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Microbial-induced mineralization and cementation of fugitive dust and engineering application

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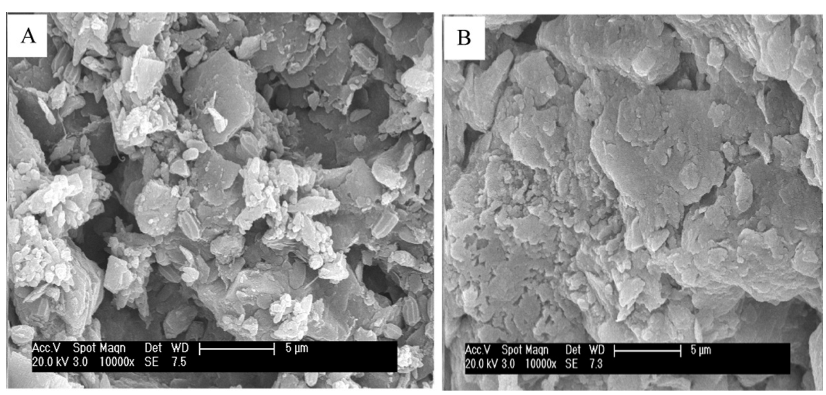
HIGHLIGHTS

- A new method was found to mineralize and cement fugitive dust.
- Microstructure of calcite-consolidation-layer was analyzed.
- Calcite-consolidation-layer had good mechanical properties.

GRAPHICAL ABSTRACT

The control of fugitive dust is becoming a hot spot at home and abroad for a time. Due to high energy consumption, large investment, complex operation and likely secondary pollution to the environment, physical and chemical methods are relatively difficult to be applied to the control of fugitive dust in large areas. In response to these aspects, cementitious materials of biological carbonates were prepared to mineralize and cement loose fugitive dust. In this study, fugitive dust could be controlled effectively in that cementitious materials of biological carbonates had superior mechanical properties, such as wind-erosion resistance, rainfall-erosion resistance, moisture and ecological compatibility.



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ABSTRACT

Microbial-induced mineralization and cementation of fugitive dust, as a new green and environmental-friendly method, is being paid extensive attention to in that it has low cost, simple operation and rapid effects. In this research, carbon dioxide was absorbed, transformed and produced carbonate ions under the enzymatic action of *Paenibacillus mucilaginosus*. Meanwhile, carbonate ions could mineralize calcium ions into calcite-consolidation-layer (CCL) which have certain mechanical properties. In this process, the fugitive dust was cemented and formed larger particles bond in the calcite-consolidation-layer (CCL). The particular composition and the morphology of calcite-consolidation-layer (CCL) were characterized by X-ray diffraction (XRD) and scanning electron microscopy (SEM). In addition, cementitious materials of biological carbonates were used to the control of fugitive dust in engineering application. The results suggested that cementitious materials of biological carbonates could mineralize and cement fugitive

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Paenibacillus mucilaginosus
Engineering application

dust, then form the calcite-consolidation-layer (CCL). Meanwhile, cementitious materials of biological carbonates had superior mechanical properties, such as wind-erosion resistance, rainfall-erosion resistance, moisture and ecological compatibility.

1. Introduction

With the rapid development of industrialization and urbanization, air pollution has become more serious than ever before. Currently, air is suffering greatly from pollution which are from motor vehicles, industrial production, coal, fugitive dust and so on [1–3]. Of all air pollution by the pollutants, those caused by fugitive dust is the most serious in that the fugitive dust are very difficult to collect, separate and degrade. When entering into the atmosphere, fugitive dust doesn't only have negative effects on air quality, but also endanger people's health [4,5].

In recent years, the control of fugitive dust is becoming a hot spot home and abroad for a time [6–8]. Generally, two measures can be taken to control fugitive dust pollution—physical method and chemical method. Physical method mainly includes sprinkling water, covering dust-controlling nets and building fence [9–11], while chemical method contains the dust-depressor type of wetting, hygroscopic, bond and complex [12–14]. Amato et al. found that Triton X-100, which was the moisture type of dust-depressor, could effectively reduce the fugitive dust in the surrounding environment [15,16]. Copeland et al. found that the moisture content of dust for dust-depressor can be made much higher than water, and the result can be heightened with the increase of dust-depressor dosage. In case of actual use on the surface of the road, the dust concentration can be made to keep lower than 10 mg/m^3 at least 4 days [17–19]. Tan et al. proved that the dust suppressor, which is composed of dissoluble starch, sodium silicate as well as glycerol, possesses the viscosity of 510 mPa · s, the saturated suppressor absorbing capacity of 64.6% and evaporation rate per unit area of 0.3 kg/(m^2 · h) under the above temperature as well as lasting anti-evaporation time of 65.17 h [20]. Zhang et al. demonstrated that the modified dust depressor has low content of free formaldehyde, high viscosity and high water retention. At the same time, study on the applied capability of the resins as a sand-fixation and dust-depressor, proved it has good solidified capability and it is fit for outdoor dust suppression [21]. Due to high energy consumption, large investment, complex operation and likely secondary pollution to the environment, physical and chemical methods are relatively difficult to be applied to the control of fugitive dust in large areas. Nevertheless, biological method, which, as a new method, has stable and reliable effects without secondary pollution, thus has become the most promising method in the control of fugitive dust.

In this research, cementitious materials of biological carbonates were prepared to bind loose fugitive dust particles based on the previous study. Carbon dioxide was absorbed, transformed and produced carbonate ions under the enzymatic action of *Paenibacillus mucilaginosus*. Meanwhile, carbonate ions could mineralize calcium ions into calcite-consolidation-layer (CCL) which have certain mechanical properties. In this process, the fugitive dust was cemented, formed larger particles bond in the CCL. The particular composition and the morphology of the CCL were characterized by X-ray diffraction (XRD) and scanning electron microscopy (SEM). In addition, cementitious materials of biological carbonates were used to the control of fugitive dust in engineering application. According to lab and engineering application, the control effect of fugitive dust of cementitious materials of biological carbonates was verified.

2. Materials and methods

2.1. Composition of cementitious materials of biological carbonates

Cementitious materials of biological carbonates consisted of two parts: bacteria powder and calcium source. Bacteria power is *Paenibacillus mucilaginosus*, while the calcium source is calcium nitrate. Cultivation of *Paenibacillus mucilaginosus* was conducted in sucrose culture (10 g of sucrose and 3 g of sodium hydrogen phosphate were dissolved in deionized water to 1 L, and the pH value was adjusted to about 7.0) at 35 °C for 24 h. Bacteria powder is made from the above bacteria liquid by freeze drying process. The appropriate temperature of *Paenibacillus mucilaginosus* growth is 10–40 °C, while the pH value is 7–9. Cementitious materials of biological carbonates were prepared by mixing *Paenibacillus mucilaginosus* and calcium nitrate in a certain proportion. According to the previous research results, the optimal proportion was: *Paenibacillus mucilaginosus* (g): calcium nitrate (g): water (L) = 3:354:1, and it was recorded as the standard dosage in 1 m^2.

2.2. Usage of cementitious materials of biological carbonates

Firstly, *Paenibacillus mucilaginosus* were put into water for 6 h to make them revive, and then added the calcium nitrate into the solution, which could be used after it dissolved completely. In order to sprinkle evenly and increase the penetration depth, it could be sprinkled after watering the soil. The sprinkling experiment is shown in Fig. 1(A).

2.3. Microscopic analysis of the CCL

The crystal structure of the CCL was examined by XRD with Bruker D8-Discover diffractometer using graphite-monochromatized high-intensity Cu Kα radiation (λ = 1.5406 Å). The scanning angle range was from 10° to 80° 2θ with the step at 0.2 s·step^{-1}.

SEM (FEI Company, Netherlands) with a GENESIS 60S energy dispersive X-ray spectroscope (EDS) spectroscopy system with magnification from 1000 to 10,000 was used to observe the morphology and to measure the elemental compositions of the precipitations. The accelerating voltage and spot size of the secondary electron detector were 20 kV and 4.0, respectively.

2.4. Mechanical properties of the CCL

2.4.1. Thickness

The thickness and hardness of the CCL are important indicators to evaluate the control effect of fugitive dust. The standard dosage of cementitious materials of biological carbonates was used in engineering application for 900 m^2, meanwhile the influence of different dosage were investigated in small-scale for 10 m^2. Cementitious materials of biological carbonates was sprinkled on the surface of the soil evenly. After permeating completely, the CCL was collected and dried at 60 °C in oven. Afterwards, the thickness of the CCL was measured by means of vernier caliper, and the hardness was measured by shore hardness tester

2.4.2. Wind erosion resistance

Compared with hair dryer method, fan method and observation method, wind tunnel test is a feasible method to test the wind-erosion resistance of the CCL in that the test result is truer. The wind tunnel test is shown in Fig. 1(B).

The wind-erosion resistance was conducted in wind tunnel test at 0 angle for 1 h, and the wind speed was 4, 6, 9, 12 m/s respectively. The wind-erosion resistance could be represented via the mass loss of unit area of the CCL. In other words, it could be represented by comparing the change of mass before and after experiment.

2.4.3. Rainfall-erosion resistance

The rainfall-erosion resistance was conducted in the artificial simulation of rainfall devices (Fig. 1(C)). The rainfall duration on the surface of the CCL was 1 h, and the rainfall intensity was 2.3–2.6 mm/h, then dried at 60 °C in the oven for 24 h, and it was recorded as a cycle. The change of mass loss and hardness and were obtained under the different cycles. According to the change, the rainfall-erosion resistance was evaluated accurately.