Research on Rotational Speed of Road Mixing Device for Large-Sized Cement Stabilized Crushed Stone

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Abstract. In order to prevent the reflection crack from happening in cement stabilized macadam base frequently, which lead to the decrease of pavement bearing capacity and working life, a new base structure- large sized cement stabilized crushed stone was raised. The rotational speed of mixing facility for this material was researched in this paper so as to obtain the best base performance, therefore, the construction process was simulated and analyzed in EDEM, which accepted the dispersion coefficient as the mixing quality index. The result shows that the index decreases with the increase of rotational speed between 65 r/min and 120 r/min and it rises a little and then remains stable when the speed is 120-150 r/min. Finally, the 120 r/min is regarded as the appropriate speed considering the index and power consumption.

1. Introduction
The semi-rigid roadbed, filled with secondary stabilized macadamia and cement-stabilized stone, accounts for about 80% of road base in China, but the road diseases, such as thermal crack and shrinkage crack, often destroy the pavement performance. Thus, the mechanism theories of disease formation are analyzed by many scholars and the optimized cement stone grade and suitable cement quality are widely used in construction. These improve its material property, though these measures could not address problems completely. For these reasons mentioned above, Chinese engineers raised the new base- large-sized cement stabilized crushed stone[1].

When we use the road mixing device as the roadbed construction machine, its rotational speed is one of the most important factor to affect the road quality. So, its motor rotational velocity arouse people’s attention.

2. Large-sized cement stabilized crushed stone roadbed

2.1. Construction process

![Figure 1. Main construction process flow diagram](image-url)
The large sized cement stabilized crushed stoned consist coarse aggregates and interstitial material, which are 40-80mm large sized stones and 0.075-19mm macadam respectively. The main construction process is as follows: paving the 160-200mm coarse aggregates, paving 160-200mm interstitial material, mix, compaction and so on[2-3].

2.2. Mixing device
The design is based on the structure of cutlass, and the arrangement follows the multi-helices principle[4-5], and the detail parameters are showed in figure2.

| Name | A | B | C | D | E | F | G | H | I | J | R | α |
|------|----|----|----|----|----|----|----|----|----|----|----|----|
| Size (mm) | 10 | 35 | 15 | 16 | 340 | 30 | 60 | 50 | 40 | 230 | 30 | 130° |

- Angle of tool axis is between 54° and 85°
- Angle of tools in the same section is between 130° and 180°
- The distance of each section is between 40mm and 80mm

Figure 2. The parameters and structure of the mixing device

3. Rotational speed

3.1. Dispersion coefficient
The dispersion coefficient is regarded as the evaluation index of mixing quality, and the smaller the value is, the better mixing quality it has.

Given that the number of large sized stone and cement macadam is \( X \) and \( Y \), the total number of particles is \( Z = X + Y \) and the proportion of coarse aggregates is \( A = X \cdot Z^{-1} \), now the road is divided into some of the same grids, thus, the number of large sized stone and cement macadam in each grid is \( x_i \) and \( y_i \), the total number of particles is \( z_i = x_i + y_i \), the proportion of coarse aggregates in each grid is \( a_i = x_i \cdot z_i^{-1} \), the normalized proportion is \( \phi_i = a_i \cdot A^{-1} \), and the standard deviation is

\[
S_X = \sqrt{\frac{\sum_{i=1}^{n} (\phi_i - \bar{\phi})^2}{n - 1}} \quad (1)
\]

\[
\bar{\phi} = \frac{\sum_{i=1}^{n} \phi_i}{n} \quad (n = 1, 2, 3, \ldots) \quad (2)
\]

So, the dispersion coefficient of large sized stone is

\[
C_X = \frac{S_X}{\bar{\phi}} \quad (3)
\]

In a similar way, we could obtain the dispersion coefficient of cement macadam \( C_Y \).
3.2. The particle model in EDEM

In order to get accurate results, the parameters in EDEM should conform to the reality. Thus, the particle size should be close to the actual particle size, the particle shape should be close to the reality, and the particle contact model should be close to the contact principle of the actual particle.

In EDEM, 4~19mm spherical particles were used to simulate water-stabilized macadam particles; the contact force and plastic deformation need not be considered when they collide, so the simplified model of water-stabilized macadam particles are the hard ball model; the actual cement-stabilized macadam particles contain some moisture, leading to agglomeration of the particles, therefore, the hertz-Mindlin with JKR, which considers the surface energy, is adopted as the contact model for the water-stabilized macadam particles[6-7]. The water-stabilized macadam particles model are showed in figure3.

![Figure 3. Water-stabilized macadam particles model in EDEM](image1)

The particle size of large diameter gravel is 40~80mm; In the simulation process, the contact force and plastic deformation of the particles need not be considered, so the simplified model of water-stabilized crushed stone particles adopts the hard ball model; Hertz-mindlin (No slip) model is adopted for the contact model because the large-size gravel does not contain moisture; the shape of the simulation particles have a certain influence on the simulation results and the closer the shape of the simulation particles is to the shape of the actual aggregate, the more realistic the simulation results will be, so we use two different types of stone. The detailed model is showed in Figure 4.

![Figure 4. Large sized stone model in EDEM](image2)
3.3. Mixing device model in EDEM

As is showed in figure 5, the model consist three parts, which are the stone container, the cover shell and tools. The length*width*height of the container is 3000*1040*600(mm), and the mixing amplitude is 1000mm. When the simulation starts, two kinds of material particles are generated in the container, then the material is mixed by tools, and the cover shell prevent the material from spattering. During the simulation, particles will contact with the geometry, and hertz-Mindlin (No Slip) will be selected as the contact model according to the actual contact situation.

![Figure 5. The mixing device model in EDEM](image)

4. The simulation result

4.1. Parameters in the simulation

The table 1 shows the properties of cement stones, large sized stones and the steel, and the table 2 shows the contact parameters between various materials.

| Material                        | Poisson’s ratio | Shear modulus (Pa) | Density (kg/m³) |
|---------------------------------|-----------------|--------------------|-----------------|
| Cement stabilized crushed stone | 0.25            | 6.436e+08          | 2307            |
| Large sized stone               | 0.2             | 5e+07              | 2723            |
| Steel                           | 0.3             | 7e+07              | 7800            |

| Material                                | Restitution | Static friction | Rolling friction | Surface energy (j/m²) |
|-----------------------------------------|-------------|-----------------|------------------|-----------------------|
| Large sized stones and large sized stones| 0.5         | 0.9             | 0.15             | 0                     |
| Large sized stones and the steel        | 0.5         | 0.4             | 0.05             | 0                     |
| Cement stabilized crushed stones and cement stabilized crushed stones | 0.05 | 0.8 | 0.15 | 2 |
| Cement stabilized crushed stones and the steel | 0.2 | 0.8 | 0.5 | 0 |
| The steel and the steel                 | 0.7         | 0.2             | 0.1              | 0                     |

In the construction process, the pavement thickness of large-size gravel base is 160–200mm. Therefore, it is assumed that the total mass of large-size gravel particles is 960Kg, and then large-sized gravel particles are produced according to the mass. The grading mass of large-size gravel particles is shown in Table 3.

| Size (mm) | 31.5 | 31.6–37.4 | 37.6–52 | 54–62 | 64–80 |
|----------|------|-----------|---------|-------|-------|
| Mass percent | 5%   | 5%        | 25%     | 30%   | 35%   |
| Mass (kg) | 24   | 24        | 120     | 144   | 168   |
The proportion of large sized stones and interstitial material is 54:46, so the latter’s mass is 818kg. The table 4 shows the gradation of the interstitial material.

| Size (mm) | Mass percent | Mass (kg) | Number |
|-----------|--------------|-----------|--------|
| 4         | 14.06%       | 115.4     | 442288 |
| 8         | 34.76%       | 284.4     | 459848 |
| 12        | 20.86%       | 170.4     | 81636  |
| 14        | 14.76%       | 120.8     | 36456  |
| 18        | 15.56%       | 127.4     | 16536  |

The further work are setting the rotational speeds and the simulation time. The simulation time is 8s and the rotational speeds have four levels, which is 65 r/min, 90 r/min and 120 r/min and 150 r/min[8].

4.2. Result
According to the simulation parameters, four kinds of large sized particle are considered in the calculation, which are 32~37mm, 38~52mm, 53~62 and 63~80mm, and four kinds of cement stabilized crushed stones are selected, which are 8mm, 12mm, 14mm and 18mm. The figure 6 and figure 7 shows the dispersion of these materials.

(a) Dispersion coefficient of 32-37mm particle
(b) Dispersion coefficient of 38-52mm particle
(c) Dispersion coefficient of 53-62mm particle
(d) Dispersion coefficient of 63-80mm particle

Figure 6. Dispersion coefficient of large sized stones
As shown in Figure 6 and Table 5, for 32~37mm and 53~62mm particle, the dispersion coefficient is the smallest when the rotational speed is 150r/min, and the order of final dispersion coefficient at different rotational speeds is $C_{150} < C_{120} < C_{90} < C_{65}$. That means its value decreases gradually with the rise of rotating speed, which indicate the higher speed the device has, the more particles mix around the rotor axis and involve in the secondary mixing, the better quality the simulation could obtain. For 38~52mm and 63~80mm particles, the index is the smallest when the rotational speed is 120r/min, and the order of final dispersion coefficient is $C_{120} < C_{150} < C_{90} < C_{65}$. In other words, the value decreases...
at first then increases with the positive change of rotating speed. The reason is that the mixing speed is too high to lead to excessive mixing and segregation between two materials.

As shown in Figure 7 and Table 5, with the progress of the simulation, the dispersion coefficients of the water-stabilized macadam particles at first increases and then decreases, and the order of the value in different speed is \( C_{120} < C_{150} < C_{90} < C_{65} \). When the rotating speed rises from 120r/min to 150r/min, the index increases slightly, which is also caused by over-mixing and segregation, which destroys the quality of materials.

In conclusion, according to the dispersion value of these materials by simulation, when the rotor speed is 120 ~ 150 r/min, the discrete coefficient is the most stable and the smallest. Because the higher the speed could consume more energy and increase the abrasion of device, we accept 120r/m as the available speed.

5. Conclusion
In this paper, a new roadbed structure- Large-Sized Cement Stabilized Crushed Stone-is raised, which solve the road diseases effectively.

Based on EDEM, this paper builds the simulation models, and sets the total mass of simulation particles, contact parameters and geometry motion parameters.

In this paper, the mixing process of the pavement structure was simulated, and the mixing quality of various size particles in the simulation process was studied by taking the discrete coefficient as the evaluation index, and finally 120r/min was determined as the appropriate speed, which could ensure the construction quality under the premise of less power consumption and tool wear.

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