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Effect of High Temperature on the Stability Performance of Polyvinyl Chloride and Nano Silica Modified Stone Matrix Asphalt Mixture

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Abstract: ***In tropical regions, temperature increased is too high in summer, which influences the road construction, especially asphalt pavement. Thus, we have to regard technical support the conditions of road construction in this region. This paper presents the effect of high temperature on the stability performance of Polyvinyl Chloride (PVC) and Nano Silica (NS) modified Stone Matrix Asphalt (SMA) using Marshall design method and rutting test. Three kinds of the SMA mixtures with 4%PVC and 3%NS, 5%PVC and 2%NS, and 6%PVC and 1%NS contents were used for water stability experiment at 60°C, the Marshall stability and Dynamic stability experiment from 60°C to 75°C. The results show that the Marshall stability and dynamic stability of three kinds modified by PVC and NS decrease when the experimental temperature increases from 60°C to 75°C. SMA mixtures modified with 5%PVC and 2%NS content has the best Marshall stability, water stability and dynamic stability on high temperature.***

Keywords: Stone Matrix Asphalt; Polyvinyl Chloride; Nano Silica; Marshall stability; Dynamic stability; Water stability.

1. Introduction

It is known that temperature has a very serious impact on road and highway constructions, especially in the tropics. The air temperature in the summer in these areas is often around 37 °C, which cause the temperature of pavement construction can be up to over 70 °C, if temperature of standard experiments is a regulation at 60 °C, test results cannot enough reflect the actual working conditions of the asphalt pavement [1]. Below high temperature, vehicles, containers or heavy truck loads may damage pavement construction. One of the most common physical sufferings of the asphalt pavement in the tropics is rutting or permanent deformation [2]. Rutting not only reduces the absorption and durability of the asphalt mixture but also brings road safety problems [3]. Walubita *et al*. also reported that the occurrence of shear deformation and surface rutting was partly related to the hot mixture asphalt (HMA) shear properties [4]. Therefore, in the stage of mix design, it is helpful to measure and quantify the shear resistance of HMA in the laboratory to screen and predict the potential rutting performance of the mixture in the field [5].

Stone Matrix Asphalt (SMA) is a kind of hot asphalt mixture; it was developed to be adapted in highways with high-traffic volume [6]. In SMA mixtures, polymer stabilization is mostly used to rise the stiffness of the bitumen mixture at high in service temperatures [7]. Polyvinyl chloride (PVC) is the world's third most common polymer, which can be processed into a wide variety of packaging products, beverage bottles, water pipes, and medical devices. The test results of asphalt mixture show that PVC additive improves the tensile strength, water resistance and rutting performance of asphalt mixture [8]. On high temperature performance nano materials can be used to improve the stability of asphalt pavement and the anti-deformation [9, 10]. Nano-Silica (NS) is widely concerned by pavement researchers because of its excellent stability, low price, high surface quality, and good dispersing ability [11]. Nur Izzi Md *et al*. reported that adding nano-silica material to bitumen mixture can make them more resistant cracking and snagging [12].

In this research, we designed three kinds of the SMA mixtures, which are made from Polyvinyl chloride and Nano silica. On the basis of Marshall and Rutting experiment, the effects of abnormal temperature changes on high temperature stability of three SMA mixtures were conducted, and water stability of these SMA mixtures was also studied.

2. Raw materials and experiments

2.1 Raw materials

The base asphalt used in this research and its physical properties are shown in Table 1.

Table 1: Basic properties of the base asphalt binder.

Basic properties	Method	Value	Unit
Penetration (100 g, 5s, 25°C)	ASTM D5	75.5	0.1 mm
Ductility (25°C, 5 cm/min)	ASTM D113	>150	cm
Softening point	ASTM D36	48.7	°C
Rotation viscosity (135°C)	ASTM D4402	0.581	Pa. s
Specific gravity at 25°C	ASTM D70	1.04	g/cm^3
Flash point	ASTM D92	320	°C

Polyvinyl Chloride as shown in Figure 1 and its basic properties listed in Table 2.

Figure 1: Polyvinyl Chloride (PVC)

Table 2: Properties of PVC sample

Appearance	Melting point (°C)	Density (g/cm^3)	Tensile strength (MPa)
White	170	1.42	60

Nano-SiO_2 powder as shown in Figure 2 was used and its properties are displayed in Table 3.

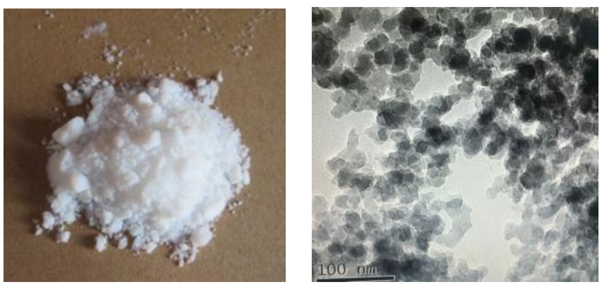

Figure 2: Nano silica SiO_2 (NS) sample

Table 3: Properties of NS sample.

Type	Appearance	Silica content (%)	Average grain size (nm)	Specific surface area (m^2/g)	pH value
SP15	White	99.8	15 ± 5	250 ± 30	5-7

Figure 3 shows the photographs of lignin fiber and its basic properties are listed in the Table 4. In this research, 0.31% lignin fiber, by weight of mixture, were uniformly combined with the hot aggregate before the asphalt binder was added.

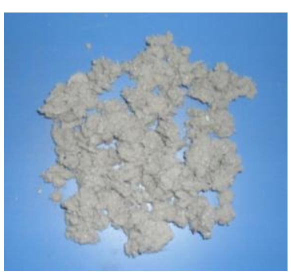

Figure 3: Properties of lignin fiber sample

Table 4: Properties of lignin fiber sample.

Appearance	Length (mm)	Diameter (μm)	Density (g/m^3)	pH value
Gray	< 5	46	1.6	7.5±1

The coarse and fine aggregates used in this experiment all are provided from Harbin City in the Heilongjiang Province of China. The aggregates were tested and the mechanical indicators of characteristics of the stone met the specifications required. The test results are presented in the Table 5. According to the China Standard [13] the SMA-16 mineral aggregate gradation limits and design is presented in Figure 4.

Table 5: Properties of aggregates

Aggregate properties	Method	Value	Unit
Crushed stone value	ASTM D6928	13.1	%
Los Angeles abrasion loss	ASTM C131	15.9	%
Apparent specific gravity	ASTM C128	2.78	g/cm^3
Water absorption	ASTM C70	0.41	%
Fine aggregate specific gravity	ASTM C127	2.78	g/cm^3
Sand equivalent	ASTM D2419	75.6	%

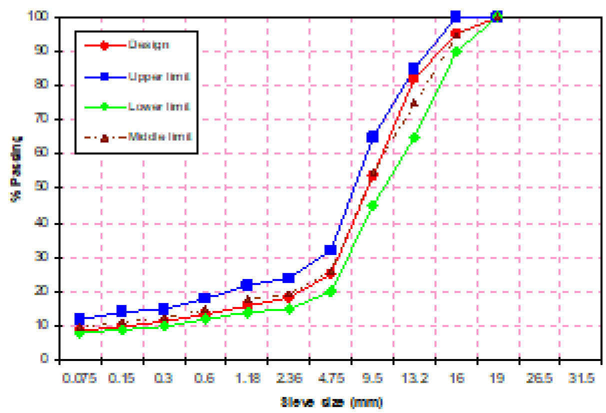

Figure 4: Gradation of aggregate used in this study

2.2 Experiments method

In this paper, PVC and NS were used in three concentrations 4%PVC and 3%NS (4P3N), 5%PVC and 2%NS (5P2N), and 6%PVC and 1%NS (6P1N) by mass of optimum binder content.

According to the rising temperature of the road surface in the tropics in summer, four kinds of temperature 60°C, 65°C, 70°C, and 75°C were designed to select the temperature conditions of the Marshall and Rutting experiments.

2.3 Sample preparation

All the experiment samples were prepared by wet method. The PVC and NS prepared by the melt blending method is simple and efficient. Three concentration of PVC (4%, 5%, and 6%) and three concentrations (1.0%, 2.0%, and 3.0%) of NS were produced. Firstly, the asphalt was heated to 180°C, and PVC was added at 170°C and stirred for 15 min at a shearing rate of 1200 r/min. Secondly, the mechanical mixing of PVC lasts for 60 min at 4000 r/min at 180°C. Finally, NS was added to the mixture and cut mutually at 160°C for 45 min at a rate of 3500 r/min.

2.4 Marshall stability test

According to the China Standard (JTG E20-2011) Marshall mixture design process is normally used to optimize the hot mixture asphalt in China. Six percentages of asphalt binder (4.0%, 4.5%, 5.0%, 5.5%, 6.0%, and 6.5%) were used to optimize the asphalt content. The optimum asphalt content was adopted to have maximum stability, maximum unit weight, and middle of acceptable limits for percent air voids (4.0-7.0%). The obtained optimum binder content for the control mixtures was 6.1%. Hence, this bitumen content was selected when preparing all the PVC and NS modified SMA mixtures, in order to maintain constancy.

SMA mixture was put into Marshall mold and compacted with Marshall automatic strike. The front and back face of sample were each hit 75 times. Marshall Stability was calculated by placing the sample in a hot water tank at 60°C, 65°C, 70°C, and 75°C for 35 min and after that loaded at a rate of 50.8 mm/min.

2.5 Marshall water immersion experiment

Water damage of SMA mixtures is one of the mainly popular road diseases that occur in asphalt pavements. Water damage refers to the loss of material physical properties caused by the existence of water in SMA mixture. The resist to water harm of the asphalt mixture was calculated by Water stability experiment (remained stability). All the samples were made using the Marshall method. The samples were randomly divided into two groups, each group including four samples. The first group was located in a water tank at a constant temperature of 60°C for 35min, and the second group was located in a water tank at a constant temperature of 60°C for 48h. Each experiment sample was tested for no more than 30 seconds. Hence, the remained stability was measured using equation (1) as follows [14]:

$$MS_0 = \frac{MS_1}{MS} \times 100 \quad (1)$$

Where:
MS_1 is the Marshall Stability at 60°C after 48h water immersion (kN);
MS is the Marshall Stability at 60°C, after 35min water immersion (kN);
MS_0 is the Remained Stability (%).

2.6 Wheel tracking experiment

In order to calculate the high temperature stability of SMA mixture, the wheel tracking experiment was carried out. The wheel tracking experiment was completed at four grade temperature (60°C, 65°C, 70°C, and 75°C), and all samples were kept at the designed temperature for five hours. The square slab sample with 30 cm long × 30 cm wide × 5 cm high was produced in this test. In this experiment, a single wheel model with a standard tire pressure of 700 Pa was installed on the surface of the SMA samples. The wheel was moved on the sample with a speed of 42 cycles per min along one direction. The Dynamic Stability (DS) was measured using Equation (2) as follows [13]. A higher DS value means better protest to enduring deformation.

$$DS = \frac{(t_2 - t_1).N.C_1.C_2}{(d_2 - d_1)} \quad (2)$$

Where:
DS is the Dynamic Stability of SMA mixture, cycle/mm;
d_1, d_2 are the Rut depth at time t_1 (45 min) and time t_2 (60 min), mm;
C_1, C_2 are the Machine correction coefficient, (here both are 1.0);
N is the rate of experiment wheels rolling passes per min, = 42 cycles/min.

3. Results and Discussion

3.1 Marshall stability experiment

Figure 5 is presented the Marshall Stability experiment results. As shown in Figure 5, the high temperature difference has a great influence on the Marshall stability of the three SMA mixtures, and the Marshall stability decreases greatly with the increase of temperature. When test temperature was risen from 60°C to 75°C the Marshall stability of the 4P3N modified asphalt mixture was decreased from 10.8 kN to 6.08 kN, with a 43.70% decrease; next was the 5P2N asphalt mixture, with a 39.56% decrease; the changes of the 6P1N asphalt mixture was the smallest with 32.71% decrease. The reason is that stability of 6P1N is higher, and it has high temperature resistant deformation and shear force is better than 4P3N and 5P2N modified asphalt.

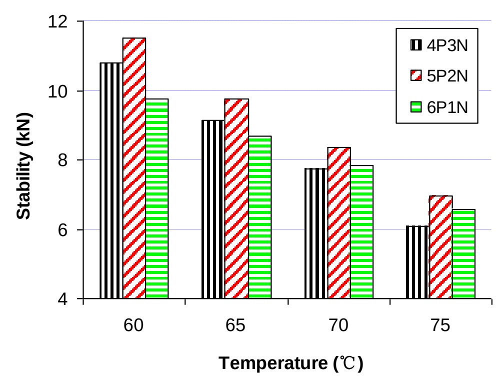

Figure 5: Relationship between Marshall Stability at high temperature of three PVC and NS contents

3.2. Water stability experiment

The experiment results of Remained stability after adding different contents of PVC and NS in are shown in Figure 6. It can be seen from Figure 6 that all three PVC and NS contents meet the minimum requirement of 80%. The SMA mixtures modified by 5%PVC and 2%NS has higher remained stability value than other SMA mixtures. By adding PVC and NS, the structure of SMA is strengthened and the damage of SMA structure by water is prevented. However, with 6P1N and 4P3N content, the void ratio of asphalt mixture become larger than 5P2N content, enough to contain amount of saturated water, resulting in the increase of pore water pressure, thus strengthening the water damage and then weakening the stability of SMA. In addition, it is evident that SMA mixture modified with 5%PVC and 2%NS will be the best anti-water damage.

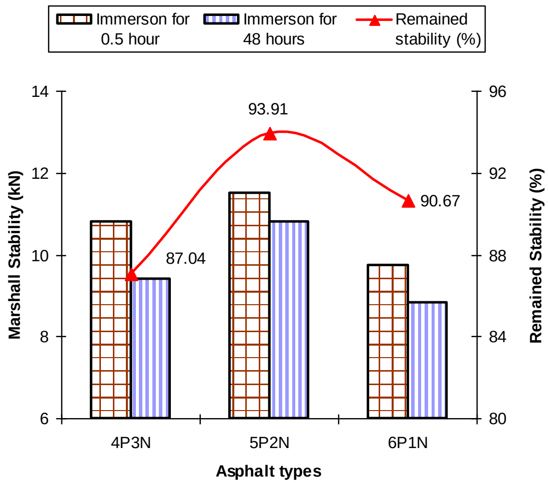

Figure 6: Relationship between Residual Stability and PVC and NS contents

3.3. Wheel tracking experiment

Figure 7 shows the wheel tracking experiment results of three SMA mixtures. As shown in Figure 7 the Dynamic stability of the three SMA mixtures from 60°C to 70°C meet the specification requirements (DS ≥ 3000 cycle/mm). Furthermore, at 75°C the Dynamic stability of 4P3N content did not meet the requirements, while the 5P2N and 6P1N contents meet the standard requirements.

The changes of the Dynamic stability of various PVC and NS modified SMA mixtures were not the same at high temperatures, when experiment temperature was risen from 60°C to 75°C, the Dynamic stability of the 4P3N concentration decreased to 62.29%, 5P2N concentration decreased 57.36%, and 6P1N concentration decreased 61.42%. It can be observed that the changes of 5%PVC and 2%NS concentration had the smallest magnitude, and at 75°C it had rutting resistant better than other concentrations. The main reason is: 5P2N could stabilize and hold the sticky asphalt on its surface to resist the shear force and reduce the fluidity better than 4P3N and 6P1N concentration.

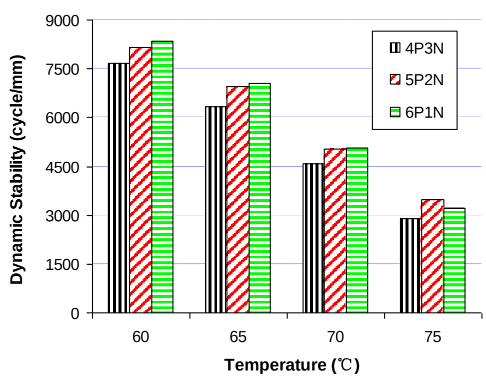

Figure 7: Relationship between Dynamic Stability at high temperature of three PVC and NS contents

4. Conclusion

The high temperature stability of SMA mixture modified by PVC and NS was studied. The following points can be concluded from this research:

1) The Marshall stability of three SMA mixtures is greatly affected by the high temperature. With the increase of temperature, the Marshall stability decreased greatly. At temperatures 60-75°C the Marshall stability of the three SMA mixtures are all acceptable, and the 6%PVC and 1%NS concentration has the best Marshall Stability to against high temperature.
2) SMA mixture with 5%PVC and 2%NS content has higher remained stability value than others SMA mixtures, which indicated that 5%PVC and 2%NS modified asphalt mixture possess the best anti-water damage.
3) The Dynamic stability of the three SMA mixtures at 60-70°C meets the specification requirements. Furthermore, the Dynamic stability of 4%PVC and 3%NS content at 70-75°C did not satisfy, while the 5%PVC and 2%NS and 6%PVC and 1%NS content satisfy the standard requirements.
4) For hot weather climates, SMA mixtures with 5%PVC and 2%NS concentration shows better Marshall stability, dynamic stability, and water stability, than other concentrations.

5. Acknowledgments

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6. Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Dang Van Thanh, Cheng Pei Feng (2013) Study on Marshall and Rutting test of SMA at abnormally high temperature, *Construction and Building Materials*, Vol.47, pp.1337-1341. https://doi.org/10.1016/j.conbuildmat.2013.06.032

[2] R.A. Tarefder, M. Zaman, K. Hobson (2003) A laboratory and statistical evaluation of factors affecting rutting, *International Journal Pavement Eineering*, Vol.4, pp. 59-68.

[3] J. Chen, Y. Zhang, H. Li, Y. Gao (2016) Rutting-induced permeability loss of open graded friction course mixtures, *Journal of testing and evaluation*, Vol.44, pp.719-724.

[4] L. Walubita, S. Lee, J. Zhang, A.N.M. Faruk, S. Nguyen, T. Scullion (2013) HMA Shear Resistance Permanent Deformation, and Rutting Tests for Texas Mixes: Year-1 Report technical Report FHWA/TX-13/0-6744-1, *Texas A&M Transportation Institute*, College Station, TX-77843, USA.

[5] L.F. Walubita, L. Fuentes, S.I. Lee, I. Dawd, E. Mahmoud (2019) Comparative evaluation of five HMA rutting-related laboratory test methods relative to field performance data: DM, FN, RLPD, SPST, and HWTT, *Construction and Building Materials* , Vol.215, pp.737-753. https://doi.org/10.1016/j.conbuildmat.2019.04.250

[6] National Asphalt Pavement Association (Ed) (2002) Designing and Constructing SMA Mixtures – State-of-the-Practice, *National Asphalt Pavement Association*.

[7] An introduction to stone mastic asphalt (SMA) (1991) Introductory handout. Scanroad, Sweden, Nobel Industry.

[8] Hassan Ziari, Elahe Nasiri, Amir Amini, Omid Ferdosian (2019) The effect of EAF dust and waste PVC on moisture sensitivity, rutting resistance, and fatigue performance of asphalt binders and mixtures, *Construction and Building Materials*, Vol. 203, pp.188-200. https://doi.org/10.1016/j.conbuildmat.2019.01.101

[9] R. Li, F. Xiao, S. Amirkhanian, Z. You, J. Huang (2018) Developments of nano materials and technologies on asphalt materials – a review, *Construction and Building Materials*, Vol.143, pp.633-648. https://doi.org/10.1016/j.conbuildmat.2017.03.158

[10] C. Fang, X. Yu, R. Yu, P. Liu, X. Qiao (2016) Preparation and properties of isocyanate and nano particles composite modified asphalt, *Construction and Building Materials*, 2016, Vol.119, pp.113-118. https://doi.org/10.1016/j.conbuildmat.2016.04.099

[11] M. Enieb, A. Diab (2017) Characteristics of asphalt binder and mixture containing nanosilica, *International Journal of Pavement Reseach Technology*, Vol.10, pp. 148-157.

[12] N.I.M. Yusoff, A.A.S. Breem, H.N.M. Alattug, A. Hamim, J. Ahmad (2014), The effects of moisture susceptibility and ageing conditions on nano-silica/polymer-modified asphalt mixtures, *Construction and Building Materials*, Vol.72, pp.139-147. https://doi.org/10.1016/j.conbuildmat.2014.09.014

[13] JTG E20 (2011) Standard Test Method of Bitumen and Bituminous Mixtures for Highway Engineering, *Chinese Standard*.

[14] American society for testing and materials (ASTM). *Standard specification*, 2000, Section 4, Vol. 4/3.