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Microbial-Induced Mineralization and Cementation of Fugitive Dust and Engineering Application

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

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 [YQ et al. (2006); Han et al. (2008); Han et al. (2010)]. 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 [Chen et al. (2012); He et al. (2007)].

In recent years, the control of fugitive dust is becoming a hot spot home and abroad for a time [Xu et al. 2005; Han et al. (2003); Wang et al. (2004)]. 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[Zhang et al. (2010); Zhou et al. (2004); Zha at al. (2007)], while chemical method contains the dust-depressor type of wetting, hygroscopic, bond and complex[Bai et al. (2005); Peng et al. (2005); Zhang et al. (2009)]. 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 [Amato et al. (2010); Copeland et al. (2009)]. 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 [Karin et al. (2011); Medeiros et al. (2012); Jin LZ et al. (2007)]. 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 $kg/(m^2 \cdot h)$ under the above temperature as well as lasting anti-evaporation time of 65.17 h [Tan et al. (2005)]. 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[Zhang et al. (2007)]. 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.

MATERIALS AND METHODS

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. 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 $1m^2$.

Usage of cementitious materials of biological carbonates

Firstly, *Paenibacillus mucilaginosus* were put into water for 6 hours 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.

RESULTS AND DISCUSSION

Composition and micro-structure of the CCL

The XRD patterns of the CCL obtained by sprinkling water (A) and by sprinkling cementitious materials of biological carbonates (B) are shown in Figure 1. As Figure 1 (A) showed, the peaks of XRD pattern were well consistent with JCPDS card number 46-1045 and 52-0803, and the CCL was characterized as mixture of silica and aluminium oxide. However, the new peaks were found in Figure 1 (B) which were in keeping with JCPDS card number 03-0612, and the new substance was calcite in addition to silica and aluminium oxide. The results illustrated that calcite could be prepared by cementitious materials of biological carbonates.

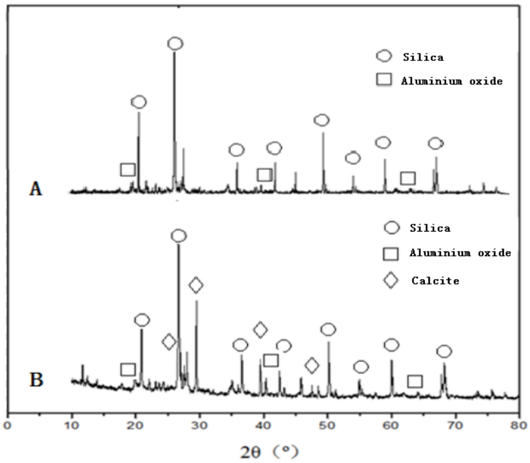

Figure 1. The XRD patterns of the CCL obtained by sprinkling water (A) and by sprinkling cementitious materials of biological carbonates (B)

Figure 2 displayed EDS spectra of the CCL obtained by sprinkling cementitious materials of biological carbonates. An elemental analysis of the CCL composition was performed by EDS which certify the presence of elemental C, O, Si, Al and Ca in the sampled particles (Figure 2). EDS result is consistent with the XRD results completely.

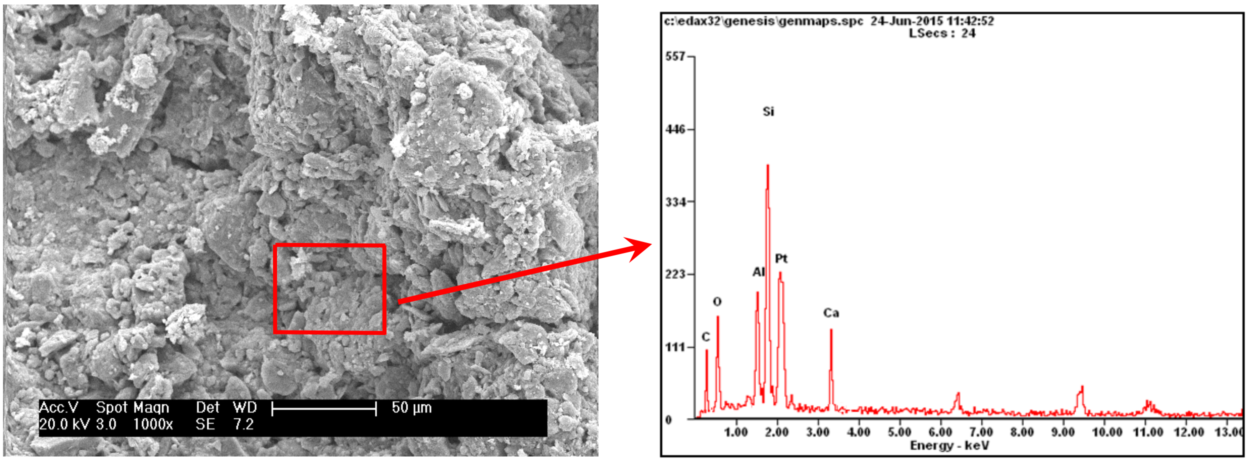

Figure 2. The EDS spectrum of the CCL obtained by sprinkling cementitious materials of biological carbonates

SEM photographs of the CCL obtained by sprinkling water (A) and by sprinkling cementitious materials of biological carbonates (B) are shown in Figure 3. As Figure 3 (A) showed, the overall evaluation of the morphology of the CCL indicated the soil particles were loose and without being bonded together. By comparison, the soil particles were bonded together, form a complete block and small soil particles were observed hardly in Figure 3 (B).

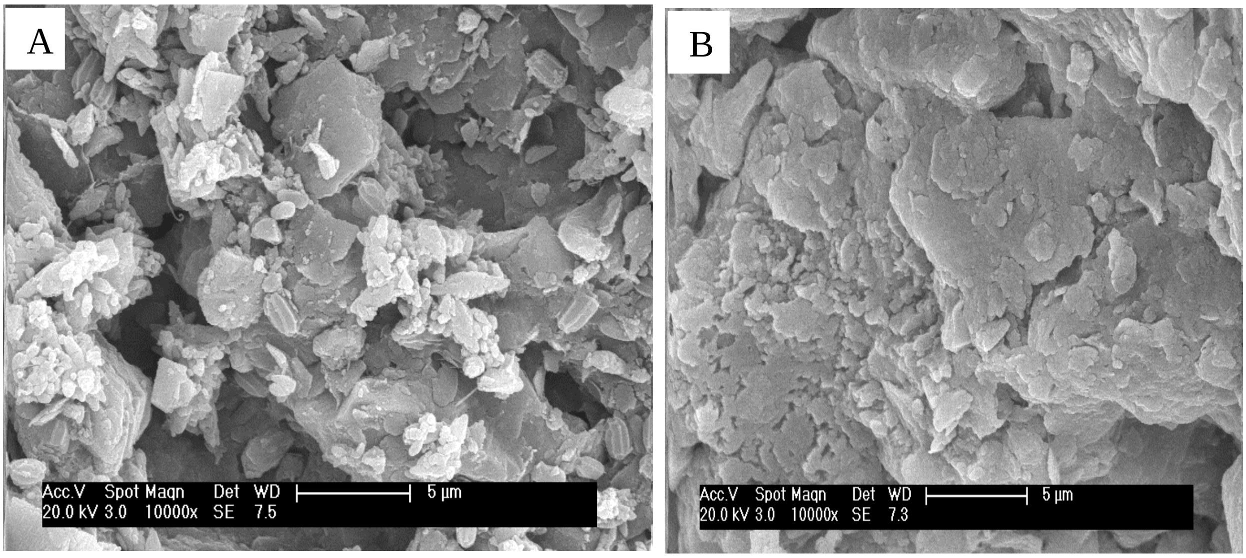

Figure 3. The SEM photos of the CCL obtained by sprinkling water (A) and by sprinkling cementitious materials of biological carbonates (B)

From above results, it could be concluded that cementitious materials of biological carbonates could bind loose dust particles and formed the CCL .

The control effect of fugitive dust in engineering application

The influence of the dosage of cementitious materials of biological carbonates on the control effect of fugitive dust was investigated. Water of the same volume, half of the standard dosage, the standard dosage, two times of the standard dosage and three times of the standard dosage were recorded as 0N, 0.5N, 1N, 2N and 3N respectively.

Thickness and hardness of the CCL

The influence of the different dosage of cementitious materials of biological carbonates on thickness and hardness of the CCL are shown in Figure 4. As shown in Figure 4, the thickness and hardness of the CCL which was obtained by sprinkling water of the same volume were little extraordinary compared with that which was obtained by sprinkling different dosage of cementitious materials of biological carbonates. Besides, with the increase of the dosage, the thickness and hardness of the CCL increased significantly. When the dosage was 1 N, the thickness was 13.16 mm and the hardness was 24.6 °. It indicated that the cementitious materials of biological carbonates could mineralize and cement fugitive dust effectively into the CCL which had a certain mechanical properties and therefore, was feasible.

3.2.2 Wind-erosion resistance of the CCL

The influence of the different dosage of cementitious materials of biological carbonates on wind-erosion resistance of the CCL are shown in Figure 5. Figure 5 showed, when the dosage was 0 N, the mass loss under different wind speed were about 500, 1300, 2000 and 2600 g/(m^2·h) respectively. With the increase of wind speed, the mass loss was significantly increased. However, the mass loss were all less than 30 g/(m^2·h) when the dosage was 0.5 N, 1 N , 2 N and 3N, and no matter how much the wind speed, the change of the mass loss was not obvious. Compared with the literature [Zhang et al. (2013), Chen et al. (2008)], cementitious materials of biological carbonates had superior wind-erosion resistance.

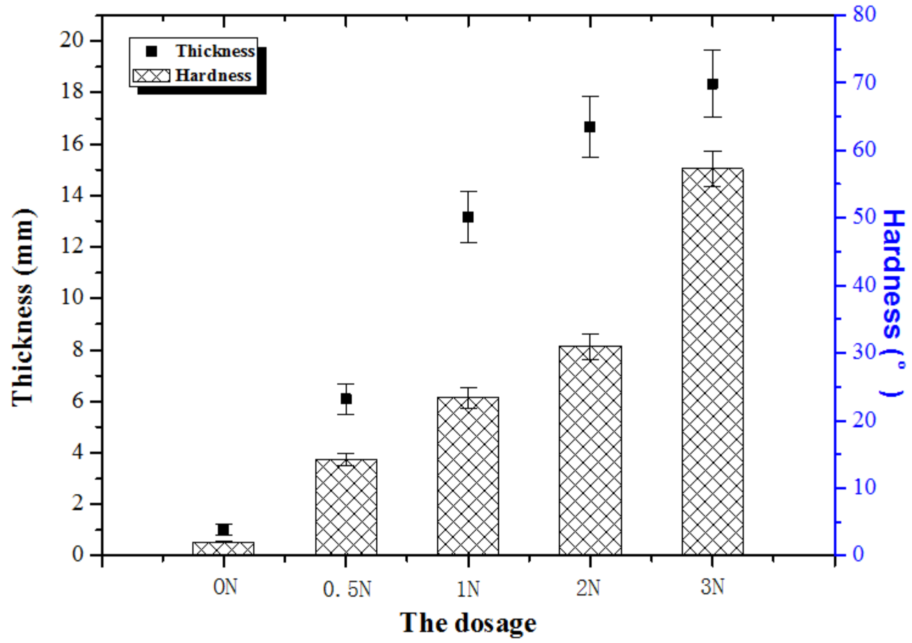

Figure 4. The influence of the different dosage of cementitious materials of biological carbonates on thickness and hardness of the CCL

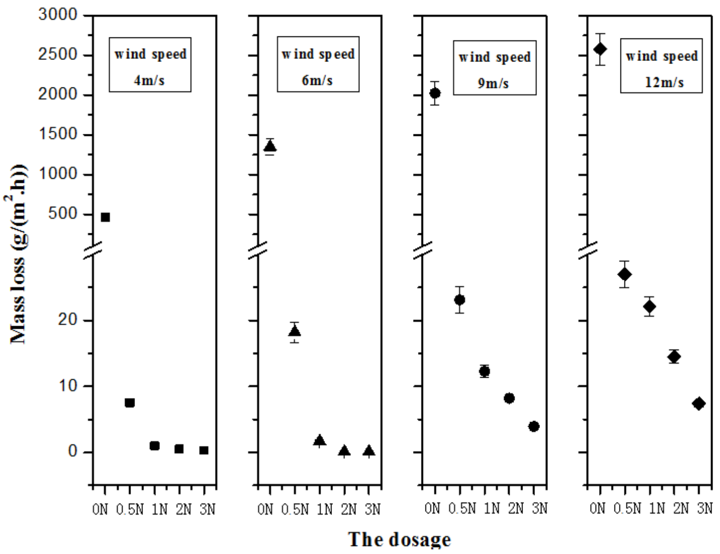

Figure 5. The influence of the different dosage of cementitious materials of biological carbonates on wind-erosion resistance of the CCL

Rainfall-erosion resistance of the CCL

The influence of the different dosage of cementitious materials of biological carbonates on rainfall-erosion resistance of the CCL are shown in Figure 6. In the one cycle, the mass loss was about 750 g/(m^2·h) and the hardness residual ratio was almost non-existent when the dosage was 0 N. Nevertheless, the mass loss were all less than 100 g/(m^2·h), then the change of the hardness was little and the hardness residual ratio were more than 93 % when the dosage was 0.5 N, 1 N, 2 N and 3 N. Compared with the one cycle, the mass loss were all significantly increased and the hardness residual ratio were clearly decreased in the two cycle. In spite of this, the hardness residual ratio were more than 90 % when the dosage was 1 N, 2 N and 3 N in the two cycle. It indicated that the cementitious materials of biological carbonates had a good property of rainfall-erosion resistance.

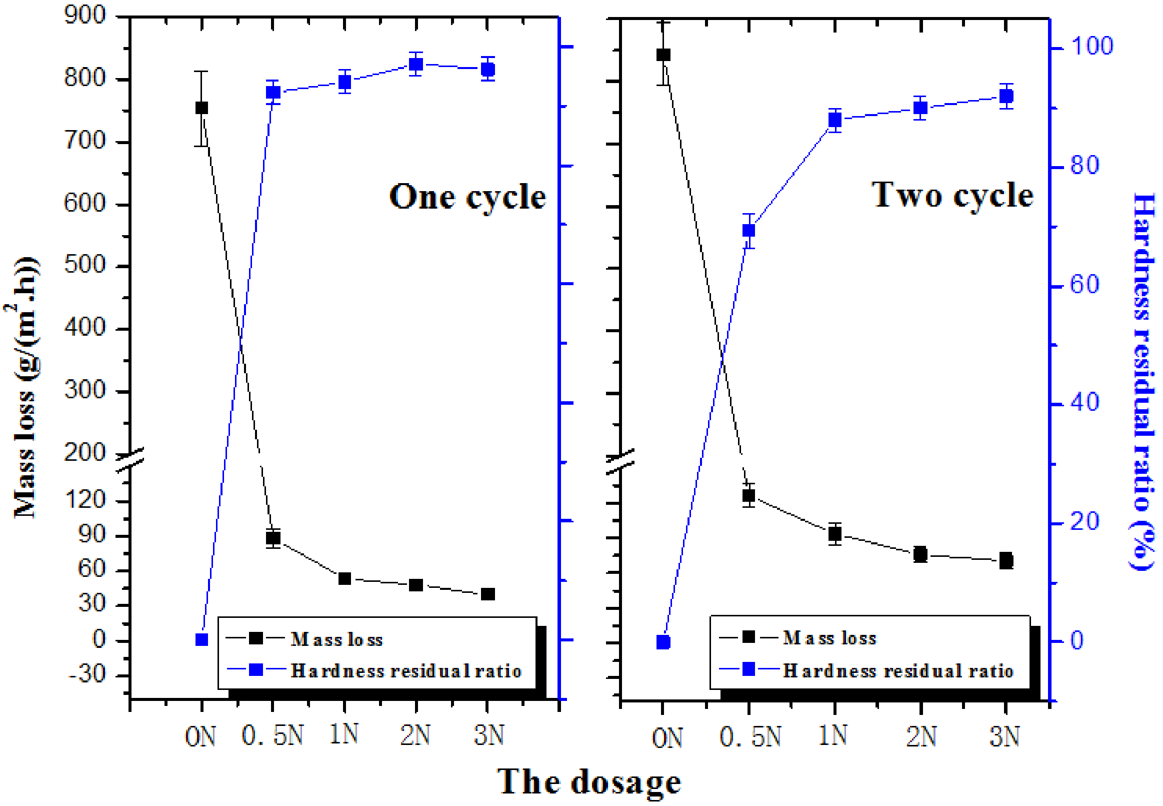

Figure 6. The influence of the different dosage of cementitious materials of biological carbonates on rainfall-erosion resistance of the CCL

Air quality after sprinkling cementitious materials of biological carbonates

The data of the PM 2.5 which was monitored by air quality monitor for five days continuously is shown in Figure 7. It was apparent from Figure 7 that the control effect of fugitive dust where the same volume water and sprinkled cementitious materials of biological carbonates were sprinkled, were satisfactory compared with the non-sprinkled soil. Besides, the effect when sprinkling cementitious materials of biological carbonates was much better than the effect when sprinkling the same volume water. Such differences might be caused by the fact that the fugitive dust was cemented, formed larger particles bond in the CCL and entered atmosphere hardly. In order to obtain better result, widespread sprinkle, secondary sprinkle and combining the application of water and cementitious materials of biological carbonates could reinforce the control effect of fugitive dust.

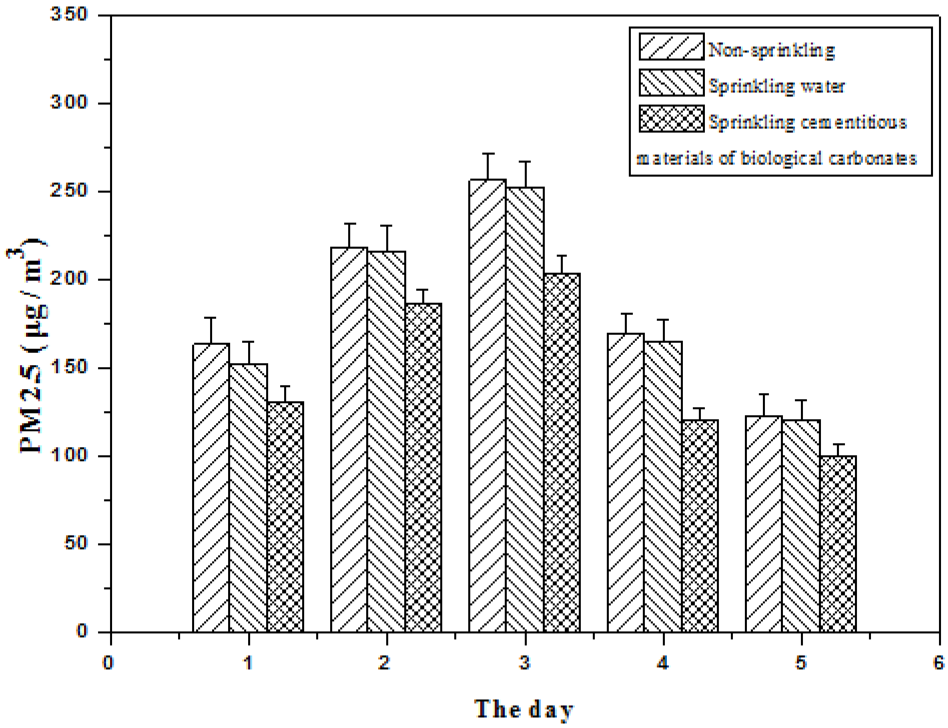

Figure 7. The data of the PM 2.5 monitored by air quality monitor

CONCLUSION

From the laboratory study and engineering application, conclusions could be drawn as follows: carbon dioxide was absorbed, transformed and produced carbonate ions under the enzymatic action of *Paenibacillus mucilaginosus*. Meanwhile, carbonate ions could mineralize calcium ions into the CCL which have certain mechanical properties. In this process, the fugitive dust was cemented and formed larger particles bond in the CCL. The particular composition and the morphology of the CCL were characterized by XRD and SEM. The result illustrated that calcite could be prepared and fugitive dust particles were bonded together which formed a complete block. In addition, cementitious materials of biological carbonates were used to the control of fugitive dust in engineering application. The results suggested that 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. When the dosage was 1 N, the thickness was 13.16 mm and the hardness was 24.6 º. In the case of wind speed of 12 m/s, the mass loss was less than 30 g/(m^2·h). After two times of rainfall erosion of 2.3~2.6 mm/h, the hardness residual ratio was more than 90 %. Thus, this method should be large-scale popularized applied in the control of fugitive dust.

ACKNOWLEDGEMENT

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