Evidence shows that, after the material is broken, the fly ash particles remain on the broken surface and the epoxy surrounds the particle (there is no gap around the grain). In it, the nanoclay is also distributed evenly and crept into the area of flame retardant additives (the position of the arrows), and there is no phenomenon of clustering and agglomeration, showing the good compatibility of the combination nanoclay-fly ash-epoxy.

From the research results, it was found that, when combining nanoadditives (nanoclay I.30 E) with fly ash at different rates, the electrical strength was kept at the prescribed level. At the rate of 3% by weight of nanoclay combined with 40% by weight of fly ash, the electric strength is higher than the other ratios (16.8 kV/mm). Meanwhile, epoxy resin-based composite nanomaterials with 2% by weight of nanoclay were studied by A. Guevara-Morales et al. [10] with an electrical strength of 14.7 kV/mm. In the case of only 40% by weight of fly ash, the electric strength is 14.4 kV/mm, as published by Bachtrong et al. [1]. Thus, the combination of fly ash and nanoclay additives is a synergy, when in the right ratio, and the electrical strength is enhanced to suit the fabrication of insulating materials. From electrical tests, it was found that the breakdown strength of all nanocomposite materials was higher of the epoxy matrix.

4. Conclusions

- (a) In conclusion, this work shows that using fly ash from thermal power plants in producing materials at different proportions, namely, 10%, 20%, 30%, 40%, and 50%, can decrease the mass resistivity, surface resistivity, and electrical strength due to the influence of the oxide components and polar groups in the fly ash. Moreover, the mechanical properties including tensile, flexural, and compressive one decline slightly. However, when nanoclay with the amount of 1, 3, and 5% by mass is added, the dielectric properties tend to increase and the mechanical properties are significantly improved.
- (b) In terms of the fire retardant properties, fly ash and nanoclay are potential flame retardant additives and ecofriendly which will be used in the future and substitute for halogenated flame retardant additives that have an adverse effect on humans and the environment. The material produced in this project has an oxygen index of, at least, 26.8% and a flame retardant velocity of 14.01 mm/min under the standard of flame retardant materials.
- (c) Electrical properties of nanocomposite materials samples such as mass resistivities, surface resistivities, and electrical strength are under the limits of insulating materials. Most of them reach the high value of 101.3 (W cm), and the electrical durability is from 13.1 to 16.8 (kV/mm) which is resistant in the electric field environment.
- (d) This is the foundation for epoxy composite-flyash-nanoclay applying in electrical engineering with qualified mechanical properties and fire retardancy.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The authors wish to thank the Faculty of Chemical Technology, Hanoi University of Industry, Vietnam, for funding this work.

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