Hindawi
Journal of Chemistry
Volume 2020, Article ID 6953594, 9 pages
https://doi.org/10.1155/2020/6953594

*Research Article*

# Nanometer Montmorillonite Modified Fly Ash Ecological Slope Protection Material and Its Preparation and Application

**Guochong Lou**[1,2] **Qinghui Zhong**[3] **and Jianguo Xie**[3]

[1]*School of Civil Engineering, Shijiazhuang Tiedao University, Shijiazhuang 050043, Hebei, China*
[2]*Key Laboratory Jointly Established by Ministry of Road and Railway Engineering, Shijiazhuang Tiedao University, Shijiazhuang 050043, Hebei, China*
[3]*Shanghai Tieyan Information Technology Consulting Research Institute, Shanghai 201499, China*

Correspondence should be addressed to Guochong Lou; lougc@stdu.edu.cn

Received 7 August 2020; Revised 17 September 2020; Accepted 27 September 2020; Published 14 October 2020

Academic Editor: Tifeng Jiao



In order to scientifically and reasonably evaluate and select the quality and effect of ecological slope protection construction project and the structural form of ecological slope protection, this paper mainly studies nanomontmorillonite modified fly ash ecological slope protection material and its preparation method and related applications. The nanomontmorillonite modified fly ash ecological slope protection material and its application in this paper are based on nanomontmorillonite modified fly ash as the basic carrier, and the pore structure is used to plant grass for slope protection to achieve the purpose of ecological slope protection. Firstly, the nanomontmorillonite modified fly ash ecological slope protection material was prepared through the selection of raw materials, the mix ratio design, and the reasonable selection of the preparation process, and the range analysis method was used to optimize the mix ratio of nanomontmorillonite modified fly ash. By reasonable selection of alkali-reducing measures, selection of slope protection vegetation, preparation of planting substrates, and research on phytobiology, through experimental analysis, we obtained nanomontmorillonite modified fly ash with high strength and good water permeability and alkalinity in the pores to meet the requirements of plant growth ecological slope protection materials. Finally, through engineering practice, we explored the construction method of nanomontmorillonite modified fly ash ecological slope protection material and obtained good ecological slope protection benefits. The experimental data show that, for dispersive soil, when the degree of compaction is 80%, the compressive modulus of the soil is 3.46 MPa; when the degree of compaction is 86%, the compressive modulus of the soil becomes 4.51 MPa, an increase of 46.57%. The experimental results show that the nanomontmorillonite modified fly ash ecological slope protection material can help the soil become more compact.

## 1. Introduction

The slope protection construction project is an important part of the urban reconstruction project, and the ecological slope protection technology has been widely used in recent years. Nanomontmorillonite is an aluminosilicate mineral. It has a multilayer porous three-dimensional structure, a large specific surface area, and a large cation exchange capacity. It has the unique advantage of assisting in ecological slope protection. Nanomontmorillonite modified fly ash ecological slope protection material is used for modification, and the nanolayer structure of montmorillonite is not damaged after modification. Ecological slope protection is an engineering protection measure that uses natural or artificial materials to construct a stable ecological slope. It not only satisfies the basic function of slope protection, but also effectively integrates the urban landscape, culture, and ecology. The slope protection ecosystem plays an important role in increasing biodiversity and has gradually become an ecologically ideal slope protection technology with broad prospects.

This study summarizes the main factors of the water purification effect of ecological slope protection materials through experiments and can play a specific guiding role in the selection of slope protection materials in ecological slope protection projects [1]. The study of ecological slope protection materials aims to realize the harmonious coexistence of human activities and nature. The inevitable requirement for the coordinated development of economic development and environmental protection is to repair the ecological problems caused by traditional slope protection, and the relationship between engineering construction and environmental damage. In addition, the research of ecological slope protection materials has contributed to the promotion and improvement of ecological slope protection technology suitable for China's national conditions and engineering practices [2].

At present, the research related to nanomontmorillonite modified fly ash is getting more and more in-depth. Alongi and Carosio conducted a research on a completely inorganic intumescent flame-retardant nanocoating composed of nanomontmorillonite nanosheets embedded in an ammonium polyphosphate matrix. The coating deposited from the diluted water-based suspension/solution through multistep adsorption uniformly covers each cotton fiber with an average thickness of less than 50 nm, and the addition amount is up to 5%. When the paint addition amount reached 5%, no fire was observed in the 35 $kW/m^2$ heat flux cone calorimetry test. However, the research data is not accurate enough [3]. In their research, Hong et al. synthesized subnanometer zero-valent copper (ZVC) using montmorillonite minerals as templates. The discrete distribution of surface charges on montmorillonite can effectively separate the formed ZVC particles and inhibit their aggregation. ZVC templated with montmorillonite (ZVCMMT) has excellent reactivity, and more than 90% of atrazine (15 $\mu$M) can be degraded within a few minutes. The hydroxyl group is confirmed to be a reactive substance, which is generated by ZVC activating oxygen. It also shows that the degradation process strongly depends on the hydration state of the synthesized ZVCMMT. Compared with freshly prepared ZVCMMT, freeze-dried ZVCMMT exhibits higher reactivity, which can be explained by the higher residual adsorption on the surface of freeze-dried ZVCMMT [4]. Xie et al. prepared nanomontmorillonite (MMT) plastic polymer electrolyte membrane by solution casting method. The organophilic modification of nanomontmorillonite is used as a channel for lithium ion transfer. By electrochemical impedance spectroscopy, the membrane composed of nano-OMMT electrolyte has a higher ionic conductivity of $1.67 \times 10^{-4}$ S $cm^{-1}$ and a transference number of 0.67. SEM is used to determine the morphology of the electrolyte cross section. Fourier transform infrared spectroscopy studies explain the reason why lithium ion nano-OMMT channels are beneficial. The LiO-Si interaction between lithium ions and OMMT nanoparticles provides guiding transmission of lithium ions, thereby promoting the transfer fluidity of lithium ions in the plastic polymer electrolyte [5]. He et al. used ammonium polyphosphate-montmorillonite nanocompound to retard epoxy resin and compared it with the physical mixture of ammonium polyphosphate and montmorillonite. The thermal decomposition of epoxy resin composites was studied by thermogravimetric analysis. Through limited oxygen index measurement, UL-94 test, and cone calorimeter test, the flame retardancy of epoxy resin composites was studied. Ammonium polyphosphate-montmorillonite nanocompounds show better flame retardancy (limiting oxygen index, UL-94, ignition time, peak heat release rate, etc.) than ammonium polyphosphate + montmorillonite mixture. The morphology of epoxy resin composite material was studied by scanning electron microscope. The rapid and effective formation of the carbon layer should be the main reason why the ammonium polyphosphate-montmorillonite nanocompound has better flame retardancy than the ammonium polyphosphate + montmorillonite mixture [6].

The main innovations of this paper include the following aspects: (1) This paper studies the engineering properties and modification mechanism of fly ash modified dispersive soil. Fly ash can effectively improve the dispersion characteristics of dispersive soils. Its mechanism of action is mainly through ion exchange and hardening reaction, reducing the dispersibility and compressibility of the soil, and improving the strength and impermeability of the soil. (2) The research in this paper found that PHBH can be used as a new type of environmentally friendly packaging material to prepare a polymer matrix for packaging films with a wide range of uses. Nanomontmorillonite has a natural nanoscale silicate layer, high aspect ratio, and interaction between polymer chains, which can improve the crystallization, mechanical properties, and barrier properties of PHBH.

## 2. Nanomontmorillonite Modified Fly Ash Ecological Slope Protection Material

*2.1. Modification Method of Fly Ash.* The porous structure of fly ash and its huge specific surface area provide a favorable foundation for the development and research of fly ash utilization, and it has received extensive attention from international researchers [7, 8]. However, due to insufficient physical and chemical properties of fly ash, its effect and scope of application are limited. In order to improve the added value and utilization rate of fly ash, modification methods of fly ash have been gradually developed. The commonly used correction methods are mainly divided into two categories: physical methods and chemical methods [9].

*2.1.1. Mechanical Mechanics Method.* The mechanical grinding method is a physical method. This method is mainly used for the further processing of fly ash, using mechanical methods such as crushing and crushing to refine the particle size and make it uniformly dispersed [10, 11]. The mechanical treatment method is used to destroy and separate part of the vitreous structure inside the fly ash, reduce the viscosity effect, expose the active materials of the fly ball such as $Al_2O_3$ and $2SiO_2$, increase the specific surface area, and improve the surface activity and physical properties of the fly ash, characteristics, adsorption performance, etc. According to the method of mechanical and physical changes of fly ash, the changes in the structure and characteristics of fly ash are limited, so there is little increase in activity [12, 13].

*2.1.2. High Temperature Treatment Method.* Under appropriate high temperature conditions, the moisture in the fly ash volatilizes and opens several closed pores at the same time to increase the porosity of the fly ash and increase the activity of the fly ash. However, the specific structure of fly ash will be destroyed even at high temperatures, and the specific characteristics of fly ash will also change [14]. Therefore, the high temperature treatment of fly ash has certain restrictions, and the temperature must be properly controlled.

*2.1.3. Acid-Base Modification Method.* Acid-base modification methods include acid modification method and alkali modification method. These two treatment methods are similar. The fly ash is put into an acid solution or an alkali solution, and the reaction is carried out under a certain time and reaction conditions. After washing and filtering processes, the changed fly ash is formed. Both acid solution and alkali solution will destroy the surface structure of fly ash, increase the porosity, and further decompose the active material of fly ash to expose it, thereby increasing the surface activity of fly ash [15, 16].

*2.1.4. Surface Modification Method.* The surface modification method of fly ash is usually caused by the interaction of modifier and fly ash particles. The mechanism of action of this method is divided into physical action and chemical action. The former is mainly composed of intermolecular forces, including deep coating and adsorption on the surface. The latter is mainly changed by chemical reaction or chemical adsorption [17]. Surface modification methods such as surface modification, transplantation, and polymerization have better modification effects on fly ash and are one of the commonly used methods in fly ash modification technology.

*2.2. Structure and Properties of Nanomontmorillonite.* Nano-MMT (nanomontmorillonite) is a low-priced, abundant clay mineral. Clay minerals are widely distributed in nature, especially on weathered crust and sedimentary rocks [18, 19]. Clay is a kind of hydrophilic silicate mineral with a layered structure. Its particles are very fine, and the particle size is generally less than $2\,\mu$m. Clay contains bentonite, kaolin, illite, ATPARIGHT, chlorite, etc. depending on the nature and origin.

Nanomontmorillonite is the main component of bentonite minerals. In addition to the main components of nanomontmorillonite, bentonite also contains a small amount of other clay minerals such as long quartz and mica crystal chips. Nanomontmorillonite has a fine layered structure showing various colors such as white, gray, light yellow, light red, purple, and black, and its color varies according to the origin and the inorganic and organic substances contained. The main chemical composition of nanomontmorillonite is $Al_2O_3$ $SiO_2H_2O$, and the theoretical percentage content of each composition is $SiO_2$: 62.7%, $Al_2O_3$: 26.3%, $H_2O$: 8% [20]. However, in fact, the composition of nanomontmorillonite is very complex, and its chemical composition varies greatly depending on the origin and characteristics. The molecular formula of the theoretical structure of nanomontmorillonite is usually considered as $Na_xAl_2[Si_4O_{10}(OH)_2nH_2O]$. This is a multilayer network structure composed of two layers of silicon-oxygen tetrahedron and an aluminum-oxygen octahedral layer sandwiched between each layer. The thickness is about 1 nm, the tetrahedron and the octahedron are connected by a common oxygen atom, and the length and width are both submicron. The multilayer network structure not only increases the specific surface area of montmorillonite to $700\,m^2/g$ and sometimes to $800\,m^2/g$, but also provides excellent barrier properties. There are multiple cations such as $Li^+$, $Na^+$, $Mg^{2+}$, $Ca^{2+}$, and $Fe^{2+}$ between the nano-MMT layers, and each layer has electronegativity, so the same amount of cations is adsorbed between the layers. Generally, the cation exchange content of nano-MMT is $100 \pm 50$ m mol/100 g. This is mainly due to the isomorphic replacement of nano-MMT crystals [21, 22]. The $Si^{4+}$ of the silicon-oxygen tetrahedron can be replaced by the high-valent cation $Al^{3+}$, and the $Al^{3+}$ of the aluminum-oxygen octahedron can be replaced by the low-valent cations $Li^+$, $Na^+$, $Mg^{2+}$, $Ca^{2+}$, $Fe^{2+}$, etc. Through this homomorphic replacement, negative charges will be generated between the crystalline layer structures. These negative charges must absorb cations of equal charge to maintain the balance of charges between layers. According to these effects, nano-MMT has the ability to adsorb cations and polar organics [23].

*2.3. Adsorption Isotherms.* The adsorption isotherm refers to the relationship curve between the concentration of solute molecules in the two phases when the adsorption process of solute molecules at the two-phase interface reaches equilibrium at a certain temperature. Through static experiments, the adsorption data of shale on ceramsite sites of nitrogen and phosphorus, zeolite, quartz sand, and volcanic rocks have been obtained [24, 25]. Next, using Freundlich and Langmuir's adsorption isotherm models, the adsorption process is analyzed and explained, and the adsorption capacity of nitrogen and phosphorus is compared and analyzed. In order to achieve slope protection and water purification effects, a matrix material suitable for slope protection is chosen.

*2.3.1. Freundlich Adsorption Isotherm*

$$q = kc^{(1/n)}. \tag{1}$$

In the formula, $k$ and $n$ are constants; $q$ represents the adsorption amount of the substrate at equilibrium, mg/g; and $c$ represents the concentration of the substrate in the solution at adsorption equilibrium, mg/L. By taking the logarithms on both sides of (1), the following formula can be obtained:

$$\lg q = \frac{1}{n}\lg c + \lg k. \tag{2}$$

Using $\lg q$ and $\lg c$ as a linear regression graph, a straight line can be obtained. The slope of the straight line is $1/n$ and the intercept is lg $k$. From this, the constants $n$ and $k$ can be obtained, and then the Freundlich adsorption equation can be derived.

*2.3.2. Langmuir Adsorption Isotherm*

$$q = \frac{k_1 c}{1 + k_2 c}, \tag{3}$$

$$k_1 = q_m * k_2. \tag{4}$$

In the formula, $q$ represents the maximum equilibrium adsorption capacity, mg/g; and $k_1$, $k_2$ are constants. Formula (5) can be obtained by taking the reciprocal of both sides of formula (3).

$$\frac{1}{q} = \frac{1}{k_1} * \frac{1}{c} * \frac{1}{q_m}. \tag{5}$$

Plot $1/c$ and $1/q$, and get a straight line after linear regression. The slope of the straight line is $1/k_1$ and the intercept is $1/q_m$. From this, $q_m$, $k_1$, and $k_2$ can be calculated, and the Langmuir adsorption isotherm equation can be obtained.

*2.4. Mechanism of Ecological Slope Protection*

(1) The mechanism structure diagram of ecological gradient protection plants is shown in Figure 1.

(2) Analyze the mechanism of ecological slope protection from the formula; the mechanical formula of slope stability is

$$k = \frac{Q}{F}. \tag{6}$$

Among them, $k$ is the slope stability coefficient; $Q$ is the anti-sliding force of the soil (rock) body of the slope, $N$; and $F$ is the sliding force of the side slope, and $N$ passes through the slope after the vegetation protection project to produce the anti-sliding force of the vegetation engineering slope. The stability mechanics formula is

$$K = \left(\frac{(Q + Q_z)}{F}\right). \tag{7}$$

Among them, $Q_z$ is the anti-sliding force of vegetation engineering, $N$. It can be seen from the above formula that the increased slope stability coefficient after vegetation slope protection is

$$K_s = \frac{Q_Z}{F}. \tag{8}$$

(3) Comparative analysis of traditional slope protection and ecological slope protection is carried out.

The traditional form of slope protection only pays attention to the stability of the slope protection structure and other engineering protection performances, and it does not consider the ecological performance of slope protection in terms of ecology, environment, and landscape [26, 27]. The slope protection, slope structure, and the stability of other engineering protection performances for protecting ecology have also been noted. The discovery of traditional artificial materials and technologies pays attention to improving traditional slope protection methods. At the same time, the ecological environment and biological requirements are more important in the design and construction process. The advantage of the traditional slope protection is its high civil protection ability, but its investment is relatively large and it is not important for environmental protection. In addition, it is very difficult to meet the specific requirements of the sustainable development strategy. The appearance is not beautiful enough, and if there is no vitality, it will be too dull. Slope protection is fully in line with the development trend of protecting the ecological environment, can effectively protect the surrounding environment, and has a high decorative value. Therefore, ecological slope protection is an improvement based on the expansion of the basic functions of slope protection. With the deepening of ecological and environmental protection concepts such as sponge cities and ecological towns, traditional slope protection needs to be converted into ecological slope protection technology. Ecological slope protection is a new stage in the development of slope protection engineering.

## 3. Preparation of Nanomontmorillonite Modified Fly Ash Ecological Slope Protection Material

*3.1. Preparation Materials.* Materials used in preparation are nanomontmorillonite, modified fly ash, matrix fly ash, MMT/SBS composite modified fly ash, PHBH, in which HH content is 11% and molecular weight is $6 * 10^5$, 3-aminopropyl triethoxy silicon, alkane (KH550), absolute ethanol, 95% ethanol, chloroform, and dichloromethane.

*3.2. Experimental Equipment.* Experimental equipment includes electric heating constant temperature blast drying oven, vacuum drying oven, rotary evaporator, electronic balance, magnetic stirrer, high precision digital display constant temperature heating table, constant temperature water bath, condenser tube 250 ml, pipette gun 0.1~2.5 $\mu$l, laboratory ultrapure water heater, scanning electron microscope, thermogravimetric analyzer, X-ray diffractometer, upright hot stage microscope, Fourier transform infrared spectrum analyzer, universal testing machine, air permeability tester, water vapor transmission rate tester, and high-shearing dispersion emulsifier.

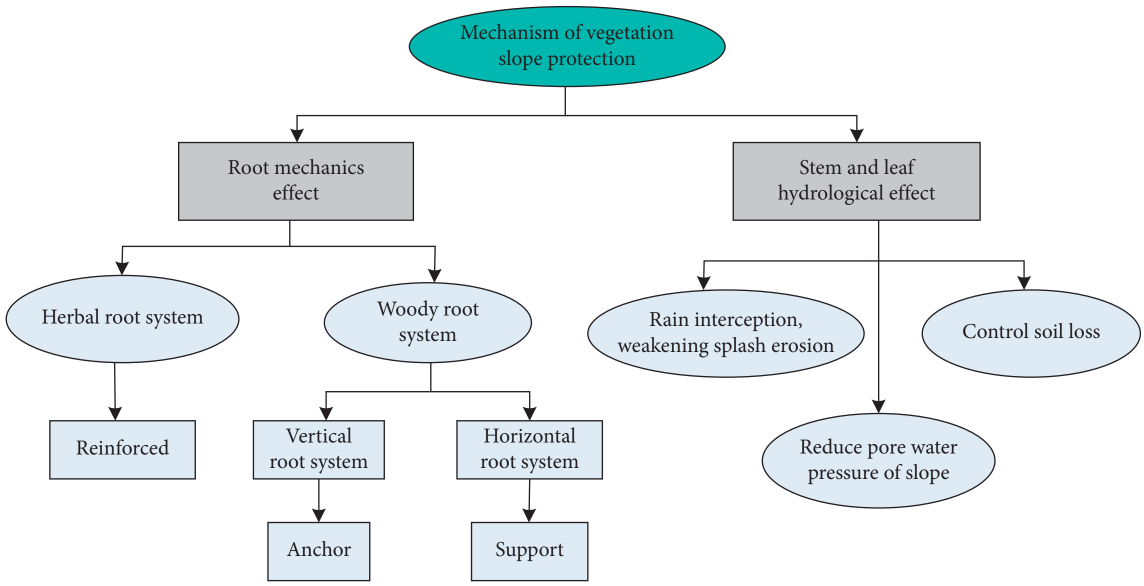


Figure 1: The mechanism structure diagram of ecological gradient protection of plants.

*3.3. Data Processing.* We used Microsoft Excel 2010 for data processing and graphing and SPSS 17.0 (Duncan test) for significant difference analysis.

*3.4. Preparation Steps of Nanomontmorillonite Modified Fly Ash Ecological Slope Protection Material.* The test method for preparing nanomontmorillonite modified fly ash adopts the melt blending method, including MMT modified fly ash and MMT/SBS composite modified fly ash. Heat the fly ash base ash to 160 degrees to make it in a molten state, with weigh of 800 g, and mix the weighed montmorillonite (8 g, 24 g, 40 g) with 800 g fly ash base ash in a mixer; the mixing process takes about 10 min. Subsequently, the high-shear dispersing emulsifier produced by our company was used to prepare MMT modified fly ash with three contents of 1%, 3%, and 5%. The shear speed is 5000 rad/min, the shear time is 1 h, and the shear temperature is 170°C. When preparing the modified fly ash of MMT/SBS composite material, the finished SBS modified fly ash is first heated to 170 degrees to make it in a molten state. Pay attention to mixing the fly ash evenly to reduce the influence of fly ash segregation. Weigh 800 g of SBS modified fly ash, and, after stirring evenly, mix the weighed montmorillonite (8 g, 24 g, 40 g) and 800 g of SBS modified fly ash using a mixer. The mixing process takes about 10 minutes, and then the high-shear dispersing emulsifier produced by our company is used to prepare MMT/SBS composite modified fly ash with three contents of 1%, 3%, and 5%. The preparation conditions are also a shear rate of 5000 rad/min, a shear time of 1 h, and a shear temperature of 170°C, which are consistent with the preparation conditions of MMT modified fly ash. The modification of two types of fly ash by MMT modifier can be compared.

## 4. Application Analysis of Nanomontmorillonite Modified Fly Ash Ecological Slope Protection Material

*4.1. Photocatalytic Performance of Nanomontmorillonite Modified Fly Ash Material under Visible Light.* In order to further explore the photocatalytic performance of the composite material, the degradation rate curve of methylene blue under visible light conditions is shown in Figure 2. It can be seen from Figure 2 that, under visible light, as the light time increases, the pollutants in the solution are gradually degraded. In the dark reaction stage, similar to the phenomenon mentioned earlier, the nanomontmorillonite modified fly ash adsorbs pollutants to the surface due to a large specific surface area, resulting in a decrease in absorbance.

Compared with nanomaterials, nanomontmorillonite materials have higher photocatalytic efficiency, which can reach about 92% within 160 min. In the process of sample preparation, the nanomontmorillonite material is mixed with nanomaterial elements to reduce the forbidden bandwidth, so that, under visible light, electrons in the valence band can still jump across the energy barrier to the conduction band, thereby exhibiting photocatalysis performance. Under visible light, the degradation rate of nanomontmorillonite modified fly ash with the same quality is lower than that of nanomontmorillonite material, which is only about 75% within 160 minutes. The possible reason is that the amount of nanomontmorillonite modified fly ash is

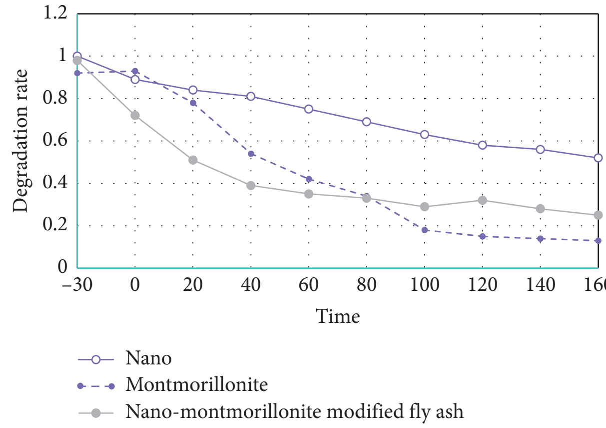


Figure 2: Degradation rate curve of methylene blue for composite materials under visible light.

less, resulting in the inability to provide enough active sites during the degradation process. Therefore, the mass of the composite nanomontmorillonite modified fly ash in the experiment was increased from 20 mg to 40 mg, so that the photocatalytic effects of different quality catalysts can be compared. The comparison results are shown in Figure 3. When the quality of nanomontmorillonite modified fly ash is doubled, its degradation rate of pollutants increases from 75% to about 93% within 160 minutes. This is due to the increase in the quality of the catalyst, which provides more supplies. The photocatalytic performance of the active sites of the reaction is significantly improved.

In the preparation process of the composite material, its loading rate is only 23.6%, which greatly saves the amount of photocatalyst and makes it possible to use high-value fly ash.

*4.2. Effect of Compaction on Soil Compression Characteristics.* Tables 1 and 2 present the test results of compressibility and compressibility of modified fly ash soil with different compaction degrees. Figures 4 and 5 show the relationship curves of the compressibility, compression modulus, and compaction degree of the modified soil with fly ash at different dosages at 0 d curing age.

It can be seen from Table 1 and Figure 4 that as the degree of compaction increases, the compressibility of the fly ash modified soil gradually decreases. For dispersibility, when the degree of compaction is 80%, the compressibility of the soil is 0.63 $MPa^{-1}$, and when the degree of compaction is 82%, the compressibility of the soil is reduced to 0.45 $MPa^{-1}$, which is reduced by 1%; when the degree of compaction is 84%, the compressibility of the soil decreases by 15.78%; when the degree of compaction is 86%, the compressibility of the soil is 0.36 $MPa^{-1}$. It can be seen that the compressibility of dispersive soils gradually decreases with increasing compaction. It can be seen in Table 1 and Figure 4 that when the dosage of fly ash is 2%, 4%, 6%, 8%, and 10%, the compressibility of the modified soil has a relatively similar change rule.

It can be seen from Table 2 and Figure 5 that the compressibility of the modified soil with different fly ash dosages is basically the same as the degree of compaction. The performance is as follows: under the same dosage of fly ash, with the increase of compaction degree, the compression modulus of the modified soil gradually increases, and the soil compressibility decreases. For dispersive soil, when the degree of compaction is 80%, the compressive modulus of the soil is 3.46 MPa; when the degree of compaction is 82%, the compressive modulus of the fly ash modified soil increases by 12.98%; when the degree of compaction is 84%, the compressive modulus of the soil increases to 3.80 MPa; when the degree of compaction is 86%, the compressive modulus of the soil becomes 4.51 MPa, an increase of 46.57%. It can be seen that as the degree of compaction increases, the compressive modulus of dispersive soil gradually increases. It can be seen from Table 2 and Figure 5 that when the dosage of fly ash is 2%, 4%, 6%, 8%, and 10%, the compressive modulus of the modified soil has a relatively similar change rule. Compression modulus reflects the ability of soil to resist deformation. Modified soil will produce different soil structures under different compaction degrees, which leads to the difference in soil deformation characteristics. At the same dosage, the greater the degree of compaction of the soil, the lower the internal porosity of the soil, and the lower the compressibility of the soil.

*4.3. Thermal Decomposition Performance Analysis.* The dispersion effect and intercalation effect of nanomontmorillonite in PHBH have a certain influence on thermal stability. The processing conditions and the nanomontmorillonite-polymer interaction are two important factors that affect intercalation and dispersion. Silane coupling agent KH550 not only has aminopropyl group combined with polymer, the silanol formed after hydrolysis can also react with hydroxyl on the surface of nanomontmorillonite to form hydrogen bond and condense into Si-OM (M stands for inorganic surface of powder particles) covalent bond. Therefore, the addition of the silane coupling agent helps to enhance the dispersion effect and intercalation effect of the nanomontmorillonite, thereby improving the thermal stability of the nanocomposite. The thermogravimetric analysis of PHBH/MMT and PHBH/MMT/KH550 shows that compared with PHBH/MMT

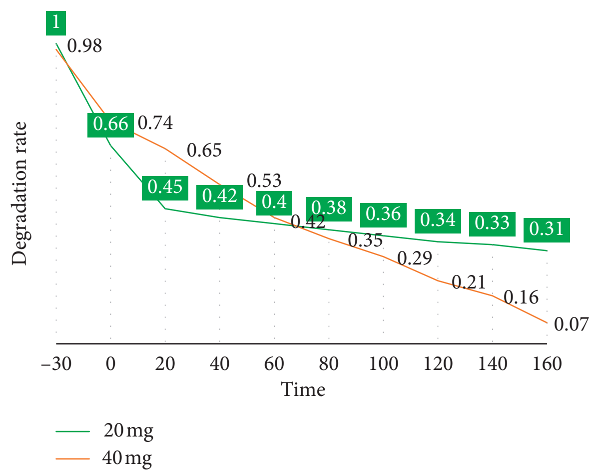


Figure 3: Degradation rate curve of methylene blue with different qualities of nanomontmorillonite modified fly ash under visible light.

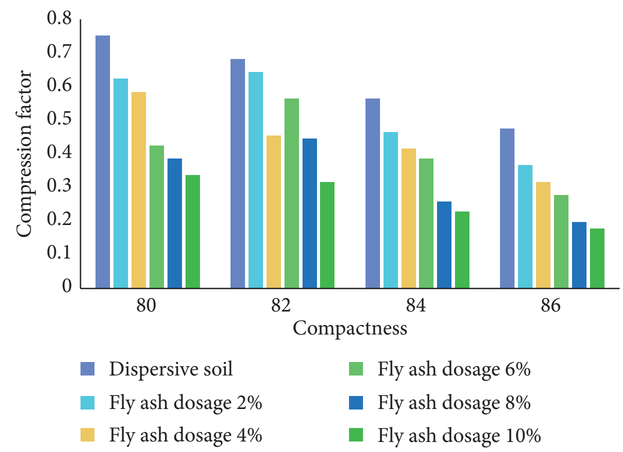


Figure 4: The relationship between compression factor and compaction.

Table 1: Compression coefficient ($MPa^{-1}$) of modified fly ash soil with different compaction degrees.

| Compactness (%) | Fly ash content (%) | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 2 | 4 | 6 | 8 | 10 |
| 80 | 0.76 | 0.63 | 0.59 | 0.43 | 0.39 | 0.34 |
| 82 | 0.69 | 0.65 | 0.46 | 0.57 | 0.45 | 0.32 |
| 84 | 0.57 | 0.47 | 0.42 | 0.39 | 0.26 | 0.23 |
| 86 | 0.48 | 0.37 | 0.32 | 0.28 | 0.20 | 0.18 |

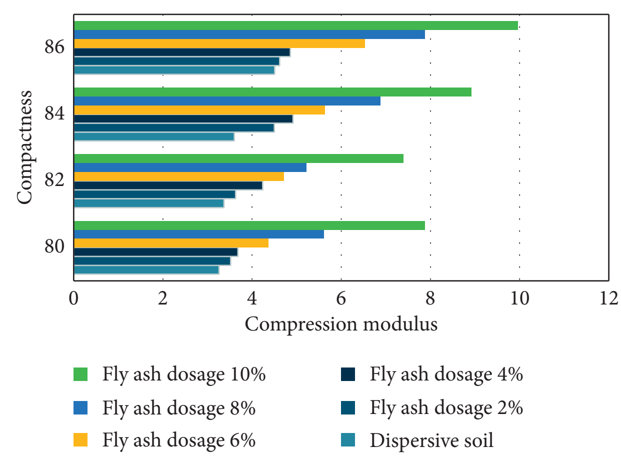


Figure 5: The relationship between compression modulus and compaction.

Table 2: Compressive modulus of fly ash modified soil with different compaction degrees (MPa).

| Compactness (%) | Fly ash content (%) | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 2 | 4 | 6 | 8 | 10 |
| 80 | 3.26 | 3.52 | 3.681 | 4.37 | 5.61 | 7.88 |
| 82 | 3.37 | 3.63 | 4.24 | 4.71 | 5.22 | 7.39 |
| 84 | 3.6 | 4.5 | 4.92 | 5.63 | 6.88 | 8.92 |
| 86 | 4.51 | 4.62 | 4.86 | 6.53 | 7.88 | 9.96 |

nanocomposite, after adding silane coupling agent KH550, the thermal decomposition temperature of PHBHMMT/KH550 nanocomposite increases, and the thermal stability improved. Table 3 shows the thermal weight loss data of PHBH/MMT/KH550 nanocomposites with different proportions of KH550.

According to data analysis, when the KH550 addition amount is 5 wt%, $T_5$ is the largest, and if the addition amount of KH550 continues to increase, $T_5$ decreases. According to the Hoffman elimination reaction and the nucleophilic attack reaction of the ammonium counterion, the surface modifier can promote the thermal decomposition of PHAs family polymers. Therefore, when the addition amount of KH550 exceeds a certain value, it will instead promote the thermal decomposition of PHAS. After adding the coupling agent to the PHBH/1 wt% MMT nanocomposite, the $T_{10}$, $T_{30}$, and $T_{50}$ of the PHBH/MMT/KH550 nanocomposite are significantly higher than those of the nanocomposite without the modifier. This is because of the coupling agent. After KH550 is added to PHBHMMT nanocomposites containing a small amount of MMT, the barrier effect of MMT plays a major role, and KH550 makes PHBH and nanomontmorillonite form a cross-linked structure, which limits the movement of the polymer backbone and effectively improves the thermal stability of the cross-linked hybrid composite PHBH/MMT/KH550. When the amount of KH550 added is 1 wt%, 3 wt%, 5 wt%, 7 wt%, the residual carbon content of PHBHMMT/KH550 at 700 degrees is higher than that of PHBH/MMT. Among them, PHBH/MMT/3 wt% KH550 nanocomposite membrane has the highest carbon residual content. It can be considered that the addition of KH550 makes PHBH and nanomontmorillonite form a cross-linked structure, and the presence of inorganic nanomontmorillonite improves the thermal stability of the hybrid composite membrane. When the addition of KH550

Table 3: Thermal weight loss data of PHBH/MMT/KH550 nanocomposites with different proportions of KH550.

| Sample | $T_5$ | $T_{10}$ | $T_{30}$ | $T_{50}$ | $T_{max}$ | Char yield (%) |
|---|---|---|---|---|---|---|
| PHBH/1 wt% MMT | 233.43 | 238.52 | 247.94 | 253.52 | 252.97 | 23.81 |
| PHBH/1 wt% MMT/1% KH550 | 235.16 | 244.16 | 256.24 | 273.47 | 260.6 | 32.57 |
| PHBH/1 wt% MMT/3% KH550 | 232.94 | 250.1 | 262.43 | 272.75 | 264.13 | 50.8 |
| PHBH/1 wt% MMT/5% KH550 | 243.26 | 269.66 | 259.88 | 266.63 | 263.85 | 29.74 |
| PHBH/1 wt% MMT/7% KH550 | 228.72 | 237.38 | 250.46 | 253.95 | 235.1 | 31.31 |
| PHBH/1 wt% MMT/9% KH550 | 218.82 | 244.64 | 256.89 | 271.71 | 265.14 | 16.75 |

is 9 wt%, the carbon residue of PHBH/MMT/KH550 is lower than that of PHBH/MMT. This may be because the decomposition of KH550 accelerates the thermal decomposition of PHBH and reduces the carbon residue.

## 5. Conclusions

According to the types of materials used in slope protection, this paper systematically investigates and summarizes various structural forms of traditional slope protection and ecological slope protection. The difference and connection between the two are detected in terms of structural form, constituent materials, main functions, and construction technology. Detailed comparative analysis was conducted with a summary analysis of general weighting calculation methods and comprehensive evaluation methods, and range analysis was used to determine weights. The combination of comprehensive evaluation index method and gray correlation method overcomes the past comprehensive evaluation model to a certain extent. According to the subjectivity and discreteness of the judgment matrix, the resolution and sensitivity are improved, and the evaluation results are more scientific, reasonable, and reliable.

Nanomontmorillonite modified fly ash ecological slope protection material is a comprehensive material integrating rock engineering, fluid mechanics, biology, soil and water conservation, fertilizer science, silicate chemistry, horticulture, automation chemistry, environmental ecology, and other disciplines. Technology is a complex system engineering. The formation of nanomontmorillonite modified fly ash ecological slope protection material does not rely on vibration tamping, but on continuous impact compaction of the mixture in the process of high-speed injection, which has high bonding strength. The electron microscope scanning of the microstructure shows that the ecological material has a porous structure similar to that of soil, including a large number of noncapillary pores and capillary pores. According to the mercury intrusion test, the content of small pores in the ecological material particles is very high, and the total porosity is about three times that of ordinary cement, which makes the material have the characteristics of strong water retention and good air permeability.

Based on the analysis of various components of the nanomontmorillonite modified fly ash ecological slope protection material, the prepared nanomontmorillonite/hyperbranched nanocomposite material is the first tape distribution. Two seedlings are prepared for extension, and the extension rate is studied. The characteristics of different biaxially stretched membranes are based on inorganic modification, organic modification, and double-cation organic compound modification, which are introduced into anionic surface. The active agent accepts cation-anion composite modification, which improves the adsorption capacity of the original modified montmorillonite. In the absence of biaxial stretching, the tensile strength and breaking point extension of the composite film added with organic nanomontmorillonite are significantly higher than those of the pure hyperbranched unextended film. The extended film stretches as the growth rate increases. The strength is gradually increasing, and the breaking point growth continues to decrease. According to mechanical properties, when the extension ratio of the 2-axis stretched film reaches $3 * 3$, the properties of the water barrier and oxygen barrier of the nanomontmorillonite modified fly ash ecological slope protection material have reached the most suitable value.

## Data Availability

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

## Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

## Acknowledgments

This work was supported by Key R & D Projects of Hebei Province (Grant no. 19274207D).

## References

[1] G.-J. Kim, D. Kim, K.-J. Lee et al., "Effect of nano-montmorillonite on osteoblast differentiation, mineral density, and osteoclast differentiation in bone formation," *Nanomaterials*, vol. 10, no. 2, p. 230, 2020.

[2] K. Zheng, T. Chen, J. Zhang et al., "Nano-montmorillonite regulated crystallization of hierarchical strontium carbonate in a microbial mineralization system," *Materials*, vol. 12, no. 9, p. 1392, 2019.

[3] J. Alongi and F. Carosio, "All-inorganic intumescent nanocoating containing montmorillonite nanoplatelets in ammonium polyphosphate matrix capable of preventing cotton ignition," *Polymers*, vol. 8, no. 12, p. 430, 2016.

[4] R. Hong, Z. Guo, J. Gao, and C. Gu, "Rapid degradation of atrazine by hydroxyl radical induced from montmorillonite templated subnano-sized zero-valent copper," *Chemosphere*, vol. 180, pp. 335–342, 2017.

[5] M. Xie, L. Li, K. Yuan, Y. Ma, and B. Liu, "Preparation and performance evaluation of organophilic nano-montmorillonite conducting polymer electrolyte for all-solid-state lithium ion batteries," *Journal of Materials Science*, vol. 30, no. 3, pp. 2030–2036, 2019.

[6] X. He, W. Zhang, D. Yi, and R. Yang, "Flame retardancy of ammonium polyphosphate–montmorillonite nano compounds on epoxy resin," *Journal of Fire Sciences*, vol. 34, no. 3, pp. 212–225, 2016.

[7] Z. Ren, Y. Zhu, Q. Wu et al., "Enhanced storage stability of different polymer modified asphalt binders through nano-montmorillonite modification," *Nanomaterials*, vol. 10, no. 4, p. 641, 2020.

[8] G. Xu, B. Xue, L. Wei, J. Yu, Z. Yang, and S. Qin, "Effect of multistage stretching extrusion on morphology and property of organic nano montmorillonite/high density polyethylene composites," *Fuhe Cailiao Xuebao/Acta Materiae Compositae Sinica*, vol. 35, no. 7, pp. 1822–1831, 2018.

[9] M. Chi, K. Tao, Q. Chen, H. Liu, P. Gao, and Z. Gao, "Dielectric properties of nano-montmorillonite modified insulation pressboard," *Gaodianya Jishu/High Voltage Engineering*, vol. 43, no. 9, pp. 2842–2848, 2017.

[10] Y. Li, W. Zhu, T. Chen et al., "Synergistic metallogenesis of simulated radionuclide strontium by carbonate-mineralization bacteria/nano-montmorillonite," *Journal of Radioanalytical and Nuclear Chemistry*, vol. 314, no. 1, pp. 333–341, 2017.

[11] Z. Li, J. Gong, S. Du et al., "Nano-montmorillonite modified foamed paste with a high volume fly ash binder," *RSC Advances*, vol. 7, no. 16, pp. 9803–9812, 2017.

[12] M. H. Sheikh-Mohseni, S. Sedaghat, P. Derakhshi, and A. Safekordi, "Electrochemical activity of Ni-montmorillonite/Vulcan XC-72R carbon black nano-catalyst for the oxidation of methanol in acidic medium," *Journal of Nanostructure in Chemistry*, vol. 9, no. 3, pp. 217–224, 2019.

[13] H. Azimi and M. Hayati-Ashtiani, "Morphological and structural characterization of nano-structured montmorillonite for separation process applications," *Desalination and Water Treatment*, vol. 110, pp. 129–138, 2018.

[14] F. Li, W. Wu, R. Li, and Z. Fu, "Adsorption of phosphate by acid-modified fly ash and palygorskite in aqueous solution: experimental and modeling," *Applied Clay Science*, vol. 132-133, pp. 343–352, 2016.

[15] S. Wang, Y. Zhang, Y. Gu et al., "Using modified fly ash for mercury emissions control for coal-fired power plant applications in China," *Fuel*, vol. 181, pp. 1230–1237, 2016.

[16] J. Yang, Y. Zhao, J. Zhang, and C. Zheng, "Removal of elemental mercury from flue gas by recyclable $CuCl_2$ modified magnetospheres catalyst from fly ash. Part 2: identification of involved reaction mechanism," *Fuel*, vol. 167, pp. 366–374, 2016.

[17] C. An, S. Yang, G. Huang, S. Zhao, P. Zhang, and Y. Yao, "Removal of sulfonated humic acid from aqueous phase by modified coal fly ash waste: equilibrium and kinetic adsorption studies," *Fuel*, vol. 165, pp. 264–271, 2016.

[18] A. Ghazy, M. T. Bassuoni, and A. Shalaby, "Nano-modified fly ash concrete: a repair option for concrete pavements," *ACI Materials Journal*, vol. 113, no. 2, pp. 231–242, 2016.

[19] Y. Xiang, L. Wang, and Y. Jiao, "Ultrasound strengthened biodiesel production from waste cooking oil using modified coal fly ash as catalyst," *Journal of Environmental Chemical Engineering*, vol. 4, no. 1, pp. 818–824, 2016.

[20] C. Li, H. Zhu, M. Wu, K. Wu, and Z. Jiang, "Pozzolanic reaction of fly ash modified by fluidized bed reactor-vapor deposition," *Cement & Concrete Research*, vol. 92, pp. 98–109, 2017.

[21] Y. Gu, Y. Zhang, J. Lin et al., "Homogeneous mercury oxidation with bromine species released from HBr-modified fly ash," *Fuel*, vol. 169, pp. 58–67, 2016.

[22] A. M. Rashad and A. S. Ouda, "An investigation on alkali-activated fly ash pastes modified with quartz powder subjected to elevated temperatures," *Construction & Building Materials*, vol. 122, pp. 417–425, 2016.

[23] V. Masindi, W. Gitari, and H. Tutu, "Adsorption of As, B, Cr, Mo and Se from coal fly ash leachate by $Fe^3$ modified bentonite clay," *Journal of Water Reuse & Desalination*, vol. 6, no. 3, pp. 382–391, 2016.

[24] A. Ebelegi, S. S. Angaye, A. Nimibofa, and W. Donbebe, "Removal of Congo red from aqueous solutions using fly ash modified with hydrochloric acid," *Current Journal of Applied Science and Technology*, vol. 20, no. 4, pp. 1–7, 2017.

[25] A. K. Nikolaidis and D. S. Achilias, "Thermal degradation kinetics and viscoelastic behavior of poly(methyl methacrylate)/organomodified montmorillonite nanocomposites prepared via in situ bulk radical polymerization," *Polymers*, vol. 10, no. 5, p. 491, 2018.

[26] A. Hassani, A. Khataee, S. Karaca, and M. Fathinia, "Degradation of mixture of three pharmaceuticals by photocatalytic ozonation in the presence of $TiO_2$/montmorillonite nanocomposite: simultaneous determination and intermediates identification," *Journal of Environmental Chemical Engineering*, vol. 5, no. 2, pp. 1964–1976, 2017.

[27] X. Zhou and Q. Huang, "Quantitative evaluation on oil diffusion mechanisms in nano-organic-montmorillonite modified caster oil based polyurethane foam for oil/water separation," *Polymers for Advanced Technologies*, vol. 31, no. 6, pp. 1231–1244, 2020.