Experimental Study on Performance and Base Compaction of Cement Stabilized Macadam with Vibration Mixing

Bingchen Wang*

CCCU Fourth Highway Engineering Co., Ltd., 100026, Beijing, China
*Email: 56928514@qq.com

Abstract. In order to improve the engineering application prospect of vibration mixing cement stabilized macadam, the performance of vibration mixing cement stabilized macadam and the compaction performance of base course are studied in this paper. The proportioning scheme of cement crushed stone stabilized soil is designed, and the proportioning of cement stabilized crushed stone is established by compaction method and testing compressive strength. Through the indoor test, the 7-day and 28-day unconfined compressive strength of ordinary mixing and vibration mixing are compared. The results show that the 7-day strength is increased by 38.6% and the 28-day strength is increased by 32.5%. The compaction test of ordinary mixing and vibration mixing cement stabilized macadam base is carried out. The research results show that the compactness of vibration mixing cement stabilized macadam after rolling for one time and final rolling is increased by 1.5% and 3.1% respectively. The research shows that the improvement of compaction technology of cement stabilized soil pavement under vibration mixing can improve the performance index of pavement and can be popularized.

1. Introduction
Cement stabilized macadam is a common material in highway construction, and its quality directly affects the construction quality of foundation layers such as roads and airports [1-2]. In the construction of cement stabilized macadam, it is easy to appear base cracks caused by uneven materials, uneven mixing of mixture and segregation in transportation and paving. Therefore, strengthening the internal structure of cement stabilized macadam and improving the quality standard of cement stabilized macadam base have become the long-term goal of high-grade pavement construction. For a long time, many scholars have been engaged in the performance improvement of cement stabilized macadam. Shen et al. found that the autogenous shrinkage and cracking deformation of cement concrete have been greatly improved with the increase of fly ash content [3]. Divanedari et al. prepared cement mortar using cement with different fineness, and then studied the influence of cement fineness on the macroscopic and microscopic properties of cement mortar. The study found that the finer the cement particles, the higher the compressive strength and the smaller the porosity of cement mortar [4]. The research on the improvement of cement stabilized macadam road performance at home and abroad mainly focused on the grading of raw materials and the molding of pavement, but the research on the preparation and construction of mixture is not enough. Stirring plays a vital role in improving the road performance of cement stabilized macadam. Yao and Zhao improved the blades of ordinary horizontal shaft stirring equipment to strengthen the microstructure and mechanical properties of cement stabilized macadam [5-6], and achieved obvious results. In recent years, vibration mixing technology and mixing equipment have developed rapidly and entered the stage of industrial application [7-8]. The performance of cement stabilized macadam based on vibration mixing has been
significantly improved, and vibration mixing has been widely studied and put into engineering applications.

In the design and application of vibration mixing research, laboratory testing is more common to explore the performance of cement stabilized macadam, but the influence of construction technology on the performance of cement macadam base hasn’t been completely established. Therefore, this paper determines the proportion of cement stabilized macadam through the indoor test, and then studies the unconfined compressive strength to verify the superiority of vibration mixing. the influence of different compaction processes on the performance of semi-rigid base of cement stabilized macadam by ordinary mixing and vibration mixing is further studied by comparing the compaction process test, which provides the basis for the engineering application of vibration mixing cement stabilized macadam.

2. Methodology

2.1. Raw Materials
In this experiment, P•C32.5 cement from Shaanxi Yaoxian Co., Ltd. was used as cement, and limestone crushed stone produced by a stone mine in Xi’an was used as aggregate. According to the requirements for the base in JTG F20-2015 “Highway Pavement Base Construction Technical Rules”, the aggregate specification is specified in five sections: 19-26.5mm (1#), 9.5-19mm (2#), 4.75-9.5mm (3#), 2.36-4.75mm (4#) and 0-2.36mm (5#). Clean groundwater was used for mixing water. The aggregate gradation of cement stabilized macadam was shown in table 1. The maximum dry density and moisture content of the cement stabilized macadam were determined by the heavy compaction experiment. And the unconfined compressive strength specimens were tested. It was found that the cement dosage was 4.6%, the optimum moisture content was 5.5% and the maximum dry density was 2.396g/cm³. Table 2 shows the final cement stabilized macadam ratio.

| Mesh size (mm) | 26.5 | 19.0 | 9.5 | 4.75 | 2.36 | 0.6 | 0.075 |
|---------------|------|------|-----|------|------|-----|-------|
| Gradation composition (%) | 91   | 79   | 59  | 38   | 24   | 11.5| 1.5   |
| Specification requirement (%) | 100-89 | 97-71 | 67-47 | 48-28 | 35-17 | 22-8 | 7-0  |

Table 2. Proportion of cement stabilized macadam

| Proportion of cement stabilized macadam (%) | Optimum moisture content (%) | Cement dosage (%) | maximum dry density (g/cm³) |
|-------------------------------------------|-----------------------------|-------------------|---------------------------|
| 26.5~19~9.5~4.75~2.36~0                   | 5.5                          | 4.6               | 2.396                     |
| (mm) (mm) (mm) (mm)                      |                             |                   |                           |
| 23                                        |                             |                   |                           |
| 30                                        |                             |                   |                           |
| 20                                        |                             |                   |                           |
| 6                                         |                             |                   |                           |
| 21                                        |                             |                   |                           |

2.2. Test Method
In this experiment, the stirring of cement stabilized macadam was completed by vibration mixing equipment (Xuchang Detong DT6002BT, 600 tons/hour). The equipment can realize the preparation of cement stabilized macadam by the ordinary and vibration mixing process. According to “Highway Engineering Inorganic Binder Stabilized Material Test Procedures-JTG E51-2009”, the required test samples were prepared and cured in a standard environment (20°C±2°C, humidity≥95%). The performances (7d, 28d unconfined compressive strength) were tested in accordance with regulations. In addition, two double-drum rollers, two single-drum rollers (XS222J, excitation force greater than 30t) and rubber-drum rollers (XP302, 30t) were selected to conduct compaction tests on the base according to the requirements in the construction specifications.
3. Results and Discussion

3.1. Unconfined Compressive Strength of Cement Stabilized Macadam

Through laboratory tests, the comparison of unconfined compressive strength of cement stabilized macadam based on ordinary and vibration mixing is shown in table 3. It can be seen from the table that the 7d unconfined compressive strength of the samples is 4.4 MPa by ordinary mixing and 6.1 MPa by vibration mixing, which both meet the standard requirements. Compared with the two methods, the strength by vibration mixing increases by 38.6%. The test results show that the vibration mixing can strengthen the mechanical properties of the base pavement, indicating that the application of vibration mixing in cement stabilized macadam has more advantages and wider engineering application.

Table 3. Indoor 7d unconfined compressive strength test results.

| Mixing type | Cement content (%) | Curing period | Average unconfined compressive strength (Mpa) | Coefficient of variation (%) |
|-------------|--------------------|---------------|---------------------------------------------|-----------------------------|
| Ordinary    | 4                  | 7d            | 4.4                                         | 9.8                         |
|             |                    | 28d           | 6.43                                        | 9.1                         |
| Vibration   | 4                  | 7d            | 6.1                                         | 4.4                         |
|             |                    | 28d           | 8.52                                        | 5.3                         |

3.2. Compaction Performance of Cement Stabilized Macadam by Vibration Mixing

3.2.1. Compaction Degree and Strength of Cement Stabilized Macadam. Compaction is the process that the internal friction and cohesion of the compacted materials are overcome, the solid particles are displaced and close to each other, the air and water between the solid particles are reduced, and last the compacted material becomes dense. It is also the last process in pavement construction, and the compaction effect is the most important indicator for judging the pavement performance. In this test, vibration mixing cement stabilized macadam base are compacted by three compaction processes: initial compaction, re-compaction and final compaction. At initial compaction stage, the rubber wheel roller and double steel wheel roller are used. the rubber wheel roller is ahead of the double steel wheel roller, both of them are followed by the paver, and the rolling times are not less than twice. In re-compaction period, a heavy single-drum vibratory roller is selected to compact the base using small excitation force once and large excitation force not less than 4 times, then small excitation force once and large excitation force not less than twice. And last, the road is rolled 2-3 times by rubber roller or combination of rubber roller and double steel roller at final compaction stage. Table 4 shows the comparison of compactness and 7d unconfined compressive strength of the two kinds of mixing cement stabilized macadam after initial and final compaction. From table 4, it can be seen that the difference of compaction degree between the two mixing processes is 1.5% after initial compaction and 3.1% after final compaction. The compactness of vibration mixing cement stabilized macadam is higher. Compared with ordinary mixing, the average 7d unconfined compressive strength of vibration mixing has increased by 41.9%. The compaction test results indicate that this difference is mainly determined by the basic properties of the two mixtures. The cement hydration in the vibration mixing mixture is more sufficient and the cement particles are more dispersed. Therefore, in the same compaction times, the compaction degree of the vibration mixing cement stabilized macadam base is higher than that of the ordinary mixing, and the compressive strength is also higher.

Table 4. Compaction performance of cement stabilized macadam under two mixing processes.

| Mixing type | Compactness (%) | Average of 7d unconfined compressive strength (MPa) |
|-------------|-----------------|-----------------------------------------------|
| Initial     | Final           |                                              |
| Ordinary    | 87.1%           | 99.4                                         | 4.2                           |
| Vibration   | 88.6%           | 102.5                                        | 5.96                          |
3.2.2. Pavement Construction Example. The proportion of cement concrete in the test section is used to prepare cement stabilized macadam by vibration mixing. In pavement construction, the relevant standards follow the “Highway Pavement Base Construction Technical Rules JTG F20-2015”, and the stable material paver with paving power not less than 120 kW is used to pave the mixture. The paving speed should be controlled at 1.5 m/min - 2.0 m/min, and the paving should be as uniform and uninterrupted as possible. The thickness and elevation of the base should be strictly controlled to ensure that the transverse slope of the arch meets the design requirements. Compaction process is the process described above, the initial compaction: pavement is compacted 1-2 times by a 26-ton rubber wheel and a 22-ton double steel roller with the speed of 1.5~1.7km/h. Re-compaction: rolling was carried out by a 26-ton heavy vibratory roller with rolling speed of 1.8-2.2 km/h for 6 times. Final compaction: Finally, the pavement is rolled by a 30T rubber roller to the surface without trace. As shown in figure 1, the cement stabilized macadam base and its performance in the construction example are shown. The vibration mixing cement stabilized macadam mixture has almost no segregation, and the surface is overall uniform. The comparison results show that after the ordinary mixing of the mixture is completed, the difference between the macro- and micro-structures in the mixture has been formed, and finally it is conducted on the formed cement stabilized macadam pavement.

![Figure 1. Cement stabilized macadam base and its performance in engineering application.](image)

4. Conclusion
In this paper, the performance and compaction performance of cement stabilized macadam by vibration stirring and ordinary stirring are compared and studied. The main conclusions are as followed:

1) Compared with ordinary mixing, the 7d compressive strength of vibration mixing cement stabilized macadam increased by 36.4%, and the 28d compressive strength increased by 32.5 %;

2) The compaction tests of cement stabilized macadam by vibration mixing were compared between the two compaction processes, and it was found that the difference of compaction degree between the two processes after final pressure was 3.1%, and the difference of 7d compressive strength was 6.67 %. Moreover, the compaction of vibration mixing cement stabilized macadam is more dense, and the segregation was reduced.
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