Laboratory Evaluation of Warm Mix Asphalt Mixture

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ABSTRACT: Several new processes have been developed to reduce the mixing and compaction temperatures of hot mix asphalt without sacrificing the quality of the pavement. Warm mix asphalt (WMA), which reduces the production temperatures (mixing and compaction) while maintaining the performances of hot mix asphalt (HMA), is becoming an attractive paving material. The product is important to the protection of humankind and the environment. In this paper, the asphalt mixtures with and without Aspha-min, Sasobit and the warm mix additive prepared in the laboratory were studied. Tensile strength ratio test, three point bending test, indirect tensile fatigue test and wheel tracking test were used to evaluate the performances of the asphalt mixtures. Results showed that, the WMA mixtures using Aspha-min and Sasobit produced at the temperature 25°C lower than the normal and the WMA mixtures using self-preparation produced at the temperature 20°C lower than the normal both exhibited a relatively good performance compared with the control HMA mixture, and it was further recommended for use in pavement construction.

KEY WORDS: Warm mix asphalt, volumetric properties, moisture susceptibility, fatigue cracking.

1 INTRODUCTION

Warm mix asphalt (WMA), which reduces the mixing and compaction temperatures of conventional hot mix asphalt (HMA) while maintaining the performances of the pavement, is becoming an attractive paving material (Newcomb, 2005). Reducing mixing and compaction temperatures by using WMA in place of HMA will yield beneficial environmental effects: decreased energy consumption, reduced emissions and odors, improved working conditions (Hurley et al. 2006).

For the workability of the mix to be improved through the technologies, compaction energy requirements should be reduced or at least not increased and the in-place density be enhanced (Hurley et al. 2005). Enhanced compaction is, of course, a key parameter regarding performance. Lower mixing temperature will reduce oxidative hardening, which should reduce susceptibility to cracking by improving pavement flexibility and longevity. Today's versions of WMA are the brainchild resulting from the 1997 German Bitumen Forum (Zettler, 2006). In fact, the Europeans have been using technologies to lower mixing/placement temperature, and the results have been very promising (Barthel et al., 2003). In the U.S., these technologies are being tried in an attempt to realize these potential benefits (Kuennen, 2004). WMA technologies have been successfully used. (Wasiuddin et al.2007) indicated that the warm mix asphalt additives no negative effect on high-temperature grading due to high-temperature viscosity reduction.

The main objective of this study was to evaluate the properties of mixtures containing WMA additives through a series of experimental tests. To prepare different samples of the asphalt mixtures, different warm mix asphalt additives were added into the mixture to evaluate the tensile strength ratio test, three point bending test, indirect tensile fatigue test and wheel tracking test properties of the asphalt mixtures. Meanwhile, the conventional hot mix asphalt and the mixture produced at the low temperature without any additives were prepared, which was used as the control mixtures.

2 EXPERIMENTAL PROGRAM AND PROCEDURES

2.1 Materials

AH-70 paving asphalt as the virgin asphalt binder in this study was obtained from Guochuang Asphalt Co. Ltd. in Hubei province, P.R.China, with penetration of 76.2 (0.1 mm at 25°C, 100 g and 5 s) , ductility of 150cm at 15°C, and softening point of 46.0°C.

The aggregates basalt was from Jingshan of Hubei Province, P.R. China. Basalt aggregates with bulk specific gravity of 2.908g/cm^3 were used in the asphalt mixtures. And the mineral filler is limestone with apparent density 2.81g/cm^3.

Aspha-min produced by Eurovia GmbH Germany is a manufactured synthetic zeolite with an internal content of water. During mixing, water is released and creates a volume expansion of the binder that results in asphalt foam and allows increased workability and aggregate coating at lower temperature. During the production of HMA, Eurovia recommended that Aspha-min was added at a rate of 0.3 percent by mass of the mix, which has shown a potential 30°C reduction in typical HMA production temperatures in previous research.

Sasobit produced by Sasol Wax Germany is a wax-type product of coal gasification that dissolves in asphalt binder at high temperature and results in a reduction in its viscosity during mixing. Sasobit is described as an asphalt flow improver, both during the asphalt mixing process and laydown operations, due to its ability to lower the viscosity of the asphalt binder. This decrease in viscosity allows working temperatures to be decreased by 18-54°C.

Self-preparation warm mix asphalt additive is a manufactured synthetic zeolite made from fly ash through a series of procedures which mainly including hydro-thermal synthesis. It contains a certain internal content of 20% water and the components are mainly SiO_2, Al_2O_3, Na_2O, the apparent density is 2 g/cm^3 and the particle size is 5-100 μm. The dosage was added at a rate of 0.3 percent by mass of the mixture.

2.2 Mixture Design

The Superpave 12.5mm mix design procedure was employed to design the conventional hot mix asphalt mixture and the gradation curve was shown in Figure 1. The same target gradation was used for the other mixtures in the study.

The mixing and compaction temperatures for asphalt can be determined to deliver 0.17±0.02Pa·s and 0.28±0.03Pa·s for HMA mixing and compaction, respectively. The viscosity-temperature curve of the asphalt binder was shown in Figure 2. So the mixing temperature was set at 155°C for and the compaction temperature was set at 145°C for the HMA in this study.

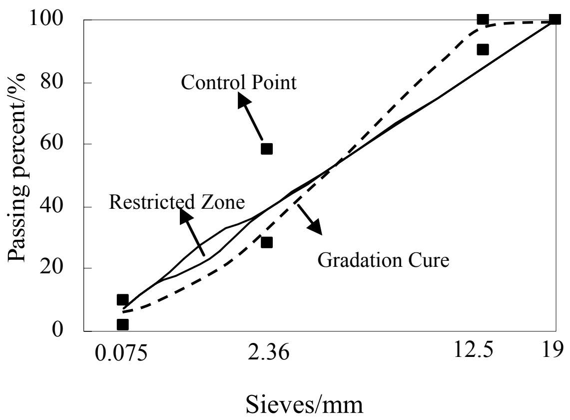

Figure 1: The same gradation curves are used for all the mixtures.

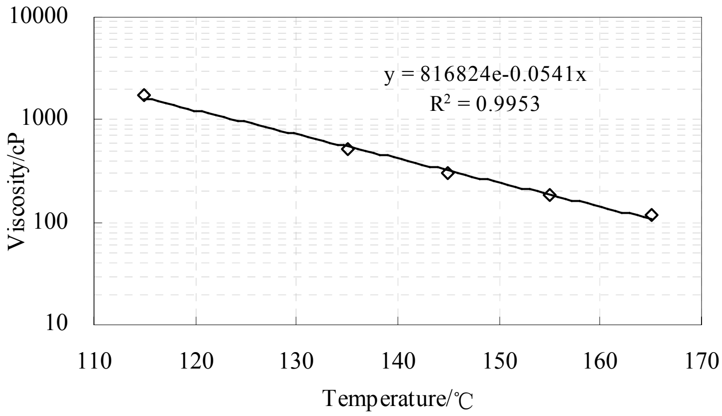

Figure 2: The viscosity-temperature curves of the asphalt binder.

Table 1: The temperature parameters of all mixtures.

Mixture Types	Additive	Asphalt (°C)	Aggregate (°C)	Mixing (°C)	Compaction (°C)
HMA	—	160	170	155	145
S	Sasobit	140	145	130	120
A	Aspha-min	160	145	130	120
P_1	Self-preparation	160	150	135	125
P_2	Self-preparation	160	140	125	115
O	—	160	145	130	120

The temperature parameters of all mixtures used for the study are outlined in Table 1. Sasobit and zeolite were used as warm mix asphalt additives, which can make the mixed and compacted temperature 25°C lower. The self-preparation was also used as warm mix asphalt additive, which make the mixed and compacted temperature 20°C and 30°C lower. During the conventional hot mix asphalt mixture specimen's preparation, the optimum binder content was 4.76%. This asphalt content was used throughout the remainder of the study, whenever test specimens were made. Aspha-min at a rate of 0.3% by mass of the mixture was added to the mix at the same time with the bitumen. It is recommended that the optimum percentage of Sasobit addition is 3% by weight, in this paper, the asphalt mixture with this content was tested. For the S mixture, the Sasobit modified binder was prepared firstly, and then the modified binder was added in the mix. Sasobit is completely soluble in bitumen at temperature above 120°C. So the asphalt binders containing Sasobit particles were prepared using a low shear mixer at 150°C and a speed of 125 rpm. The mixing time was 20 minutes.

2.3 Mixture Performance Testing

To evaluate mechanical performance of asphalt mixtures, the cylinder specimens (101.6 mm diameter and 63.5 ± 1.3 mm high) were produced with 75 blows compacting energy per side and 50 blows compacting energy per side by Marshall Compactor, and the slabs were prepared firstly on wheel-roller machine. The size of the slab samples was 300 mm in length, 300 mm in width and 50 mm in thickness.

Two groups of duplicate specimens (four samples for each group) were prepared. The first group of samples was submerged in water at 60°C for 30 min, and the second group of samples was submerged in water at 60°C for 48 h. The Marshall stabilities were measured. Consequently, the residual stability is determined as the following equation:

$$MS_R = \frac{MS_2}{MS_1} \times 100\% \tag{1}$$

Where MS_R is used to evaluate the moisture susceptibility of asphalt mixture, and a higher MS_R value indicates lower moisture damage. MS_2 is the Marshall stability after experiencing water effect (48 h), MS_1 is the Marshall stability of fresh mixture.

Three point bending tests were performed to evaluate the low temperature cracking of the asphalt concretes The slabs sample were cut into the beam specimens with the length of 250mm, the height of 35mm and the breadth of 30mm. The tests were carried on a universal testing machine (UTM-25) at -10°C with a loading rate of 50mm/min.

The indirect tensile test was conducted to evaluate the fatigue properties of asphalt mixture by means of Universal Testing Machine. Repeated haversine loads were applied at the columniform specimen. The loading time was 0.1 s following by a rest period of 0.4 s and the size of sample was 40 mm thick and 100 mm diameter while test temperature was 15°C. Three stress ratios (0.3, 0.4 and 0.5) were involved, which were defined as the applied stress amplitude divided by the indirect tensile strength of asphalt mixtures. The fatigue property of asphalt mixture can be depicted by the fatigue equation as follows:

$$N_f = K(\sigma)^{-n} \tag{2}$$

Where: N_f is the fatigue life, σ is the applied stress, K, n are constants, listed in Table 2.

The wheel-tracking test was employed to measure rutting resistance of asphalt mixture. It was carried out under a wheel pressure of 0.7 MPa at the temperature of 60°C with the specimen shape of 300mm in width, 300mm in length and 50mm in thickness. Dynamic stability (DS), defined as the passes to get 1 mm rutting, was calculated by the following equation:

$$DS = \frac{(t_2 - t_1) \times 42}{d_2 - d_1} \tag{3}$$

Where: t_2 =60min; t_1 =45min; d_2 =Rutting depth at time of t_2 ; d_1 =Rutting depth at time of t_1 .

3 RESULTS AND DISCUSSION

3.1 Volumetric Properties

Properties of asphalt mixtures are dependent on their volume. The amount of air voids in a mixture is extremely important and closely related to stability and durability. The air voids were used as the function to estimate the compaction of different asphalt mixtures. To this test, mixture HMA, A, S, P1, P2, and O were evaluated. The results are shown in Figure 3.

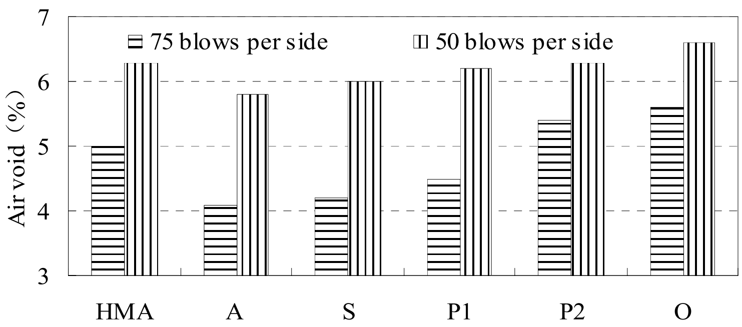

Figure 3: The air void of all mixtures at different blows.

In general, the air void content is significantly increasing with decreasing the compaction temperature, and this can be proved by the HMA and O mixtures. The results indicate that the A, S, P1, and P2 mixtures obviously show lower air void than the O mixtures for both the 75 and 50 blows per side. And compaction of the asphalt mixture was improved by the warm mix asphalt additives. The air void of the HMA, A, S, and P1 mixtures for 75 blows per side are between 4.0% and 5.0%, which is the best air voids value for the dense-graded asphalt concrete. It is, therefore, clearly seen that the inclusion of the additive significantly improve the workability behavior of mixtures.

3.2 Moisture Susceptibility

Because of the lower production temperature, warm mix asphalt aggregate may contain some unevaporating water and exhibit lower or equal water susceptivity compared to conventional asphalt mixtures. The moisture susceptibility of asphalt mixture was also measured through laboratory performance test.

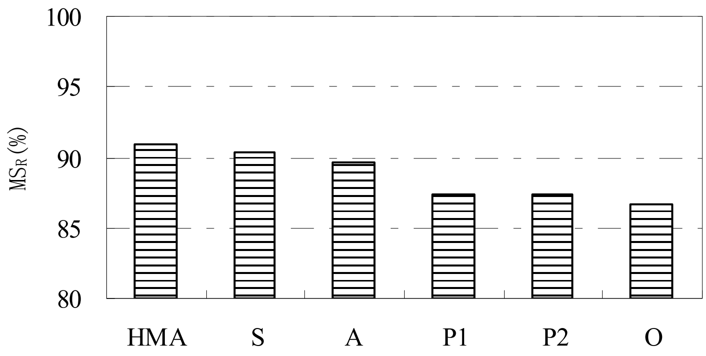

Figure 4: The residual stability of all mixtures.

From the Figure 4, it can be seen that the MS_R of all mixtures can fulfill the specification demand, which requires the value must be greater than 80%. Even the lower temperature production of mixtures without additives can fulfill the demand, this may be the reason that MS_R mainly depends on the gradation of mixture.

Tensile strength ratio test was used to evaluate the influence of the addition of additives. The test compares the strength of samples both dry and after subjecting moisture conditioned samples to at least one freeze/thaw cycle. A common specification requires a retained strength ratio after one freeze/thaw cycle to equal or exceed 75 percent. In this study, the three freeze/thaw cycles were adopted.

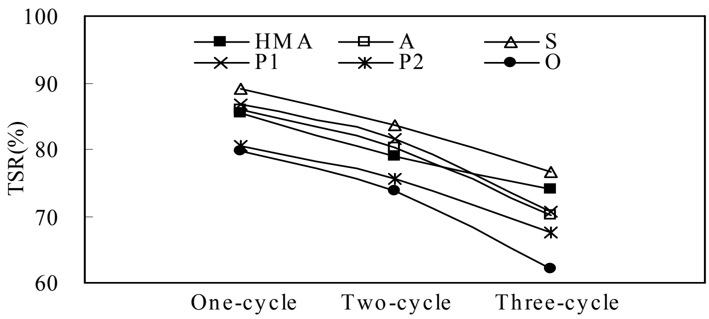

Figure 5: The tensile strength ratio of all mixtures.

Figure 5 indicates that the value of the A, S and P1 mixture are similar, which indicate that the resistance to stripping of the A, S and P1 mixture is equal with conventional mixture. The value of the O and P2 mixture is obviously less than the other. It means that the production temperature have an important influence on the moisture properties.

3.3 Low Temperature Properties

Three point bending tests were performed to evaluate the mechanical properties of the asphalt concretes in terms of resistance to low temperature cracking. In general, asphalt mixtures that exhibit greater strain at failure in the low temperature range have better flexibility which leads to superior resistance to cracking. Consequently, the results of bending tests at -10°C in terms of strain at failure are shown in Figure 6.

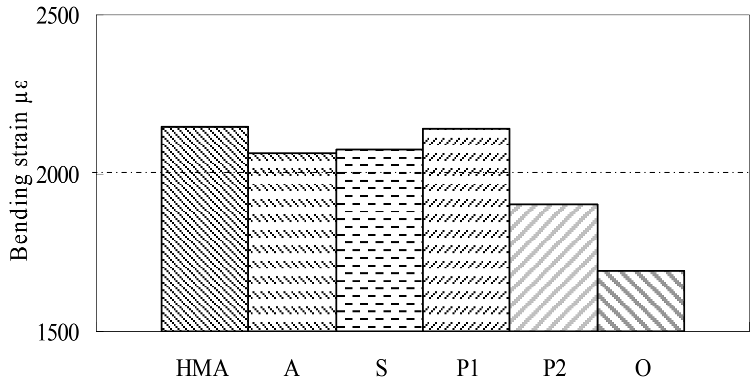

Figure 6: The bending strain of all mixtures.

From observation of the plots, same conclusions can be made. First, the lower production temperature of mixture without any additives increased the cracking potential over the hot mix asphalt. Second, the strain values of P2 and O mixtures are less than 2000, which have bad low temperature property according to the specification. It indicates that the 30°C for the self-preparation warm mix asphalt additive are too much, so the properties of P2 mixture are not considered in the following tests.

3.4 Resistance to Fatigue Cracking

Fatigue cracking due to repeated traffic loading is one of the major distresses in asphalt concrete pavements. There are two kinds of load controlling modes for asphalt mixtures fatigue test: one is stress controlling mode and the other is strain controlling mode. This paper applied the stress controlling mode because the former appeared more practical to asphalt pavement.

The results from the indirect tensile fatigue test in the form of the number of load cycles to failure plotted against tensile stress are shown in Figure 7.

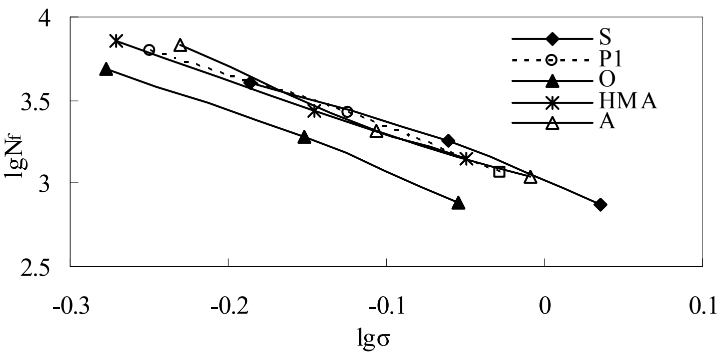

Figure 7: The fatigue cycles against tensile stress of all mixtures

Table 2 shows the results of indirect tensile fatigue test for five kinds of asphalt mixtures (used same aggregate and gradation) and their fatigue coefficients while Figure 7 shows the curves by using the stress versus cycle's life to failure. It can be seen that the fatigue life of five types of mixtures show stable decrease with the increase of stress level. Except for the mixture of O, the other four kinds of mixtures have the similar curves. It matches well with the material fatigue coefficients K. Associate with the K of mixtures shown in Table 2, asphalt mixture O shows the smallest value. In addition, HMA, S, A, and P1 asphalt mixtures show the similar value of K. It indicates that the fatigue property of asphalt mixtures can be improved with the addition of warm mix asphalt additives. Of course, in a constant stress fatigue test, the warm mix asphalt mixtures demonstrate equal performance compared to conventional asphalt mixture. Moreover, it can be seen that warm mix asphalt additives can effectively improve the fatigue resistance property of the asphalt mixture while produced at lower temperature.

Table 2 Material fatigue coefficients of all mixtures.

Mixture Types	Failure Stress	n	K	R^2
HMA	11.22	3.215	956.3	0.997
S	13.64	3.281	1025.7	0.989
A	12.31	3.607	959.0	0.988
P1	11.79	3.261	983.6	0.995
O	11.07	3.589	506.4	0.996

3.5 Wheel Tracking Test Results

Wheel tracking test was used to examine the rutting resistance properties of mixtures under wheel pressures and high temperatures.

Figure 8 shows the DS results of all asphalt mixtures. It can be observed the DS of all mixtures can fulfill the specification demand of 1000 passes/mm, It means that all mixture have the better rutting resistance properties. The O mixture with the value 1145 passes/mm is less than the other four mixtures. It indicates that the addition of warm mix asphalt additives can be more prone to compaction.

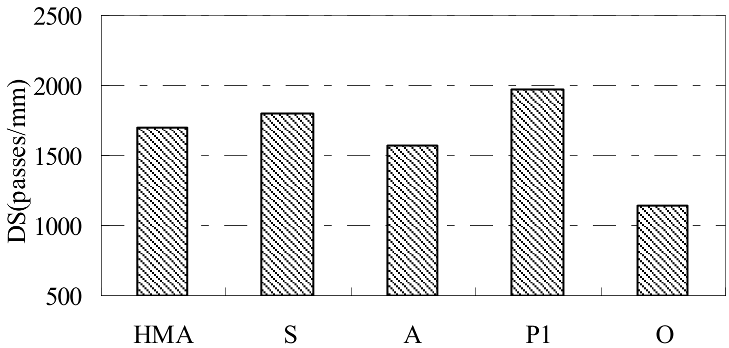

Figure 8: The dynamic stability of all mixtures.

4. TEMPERATURE RECUCTION MECHANISM OF SELF-PREPARATION ADDITIVE

The self-preparation additives contain some water which is released in the temperature of 87-216°C. This results in a large increase in the volume of the asphalt which facilitates coating at lower temperatures. Some vapour remains in the asphalt during compaction reducing effective viscosity and facilitating compaction.

5 ENVIRONMENTAL CONSIDERATIONS

In today's world it is a requirement to consider the impact that our actions will have on the environment, especially with regards to the preservation and sustainability of the environment for the future generations. The most obvious environmental advantage with regards to the use of warm mix asphalt for road construction is decreasing the temperature in the production of WMA, which will lower fuel usage and decrease emissions directly connected to fuel use. This should lower the emissions of greenhouse gases (CO_2) and traditional gaseous pollutants (CO, NO_x, and SO_2).

6 SUMMARY AND CONCLUSIONS

The following conclusions were determined based upon the limited experimental data presented in this research project:

(1) Warm mix asphalt using Sasobit and Aspha-min slightly affects the resistance to moisture susceptibility, low temperature properties, fatigue cracking and wheel tracking properties compared with the conventional hot mix asphalt and can fulfill the specification demand. Compared with the control hot mix asphalt mixture, the pavement performance results indicate that it is feasible to prepare the excellent pavement of warm mix asphalt mixture. This is due to the fact that warm mix asphalt additives play an important role in improving the workability of mixtures at the lower production temperature.

(2) For the AH-70 asphalt binder, the self-preparation warm mix asphalt can decrease the mixing and compaction temperatures about 20°C without sacrificing the pavement performance.

(3) Properties of the mixture produced at a low temperature without additives were unacceptable. So the mixing and compaction temperature plays an important role in the properties of asphalt mixtures. And only with the warm mix additives, the properties of low temperature produced mixture can fulfill the specification.

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REFERENCES

Barthel, W., M. Von Devivere, 2003. *Warm Asphalt Mixes by Adding Aspha-Min, A Synthetic Zeolite*. Proceedings of the 48th Annual Convention, National Asphalt Pavement Association, San Diego.

Hurley, G.C., and B.D, Prowell, 2006. *Evaluation of Potential Processes for Use in Warm Mix Asphalt*. Journal of the Association of Asphalt Paving Technologists, Vol.75, pp.41-90.

Hurley, G.C., and B.D, Prowell, 2005. *Evaluation of Aspha-Min Zeolite for Use in Warm Mix Asphal,* Report NCAT 05-04, National Center for Asphalt Technology, Auburn University, Auburn, Alabama.

Hurley, G.C., and B.D. Prowell, 2006. *Evaluation of Evotherm for Use in Warm Mix Asphalt*. Report NCAT 06-02, National Center for Asphalt Technology, Auburn University, Auburn, Alabama, 2006.

Hurley, G.C., and B.D. Prowell, 2005. *Evaluation of Sasobit for Use in Warm Mix Asphalt*. Report NCAT 05-06, National Center for Asphalt Technology, Auburn University, Auburn, Alabama.

Kuennen, T., 2004. *Warm Mixes are a Hot Topic*. Better Roads, James Informational Media, Inc., Des Plaines, Illinois.

Newcomb, D, 2005. *Warm Mix: The Wave of the Future*. National Asphalt Pavement Association, Vol.10, No.4, pp.33-36.

Wasiuddin N, Selvamohan S, Zaman M, Guegan M, 2007. *Comparative Laboratory Study of Sasobit and Aspha-min Additives in Warm-mix Asphalt*. Transport Res Board, pp.82–88.

Zettler, R., 2006. *Warm Mix Stands Up to Its Trials*. Better Roads, James Informational Media, Inc., Des Plaines, Illinois.