Zhao *et al. Int J Concr Struct Mater* (2022) 16:16
https://doi.org/10.1186/s40069-022-00505-z

International Journal of Concrete Structures and Materials

RESEARCH Open Access

Impact of Mixing Methods and Cement Dosage on Unconfined Compressive Strength of Cement-Stabilized Macadam

Kaiyin Zhao, Lijun Zhao*, Jinru Hou, Zhongxu Feng and Wenzhi Jiang

Abstract

The technology of vibratory mixing has been applied to improve the compressive strength of cement-stabilized macadam (CSM). The aim of this study is to investigate the effect of vibration acceleration and cement dosage on the unconfined compressive strength and density of CSM. The mixtures with four cement dosages (2%, 3%, 4%, and 5%) were prepared by conventional mixing (0 g) and vibratory mixing (1 g, 2 g, and 3.5 g). The unconfined compressive strength was tested under different mixing methods. And the microstructure of CSM was analyzed by scanning electron microscope. The results indicate that samples using vibratory mixing have higher strengths, lower coefficient of variation, and denser microstructures, compared with the conventional compulsory mixing. Compared with 15% in conventional mixing, the strength variable coefficient of CSM is less than 10% in the vibratory mixing method. As the cement dosage and the vibration acceleration increase, the unconfined compressive strength increases. However, cement dosage has a more significant influence on improving the unconfined compressive strength than the mixing method. With the increase of every 1% in cement dosage, the 7-day strength of conventional mixing and in vibratory mixing average increased by 59% and 38%, respectively. However, the maximum improvement rate of the UCS value is 20–56.7% when vibration acceleration increased from 0 to 1 g. Especially when cement dosage is high, the effect of vibratory mixing on improving strength is limited. Besides, vibratory mixing reduces the original cement dosage by over 1.6% with the qualified unconfined compressive strength at vibration acceleration of 2 g, which is recommended in construction practice.

Keywords: cement stabilized macadam (CSM), unconfined compressive strength, vibratory mixing, cement dosage

1 Introduction

Cement stabilized macadam (CSM) has been widely used as the asphalt pavement base in all kinds of roads and expressways in China, owing to its high mechanical performance, anti-erosion property, and crack resistance (Sha, 2008; Zheng et al., 2018). As a major bearing layer of pavement structures, the unconfined compressive strength (UCS) value is the main property of CSM, which is strongly related to the stiffness, fatigue resistance, and durability of CSM (NCHRP, 2013). Therefore, the 7-day UCS value is the leading indicator in the construction quality control of CSM base in the relevant Chinese standards (JTG/T F20-2015). UCS value of CSM is affected by raw materials, mix proportion, mixing method, compaction standard, and curing condition, etc. Usually, cement dosage plays an important role. The maximum dosage of cement to the whole weight of CSM is generally not more than 6% (JTG D50-2017, 2017). Lower cement content is harmful to the water stability and load resistance of CSM. To increase the mechanical strength and stability of CSM, a higher cement dosage is necessary. Zhang et al. (2010) studied the effect of

*Correspondence: zhaolj@chd.edu.cn
Key Laboratory of Highway Construction Technology and Equipment of Ministry of Education, School of Construction Machinery, Chang'an University, Xi'an 710064, China
Journal information: ISSN 1976-0485 / eISSN 2234-1315

different cement contents (4%, 5%, 6%, and 7%) on the flexural properties of CSM with polypropylene fiber and found that the flexural strength increased as cement content increased. The work of Du et al. (2019) showed that the UCS of CSM grew with an increase of cement content and the increase rate of UCS is higher as the cement content increases from 4.0 to 4.5% than from 3.5 to 4.0%. Similar results are also found in another research (Deng et al., 2019, Guan et al., 2018). However, the CSM with higher cement content is prone to cracking, which is harmful to the structural strength of CSM and reduced the quality of roads (Li et al., 2017). To solve these issues, researchers try to add admixture to improve the mechanical properties and anti-crack properties of CSM, such as polypropylene fiber (Zhang & Li, 2009), crumb rubber (Sun et al., 2020), asphalt emulsion (Du, 2019), etc. Nevertheless, there is a limitation on the use of these special materials somewhere and more admixture means more complicated materials. This work tries to focus on the mixing method of CSM and explore the better mixing method to improve the mechanical performances of CSM.

Mixing is an essential element in the production of cement-based materials. The mixing method includes the type of mixer, mixing time, mixing speed, mixing sequence, etc., which greatly influence the properties of cement-based materials. Different mixers have different mixing principles, such as drum mixer, pan mixer, horizon mixer, etc. (Beitzel et al., 2003; Ferraris, 2001). Hemalatha et al. (2015) found that Erich mixer obtained higher compressive strength of self-compacting concrete (SCC), Chang and Peng (2001) showed that the high-performance concrete using horizontal two-shaft mixer had higher compressive strength. However, there is a low mixing efficiency area and low mixing intensity still existing in the present mixing technology. Also, variation of mixing blade and mixing speed affects the properties of a cement-based material. Yao et al. (2013) investigated the effect of different mixing blades on the compressive strength of concrete and found that using a double-blade two-shaft mixer gained higher strength than an ordinary biaxial mixer. The single scraper spiral blade can achieve higher compressive strength than the double scraper spiral blade and spade shape blade in a two-shaft mixer (Zhang & Feng, 2011). Mixing speed varies with different mixed materials, such high mixing speed is beneficial to disperse the fine powder or mix the mixture without coarse aggregate (Abd EI-Motaal et al., 2020), whereas the mixture with coarse aggregate usually needs a lower mixing speed (≤ 100 rpm) (Zhao et al., 2020). Besides, as an increase of requirement of cement-base materials, more components (silica fume, limestone filler, etc.) and admixture (water reducer, etc.) are added to the mixture to improve the properties, leading to longer mixing time needed (Chopin et al., 2004; Vandanjon et al., 2003). Therefore, higher mixing efficiency and better mixing technology are necessary to explore.

In recent years, the vibratory mixing method has been applied to improve the mechanical performance of different cement-based materials in China, such as steel fiber-reinforced concrete (SFRC) (Zheng et al., 2018), high-strength lightweight aggregate concrete (HSLWAC) (Luo et al., 2020; Xiong et al., 2019), and high-strength concrete (HSC) (Zhao et al., Zhao, Jiang, et al., 2019), especially cement-stabilized macadam (CSM) (Wang & Tan, 2021). Before this, the application of vibration in cement-based materials has proved its advantages on consolidating mixture (Liu et al., 2016; Zemam, 2020), reducing the internal friction force of fresh concrete (Safawi et al., 2004), and eliminating the voids and entrapped air present in the mixture (Koch et al., 2019). Other vibratory mixing methods, like using an immersion vibrator in the middle stage of mixing when the mixer was stopped, are also studied to improve the properties of cement-based materials., Juradin et al. (2014) found that the introduction of vibration in the mixing stage provided an improvement to the workability of fresh concrete without affecting compressive strength, while Jia et al. (2019) found an improvement in compressive strength and frost-resistance. The reason for different strength results is the difference in the numbers of vibration and vibration methods. And in the test conducted by Juradin and Peng Jia, vibration and mixing did not take effect simultaneously. The vibratory mixing method used in this work involves a patented vibratory (Zhang, 2018) mixer that blends the mixture under vibration by introducing mechanical vibration to an ordinary two-shaft mixing process. The vibratory force generated by a vibration exciter on the mixer is applied to the mixture with an amplitude–frequency combination. For the research on the UCS of CSM, there is evidence that vibratory mixing can increase the UCS of CSM than ordinary mixing. For instance, Lv et al. (2020) investigated the effect of vibratory mixing on the mechanical properties under different loading modes and found that the vibration mixing method increased the UCS of CSM by 14%. Similar results are also observed in the research of Bi et al. (2017), Dong et al. (2018), Li et al. (Li, Wei, et al., 2021) and Lv et al. (2021) which mainly focus on the comparative study between vibratory mixing and ordinary mixing under different cement dosage or load conditions. For process parameters during the vibratory mixing, only a few attentions are conducted. For example, Zhao et al. (2021) prepared the concrete with different mix proportions using vibratory mixing and gained the result that vibration acceleration at 2 g and vibration amplitude of

0.82 mm is enough to have high compressive strength for high w/c ratio concrete, but higher vibration energy is necessary for low w/c ratio concrete. Zhao, Zhao, et al. (2019), Zhao, Jiang, et al. (2019)) obtained the reasonable parameters of vibratory mixing, including mixing time for 40 s, vibration frequency at 40 Hz, and mixing speed at 2.5 m/s, using an orthogonal experiment. Zhao, Zhao, et al. (2019), Zhao, Jiang, et al. (2019)) proposed a mixing method that combined vibratory mixing with three-step mixing technology, resulting to improve greatly the compressive strength of high-strength concrete (HSC). And Xue (2016) also attained the optimum unconfined compressive strength of CSM by mixing for 40 s. However, the current investigation on the vibration acceleration of vibratory mixing with various cement dosages is quite limited.

The main purpose of this work is to study the effect of vibration acceleration on the performances of cement-stabilized macadam and try to find optimum vibration parameters to reduce the cement dosage without decreasing the strength. Therefore, three vibration accelerations of vibratory mixing were used to prepare the CSM with four cement dosages. The UCS (UCS) at 3 days, 7 days, 14 days, water absorption, and dry density with both vibratory mixing and conventional mixing were conducted under different mixing methods and cement dosage. Moreover, the SEM images were evaluated the microstructure of CSM. Then, the relationship between the 7-day UCS value and density under vibratory mixing and conventional mixing was revealed. This work provides a reference for producing the CSM using vibratory mixing and a useful way of reducing cement consumption.

2 Experimental Details

2.1 Raw Materials

In this paper, the Complex Portland cement with a strength grade of 32.5 was used, and its chemical and physical properties are shown in Table 1. Limestone macadam produced in Shaanxi Province of China was used as aggregates; it had specifications of 0 ~ 5 mm, 5 ~ 10 mm, 10 ~ 20 mm, and 20 ~ 30 mm. Skeleton dense-graded aggregates are able to form interlocked denseness effectively, providing the mixture with better mechanical performance, and therefore recommended in base courses of expressways and first-class highways in China (Jiang et al., 2010). Skeleton dense gradation was also used in this study. Urban tap water was used for mixing. All the raw materials met the requirements of the *Technique Guidelines for Construction of Highway Roadbases* (JTG/T F20-2015).

2.2 Aggregate Gradation and Mix Proportion

As shown in Fig. 1, the gradation was determined according to the middle value of macadam gradation specified by JTG E42-2005 (2005). The cement with different dosage (i.e., 2%, 3%, 4%, and 5% by mass) and gradation of aggregate: $m_{0-5} : m_{5-10} : m_{10-20} : m_{20-30} = 30 : 13 : 34 : 23$ were used to prepare CSM. Moisture content with different cement dosages was determined by the optimal water consumption in the condition of maximum dry density of the mixture obtained by a standard compacting test following JTG E51-2009 (2009). Optimal water content corresponding to mixture with cement dosage of 2.0%, 3.0%, 4.0%, and 5.0% is given in Table 2. These percentages represent the mass ratio between cement and macadam used in each batch of mixture.

2.3 Sample Preparation

To analyze the influence of the mixing method on the performance of CSM, the raw materials were mixed in a twin-shaft batch mixer with both vibratory mode and non-vibratory mode, which was produced by Xuchang DETONG Vibratory Mixing Technology Co., Ltd. A prototype vibration mixer was designed and fabricated according to the mixing principle of a twin-shaft batch mixer, as shown in Fig. 2, with a nominal volume of 60 L. A 4.0 kW mixing driving motor was used to drive two mixing shafts to make counter synchronous rotation at a speed of 55RPM using a chain. There were seven mixing blades that were interruptedly and spirally mounted on each mixing shaft. Similar to an ordinary twin-shaft batch mixer (Kemmann, 2004), mixing blades propelled axial movement of the mixture. The mixing blades on

Table 1 Chemical and physical properties of the cement.

Type	Chemical				Physical						
	Loss on ignition (%)	SO_3 (%)	MgO (%)	Chloride (%)	Blaine (m^2/g)	Setting time (min)		Compressive strength (MPa)		Flexural strength (MPa)	
						Initial	Final	3d	28d	3d	28d
P·C 32.5	2.1	3.1	2.2	0.02	339	121	225	12.2	39.5	4.0	6.6

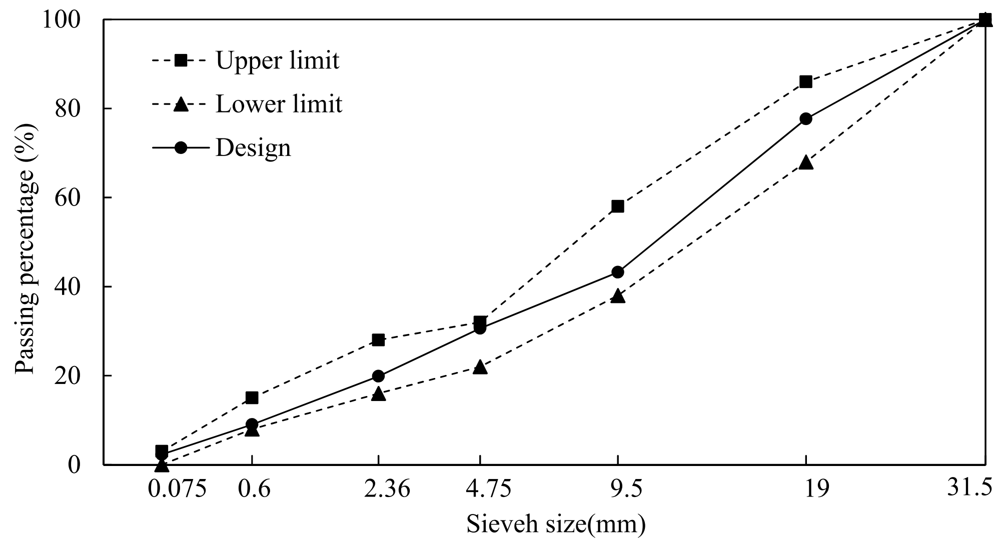


Fig. 1 Gradation curve of limestone aggregates.

Table 2 Standard compaction test results of the CSM with different cement dosages.

Cement dosage (%)	Optimum water content (%)	Maximum dry density (g/cm^3)
2.0	4.67	2.415
3.0	4.85	2.423
4.0	5.02	2.430
5.0	5.18	2.436

two shafts moved in opposite directions. As a result, when the mixing shaft is rotated in the prescribed direction, the mixture would move with axial circulation in the mixing chamber. The vibratory mode was driven by a 2.2 kW vibration driving motor, in which maximum vibration acceleration was set to 1.0 g, 2.0 g, and 3.5 g by adjusting the rotational speed of the vibration transmission shaft.

All aggregate weighed required by each batch were added in the mixer for 10 s, then mixing for 30 s after adding water. The mixing procedure is shown in Fig. 3. Vibratory mixing (VM) and conventional mixing (CM) both were used to prepare the samples with the same mixing procedure. In this work, the vibratory mixing was run by turning on the mixing motor and the vibration motor simultaneously. And the conventional mixing mode was carried out by operating the mixing motor without the vibration motor.

The experiment was carried out according to the assignment of Table 3. Vibration acceleration was the maximum acceleration available on the mixing shaft within the mixing chamber, whereas this value was "0" in the conventional compulsory mixing event. Every time the mixing was completed, sampling was carried out at six locations of the mixture in the container (①~⑥ shown in Fig. 3d). The mixture was made into six samples for each batch. Sampling depth was about 1/2 of the height of the mixture pile, with the sampling amount depending on the amount of mixture available in each batch of mixing.

2.4 Test Method

2.4.1 Unconfined Compressive Strength Test

The unconfined compressive strength was determined according to the Chinese standard JTG E51-2009 (2009). Cylindrical specimens with a height of 150 mm and a diameter of 150 mm were put into a plastic bag for standard curing for 7 days in an environment with a temperature of 20 ± 2 °C and humidity of ≥ 95%. At the curing age, all the samples were maintained in 20 ± 2 °C water for 24 h and then were loaded at the same speed of 0.8kN/s. The test results were average values of three repeated samples for each mixing condition. And the density value is calculated by weighing the mass and volume of the sample. To analyze the influence of curing age on the UCS under different mixing methods, the sample with a cement dosage of 5.0% was used to test the UCS at 3 days, 7 days, and 14 days.

2.4.2 Scanning Electron Microscope (SEM) Test

The purpose of the SEM tests is to observe the microstructure of concrete specimens with VM and CM. This specimen with 5% cement dosage was broken into small pieces after curing for 28 days. The samples

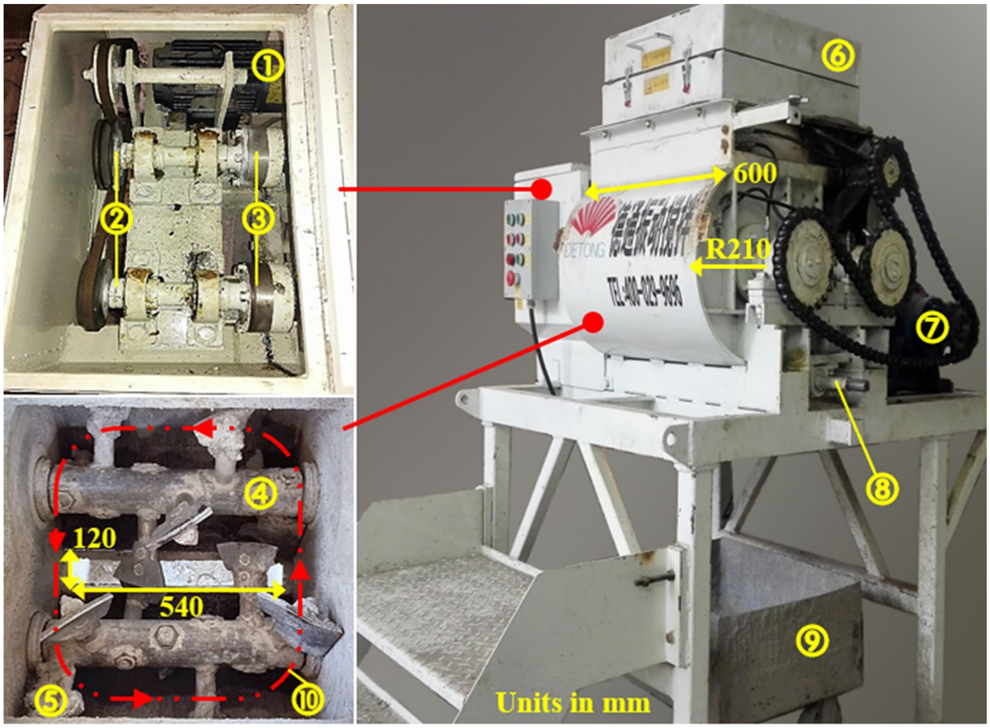


Fig. 2 Vibration mixer. (1) vibration driving motor; (2) vibration transmission shaft; (3) eccentric connecting device; (4) mixing shaft; (5) mixing blade; (6) top cover; (7) mixing driving motor; (8) discharging gate; (9) mixed material container; (10) axial circulation of the mixture

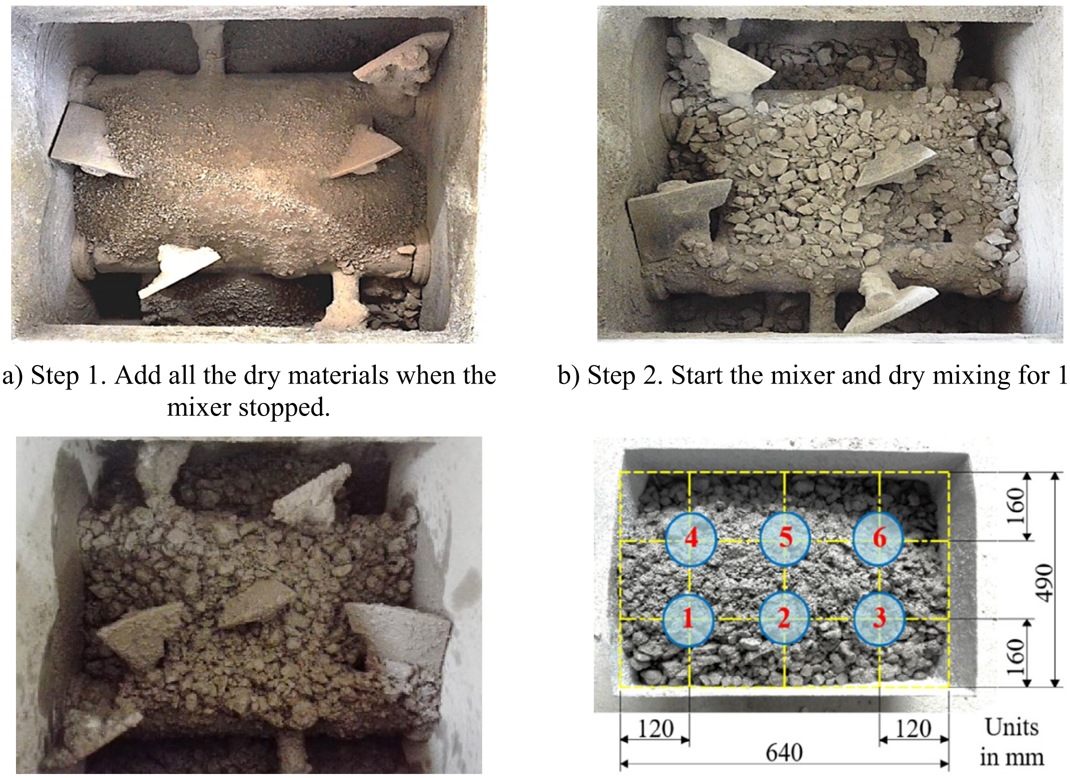
with dimensions of 10 mm × 8 mm × 6 mm were taken from close to the middle of the cylinder and smoothly polished by using abrasive paper. The prepared samples were soaked in absolute ethyl alcohol for 48 h and replaced ethyl alcohol every 24 h to terminate the hydration reaction. After that, the samples were dried in an oven at a temperature of 50 °C and then were coated with a golden conductive film at the sample surface. The SEM (JSM-6460LV, JEOL, Japan) was employed to observe the microstructures of the samples.

3 Results and Discussion

Table 4 shows the results of CSM's UCS with different cement dosages and mixing methods. Compressive strength in 3-day, 7-day, and 14-day tests was the mean value of six samples. As evidenced by test results, with curing age and cement dosage remaining the same, CSM's average compressive strength obtained in the vibratory mixing mode was higher than that in the conventional mixing mode at all accelerations. CSM's strength variable coefficient obtained in the vibratory mixing mode was lower than that in the conventional mixing mode. The effect of the different accelerations and cement dosages on the UCS is evaluated as follows.

3.1 The Effect of Vibration Acceleration

Fig. 4 shows the relationship between 7-day UCS, coefficient of variation, and vibration acceleration with different cement dosages. As shown in Fig. 4a, b, vibratory mixing increased the UCS and decreased the coefficient of variation. It is due to that vibratory mixing dispersed cement particles uniformly and increased the number of collisions between particles, leading to the uniform coating of hydration products around the aggregates and strengthening the bond strength between aggregate and cement matrix, thereby increasing the UCS value of CSM (Lv et al., 2020). And whatever the cement dosage was, CSM's average compressive strength rose as vibration acceleration increased. Compared with the conventional mixing, the average compressive strength of CSM was improved by 20.0 ~ 56.6% at the acceleration of 1 g, 32.8 ~ 72.5% at 2 g, and 40.8 ~ 80.5% at 3.5 g. The improvement percentage of compressive strength was determined by cement dosage. The larger the cement dosage is, the higher the compressive strength and the lower the improvement percentage by vibratory mixing is. It is owing to that the strength of the mixture is strengthened with the increase of cement content, thereby decreasing the effect of vibratory mixing on improving the strength of CSM (Zhao et al., Zhao, Jiang, et al., 2019). At the same cement dosage, the magnitude



a) Step 1. Add all the dry materials when the mixer stopped.

b) Step 2. Start the mixer and dry mixing for 10s.

c) Step 3. Wet mixing. Both conventional mixing and vibratory mixing are done for 30s.

d) Step 4. Discharging and taking six samples for the UCS test.

Fig. 3 Mixing procedure.

Table 3 Experimental assignment.

Mixing method	Mixing code	Acceleration (g)	Cement dosage (mass, %)	Unconfined compressive strength (MPa)			Test number
				3d	7d	14d	
Conventional compulsory mixing (CM)	CM0	0	2.0		★		1
		0	3.0		★		1
		0	4.0		★		1
		0	5.0	★	★	★	1 × 3
Vibratory mixing (VM)	VM1.0	1.0	2.0		★		1
		1.0	3.0		★		1
		1.0	4.0		★		1
		1.0	5.0	★	★	★	1 × 3
	VM2.0	2.0	2.0		★		1
		2.0	3.0		★		1
		2.0	4.0		★		1
		2.0	5.0	★	★	★	1 × 3
	VM3.5	3.5	2.0		★		1
		3.5	3.0		★		1
		3.5	4.0		★		1
		3.5	5.0	★	★	★	1 × 3

Table 4 Unconfined compressive strength results of CSM under different mixing conditions.

Cement dosage (%)	Mixing code	Curing ages (days)	Unconfined compressive strength			Percentage strength increase compared with CM0
			Average compressive strength (MPa)	Standard deviation (MPa)	Coefficient of variation Cv (%)	
2.0	CM0	7	1.59	0.269	16.9	0.0
	VM1.0	7	2.49	0.258	10.4	56.6
	VM2.0	7	2.73	0.261	9.6	71.7
	VM3.5	7	2.87	0.222	7.7	80.5
3.0	CM0	7	2.36	0.366	15.5	0.0
	VM1.0	7	3.60	0.274	7.6	52.5
	VM2.0	7	4.07	0.390	9.6	72.5
	VM3.5	7	4.26	0.307	7.2	80.5
4.0	CM0	7	3.48	0.575	16.5	0.0
	VM1.0	7	4.74	0.460	9.7	36.2
	VM2.0	7	5.46	0.460	8.4	56.9
	VM3.5	7	5.77	0.380	6.6	65.8
5.0	CM0	3	4.15	0.648	15.6	0.0
	VM1.0	3	4.93	0.506	10.3	18.8
	VM2.0	3	5.19	0.514	9.9	25.1
	VM3.5	3	5.49	0.542	9.9	32.3
	CM0	7	4.39	0.631	14.4	0.0
	VM1.0	7	5.27	0.502	9.5	20.0
	VM2.0	7	5.83	0.563	9.7	32.8
	VM3.5	7	6.18	0.493	8.0	40.8
	CM0	14	5.38	0.869	16.2	0.0
	VM1.0	14	6.27	0.662	10.6	16.5
	VM2.0	14	6.99	0.732	10.5	29.9
	VM3.5	14	7.27	0.536	7.4	35.1

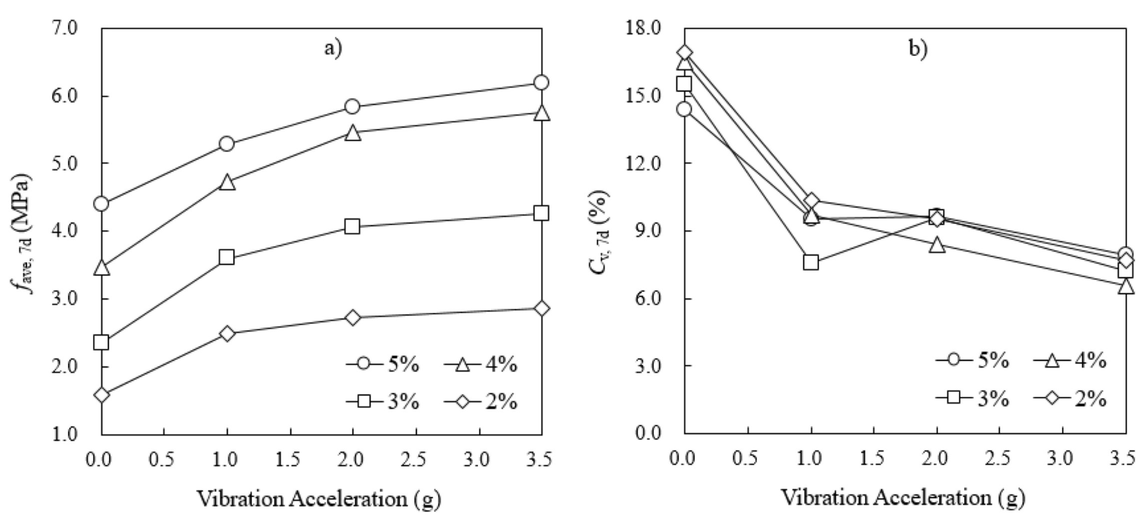


Fig. 4 7-Day UCS versus vibration acceleration for CSM with different cement dosage. **a** 7-day UCS; **b** coefficient of variation of strength.

of strength increment varied with different accelerations. The compressive strength of CSM showed the same rules with four cases of cement dosages: (1) when acceleration rose from 0 to 1 g, the maximum increase of compressive strength could be observed; (2) as acceleration continued to increase from 1 to 3.5 g, an increase of compressive strength declined gradually. Since the vibration acceleration increase would impose an extra dynamic load on the mixer and thus reduce its reliability, the maximum acceleration was set to 3.5 g to make sure the mixer worked in a favorable condition during the tests. The compressive strength of CSM might be further improved if the acceleration continued to increase, but the increase turned smaller, in the case of an excessive acceleration material sedimentation and segregation might even cause a strength decline (Zhao et al., 2018). In terms of cement dosages and grading type in this test, an acceleration of 1 ~ 2 g was sufficient to make a significant difference in strength improvement. In view of the fact that the cement dosage of CSM was generally 5% in the practical construction of a base course in China (Wang et al., 2015), it was recommended that the maximum vibration acceleration on the mixing shaft be set to be approximately 2 g.

The strength variable coefficient of the same batch was obtained by measuring the CSM strength at six locations within the mixing chamber. A smaller strength variable coefficient indicated better mixing uniformity of the mixture. As shown in Fig. 4b, vibratory mixing had significantly reduced the variable coefficient of 7-day UCS in all four cases of cement dosages. Compared with the strength variable coefficient of CSM higher than 15% in the conventional mixing mode, that value in all ranges of vibration acceleration was kept at 10% or smaller. As acceleration increased, the variable coefficient declined, which might be because the internal friction force between the mixture particles was reduced by vibration during mixing, promoting more rapid movement and better distribution of various constituents within the chamber (Dong et al., 2019) and thus improving mixing uniformity with the same mixing time.

Fig. 5 shows the relationship between 3-day, 7-day, and 14-day average UCS of CSM, its variable coefficient, and vibration acceleration when cement dosage was 5%. It was evident that, like 7-day UCS, 3-day and UCS at 14 days rose, while the strength variable coefficient declined as vibration acceleration increased.

3.2 The Effect of Cement Dosage

Fig. 6 shows the relationship between the 7-day average UCS value, its variable coefficient, and cement dosage in different mixing methods. As indicated by Fig. 6, the UCS value of CSM in both conventional mixing and vibratory mixing at all accelerations increased as cement dosage increased, while the coefficient of variation of strength under different cement dosage is not significant. As the cement dosage increases, hydration products generated by that cement particle participate in hydration reaction increase, improving the bond strength of interfacial zone between matrix and aggregate, further increasing the UCS value of CSM (Li et al., Li, Wei, et al., 2021; Zhang et al., 2010). When cement dosage increased from 2 to 5%, with the increase of every 1% in cement dosage, the compressive strength of conventional mixing and in vibratory mixing average increased by 59% and 38%, respectively. It can be

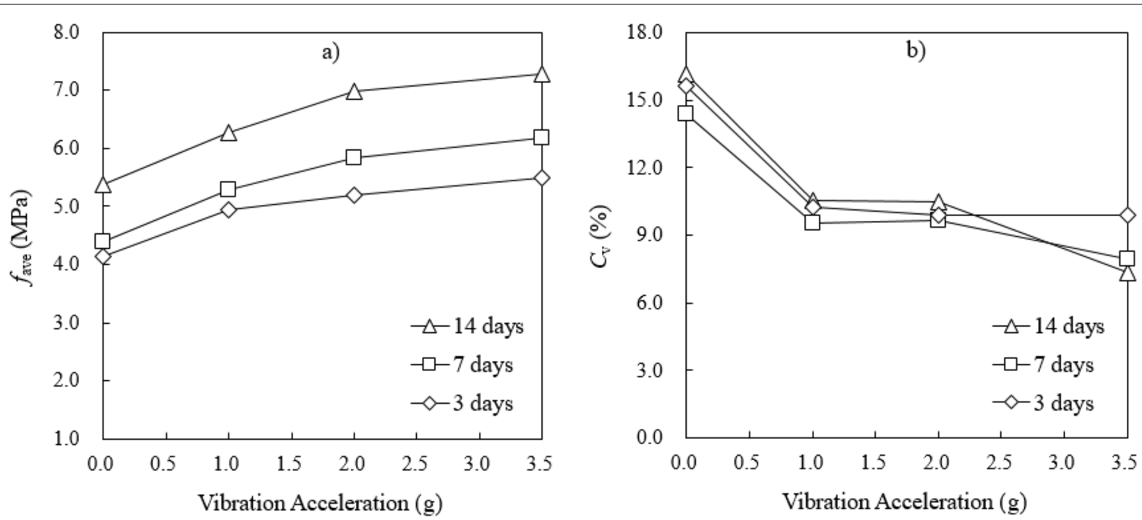


Fig. 5 UCS versus vibration acceleration under different curing ages for CSM with 5% cement dosage. **a** UCS; **b** coefficient of variation of strength.

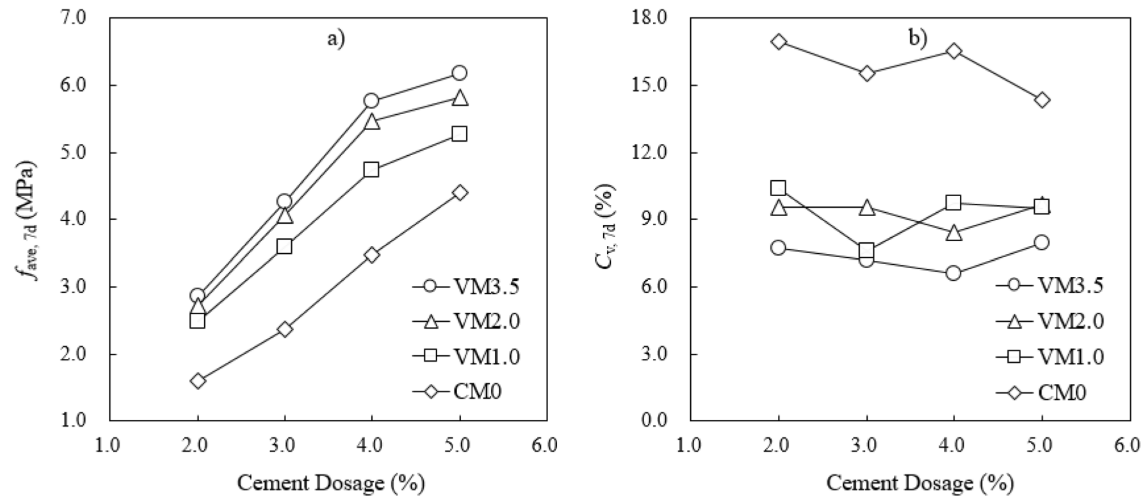


Fig. 6 7-Day UCS versus cement dosage under different mixing methods. **a** Average UCS; **b** coefficient of variation of strength.

Table 5 Person value between the 7-day UCS and cement dosage and vibration acceleration.

Factor	Person value
Cement dosage (%)	0.81
Vibration acceleration (g)	0.45

seen that the effect of vibratory mixing on improving the strength of CSM is gradually weakened with the increase the cement content, which also is observed in the work of Li et al. (Li, Wei, et al., 2021). However, the maximum improvement rate of UCS value is 20–56.7% when vibration acceleration increased from 0 g (CM) to 1 g (VM1.0), and the improvement rate gradually decreased with the increase of every 1 g in vibration acceleration. It is indicated that cement dosage had a more significant impact on improving the UCS compared to the mixing methods. Moreover, the correlation of test data also suggested that the Pearson correlation coefficient between 7-day UCS and cement dosage was 0.81, evidencing a stronger relationship than the correlation coefficient (0.45) between 7-day UCS and acceleration, as shown in Table 5. It is no doubt that the compressive strength of CSM could be improved by increasing the cement dosage, and the same result can be found in Deng's work (2019). However, higher cement makes CSM vulnerable to cracks in practice (Zhang, 2016), which is harmful to the stability of CSM. The new version of Chinese standard JTG/T F20-2015 has explicitly stipulated that "it is forbidden to enhance strength by solely increasing cement dosage in practical constructions". Therefore, it is particularly important to increase the UCS value by mixing method without increasing the cement content.

As stipulated by Chinese standard JTG/T F20-2015 (2015), the formula of the representative value of 7-day UCS for the different class highways is shown in Eqs. (1) and (2). The representative value of 7-day UCS is required to be higher than the standard value. CSM is used for base courses of highways that are of the second class and under, the standard value of 7-day UCS ($f_{\text{rep,7-day}}$) should be 2.0 ~ 6.0 MPa. CSM is used for the base courses of the expressway and the first-class highway, and the standard value should be 3.0 ~ 7.0 MPa. Fig. 7 shows the relationship and fitting curve between the representative value of 7-day UCS and cement dosage in both conventional mixing and vibratory mixing at an acceleration of 2 g. The fitting equations, which represent the performance of specimens for the preparation using the vibratory mixing and conventional mixing conditions, are shown in Eqs. (3), (4), (5), and (6), respectively.

$$f_{\text{rep,7 - day}} = f_{\text{ave,7 - day}} \cdot \left(1 - 1.282 \cdot C_{v,\text{7 - day}}\right) \quad (1)$$

$$f_{\text{rep,7 - day}} = f_{\text{ave,7 - day}} \cdot \left(1 - 1.645 \cdot C_{v,\text{7 - day}}\right), \quad (2)$$

where $f_{\text{rep},7-\text{day}}$ is a representative value of unconfined compressive strength at 7 days. $f_{\text{ave},7-\text{day}}$ is an average value of unconfined compressive strength at 7 days. $C_{v,7-\text{day}}$ is variation coefficient of unconfined compressive strength.

For the second-class highway and under, vibratory mixing:

$$y = 0.9433x + 0.6854, R^2 = 0.94. \quad (3)$$

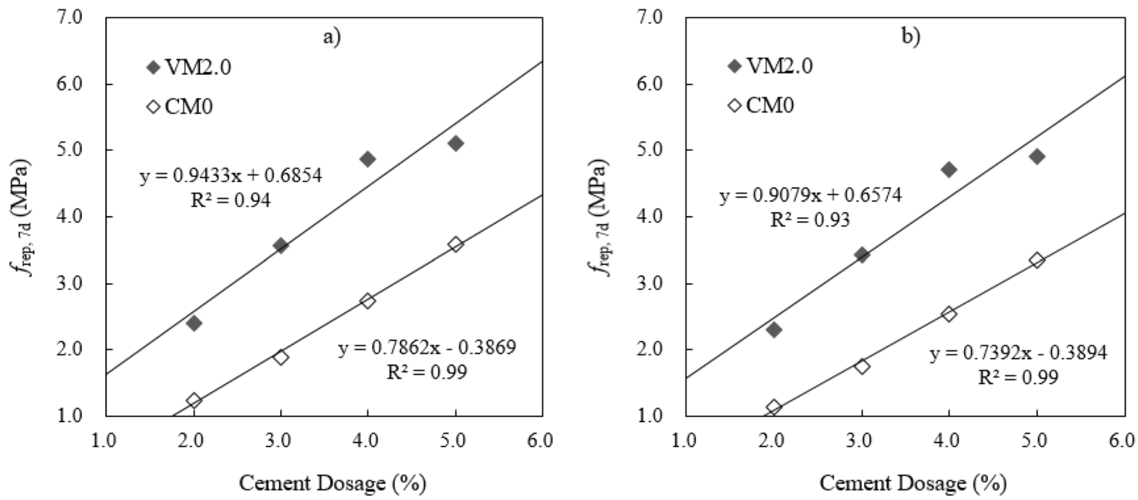


Fig. 7 7-Day UCS versus cement dosage under different highway grades: **a** for the second-class highway and under (JTG/T F20-2015 2015); **b** for expressway and the first-class highway (JTG/T F20-2015 2015).

Conventional mixing

$$y = 0.7862x - 0.3869, R^2 = 0.99. \tag{4}$$

For the expressway and the first-class highway, vibratory mixing

$$y = 0.9079x + 0.6574, R^2 = 0.93. \tag{5}$$

Conventional mixing

$$y = 0.7392x - 0.3894, R^2 = 0.99, \tag{6}$$

where y and x are the unconfined compressive strength values and cement dosage, respectively.

It is shown from Eqs. (3), (4), (5), and (6) that the strength related to the two types of mixing methods showed a line function relationship with the cement dosage, regardless of highway grade. Fig. 7 also indicates when CSM was used for the second-class highway and under, the minimum cement dosage was 3.0% in conventional mixing mode with current grading, whereas minimum cement dosage declined to only 1.4% at an acceleration of 2 g in the vibration mode. When CSM was used for expressways and first-class highways, the minimum cement dosage was 4.6% in conventional mixing mode and 2.6% at an acceleration of 2 g in vibratory mixing mode. Compared with conventional mixing, vibratory mixing was able to reduce cement dosage by over 1.6% while satisfying the requirements for UCS, and the higher the strength requirement is, the more the amount of cement to be saved.

3.3 The Relationship Between Strength and Density

Fig. 8 shows the 7-day UCS of CSM with four cement dosages in a function of the density before soaking. Sample density was worked out by measuring their masses and volumes on the sixth day of the curing period before soaking. Conventional mixing and vibratory mixing showed the same rules: as cement dosage increased, sample density and compressive strength were improved. In the CSM with more coarse aggregates and fewer fine aggregates, it was the cementation effect of cement hydration products among aggregates that formed CSM as a whole, with a certain strength. With the same grading, increased cement dosage would generate more hydration products calcium silicate hydrate (C–S–H) that were filled into the gaps between aggregates, and thus improving density (Wongkeo et al., 2014) and providing additional strength (Hatungimana et al., 2019), enabling more available materials in CSM to bear compressive force.

Regardless of mixing methods and cement dosages, it has been observed that compressive strength is a line function of density. The higher the density, the higher the UCS. The fitting equations are shown in Eqs. (7) and (8), respectively.

Vibratory mixing

$$y = 86.207x - 209.98, R^2 = 0.88. \tag{7}$$

Conventional mixing

$$y = 78.758x - 192.57, R^2 = 0.92 \tag{8}$$

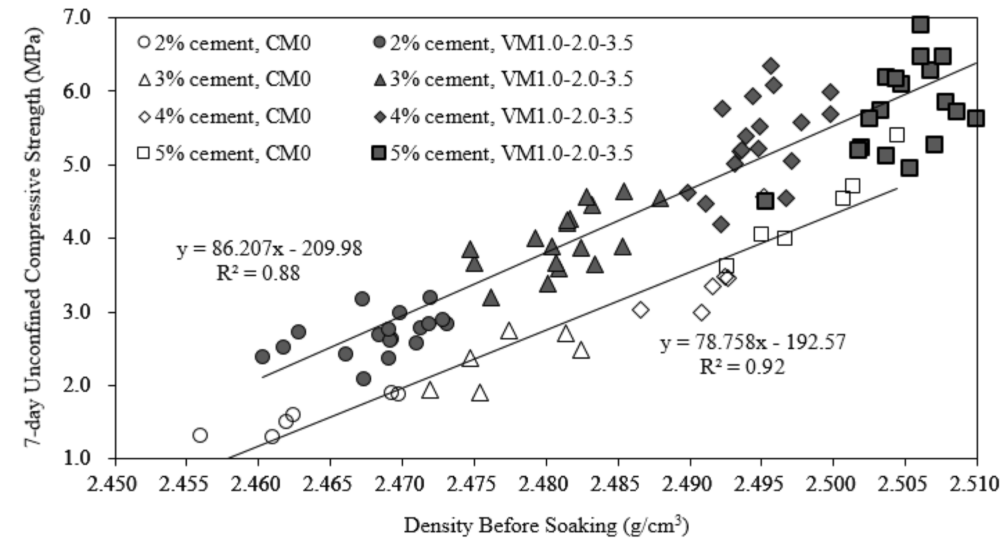


Fig. 8 7-Day UCS of CSM with four cement dosages in a function of the density before soaking.

where y and x are the unconfined compressive strength values and density respectively.

From Fig. 9, it is indicated that at the same cement dosage, the densities before soaking of a specimen prepared by vibratory mixing are slightly higher than that of a conventional mixing specimen with all ranges of acceleration. It may be attributed to the improvement in the microstructure of the material in vibratory mixing. Fig. 10 indicates that with the same cement dosage, the water absorptions of specimens made by vibratory mixing are lower after soaking at about 24 h than conventional mixing. It is widely known that the water absorption of building materials depends on the porosity and pore characteristics of the material in addition to the nature of the material itself. In general, the larger the porosity, the more open pores, and the greater water absorption rates (Hall, 1989). High density and low water absorption rate indicate that the vibratory mixing specimen has small porosity and few open pores inside.

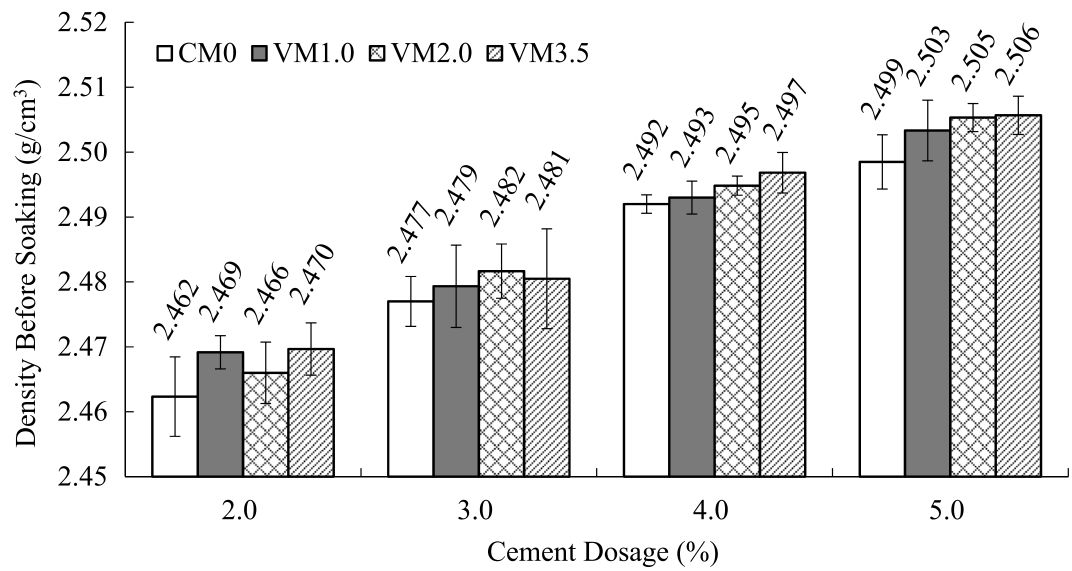


Fig. 9 Comparison of the effect of different mixing methods on the average density of CSM with different cement dosages.

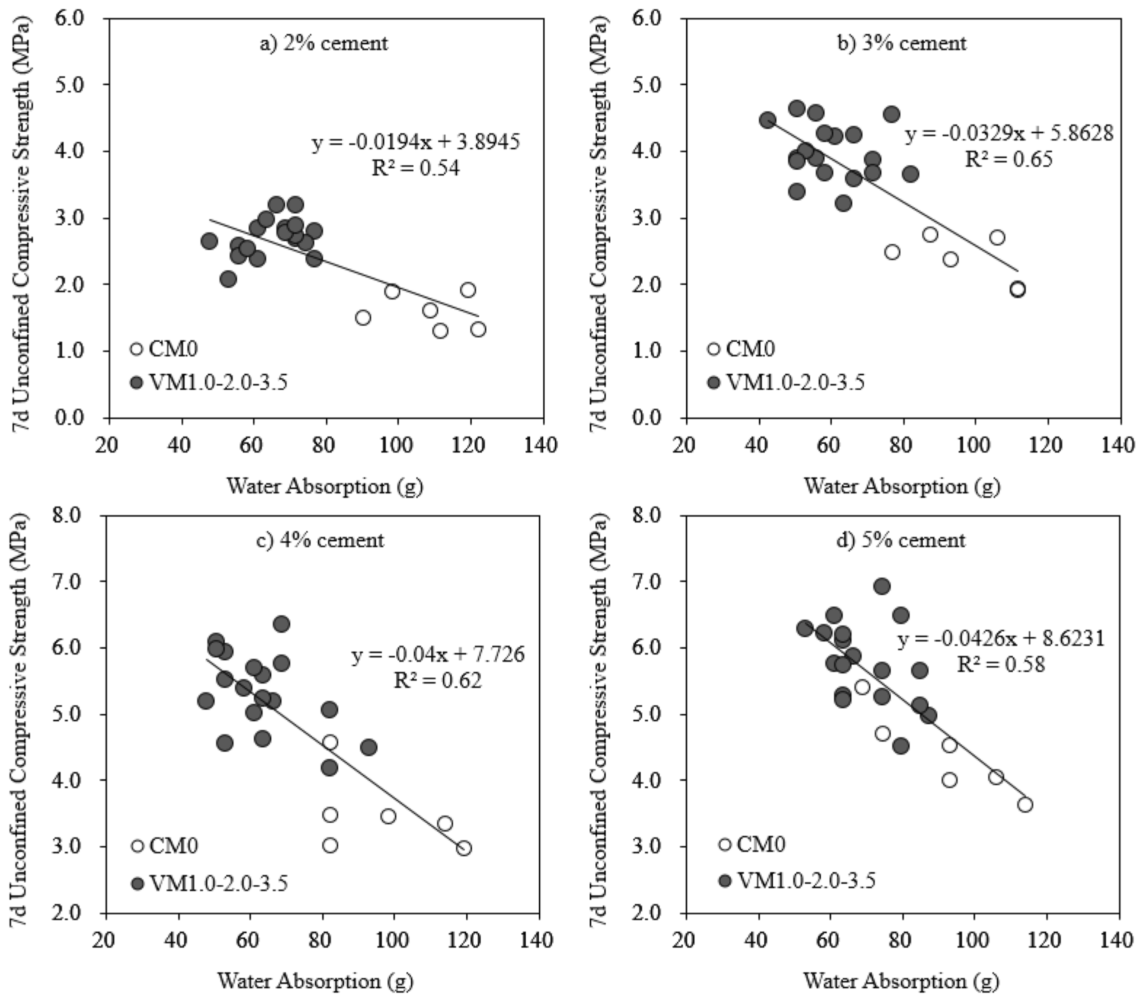


Fig. 10 The relationship between water absorption and 7-day UCS of the CSM with different cement dosage: **a** 2% cement dosage; **b** 3% cement dosage; **c** 4% cement dosage; (5) 5% cement dosage.

3.4 Microstructure Analysis

As shown in Fig. 11, the microstructure of samples prepared by vibratory mixing appeared more compact, with a higher degree of pore closure and larger uniformity of distribution compared with specimens prepared by the conventional mixing. Nevertheless, the microstructure change of CSM under different vibration acceleration is not obvious, as shown in Fig. 11b–d. C–S–H is the main hydration product and binding phase in all Portland cement-based systems, which determine the strength of the hardened mixture (Richardson, 1999). Samples with vibratory mixing contained more C–S–H that intertwined with each other and filled the interspace of the samples, which reduced the pore size and connected pores. Moreover, the interfacial zone was improved by vibratory mixing, which is beneficial to the increase of UCS value. It is attributed to that vibratory mixing can generate a large number of C–S–H gels at the periphery of coarse aggregate by destroying the cement flocculation and accelerating the hydration reaction (Feng, 2001). And these hydration products can impregnate the periphery of the aggregates, forming the "Interlock" between coarse aggregate and cement matrix, improving the bond strength of the interface greatly (Xiong, 2019). The samples with conventional mixing showed a loose and porous microstructure due to a lack of C–S–H, as shown in Fig. 11a. Compared with uniformly distributed closed pores, the unevenly distributed interconnected pores tend to be a weak part of the CSM structure. Fu et al. () have revealed that vibratory mixing can refine pores of normal concrete, especially the large ones with a pore size above 100 nm. The compact microstructure and evenly distributed closed pores, while the CSM density increased less, ensured a higher compressive strength of vibratory mixed samples.

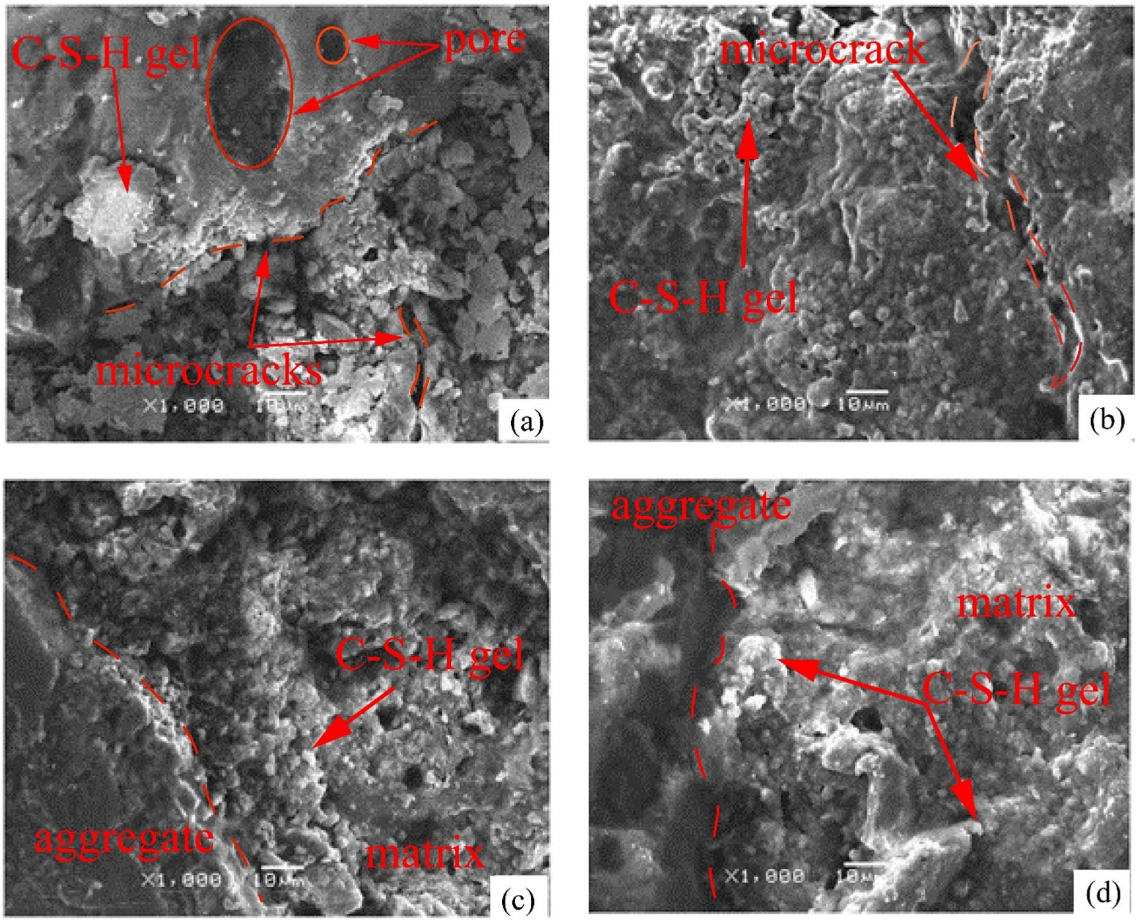


Fig. 11 SEM micrographs of CSM samples with a 5% cement dosage under different mixing methods. **a** CM0; **b** VM1.0; **c** VM2.0; **d** VM3.5.

3.5 The Effect of the Location of the Samples

To reduce the negative impact of vibration on mixing driving and transmission mechanism, values of vibration acceleration at both ends of the mixing shaft were designed unequally. From the perspective of sampling location (Fig. 3d), locations 1 and 4 corresponded to a larger acceleration, and locations 3 and 6 corresponded to a smaller acceleration. Fig. 12 shows no significant rules between 7-day UCS and sampling locations. Acceleration at one end of the mixing shaft was at most 2.2 times larger than that at the other end. However, vibratory mixed CSM at sampling locations 1 and 4 did not always show even higher compressive strength. Also, locations 3 and 6 did not always show a lower compressive strength. This was a result of the circulatory movement of the mixture in the mixing chamber. The mixing blade arrangement and radial circulatory movement of the mixture were centrosymmetric relative to the middle of the mixing chamber, which helped reduce the strength difference of the mixture at both ends of the shaft due to the vibration effect difference. As a result, for both conventional compulsory mixing and vibratory mixing, it was crucial to make the appropriate arrangement of mixing blades. For uniform mixing, it was required that the mixing blades push the mixture to make a large-scale circulatory movement in the mixing chamber. Besides, the method in which sampling was conducted after the mixture was discharged to the container might also make a difference in reducing the impact of acceleration distribution on the sample strength at different locations (Fig. 12).

4 Conclusions

This work aimed at evaluating the impact of vibratory mixing and cement dosage on the unconfined compressive strength (UCS) of CSM. The UCS and density of CSM with four cement dosages at conventional mixing and vibratory mixing with three vibration acceleration. The main conclusions are summarized as below:

1. The UCS of CSM is largely improved by the vibratory mixing method at all investigated cement dos-

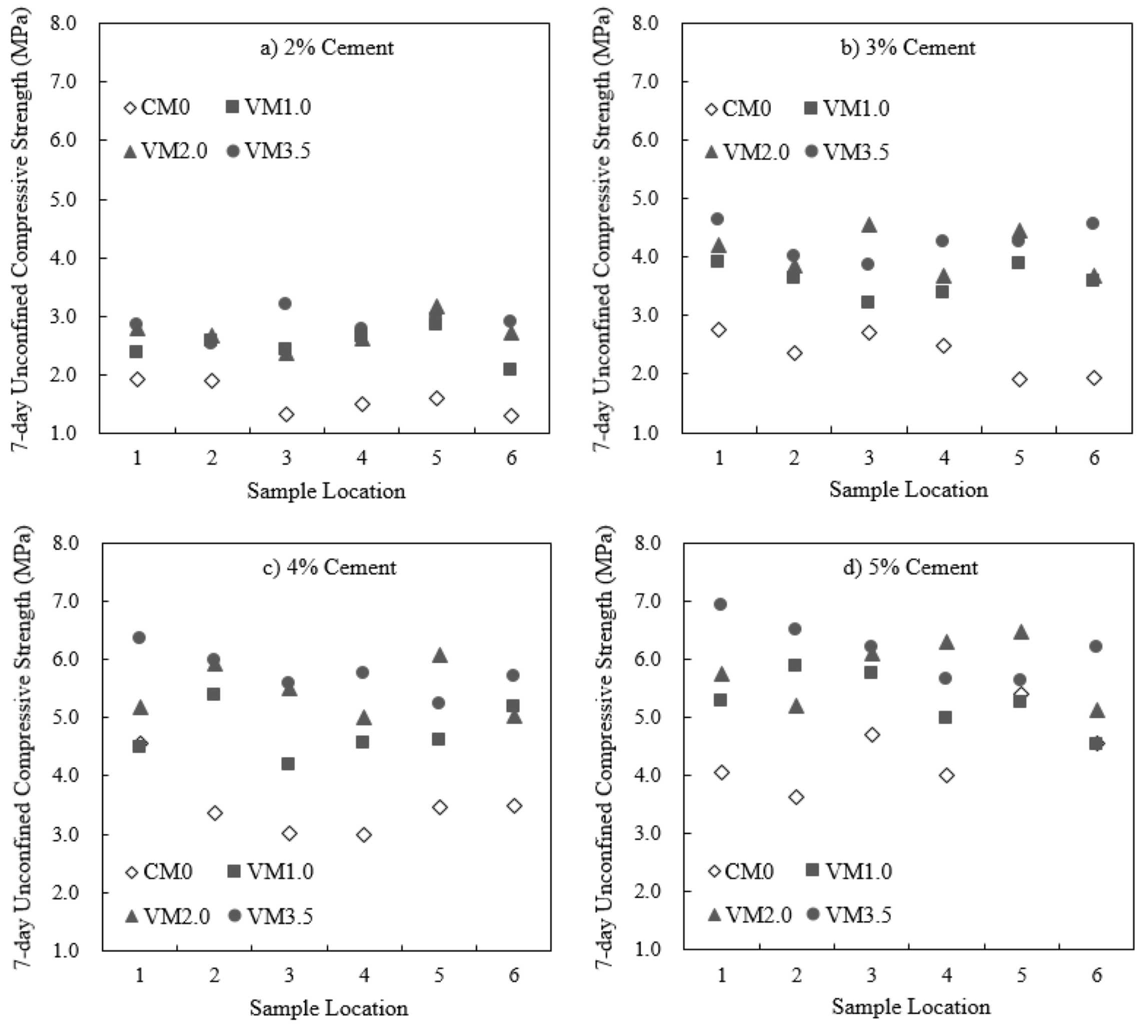


Fig. 12 7-day UCS of CSM samples from different locations (see Fig. 3d): **a** 2% cement dosage; **b** 3% cement dosage; **c** 4% cement dosage; (5) 5% cement dosage.

ages. Compared with conventional mixing, 7-day UCSs of CSM with vibratory mixing are improved by 20.0 ~ 80.5%. The strengths are enhanced with the increase of vibration acceleration, and the growth law is small (1.0 ~ 3.5 g) after the first fast (0 ~ 1.0 g). Considering the mixer reliability and cement dosages in practical construction, the recommended maximum vibration acceleration on the mixing shaft is about 2.0 g.

2. The variable coefficient of unconfined compressive strength is significantly reduced by vibratory mixing at all investigated cement dosages. Compared with 15% in conventional mixing, the strength variable coefficient of CSM is less than 10% in the vibratory mixing method. With the increase in acceleration, the variable coefficient tends to decline. Cement dosage does not exert a significant impact on the variable coefficient of UCS.
3. The vibratory mixing technology is contributed to saving cement dosages when satisfying the requirements for UCS. The UCS of CSM is increased with cement dosages in all cases. Cement dosage can exert a more significant impact on strength than the mixing method does. The higher the cement dosage, the smaller the increase of strength contributed by vibratory mixing. Cement dosage can be reduced by over 1.6% (from 3.0 to 1.4%) with vibratory mixing at an acceleration of 2 g.
4. Vibratory mixing can obtain the samples with high density and lower water absorptions, indicating small porosity and few open pores inside. Compared with conventional mixing, the microstructure of samples

made by vibratory mixing is observed to be more compact and denser by SEM.

5. Different sampling locations correspond to a varied acceleration of the mixing shaft, but there is no significant rule between UCS of samples and sampling locations. This is the result of the circulatory movement of the mixture in the mixing chamber.

Acknowledgements
The project was supported by Natural Science Foundation of Shaanxi Province of China (No. 2017JM5118). This project was also partially supported by the China Postdoctoral Science Foundation (No. 2018M633443). The authors would like to thank China Scholarship Council (201906560037) for their support for this project.

Authors' contributions
First-author ZKY, Corresponding author ZLJ, co-author HJR, and co-author JWZ conducted experimental work, analyzed, prepared results, and written manuscript. First-author ZKY partially prepared the manuscript, analyzed the effect of acceleration and cement dosage on the mechanic performance of cement-stabilized macadam, and mainly revised the manuscript. Co-author HJR partially prepared the manuscript and analyzed the relationship between strength and density. Corresponding author ZLJ partially prepared the manuscript and analyzed the effect of the location of samples, also reviewed the manuscript. The mechanism of vibratory mixing was proposed by Co-author FZX. Also, reviewed manuscript. Co-author JWZ revised the partial manuscript. All authors read and approved the final manuscript.

Authors' information
Kaiyin Zhao, Ph.D. Student. Email address: zhaokaiyin@chd.edu.cn. Chang'an University, School of Construction Machinery, Xi'an, Shaanxi, 710064, China.
Lijun Zhao, Associate Professor. Email address: zhaolj@chd.edu.cn. Chang'an University, School of Construction Machinery, Xi'an, Shaanxi, 710064, China.
Jinru Hou, Post-doc. Email address: houjr@chd.edu.cn. Chang'an University, School of Construction Machinery, Xi'an, Shaanxi, 710064, China.
Zhongxu Feng, Professor. Email address: fengzhxu@chd.edu.cn. Chang'an University, School of Construction Machinery, Xi'an, Shaanxi, 710064, China.
Wenzhi Jiang, Master Student. Email address: 1574963037@qq.com. Chang'an University, School of Construction Machinery, Xi'an, Shaanxi, 710064, China.

Funding
This study was supported by natural science foundation of shaanxi province, 2017JM5118, postdoctoral research foundation of china, 2018M633443, china scholarship council, 201906560037.

Availability of data and materials
All data are provided in the results section.

Declarations

Ethics approval and consent to participate
The authors state that the research was conducted according to ethical standards.

Consent for publication
The authors consent for publication.

Competing interests
The authors declare that they have no competing interests in this work.

Received: 1 August 2021 Accepted: 28 January 2022
Published online: 22 March 2022

References

Abd El-Motaal, A. M., Abdel-Reheem, A., & Mahdy, M. (2020). Effect of low mixing speed on the properties of prolonged mixed concrete. *Civil Engineering Journal, 6*(8), 1581–1592.

Beitzel, H., Charonnat, Y., & Beitzel, M. (2003). Assessment and classification of performance mixers. *Materials and Structures, 36*(4), 250–264.

Bi, J., Zheng, N., Zhang, F., (2017). Study on the application of vibration mixing for cement stabilized crushed stone. Southern African Transport Conference.

Chang, P. K., & Peng, Y. N. (2001). Influence of mixing techniques on properties of high performance concrete. *Cement and Concrete Research, 31*(1), 87–95.

Chopin, D., de Larrard, F., & Cazacliu, B. (2004). Why do HPC and SCC require a longer mixing time? *Cement and Concrete Research, 34*(12), 2237–2243.

Deng, C., Jiang, Y., Lin, H., & Ji, X. (2019). Mechanical-strength-growth law and predictive model for cement-stabilized macadam. *Construction and Building Materials, 215*, 582–594.

Dong, W., Feng, Z., Zhao, L., & Yao, Y. (2018). Comparative study on performance of cement stabilized macadam with vibration mixing and two-cylinder continuous mixing. *AIP Conference Proceedings., 1995*(1), 020006.

Dong, W., Feng, Z., & Zhao, L. (2019). Experimental research on the influence of vibration intensity on performance of cement stabilized macadam. *IOP Conference Series: Earth and Environmental Science., 283*(1), 012011.

Du, S. (2019). Mechanical properties and shrinkage characteristics of cement stabilized macadam with asphalt emulsion. *Construction and Building Materials, 203*, 408–416.

Du, Q., Pan, T., Lv, J., Zhou, J., Ma, Q., & Sun, Q. (2019). Mechanical properties of sandstone cement-stabilized macadam. *Applied Sciences, 9*(17), 3460.

Feng, Z. X. (2001). *Concrete mixing theory and equipment*. China Communications Press.

Ferraris, C. F. (2001). Concrete mixing methods and concrete mixers: state of the art. *Journal of Research of the National Institute of Standards and Technology, 106*(2), 391.

Fu, C. H., Feng, Z. X., Zhang, L., (2011a). Effects of mixing method on concrete air content and pore distribution. *Journal of Zhengzhou University (Engineering Science)*, 2.

Fu, C. H., Feng, Z. X., Zhang, L., (2011b). The influence of vibrating mixing on the durability of concrete. *Journal of Guangxi University (Natural Science Edition)*, 2.

Guan, H., Wang, H., Liu, H., Yan, J.-J., & Lin, M. (2018). The effect of intermediate principal stress on compressive strength of different cement content of cement-stabilized macadam and different gradation of AC-13 mixture. *Applied Sciences, 8*(10), 2000.

Hall, C. (1989). Water sorptivity of mortars and concretes: a review. *Magazine of Concrete Research, 41*(147), 51–61.

Hatungimana, D., Taşköprü, C., İçhedef, M., Saç, M. M., & Yazici, S. (2019). Compressive strength, water absorption, water sorptivity and surface radon exhalation rate of silica fume and fly ash based mortar. *Journal of Building Engineering, 23*, 369–376.

Hemalatha, T., Sundar, K. R., Murthy, A. R., & Iyer, N. R. (2015). Influence of mixing protocol on fresh and hardened properties of self-compacting concrete. *Construction and Building Materials, 98*, 119–127.

Jia, P., Du, G. C., Ren, Y. Y., & Wu, Z. D. (2019). Strength and frost-resistance properties of the vibration-mixed concrete. *Journal of Northeastern University (natural Science), 40*(12), 1784.

Jiang, Y. J., Li, M. J., Zhang, J. J., & Wang, S. (2010). Influence factors of strength properties of cement stabilization of crushed aggregate. *Journal of chang'an University (natural Science Edition), 30*(4), 1–7.

John, V. M., Damineli, B. L., Quattrone, M., & Pileggi, R. G. (2018). Fillers in cementitious materials—experience, recent advances and future potential. *Cement and Concrete Research, 114*, 65–78.

JTG E42-2005. (2005). *Test methods of aggregate for highway engineering*. Ministry of Transport of the People's Republic of China.

JTG E51-2009. (2009). *Test method of materials stabilized with inorganic binders for highway engineering*. Ministry of Transport of the People's Republic of China.

JTG D50-2017. (2017). *Specifications for design of highway asphalt pavement*. Ministry of Transport of the People's Republic of China.

JTG/T F20-2015. (2015). *Technique guidelines for construction of highway roadbases*. Ministry of Transport of the People's Republic of China.
Juradin, S., Baloević, G., & Harapin, A. (2014). Impact of vibrations on the final characteristics of normal and self-compacting concrete. *Materials Research, 17*(1), 178–185.
Kemmann, C. (2004). What twin-shaft mixing can do for you. *Concrete Producer, 22*, 47–50.
Koch, J. A., Castaneda, D. I., Ewoldt, R. H., & Lange, D. A. (2019). Vibration of fresh concrete understood through the paradigm of granular physics. *Cement and Concrete Research, 115*, 31–42.
Li, W., Lang, L., Lin, Z., Wang, Z., & Zang, F. (2017). Characteristics of dry shrinkage and temperature shrinkage of cement-stabilized steel slag. *Construction and Building Materials, 134*, 540–548.
Li, X. L., Ning, Z. F., & Ye, J. H. (2021). Strength and its formation mechanism of vibration mixing cement stabilized macadam. *Journal of Changsha University of Science & Technology (natural Science)., 18*(03), 8–15.
Li, P., Wei, D., Zhang, D., Xiong, J., & Xu, S. (2021). Study on the properties and mechanisms of a cement-stabilized aggregate mixture with vibration mixing. *Frontiers in Materials., 8*, 97.
Liu, D. H., Liu, J. L., & Xuan, P. (2016). The compaction mechanism of roller compacted concrete and the influence of VC value on its compaction quality. *Hydropower Energy Science, 5*, 128–131.
Luo, W., Xiong, G. Q., & Xiong, C. C. (2020). Preparation of steel fiber-reinforced high strength lightweight concrete using vibration mixing technology. *Journal of Central South University (science and Technology), 51*, 14–22.
Lv, S., Guo, Y., Xia, C., Wang, X., You, L., Cabrera, M. B., & Li, J. (2020). Unified approach to characterize the strength of cement stabilized macadam subjected to different loading modes. *Construction and Building Materials, 265*, 120143.
Lv, S., Peng, X., Yuan, J., Liu, H., Hu, L., Yang, S., & Liu, J. (2021). Stress path investigation of fatigue characteristics of cement stabilized macadam. *Construction and Building Materials., 292*, 123446.
NCHRP, (2013). Characterization of cementitiously stabilized layers for use in pavement design and analysis, National Cooperative Highway Research Program, Transportation Research Board, Washington State University, Pullman
Pope, A. W., & Jennings, H. M. (1992). The influence of mixing on the microstructure of the cement paste/aggregate interfacial zone and on the strength of mortar. *Journal of Materials Science, 27*(23), 6452–6462.
Rejeb, S. K. (1996). Improving compressive strength of concrete by a two-step mixing method. *Cement and Concrete Research, 26*(4), 585–592.
Richardson, I. G. (1999). The nature of CSH in hardened cements. *Cement and Concrete Research, 29*(8), 1131–1147.
Safawi, M. I., Iwaki, I., & Miura, T. (2004). The segregation tendency in the vibration of high fluidity concrete. *Cement and Concrete Research, 34*(2), 219–226.
Sha, A. M. (2008). Material characteristics of Semi-rigid Base. *China Journal of Highway and Transport, 21*(1), 1–5.
Sun, X., Wu, S., Yang, J., & Yang, R. (2020). Mechanical properties and crack resistance of crumb rubber modified cement-stabilized macadam. *Construction and Building Materials, 259*, 119708.
Vandanjon, P. O., De Larrard, F., Dehousse, B., Villain, G., Maillot, R., & Laplante, P. (2003). Homogenisation of concrete in a batch plant: the influence of mixing time and method on the introduction of mineral admixtures. *Magazine of Concrete Research, 55*(2), 105–116.
Wang, J., & Tan, Z. (2021). Mechanical and mesoscale analyses of cement stabilized macadam prepared by vibratory and nonvibratory mixing techniques. *Advances in Civil Engineering, 2021*, 1.
Wang, X. D., Zhang, L., & Zeng, F. (2015). *Application handbook of technical guidelines for construction of highway roadbases*. China Communication Press.
Wongkeo, W., Thongsanitgarn, P., Ngamjarurojana, A., & Chaipanich, A. (2014). Compressive strength and chloride resistance of self-compacting concrete containing high level fly ash and silica fume. *Materials & Design, 64*, 261–269.
Xiong, G., Wang, C., Zhou, S., Jia, X., Luo, W., Liu, J., & Peng, X. (2019). Preparation of high strength lightweight aggregate concrete with the vibration mixing process. *Construction and Building Materials, 229*, 116936.
Xue, S. Q., (2016). Vibratory mixing mechanism and experimental study on improving the cement stabilized macadam performance. Chang'an University
Yao, Y., Feng, Z., & Chen, S. (2013). Strength of concrete reinforced using double-blade mixer. *Magazine of Concrete Research, 65*(13), 787–792.
Zemam, S. K. (2020). Developing sustainable concrete compaction using a proposed multi-vibration technique. *Al-Qadisiyah Journal for Engineering Sciences, 13*(1), 46–54.
Zhang, J. X., (2016). Experimental study on road performance of low-cement graded crushed stone. *Bulletin of the Chinese Ceramic Society*, 12.
Zhang, L. Q., (2018). A twin-shaft vibration mixer. China. CN207290524U. 1 May
Zhang, L., & Feng, Z. (2011). Process of concrete mixing and its evaluation. *Journal of chang'an University (natural Science Edition), 31*(2), 101–105.
Zhang, P., & Li, Q. (2009). Effect of polypropylene fibre on mechanical and shrinkage properties of cement-stabilised macadam. *International Journal of Pavement Engineering, 10*(6), 435–445.
Zhang, P., Li, Q., & Wei, H. (2010). Investigation of flexural properties of cement-stabilized macadam reinforced with polypropylene fiber. *Journal of Materials in Civil Engineering, 22*(12), 1282–1287.
Zhao, L. J., Jiang, W. Z., Feng, Z. X., & Xue, S. (2018). Influence of mixing method on performance of compressive strength for cement stabilized macadam mixture, China. *Journal of Highway and Transport, 31*(1), 151–158.
Zhao, L. J., Jiang, W. Z., Hou, J. R., et al. (2019). Influence of mixing methods on performance of compressive strength for cement stabilized macadam mixture. *China Journal of Highway and Transport., 31*(1), 151–158.
Zhao, K. Y., Zhao, L. J., Hou, J. R., Zhang, X., Feng, Z., & Yang, S. (2021). Effect of vibratory mixing on the slump, compressive strength, and density of concrete with the different mix proportions. *Journal of Materials Research and Technology, 15*, 4208–4219.
Zhao, K. Y., Zhao, L. J., Liu, S. S., & Hou, J. (2019). Effect of three-step mixing technology based on vibratory mixing on properties of high-strength concrete. *IOP Conference Series Materials Science and Engineering., 542*(1), 012003.
Zhao, Y., Yang, X., Zhang, Q., Liang, N., Xiang, Y., & Qin, M. (2020). Crack resistance and mechanical properties of polyvinyl alcohol fiber-reinforced cement-stabilized macadam base. *Advances in Civil Engineering, 2020*, 1.
Zheng, Y., Wu, X., He, G., Shang, Q., Xu, J., & Sun, Y. (2018). Mechanical properties of steel fiber-reinforced concrete by vibratory mixing technology. *Advances in Civil Engineering, 2018*, 1.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.