STUDY ON THE APPLICATION OF VIBRATION MIXING FOR CEMENT STABILIZED CRUSHED STONE

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ABSTRACT

Cement stabilized crushed stone has become an indispensable material in the road structure. But the cement stabilized crushed stone has some serious defects. Cement based materials are very sensitive to the temperature and have relatively weak flexural performance, which can cause reflection cracks, and which will drastically shorten the life of the pavement. Widespread research has focused on this problem. Vibration mixing was used to place the cement concrete, as this can improve the anti-cracking ability, compressive strength and temperature/drying shrinkage performance by improving the homogeneity of the cement. In this paper, vibration mixing method was compared with normal mixing. Different cement contents (2%, 3%, 4%, 5%) were tested to determine how vibration affects the mechanical performance and temperature/drying shrinkage performance of the cement stabilized crushed stone. Results show that vibration mixing method can remarkably increase the compressive strength and reduce the temperature shrinkage which in turn can reduce the cement content and prevent the cracks in the cement stabilized crushed stone.

Key words: vibration mixing; shrinkage cracking; cement

1. INTRODUCTION

In China, cement stabilized crushed stone has been widely used in asphalt highway pavements. It has important advantages such as high load carrying capacity, better early strength etc (Sha, 2008). However, its cracking causes serious problems that have adverse effects on the asphalt pavement which dramatically shorten the service life of the asphalt pavement (Jiang, 2001). Researchers have tried to reduce the crack damage (Zhang, 2003). The vibration mixing method was started in 1930s (Yang, 2002), as it can improve the strength and durability of the cement concrete. However, cement stabilized crushed stone is not the mainstream material of a pavement, and this method was not applied to the cement stabilized crushed stone operation process. Research on vibration mixing equipment started in 1990s in China, but it has not received enough attention. The full-size vibration mixing equipment is shown as Figure 1. It is based on the forced mixer concept, with an additional vibration motor causing the mixer shaft to vibrate while it is rotating. The increased collision energy of the cements and aggregates caused by the vibration ensure that the cement is dispersed homogeneously in the mixture.

Figure 1. Full-size vibration mixing equipment

As it is a potential method for reducing the cracking distress of the cement stabilized crushed stone, more researchers are focusing on this method. Zhang (2007) found that the vibration mixing method can accelerate the aggregate mixing and improve the homogeneity of cement, water and fine aggregates. It can thus improve the utilization efficiency of the cement as well as reduce the possibility of cracking. The objective of this paper is to quantify how the vibration mixing method affects the properties of cement stabilized crushed stone through a laboratory study.

2. MATERIALS AND EXPERIMENTS

2.1 Materials

Ordinary Portland cement C32.5 was used in the experiments. Its technical properties are shown in Table 1.

Table 1. Technical indices of cement used in the experiments.

No.	Test		Results
1	Water requirement for normal consistency（%）		26.4
2	Setting time（min）	initial set	254
		final set	376
3	Flexural strength（MPa）	3 days	5.2
		28 days	7.4
	Compressive strength（MPa）	3 days	20.4
		28 days	34.2

Limestone was used as fine and coarse aggregates. Its crushing strength value is 16.04%. The density and gradation of the limestone used is shown in Tables 2, 3 and 4.

Table 2. Density of the coarse limestone aggregate.

Size fraction（mm）	Average relative density			Average water absorption（%）
	Apparent	Surface dry	Bulk density	
19-26.5	2.765	2.723	2.700	0.877
9.5-19	2.746	2.718	2.702	0.601
4.75-9.5	2.702	2.572	2.496	3.066

Table 3. Density of the fine aggregate.

Size fraction（mm）	Average relative density	
	Relative	Absolute (g/cm^{-3})
2.36-4.75	2.613	2.609
0.6-2.36	2.788	2.784
0.075-0.6	2.808	2.803
< 0.075	2.813	2.806

Table 4. Gradation of crushed limestone aggregate.

Type	Percentage passing（%）						
	31.5mm	19mm	9.5mm	4.75mm	2.36mm	0.6mm	0.075mm
Envelope	100	90-100	60-80	29-49	15-32	6-20	0-5
Target value	100	95	70	39	23.5	13	2.5

2.2 Experiments

2.2.1 The optimum water content and maximum dry density

The optimum water content and maximum dry density of different cement contents were determined by the vibration compaction method and the results are shown in Table 5.

Table 5. The optimum water content and maximum dry density.

Cement content (%)	Optimum water content (%)	Maximum dry density (g/cm^3)
2	4.20	2.392
3	4.31	2.410
4	4.56	2.412
5	4.77	2.430

2.2.2 Preparation of the cement stabilized crushed stone specimens

Four different cement contents (2%, 3%, 4%, 5%) and two kinds of mixing methods were used to make the cylindrical specimens of 150mm diameter × 150mm high. The vibration mixing method had a frequency of 40Hz and the mixing time was 20s. All the specimens were compacted by the static pressure compaction method. Specimens were cured under standard conditions of $20^{o}C \pm 2\,^{o}C$ temperature and relative humidity greater than 95% after demoulding. The unconfined compressive strength was tested at the age of 7, 28, 60 and 90 days. Beam specimens of 100mm × 100mm × 400mm were used to test the shrinkage coefficient. The shrinkage test began on the third day and the temperature shrinkage test started at the age of 90 days.

2.2.3 Unconfined compressive strength test

The unconfined compressive strength was determined according to the standard procedure in specification JTG E51-2009, method T0805-1994(HRIMC, 2009).

2.2.4 Shrinkage coefficient test

After 3 days under water curing, the specimens were saturated. The surface was dried and the samples were placed in the shrinkage test equipment as shown in Figure 2. The micrometer gauge readings and sample weights were taken every 24 hours, for 36 days.

Figure 2. Shrinkage test equipment.

2.2.5 Temperature shrinkage coefficient test

In the temperature shrinkage test the specimens were immersed in water for 24h, and kept in an oven at 105 ^{o}C for at least 10h to12h until the temperature was constant. Thereafter the temperature shrinkage test was conducted under dry conditions. Measurements were taken at seven temperatures, from a maximum temperature of 40^{o}C to the minimum temperature of -20^{o}C. The temperature was reduced at a rate of 10^{o}C /30min until the next test temperature was reached. The temperature was then maintained for 3h, and the deformation data was recorded every two minutes.

3. RESULTS AND DISCUSSION

3.1 Unconfined compressive strength test results

Unconfined compressive strength test results are shown in Tables 5 and 6. In the tables, $\bar{R}_{c(v)}$ means unconfined compressive strength, CV means coefficient of variation, $\bar{R}_{c(v)0.95}$ means the 95 percentile strength.

Table 5. Unconfined compressive strength test results of normal mixing

Cement content（%）	Test item	Age（d）			
		7	28	60	90
2	$\bar{R}_{c(v)}$（MPa）	2.71	3.18	3.52	3.59
	C_V（%）	14.98	12.82	12.94	11.53
	$\bar{R}_{c(v)0.95}$（MPa）	2.04	2.67	2.95	3.02

3	$\bar{R}_{c(v)}$（MPa）	3.73	4.64	5.29	5.44
	C_V（%）	10.33	9.35	11.71	10.7
	$\bar{R}_{c(v)0.95}$（MPa）	3.09	3.92	4.44	4.58
4	$\bar{R}_{c(v)}$（MPa）	4.63	6.06	6.93	7.49
	C_V（%）	10.55	11.2	11.28	11.27
	$\bar{R}_{c(v)0.95}$（MPa）	3.83	4.94	5.65	6.10
5	$\bar{R}_{c(v)}$（MPa）	5.55	7.21	8.11	8.28
	C_V（%）	10.30	12.33	11.45	10.48
	$\bar{R}_{c(v)0.95}$（MPa）	4.61	5.98	6.72	6.85

Table 5. Unconfined compressive strength test results of vibration mixing.

Cement content（%）	Test item	Age（d）			
		7	28	60	90
2	$\bar{R}_{c(v)}$（MPa）	3.07	3.59	3.88	3.96
	CV（%）	11.44	10.39	9.82	10.78
	$\bar{R}_{c(v)0.95}$（MPa）	2.44	2.97	3.27	3.41
3	$\bar{R}_{c(v)}$（MPa）	4.28	5.33	6.04	6.17
	CV（%）	11.09	8.92	9.73	9.74
	$\bar{R}_{c(v)0.95}$（MPa）	3.50	4.55	5.08	5.18
4	$\bar{R}_{c(v)}$（MPa）	4.78	6.96	7.90	8.09
	CV（%）	9.73	11.21	10.20	9.85
	$\bar{R}_{c(v)0.95}$（MPa）	4.43	5.68	6.32	6.46
5	$\bar{R}_{c(v)}$（MPa）	5.83	8.28	9.26	9.47
	CV（%）	9.42	10.33	9.30	9.38
	$\bar{R}_{c(v)0.95}$（MPa）	5.34	6.87	7.69	7.85

From the unconfined compressive strength test results, it was found that vibration mixing can improve the compressive strength at all ages and reduce the coefficient of variation.

Comparing the compressive strength with different cement contents at normal and vibration mixing methods, the vibration mixing can use 1% cement less than the normal mixing to achieve the same strength. It is well known that high cement content may be the main reason for excessive cracking, and thus vibration mixing can provide a new way to improve the anti-cracking performance of the cement stabilized crushed stone.

3.2 Shrinkage coefficient test

The deformation and weight loss of the specimens were recorded to calculate the shrinkage coefficient by the following procedures:

dehydration rate during the i-th time (%): $\omega_i = (m_i - m_{i+1}) / m_p$ (1)

deformation during the i-th time : $\delta_i = X_i - X_{i+1}$ (2)

strain during the i-th time (%): $\varepsilon_i = \delta_i / l$ (3)

shrinkage coefficient during the i-th time (%): $\alpha_{di} = \varepsilon_i / \omega_i$ (4)

shrinkage coefficient : $$\alpha_d = \frac{\sum \varepsilon_i}{\sum \omega_i}$$ (5)

where :

m_i—The weight of the specimen after the i-th time (g);

m_p —The weight of the specimen after drying to constant weight (g);

X_i—micrometer gauge reading after the i-th time (mm);

l—length of the specimen (mm)

The strain and shrinkage results are shown in Figures 3 and 4. Note that VM means vibration mixing and NM means normal mixing.

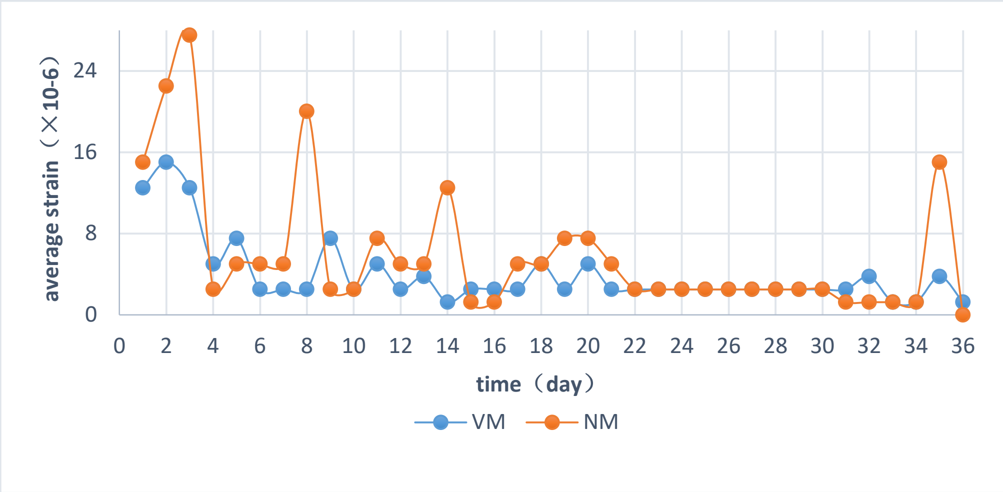

Figure 3. The average strain of the specimens.

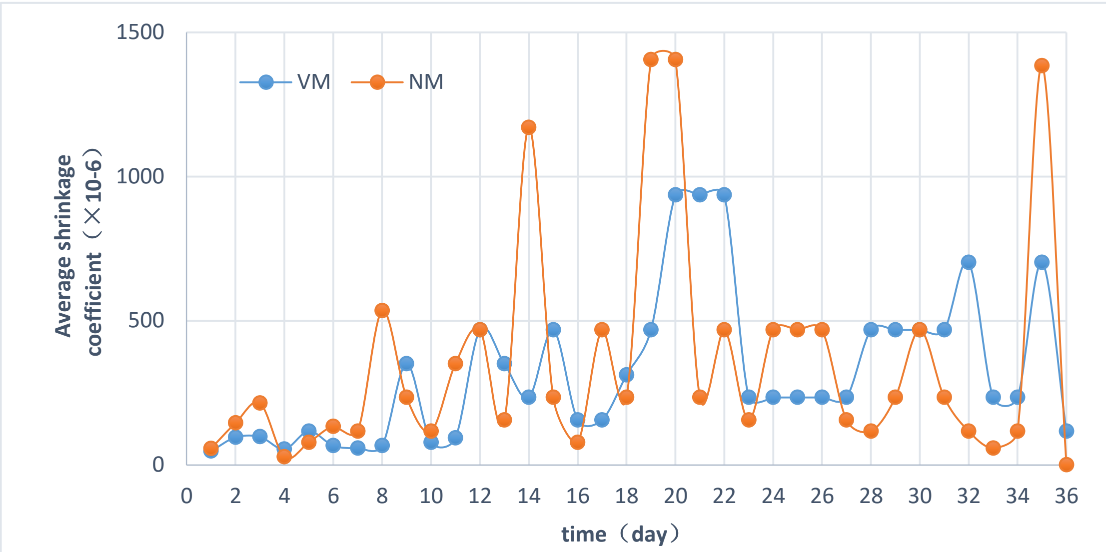

Figure 4. The average shrinkage coefficient of the specimens.

From the results it is evident that the VM group average strain is lower than for the NM group which means VM group has better shrinkage performance. Because all the specimens were tested under the normal natural environment of temperature and humidity to simulate the real construction environment, the two curves have irregular fluctuations. Nevertheless, under this test condition, the total strain and shrinkage of the VM curve is nearly half of NM curve, and it is concluded that vibration mixing method can effectively prevent the shrinkage cracking of cement stabilized crushed stone during drying.

3.3 Temperature shrinkage coefficient test results

The temperature shrinkage coefficient is calculated by the following formulas

Temperature shrinkage strain : $\varepsilon_i = \frac{l_i - l_{i+1}}{L_0}$ (6)

Temperature shrinkage coefficient : $\alpha_t = \frac{\varepsilon_i}{t_i - t_{i+1}}$ (7)

where :

l_i—the total strain during the i-th temperature interval (mm) ;

L_0—the length of specimen at the beginning (mm) ;

t_i—the i-th temperature interval (℃)

Figure 5 shows that both vibration mixing and normal mixing show the same but irregular trends in average shrinkage for the different temperature intervals. It is worth noting that the temperature shrinkage coefficient of vibration mixing at all the temperatures is lower than normal mixing, which means vibration mixing slightly reduced the shrinkage of cement stabilized crushed stone when temperature is changing.

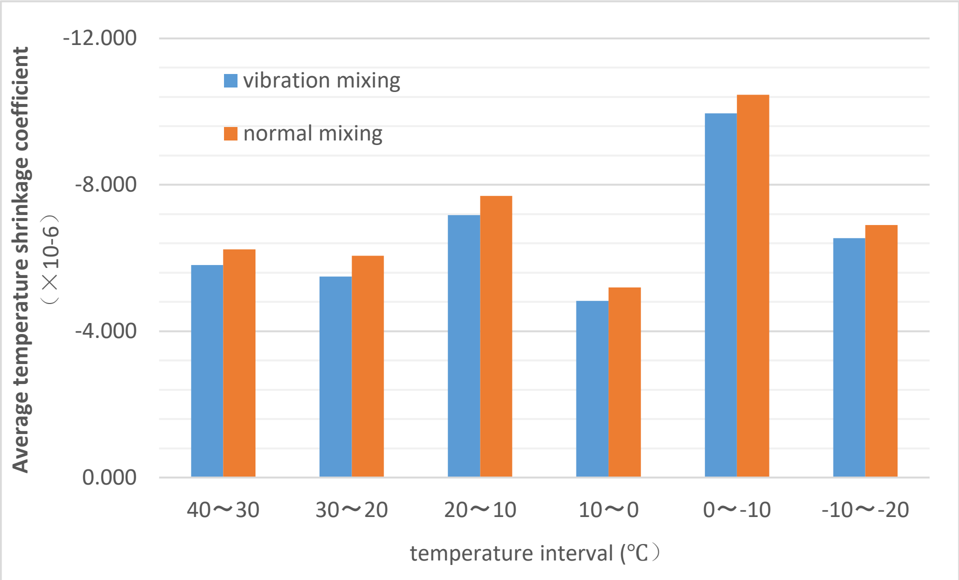

Figure 5. Average temperature shrinkage coefficient for different temperature intervals.

4. CONCLUSIONS

The vibration mixing method can improve the efficiency of cement use by improving the uniformity of cement dispersion. Therefore, the vibration mixing can reduce the cement content and enhance the compressive strength, reduce the likelihood of severe cracking.

The vibration mixing method can reduce the drying shrinkage when cement stabilized crushed stone dries out, and this will reduce the risk of drying cracking.

The temperature shrinkage was also found to decrease by vibration mixing although the decrease is small. Since the temperature shrinkage characteristics of cement stabilized crushed stone is difficult to reduce, the vibratory mixing could also reduce the shrinkage cracks as a result of temperature changes.

REFERENCES

Highway Research Institute of Ministry of Communications, 1979, “Test Methods of Materials Stabilized with Inorganic Binders for Highway Engineering (JTG51-2009)”, pub China Communications Press, PRC, p.96 (2009)

Jiang, YJ, 2001, Study on the Study on Shrinkage Crack of Cement Stabilized crushed stone Base, Chang’an University, Academic dissertation.

Sha, AM, 2008, Structural Characteristics of Semi-rigid Base Course Material, China Journal of Highway and Transport, 21 p.1.

Yang, HH, 2002, Evaluation Method for Anti-cracking Performance of Semi-rigid Base Course. Journal of Chang’an University (Natural Science Edition), 22 p.13.

Zhang, GZ, 2003, the Study on Crack Resistance Cement-Stabilized Macadam Materials Mix Design Methods. Shanxi Science& Technology of Communications, (S2), p.4.

Zhang, LQ, 2007, Study on the mechanism of cement vibration mixing and industrial application, Chang’an University, Academic dissertation.