

Study on early strength agent for improving early strength performance of water-stabilized macadam material

Linmin^{1,a}, Guo Yuchen^{1,b}, Tian Beisi^{2,c} and Song Yunlian^{1,d}

¹School of civil engineering, Inner Mongolia University of Technology, Hohhot 010051, China;

²Chang'an University, Xi'an 710064, China.

^a751904198@qq.com, ^b463843103@qq.com, ^c695320909@qq.com, ^dsyllsj@sina.com

Correspondent author: Song Yun Lian, Ph. D, Professor. E-mail:dsyllsj@sina.com

Abstract: Because triethanolamine (TEA) and anhydrous sodium sulfate (Na₂SO₄) can both improve the performance of cement stabilized macadam material, an optimal dosage group is found by compounding the two materials to improve the dry shrinkage performance of cement stabilized macadam material. Based on unconfined compression test and dry shrinkage strain test, the changes of compressive strength of water-stabilized macadam materials caused by different compound dosage groups and original materials were compared. The results show that the three dosage groups can improve compressive strength and reduce the dry shrinkage strain of the cement stabilized macadam material. The compressive strength of 2.0 % anhydrous sodium sulfate and 1.0 % triethanolamine was the best, increasing 73.8 %; moreover, the dosage group can effectively reduce shrinkage cracks, which is 3.88 % less than that of the blank control group. The test data were tested by correlation analysis and there were significant differences between the control group and each dosage group, which indicated that the admixture had a significant improvement on the material properties.

1. Introduction

With the gradual improvement of the society's requirements on the service quality and life of roads, more and more roads begin to use cement stabilized macadam as the base layer. Because of the semi-rigid characteristics of this base layer, cement stabilized macadam has excellent load spreading ability under repeated loads, and has certain tensile strength, fatigue strength and good water stability characteristics^[1]. Zhang Feng and Bai Yin, through the research of domestic and foreign literatures, put forward that the development of early strength agents that meet the requirements of low temperature early strength and have good workability is an important research direction at present^[2]. Many foreign scholars such as Péra J and Ambroise J^[3], Janotka I^[4], Czernin^[5], Chatterjee A.K^[6] etc, they studied that common silicate cement and other kinds of cements are mixed with different proportion, a variety of early strength cement which can accelerate the forming strength of cement in varying degrees has been prepared. In terms of dry shrinkage strain, many experts and scholars at home and abroad have carried out a lot of research. Peng weibing^[7], t Paul tengg, P.E.^[8] and others found that although cement stabilized macadam material has good bearing capacity, it is prone to dry shrinkage deformation. When the tensile strength of internal structure is not enough to resist shrinkage stress, cracks will occur, which seriously affects the stability of subgrade and its service life. Many scholars in Bulgaria^[9] and Japan^[10] respectively used sodium carbonate, sodium aluminate, aluminate



and aluminide as main materials to improve the performance of cement stabilized macadam materials. In this paper, through unconfined compression test and dry shrinkage strain test, the effect of tea and Na₂SO₄ on the performance improvement of water-stabilized macadam material was studied.

2. Experiment materials

2.1 Cement

According to the "Technical rules of Highway pavement Base Construction" (JTG-T- F20-2015)^[11], ordinary portland cement, pozzolanic portland cement and slag portland cement can be used in the test, but cement with initial setting time of more than 3 hours and final setting time needs to be more than 6 hours and less than 10 hours. The bulk ordinary Portland cement of Jidong cement Plant in Inner Mongolia was used in experiment in this paper. The results of cement testing are shown in Table 1.

Table1 results of cement test

project	time of setting/min		compression strength/MPa		rupture strength /MPa	
	initial setting time	final setting time	3d	28d	3d	28d
technical requirements for cement raw materials	≥180	≥360 and ≤600	≥16	≥32.5	≥3.5	≥5.5
experimental result	245	420	17.8	43	4.4	8.7

2.2 Aggregate

The limestone in Mount Daqing Mountain stone plant in Hohhot was used. According to the Test Rules for Aggregate in Highway Engineering (JTGE42-2005)^[12], the aggregate crushing value is 17.8 and the aggregate needle sheet content is 3% to 5%.

2.3 Raw materials of early strength agents

Triethanolamine: the chemical formula is (HOCH₂CH₂)₃N, triethanolamine produced by Tianjin Chemical Co., Ltd. is adopted, the reagent content is more than or equal to 85.0%. Anhydrous sodium sulfate: the chemical formula is (Na₂SO₄), anhydrous sodium sulfate produced by Tianjin Chemical Co.,Ltd. is adopted, and the reagent content is more than or equal to 99.0%.

3. Test Scheme and Method

3.1 Unlimited compression test

The three compound admixture groups that have been prepared are named as: admixture group I (2.0% triethanolamine and 1.0% anhydrous sodium sulfate), admixture group II (2.0% anhydrous sodium sulfate and 0.75% triethanolamine), and admixture group III (1.5% anhydrous sodium sulfate and 1.0% triethanolamine). The control group without any admixture was set as the admixture group 0 dosage group. Thirteen specimens were made in each group, and the time period were 12 hours, 1 day, 2 days, 3 days, 7 days and 28 days. A total of 312 specimens were made. The unconfined compression experiment was done by the digital-display concrete pressure tester(YE-2000B).

After 28 days curing time, the experiment result shows that three kinds of composite admixture groups can greatly improve the compressive performance of cement stabilized macadam. The SPSS software is used to analyze the Friedman statistics of the dosage group and the pressure. The relationship between the unconfined compressive strength and the curing time of four dosage groups was drawn in Figure 1. The figure shows that the longer the test period, the better the effect of increasing the compressive strength of the I and II type admixture groups.

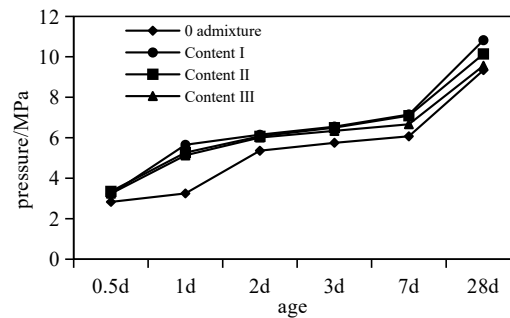


Figure 1. Unconfined compressive strength values

The experiment results show that the unconfined compressive strength is 5.65MP based on the group I, 5.27MP based on the group II and 5.13MP based on the group III according to the 24h experiment specimens. Based on the zero dosage group, the strength of the specimen in the group I, II and III increased by 73.8%, 62.2% and 57.8% respectively.

3.2 Dry shrinkage strain test

According to the dry shrinkage test method in Highway Engineering Inorganic Binder Stable Material Test Regulations (JTGE51 - 2009) [13], four groups of specimens of 100 mm * 100 mm * 400 mm cuboid middle beam were selected, with 0 dosage, dosage I, dosage II, dosage III, 6 specimens in each group, 3 specimens were used to measure the shrinkage deformation of the specimens, and 3 specimens used to calculate the water loss rate.

The dry shrinkage strain test was started after the curing room with a temperature of $20\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$ and a relative humidity of $60\% \pm 5\%$ was installed. At the beginning of 7days, the dial indicator is read every day to record the data. During the following 7days to 30days, the data is read every two days to record the experimental data, and the graph 2 of the relationship between dry shrinkage and time is drawn.

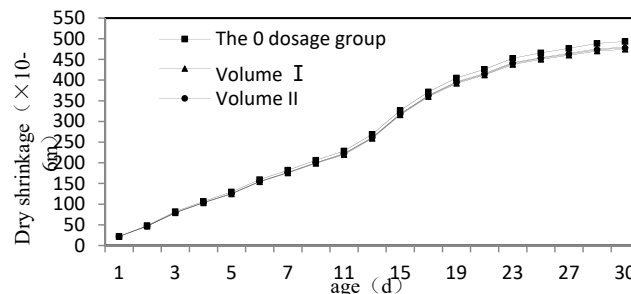


Figure 2 the curve between time and cumulative average dry shrinkage

As can be seen from figure 2, the dry shrinkage curves of the four groups of dosage are almost the same in the 1day- 11day age. During the 12day - 20day test period, the dry shrinkage curves of the four groups of cement stabilized macadam specimens increased rapidly, and the slope of the curves was also significantly higher than that of the 1day - 11day dry shrinkage curves; In the 20day - 30day test period, the growth slope of the cumulative shrinkage curve gradually decreased from high to low, and the growth curve tended to be almost flat after 27 days. It can be seen from this that the trend of dry shrinkage growth curves of the four test groups is almost the same, but the peak values in each time period are different, among which the peak value of the dosage I is the smallest. This shows that the dry shrinkage of the four groups of specimens will gradually increase with the increase of time. Although the dosage group cannot change this change trend, it can reduce the dry shrinkage of the material, among which the dry shrinkage of dosage I is the smallest.

Substituting the data into the dry shrinkage strain formula (2):

$$\varepsilon_d = \Delta L / L_0 \quad (2)$$

In this formula, ε_d means dry shrinkage strain, it refers to the shrinkage per unit length of the test piece caused by water loss ($\times 10^{-3}$). L_0 is the initial length of the standard specimen (mm). ΔL is the dry shrinkage, it refers to the shrinkage of the specimen ($\times 10^{-6}$) when water loss occurs.

Obtain the dry shrinkage strain ε_d ($\times 10^{-3}$) as shown in table 2:

Table 2 the strain of dry shrinkage

group	0 dosage	Content I	Content II	Content III
ΔL	493.49	474.32	477.39	479.62
L0	399.4	399.6	399.6	399.5
ε_d	1.236	1.187	1.195	1.201

Through the dry shrinkage strain test, it was found that the resistance of the three dosage groups to dry shrinkage strain was better than that of the zero group. Moreover, the dry shrinkage strain of cement stabilized macadam material with the content of I was the smallest and the most stable, and the effect is obviously better than that of the experimental group with the content of II and III.

In order to further study the differences between the four dosage groups, we use SPSS software to test the homogeneity of variance and one-way ANOVA between the dosage group and the dry shrinkage group. If the variance homogeneity test < 0.05 , then the homogeneity test is not passed, and if the result > 0.05 , the variance homogeneity test can be used to further variance analysis^[14]. The results of homogeneity test and analysis are shown in table 3, single factor analysis of variance is shown in table 4, and multiple comparisons between dosage groups and dry shrinkage are shown in table 5:

Table 3 test of homogeneity of variance

Levene statistics	df1	df2	conspicuousness	Levene statistics
0.000	3	72	1.000	0.000

Table 4 Analysis of single factor ANOVA

	quadratic sum	df	mean square	F	Sig.
Inter-group	11.336	3	3.779	0.024	0.995
Intra-group	11278.637	72	156.648		
amount	11289.974	75			

Note: df in the table is the variance ; F is the test statistic; Sig. is the significant level.

Table 5 dry shrinkage and multiple comparison dosage group

dependent variable: Dry shrinkage

		mean difference (I-J)	standard error	Sig.	95% confidence interval	
(I) group	(J) group				lower limit value	upper limit value
LSD	0	1	1.00895	0.804	-7.0859	9.1038
		2	0.84737	0.835	-7.2475	8.9422
		3	0.73000	0.858	-7.3648	8.8248
	1	0	-1.00895	0.804	-9.1038	7.0859
		2	-0.16158	0.968	-8.2564	7.9333
		3	-0.27895	0.945	-8.3738	7.8159

2	0	-0.84737	4.06069	0.835	-8.9422	7.2475
	1	0.16158	4.06069	0.968	-7.9333	8.2564
	3	-0.11737	4.06069	0.977	-8.2122	7.9775
3	0	-0.73000	4.06069	0.858	-8.8248	7.3648
	1	0.27895	4.06069	0.945	-7.8159	8.3738
	2	0.11737	4.06069	0.977	-7.9775	8.2122

With the Levene variance homogeneity test, the significant in table 3 is 1.000 greater than 0.05, indicating that two sets of data can be analyzed by variance. It is not difficult to find through table 4 that there are significant differences among the mixed groups between the four dosage groups, indicating that the dose ratio of triethanolamine and anhydrous sodium sulfate will affect the dry shrinkage of the material. Because there was no significant difference in the group, it was indicated that the dry shrinkage of each specimen in the same dosage was basically the same. Then two-two pairs of data were compared between four mixed groups, and the results were as table 5. It was found that the significant difference between the 0 dosage group and III was the largest, while the maximum mean difference of I in 30 days was more than that of the other three dosage groups, and the amount of I in the 30-day experiment was the least.

4. Conclusion

1) All three new admixture groups can improve the compressive strength resistance of cement stabilized macadam material. The compressive strength also can be significantly improved by triethanolamine and anhydrous sodium sulfate within a short time, with 2.0% anhydrous sodium sulfate and 1.0% triethanolamine cement stabilized macadam material compressive strength in all ages are optimal.

2) Through experiments, it is concluded that anhydrous sodium sulfate and triethanolamine can effectively reduce the occurrence of dry shrinkage cracks in cement stabilized macadam, and the combined early strength agent can further improve its performance. For the mixture ratio of this paper, the best effect is to mix 2.0 % anhydrous sodium sulfate and 1.0 % triethanolamine.

3) Because the mixture of 2.0 % anhydrous sodium sulfate and 1.0 % triethanolamine showed better improvement in the properties of the three materials, and the superiority of the dosage group was verified through variance analysis, so it has very good research significance as an early strength agent raw material.

References:

- [1] Wu J.T. (2009) Study on reasonable layer and reasonable thickness of semi-rigid Base. Chang'an University.
- [2] Zhang F, Bai Y, Cai Y.B. (2017) Research status of low temperature early strength Agent for concret. Material guide, 21:106-113.
- [3] Péra J, Ambroise J. (2004) New applications of calcium sulfoaluminate cement. Cement & Concrete Research, 34:671-676.
- [4] Janotka I, Krajčí L', Ray A, et al. (2003) The hydration phase and pore structure formation in the blends of sulfoaluminate-belite cement with Portland cement. Cement & Concrete Research, 33:489-497.
- [5] Czernin, W. (1962) Cement Chemistry and Physics for Civil Engineers. Lockwood.
- [6] Chatterjee A.K, (1991) Special and new cements. India 9th International Congress on the Chemistry of Cement. pp.26-29.
- [7] Peng W.B, He Z, Liang W.Q. (2003) Understanding of High performance concrete and problems of concrete cracking. China cement. 12:40-44.
- [8] T.paul Teng, P.E. (2003) Evaluation of Joint and Crack Load Transfer Final Report. US Department of Transportation Federal Highway Administration. Publication No .FHWA-RD-02-088, October 2003.

- [9] Qing Y.Z. (1998) Research achievements and prospects of concrete accelerator. Yunnan Metallurgy, 1: 16-20.
- [10] Song J.L. (2013) Development and application of high performance accelerator for shotcrete. Hebei University of Engineering.
- [11] Highway Road Science Research Institute of Ministry of communications. JTG-T-F20-2015. road base construction technical specification. Beijing: People's transportation Publishing, 2015.
- [12] Highway Science Institute of Ministry of communications. JTG E42 - 2005. highway engineering aggregate test rules. Beijing: People's transportation Publishing, 2005.
- [13] JTG E 51-2009, Test Code for Inorganic binder stabilized Materials in Highway Engineering. Beijing: people's Communications Publishing, 2009.
- [14] Xue W. (2017) Statistical analysis and application of SPSS (Fifth Edition). Renmin University of China Publishing, Beijing.