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Research on Shrinkage Chemical Properties of Cement Stabilized Macadam Material Based on a Multi-dimensional Expansion and Shrinkage Tester

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Abstract: *In order to find out the shrinkage law of cement stabilized macadam material under specific conditions, this paper studied the expansion and shrinkage properties of cement stabilized macadam material under two environmental conditions, five kinds of cement dosage conditions, suspended compacted type and skeleton compaced type based on the multi-dimensional expansion and shrinkage tester. Through the test comparison, it is confirmed that the water loss rate of cement stabilized macadam material increases with the increase of cement dosage, showing a general change rule of rising first and then stabilizing. The average increase of the total water loss rate of suspended compacted cement stabilized macadam at room temperature was greater than that of the skeleton compacted cement stabilized macadam. The dry shrinkage strain also follows the above trend. Either at room temperature or under the conditions of dry shrinkage box, the water loss rate of suspended compacted cemeny stabilized macadam is higher than that of skeleton compacted cement stabilized macadam , which can be up to 3.23% higher. By comparing the temperature shrinkage coefficient under the high and low temperature environment, the temperature coefficient of the skeleton compacted cement stabilized macadam is smaller than that of the suspended compacted cement stabilized macadam. The temperature shrinkage coefficient of the suspended compacted cement stabilized macadam increases by 5.56% on average for each 0.5% increase of the cement dosage, and the temperature shrinkage coefficient of the skeleton compacted cement stabilized macadam increases by 6.33% on average. Through the comparative analysis of tests, it can be found that the anti-reflection crack ability of the skeleton compacted cement stabilized macadam material is better, and the fine aggregate content should be strictly controlled in the construction.*

Keywords*: drying shrinkage strain, temperature shrinkage coefficient , cement stabilized macadam.*

1. Introduction

Semi-rigid base material is widely used in the middle or bottom base of high grade asphalt pavement. The application of cement stabilized macadam material is the most typical. But it sensitively, it usually produces drying shrinkage and temperature shrinkage cracks under the condition of humidity and temperature changing. Cracks further expand to the asphalt road surface, can produce reflection cracking, and reduce pavement smoothness and continuity. So it influence on the performance of the pavement using [1-3].The shrinkage forms of cement stabilized macadam material are divided into dry shrinkage and temperature shrinkage. In the mixing process, the hydration reaction and the evaporation of water will reduce the water in the mixture [4-5]. This causes dry shrinkage. When the paving is completed for a period of time, the shrinkage is basically stable, and the shrinkage of cement stabilized macadam gradually changes from dry shrinkage to temperature shrinkage. In the past, many researchers started from the composition of cement stabilized macadam materials and conducted further experimental studies on the composition and dosage of each component material affecting shrinkage [6-21]. However, the influence of the structure on the shrinkage performance has not been systematically analyzed.

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In this paper, a systematic experimental study is carried out on the shrinkage law of cement stabilized macadam material for suspended compacted and skeleton compacted structures. A new kind of multi-dimensional and multi-specification expansion and shrinkage tester is applied to the experiment of specimens, which provides a new idea for studying the expansion and shrinkage of cement stabilized macadam more accurately and comprehensively.

2. Materials and methods

2.1. Cement stabilized macadam mix design

The test cement type is p.o.42.5, which is tested according to the test method stipulated in JTG E30-2005 "Test Methods of Cement and Cement Concrete for Highway Engineering"[22-23]. The test results are shown in Table 1.

Table 1. Cement test results

Technical indicators	Specification requirements	Measured data
Fineness(%)	≤10	3.2
Initial setting time(min)	≥45	185
Final setting time(min)	≤600	247
Stability (mm)	≤5	1.2
Water consumption for normal consistency(%)	—	32.4
3d compressive strength (MPa)	≥2.5	3.7
28d compressive strength (MPa)	≥5.5	7.6
3d folding strength(MPa)	≥10	16.9
28d folding strength(MPa)	≥32.5	35.6

The test results of physical and mechanical properties of the aggregates used in this study are shown in Table 2 below.

Table 2. Physical properties of aggregate.

Physical properties	Particle size(mm)		
	31.5~15	15~5	5~0
The apparent density(g/cm^3)	2.86	2.54	2.47
Crushing value(%)	20.3	21.9	—
Needle flake content(%)	7.7	10.1	—
Sand equivalent	—	—	33

According to JTG/T F20-2015 "Technical Guidelines for Construction of Highway Roadbases" [24-25], the direct drinking water of human and animal does not need to be measured and can be directly used in the test. The water used in this test is tap water. In this paper, the mixture ratio of suspended compacted type and skeleton compacted type graded gravel is selected according to the mixture ratio recommended in JTG D50-2017 "Specification for Design of Highway Asphalt Pavement" [26]. The specific data are as follows:

(1) Suspended compacted cement stabilized macadam gradation

The pass rate of each sieve is shown in Table 3, and the grading curve is shown in Figure 1.

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Table 3. Pass rate of suspended compacted cement stabilized macadam.

Material specifications	Mass percentage under sieve (%)						
	31.5	19	9.5	4.75	2.36	0.6	0.075
Upper grading limit	100	100	80	49	32	20	5
Lower grading limit	100	90	60	29	15	6	0
Synthesis of grading	100	95.3	68.2	37.5	23.6	10.3	2.9

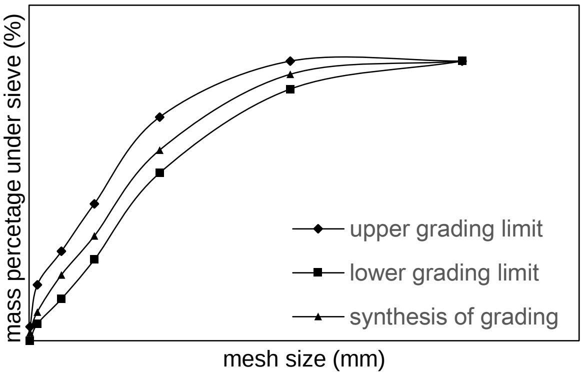

Figure 1. The gradation curve of suspended compacted cement stabilized macadam.

(2) Skeleton compacted cement stabilized macadam gradation
The pass rate of each sieve is shown in Table 4, and the grading curve is shown in Figure 2.

Table 4. Pass rate of skeleton compacted cement stabilized macadam.

Material specifications	Mass percentage under sieve (%)						
	31.5	19	9.5	4.75	2.36	0.6	0.075
Upper grading limit	100	86	58	32	28	15	3
Lower grading limit	100	68	38	22	16	8	0
Synthesis of grading	100	76.6	49.4	25.6	20.1	11.5	1.7

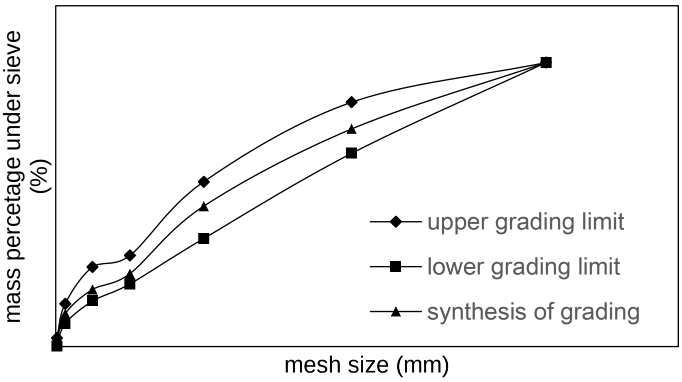

Figure 2. The gradation curve of skeleton compacted cement stabilized macadam.

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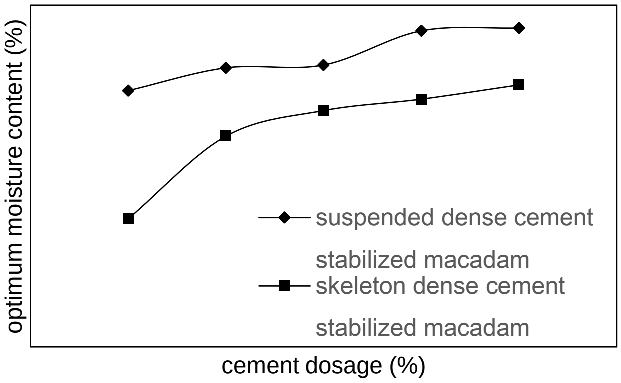

Figure 3. The optimum moisture content curve

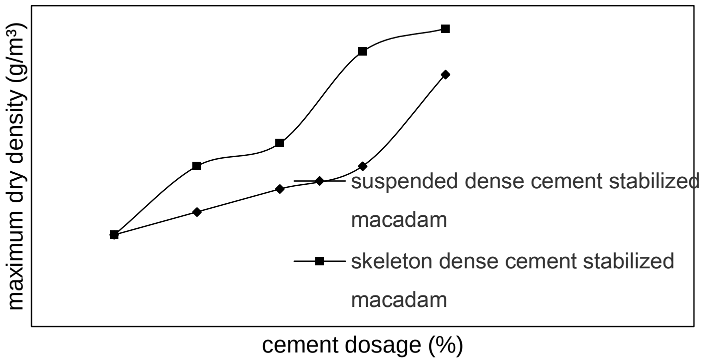

Figure 4. The maximum dry density curve

The test results of optimal moisture content and maximum dry density of two gradation types of cement stabilized macadam are shown in the above figures.

2.2. Research and development of the multi-dimensional expansion and shrinkage tester

The new expansion and shrinkage tester can measure the four directions of two-dimensional plane of the specimen. The assembly platform of the tester is optimized to be a cross, which is supported by telescopic columns in four directions. The dial table frame is installed on the four directions of the instrument base, and the slide that can make the table frame move is installed on the surface of the base. In this way, the test position can be changed in two dimensions to adapt to the change of specimen size. As there are multiple meter positions on the table frame, several more micrometers can be added in each direction to test the expansion and shrinkage of different parts of the specimen. This design makes the experiment more complete and accurate. Figure 5 is the physical drawing of the expansion and shrinkage tester.

1-Specimen platform 2-Dial gauge 3-Slide 4-Computer 5-Base
6- Base of the magnetometer 7-Level 1 bar 8-Level 2 bar 9- Magne-switch 10- Specimen
Figure 5. Physical drawing of the expansion and shrinkage tester.

This tester can measure the size of specimens up to 600mm in length and 600mm in width. It can realize real-time monitoring of specimen shrinkage deformation, and the measure accuracy can reach 0.001mm.

3. Results and discussions

3.1. Experimental study on the dry shrinkage performance of cement stabilized macadam

(1)Variation of water loss rate

At room temperature, the effect of changing cement dosage on the dry shrinkage of suspended compacted macadam and skeleton compacted macadam is basically the same. With the increase of age, the accumulative water loss rate increases. It seems that the water loss rate of suspended compacted macadam is higher at different cement dosage.

Table 5. Comparison of dry shrinkage performance indexes of two gravels at 7 days of age at room temperature

Cement dosage (%)	**Suspended compacted type (Skeleton compacted type)**			
	Cumulative water loss rate (%)	Cumulative dry shrink (10^{-3}m)	Dry shrinkage strain(10^{-6})	Dry shrinkage coefficient(10^{-6})
3.5	4.08 (3.96)	90.45 (74.92)	23.10 (18.73)	5.113 (4.730)
4.0	4.39 (4.12)	92.61 (75.52)	23.15 (18.88)	5.274 (4.583)
4.5	4.65 (4.29)	94.82 (77.43)	23.71 (19.36)	5.095 (4.512)
5.0	4.84 (4.36)	97.58 (79.53)	24.40 (19.88)	5.045 (4.560)
5.5	4.88 (4.49)	100.38 (81.36)	25.10 (20.34)	5.141 (4.530)

Table 6. Comparison of dry shrinkage performance indexes of two gravels at 7 days of age in drying shrinkage box

Cement dosage (%)	**Suspended compacted type (Skeleton compacted type)**			
	Cumulative water loss rate (%)	Cumulative dry shrink (10^{-3}m)	Dry shrinkage strain(10^{-6})	Dry shrinkage coefficient(10^{-6})
3.5	3.45 (3.37)	77.34 (67.57)	19.34 (16.89)	5.604 (5.013)
4	3.56 (3.52)	79.33 (69.69)	19.83 (17.42)	5.571 (4.950)
4.5	3.65 (3.63)	81.86 (71.24)	20.47 (17.81)	5.607 (4.913)
5	3.76 (3.72)	84.98 (74.69)	21.25 (18.67)	5.650 (5.026)
5.5	3.83 (3.77)	88.51 (75.54)	22.13 (18.89)	5.777 (5.016)

With the increase of age, the water loss rate of two kinds of specimens at room temperature and in the drying shrinkage box showed an increasing trend.

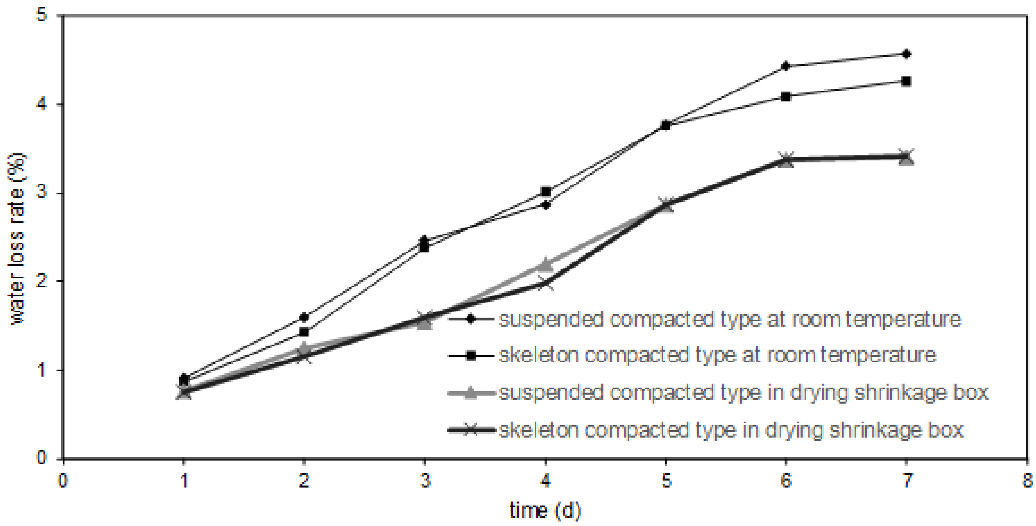

Figure 6. The water loss rate of the specimen in different environments (cement dosage 4.5%).

It can be seen from Table 5 and 6 that, for the two types of cement stabilized macadam materials in this paper, the water loss rate is directly proportional to the amount of cement dosage, and the value of cumulative water loss rate raise with the increase of cement dosage. It can be found from Figure 6 that the water loss rate of the two kinds of specimens gradually tends to be flat after the fifth day, and the change of the water loss rate also decreases gradually. In the case of the same cement dosage, the water loss rate of skeleton compacted type specimens is lower than that of suspended compacted type specimens. Whether at room temperature or under the condition of drying shrinkage box, the proportion with the lowest water loss rate is skeleton compacted type specimens with cement dosage of 3.5%, and the water loss rate of suspended compacted type specimens is higher than that of skeleton compacted type specimens about 2.76-3.23%. According to the data analysis and calculation, for every 0.5% increase in cement dosage, the accumulative water loss rate of suspended compacted type specimens increases by 5.50% on average at room temperature and 4.77% on average in drying shrinkage box. By comparison, the accumulative water loss rate of skeleton compacted specimens increased by 4.46% on average at room temperature and 4.79% on average in the drying shrinkage box. Therefore, the change of temperature and humidity has an important effect on the water loss rate of cement stabilized macadam.

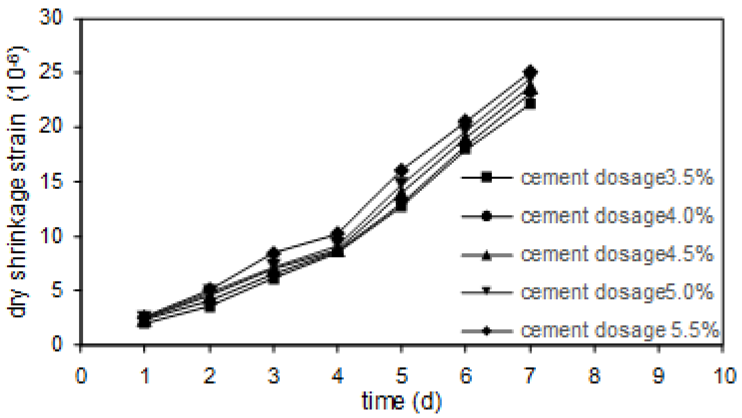

Figure 7. Curve of dry shrinkage strain at room temperature (suspended compacted type)

(2) Variation of dry shrinkage strain

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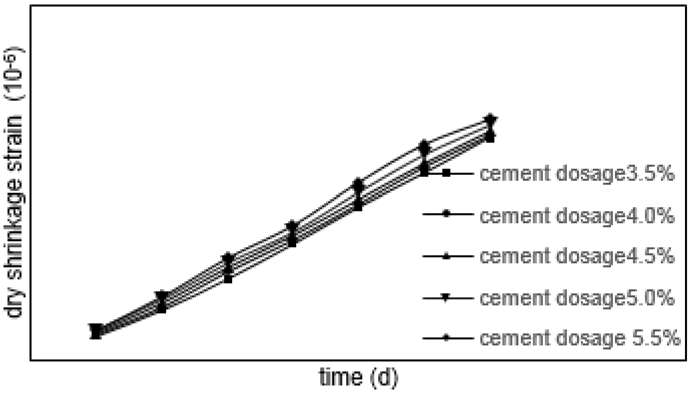

Figure 8. Curve of dry shrinkage strain at room temperature (skeleton compacted type)

It is found that the cement dosage of the cement stabilized macadam in this paper is proportional to the dry shrinkage strain. As shown in Figure 7 and 8, the minimum proportion of dry shrinkage strain was skeleton compacted type specimen with cement dosage of 3.5% at room temperature, and the dry shrinkage strain of suspended compacted type was 5.82% higher than that of skeleton compacted type on average. Comparatively speaking, the two kinds of cement stabilized macadamia specimens under the condition of drying shrinkage box also have the same change rule as above. Moreover, the difference of dry shrinkage strain between the two types of specimens in this paper is larger. According to the data analysis and calculation, for every 0.5% increase in cement dosage, the dry shrinkage strain of suspended compacted type specimens increases by 4.76% on average at room temperature and 5.74% on average in drying shrinkage box. By comparison, the dry shrinkage strain of skeleton compacted specimens increased by 3.77% on average at room temperature and 4.56% on average in drying shrinkage box. Therefore, choosing skeleton compacted cement stabilized type instead of suspended compacted cement stabilized type macadam can effectively reduce the dry shrinkage strain.

(3) Analysis of the relation between water loss rate and dry shrinkage strain

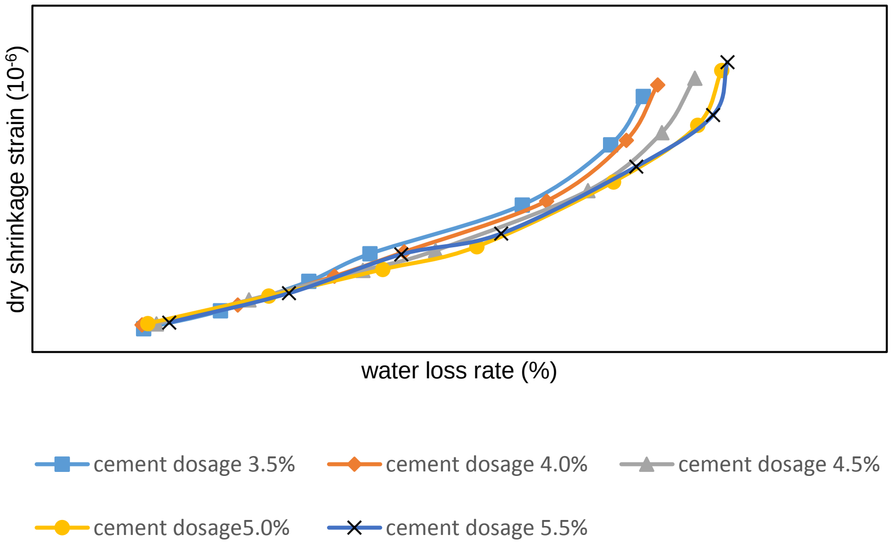

Figure 9. The relation curve of water loss rate and dry shrinkage strain at room temperature (suspended compacted type)

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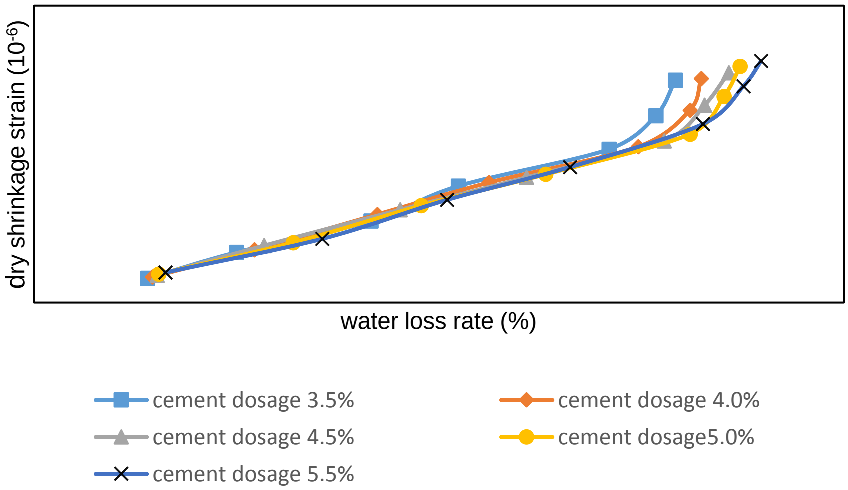

Figure 10. The relation curve of water loss rate and dry shrinkage strain at room temperature (skeleton compacted type)

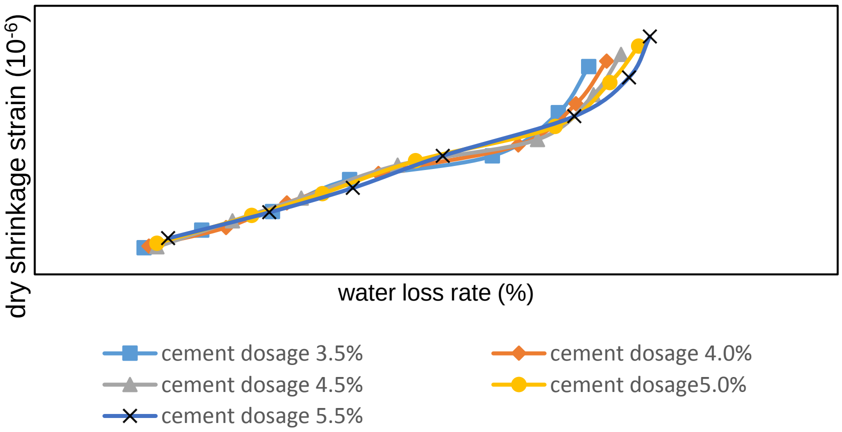

Figure 11. The relation curve of water loss rate and dry shrinkage strain in drying shrinkage box (suspended compacted type)

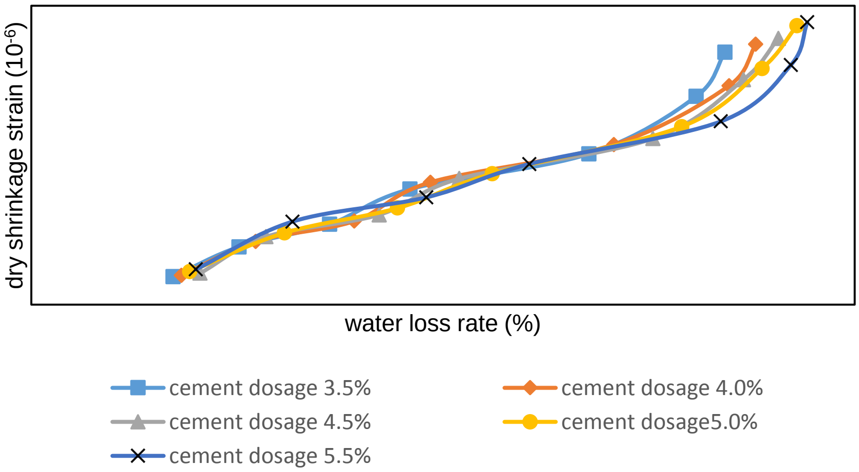

Figure 12. The relation curve of water loss rate and dry shrinkage strain in drying shrinkage box (skeleton compacted type)

From Figure 9 to 12, it can be seen that at room temperature, when the water loss rate of cement stabilized macadam is below 3.5%, the dry shrinkage strain of the aggregate basically increases at a uniform rate. When the water loss rate exceeded 3.5%, the dry shrinkage strain value increased sharply. Similarly, under the condition of dry shrinkage box, the dry shrinkage strain of cement stabilized macadam increases at a uniform rate when the water loss rate is below 3.0%. When the water loss rate exceeds 3.0%, the dry shrinkage strain increases at a faster rate.

3.2. Experimental study on the temperature shrinkage test of cement stabilized macadam

Five kinds of cement dose-mix ratios, six temperature zones and a total of 60 temperature shrinkage tests are designed for the temperature shrinkage tests.

Table 7. Temperature shrinkage cofficient of suspended dense cement stabilized macadam

Cement dosage (%)	Temperature range (℃)						Ratio
	30~20	20~10	10~0	0~-10	-10~-20	-20~-30	
3.5	7.12	8.27	8.96	5.83	5.94	5.02	6.86
4.0	7.24	8.63	9.75	5.97	6.37	5.29	7.21
4.5	7.83	9.14	10.56	6.48	6.63	5.77	7.74
5.0	8.15	9.38	10.72	6.86	7.04	6.07	8.04
5.5	8.33	9.54	11.38	7.40	7.56	6.85	8.51

Table 8. Temperature shrinkage cofficient of skeleton dense cement stabilized macadam

Cement dosage (%)	Temperature range (℃)						Ratio
	30~20	20~10	10~0	0~-10	-10~-20	-20~-30	
3.5	6.71	7.73	8.26	5.48	5.35	4.22	6.29
4.0	6.23	7.58	8.62	5.81	5.63	4.89	6.46
4.5	7.41	8.76	9.48	6.42	6.17	5.25	7.25
5.0	7.74	8.96	9.93	6.75	6.43	5.77	7.60
5.5	7.87	9.58	10.15	7.06	6.82	5.92	7.90

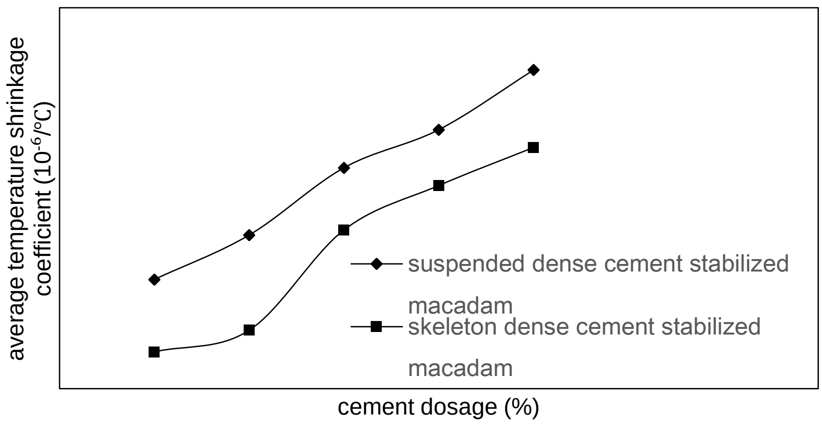

Figure 13. Curve of average temperature shrinkage coefficient of cement stabilized mixture with different proportion.

It can be seen from Table 7 and 8 that the average temperature shrinkage coefficient of test specimens increases with the increase of cement dosage. And the average temperature shrinkage coefficient of suspended compacted cement stabilized macadam mixture is higher than that of skeleton compacted cement stabilized macadam mixture. According to the data analysis and calculation, for every 0.5% increase in cement dose, the temperature shrinkage coefficient of suspended compacted cement stabilized macadam mixture increases by 5.56% on average but it increase by 6.33% on average for skeleton compacted cement stabilized macadam mixture. It can be seen from the experiment that the skeleton compacted cement stabilized macadam has higher sensitivity to temperature than the suspended compacted cement stabilized macadam, but its average temperature shrinkage coefficient is smaller than that of the suspended compacted cement stabilized macadam. Therefore, the skeleton compacted cement stabilized macadam material can be used to reduce the temperature shrinkage crack. However, it should be used carefully in areas with large annual environmental temperature difference.

4. Conclusions

In order to make up for the shortcoming that the current dry shrinkage detection equipment can only measure the expansion and shrinkage of specimens in one direction, a multi-dimensional and multi-angle expansion and shrinkage tester has been independently developed. The dry shrinkage and temperature shrinkage tests of two kinds of cement stabilized macadam specimens have been conducted from the perspective of material structure. The following conclusions have been drawn:

(1) For the two kinds of cement stabilized macadam materials in this paper, the water loss rate increased with the increase of cement dosage, and the water loss rate gradually tended to be flat after the fifth day of the test. The water loss rate of suspension compacted macadam is higher than that of skeleton compacted macadam.

(2) When the cement dosage increases, the dry shrinkage strain also grows. Comparatively speaking, the dry shrinkage strain of suspended compacted macadam is greater than that of skeleton compacted macadam at the same cement dosage. In order to reduce the dry shrinkage strain, skeleton compacted cement stabilized macadam material can be used instead of suspended compacted cement stabilized macadam material.

(3) Through data analysis, it is found that the water loss rate of cement stabilized macadam materials is proportional to the dry shrinkage strain. At room temperature, the water loss rate is below 3.5% and the dry shrinkage strain is smaller. Under the condition of dry shrinkage box, the water loss rate is below 3.0% and the dry shrink strain is smaller.

(4) The results of temperature shrinkage experiments show that the temperature shrinkage coefficient of cement stabilized macadam materials in this paper increases gradually when the temperature is above 0℃, and then decreases when the temperature is below 0℃. In comparison, the temperature shrinkage coefficient of skeleton compacted cement stabilized macadam is lower and more sensitive to temperature conditions.

(5) From the point of view of avoiding crack, this paper recommends the skeleton compacted cement stabilized macadam material as the road base material. The dosage of cement is recommended to be 3.5%. At the same time, the curing work should be done well after the semi-rigid base is paved to ensure its temperature and humidity.

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