Laboratory Performance Evaluation of Co-Polymer Based Dust Suppressant Mixed with Poorly Sand

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Abstract. Fugitive dust, generated along unpaved roads or uncovered construction sites, defined as a type of atmospheric matter (PM), is considered as a major source of air pollution in metropolitan areas. Fugitive dust can potentially cause respiratory illness and lung damage for humans, and even lead to premature death in sensitive individuals. Aiming to reduce the fugitive dust emission on unpaved roads, scientists did various lab experiences to analyze the performance of different types of dust suppressants mixed with different soils. In our previous papers, we evaluated the co-polymer-based dust suppressant (CPS) mixed with loamy sand (soils are from Sedona, Arizona) and silty clay (SP-SC) (soils are from Flagstaff, Arizona). The objective of this paper is to analyze the efficiency of fugitive dust reduction and present the quantitative laboratory evaluation of CPS mixed with poorly sand (SP). The soils were sampled from Page, Arizona. Soil classification is based on United Soil Classification System (USCS). Four concentrations of CPS (0%, 1%, 3%, and 5% by weight) were diluted and mixed with soil samples to prepared soil specimens. A series of laboratory experiments were performed on the soil specimens including moisture retention test, surface strength test, dynamic rolling test, and scanning electron microscopy (SEM) imaging. The laboratory results show that the higher the concentration of CPS is, the better CPS performs, and CPS with 5% concentration by weight controls the dust emissions better as compared with the other three concentrations, provided the results from the moisture retention rate, surface strength, dynamic rolling resistance, and interlock/cohesion effect in SEM images are promising.

1. Introduction
Fugitive dust, which is defined as atmospheric particle with diameter less than 75 micrometers by the International Organization (ISO) for Standardization, is potentially generated from unpaved roads by winds or vehicles [1] [2]. According to the World Bank’s report, approximate 33% of the total roads are unpaved. Based on the report from US Environmental Protection Agency (USEPA), unpaved roads are one of the primary sources generating the particular matters (PM) including PM less than 10 microns in aerodynamic diameter (PM₁₀) and PM less than 2.5 microns in aerodynamic diameter (PM₂.₅) [2] [3]. Unpaved roads generate 41.3% of PM₁₀ and 33.7% of PM₂.₅ [4] [5]. Fugitive dust, especially PM₁₀ and PM₂.₅, has many negative impacts on humans health and air quality, potentially leading to the damage of human respiratory system, economy loss of the environmental departments, and equipment damage of machines on the road [6] [7] [8].

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In order to protect human health and reduce the air pollution, as well as coping with the problems of fugitive dust emission generated from unpaved roads, scientists did plenty of experiments and research on the unpaved roads. Various methods were applied to reduce the fugitive dust emission. Methods of controlling the fugitive dust generation fall into three categories, namely, source extent reductions, surface improvements, and surface treatment [2]. Surface treatment methods are typically short-term control of the dust emission and have less cost. Regarding the surface treatment, water and chemical stabilizations are the most frequent suppressants used to treat the surface of the unpaved roads and control the fugitive dust emission.

In this paper, the surface treatment method is adopted and tested. Soils were sampled at Page, Arizona. A co-polymer-based dust suppressant was provided by a local company at Arizona. Co-polymer-based suppressant has been applied to loamy sand and silty clay, and the results have been discussed in our previous paper. In this paper, we dive deeply in the effects of co-polymer-based suppressant on poorly sand. The primary objective of this paper is to evaluate how efficiently the co-polymer-based suppressant reduces the fugitive dust emission and how the concentration of the suppressant affects the dust emission reduction. By diluting the dust suppressant to four different concentrations, we evaluate how the concentration would affect the functions of the dust suppressant. In this paper, we focus on the reduction of soils finer than the #200 sieve, since they are included in the category of fugitive dust. Three tests were performed in the Materials Laboratory of Northern Arizona University to examine the reduction results of the dust emission by the suppressant: dynamic rolling test, surface strength test, and Scanning Electron Microscopy (SEM) Analysis.

![Particle Size Distribution Curve](image)

**Figure 1.** Particle size distribution of the sampled soils

2. **Experiment method**

2.1. **Soil classification**

Sieve analysis was performed with the sampled soils, and the particle size distribution curve of the soil is shown in figure 1. Figure 1 shows that 3.1% of the soils pass the #200 sieve (0.075 mm), which indicates that 3.1% the untreated soils are the fugitive dust. The uniformity coefficient and the coefficient of curvature of the soil are 2 and 0.806, respectively. Soil samples were classified as sand based on United States Department of Agriculture (USDA) method, and SM-silty sand based on the Unified Soil Classification System (USCS) method.
2.2. Sample preparation
A local company at Arizona provided a co-polymer-based dust suppressant for the laboratory test. Four concentrations of the dust suppressant were prepared, namely, 0% (control group), 5%, 10%, and 15% by weight. Soil specimens were made by 200g soils and diluted suppressant solutions. Suppressant solutions were sprayed slowly on the specimen surface until the specimen was completely mixed with the suppressant. For each test and suppressant concentration, three specimens were prepared.

2.3. Dynamic rolling test
The dynamic rolling test aims to simulate and analyze the impacts of vehicles travelling on the unpaved roads. A total of 12 rubber bunch balls (3.3cm in diameter, each) were placed on the top of a soil specimen, then covered by a 3-kg weight mass (18 cm in diameter) (Figure 2). The entire set was arranged on a mechanical shaker shaking for 6 minutes (Figure 2). During shaking, rubber bunch balls were able to roll over the surface of a soil specimen to simulate dynamic vehicles travelling on the surface of unpaved roads. The sieve analysis was performed on the tested specimen to evaluate how the vehicle travelling will influence the road surface and how the particle distribution curve changes with different suppressant concentrations.

2.4. Surface strength (Penetration resistance) test
How easily small soil particles can be detached from the road surface determines how easily the unpaved roads will produce dust emissions under the effects of vehicles and winds [10]. In this paper, we perform the surface strength test, which is also named penetration resistance test, to analyze the surface strength of the soil. Surface strength of the soil specimens can indicate how hard the soil particles are bonded. The penetration method introduced by Rui Chen et. al was adopted [11].

Before conducting the penetration experiment, the soil specimens with different suppressant solutions were placed in an oven for 24 hours. The purpose of this is to initialize the moisture content in the specimens, so that the moisture content of the specimens is not a variable that affecting the surface strength of the specimens. After 24 hours in the over, the specimens were tested by penetration. Ten penetration points were selected on the surface of each specimen randomly, and the results from the ten points were averaged to obtain a final value of the surface strength of the specimen. The tested specimens are shown in Figure 3.
Figure 3. Specimens after surface strength test (penetration). Left: Specimen with 0% suppressant after penetration; Right: Specimen with 3% suppressant after penetration

2.5. Scanning Electron Microscopy (SEM) Experiment
To analyze the strength of soil interlocking and bonding, the SEM observation was performed. The SEM observation was performed with a Zeiss Supra 40VP SEM at Biology Department of Northern Arizona University. For the SEM imaging, specimens were zoomed to 51x and 215x, allowing the measurement of dimensions and observation of the soil particle interlock and bonding situations with respect to the levels of co-polymer suppressant treatment.

3. Results and discussion

3.1. Dynamic rolling test

![Particle Size Distribution Curves (Page + Co-Polymer)](image)

Figure 4. Particle distribution curves of the specimens after dynamic rolling test [9]

Particle size distribution curves (PDC) of the specimens after dynamic rolling test are demonstrated in Figure 4. Soil particles with diameter greater than 4.75 mm (#4 sieve) are classified as gravel. In
Figure 4, as the suppressant concentration increases, the percentage of soil particles finer than #4 sieve decreases. Compared Figure 4 with Figure 1, regarding to the specimen of original soil, the specimen of soil treated with water, and the specimen of soil treated with 5% suppressant solution, the percentage of soils passing #4 sieve is 100%, while the percentage of soils passing #4 sieve is below 80% in terms of specimen treated with 10% and 15% suppressant solutions.

Table 1 illustrates the percentage of soils passing #200 sieve, which is potentially to become fugitive dust in the air. It demonstrates that as the concentration of the suppressant solution increases, the percentage of soils passing #200 sieve decreases. Combining Figure 4 and Table 1, the results illustrate that the co-polymer-based suppressant can bond the soil particles better than water. In addition, with the concentrations increasing, small particles are reduced, and the bonding effects and cohesive strength of the suppressant increases.

| Suppressant concentration | Water, 0% | 5% co-polymer | 10% co-polymer | 15% co-polymer | Original |
|---------------------------|-----------|---------------|----------------|----------------|----------|
| Percentage of soils passing #200 sieve | 3.11 | 2.93 | 2.93 | 0.75 | 3.1 |

3.2. Surface strength test
The surface strength of specimens with different suppressant concentrations is shown in Table 2. The significant improvement of surface strength of specimens applied dust suppressant is demonstrated from the results shown in Table 2. As the concentration of dust suppressant increases, the surface strength of the specimens also increases. The surface strength illustrates how easily the particles are detached from the road surface. The greater the surface strength is, the harder the particles detached from the road surface is. The increase of the surface strength with the increase of dust suppressant concentrations indicates that soils particles become harder to be detached from the soil surface with the increase of dust suppressant concentration. The 15% concentration of the suppressant demonstrate the largest surface strength among other concentrations.

| Suppressant concentration | Water, 0% | 5% co-polymer | 10% co-polymer | 15% co-polymer |
|---------------------------|-----------|---------------|----------------|----------------|
| Surface strength (psi)    | 84.5      | 369.5         | 1343           | >2600          |

3.3. SEM analysis
The SEM Images under 51x and 251x are shown in Figure 5. The interlocking effects and bonding connections are observed from the SEM Images. Comparing the specimens with different concentrations under 51x (Figure 5(a), 5(b) and 5(c)), the gaps between soil particles become smaller, which indicates that the soil particles are bonded closer under the effects of dust suppressant. Comparing the particle sizes measured from the SEM analysis, the particle sizes of the specimens treated with moisture are relatively smaller than the particles size of the specimens treated with dust suppressant. For the three
concentrations, the specimen treated with 15% concentration has relatively big particle sizes. In addition, the SEM Images also demonstrate that the co-polymer-based suppressant forms a thin film on the top of soil particles and the film bonds the soil particles together, especially relatively small particles (Figure 5(d), 5(e) and 5(f)).

![Figure 5(a). 51x SEM image of 5% concentration](image)

![Figure 5(b). 51x SEM image of 10% concentration](image)

![Figure 5(c). 51x SEM image of 15% concentration](image)

![Figure 5(d). 215x SEM image of 5% concentration](image)

![Figure 5(e). 215x SEM image of 10% concentration](image)

![Figure 5(f). 215x SEM image of 15% concentration](image)

**Figure 5.** SEM Observation Images for specimens with different suppressant concentrations [9]

### 4. Conclusions

Three tests were performed on the soil specimens treated with different concentrations of a co-polymer-based dust suppressant to quantitively evaluate the mechanical responses of the poorly-sand soils sampled from Page, Arizona. Lab experiment results are concluded as follows:
1. Dynamic rolling test demonstrates that vehicle movements on unpaved roads produce fugitive dust emission. Compared with water, co-polymer-based dust suppressant can reduce the dust emitted from unpaved roads and the treated soils have better resistance to the vehicle movement. As the concentration of dust suppressant increases, the reduction of the dust emission is more significant, and the resistance to the vehicle movement of soils increases as well. It is observed that compared with other concentrations, specimens with suppressant of 15% concentration has the least percentage of soils passing through #200, which indicates the potential fugitive dust generated is the least.

2. Results from surface strength test illustrate that the co-polymer-based dust suppressant significantly increases the surface strength of poorly sand. As the concentration of the dust suppressant increases, the surface strength and resistance to vehicle movement of the treated soils also increases. The experiment indicates that specimens treated with suppressant of 15% concentration have the strongest surface strength compared with specimens treated with lower concentration.

3. The interlocking and bonding effects resulted from the suppressant were observed in the SEM Images. The gaps between particles become smaller when the concentration of the suppressant treating the soils increases. A film created by the suppressant, functioning as bonding and interlocking soil particles, was observed from the SEM Images.

4. The SEM Images in Figure 5 support the results from surface strength test and dynamic rolling test in the micro aspect. The decrease of gas between soil particles leads to stronger bonding and interlocking effects between soil particles, which results in stronger surface strength and less fugitive particles in the soils.

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