E3S Web of Conferences **165**, 04054 (2020)
CAES 2020
https://doi.org/10.1051/e3sconf/202016504054

Performance evaluation and viscoelastic model establishment of recycled hot mix asphalt

Yanhai Yang[1, a], Xitai Yan [1, b, *], Ye Yang[1, c] and Hong Cui[1, d]

[1]School of Transportation Engineering, Shenyang Jianzhu University, Shenyang Liaoning, 110168, China

Abstract. In this paper, the pavement performance of recycled hot mix asphalt with 30% recycled asphalt pavement (RAP) content is studied by mix design, splitting test, freeze-thaw splitting test and dynamic modulus test. The results show that the recycled hot mix asphalt with 30% RAP content has better high-temperature deformation resistance than hot mix asphalt, but low temperature performance is slightly worse, and the water stability is not much different. It is proved that the road performance of recycled hot mix asphalt with 30% RAP content is the same as that of hot mix asphalt. Recycled hot mix asphalt with 30% RAP content can be widely used. The flexural creep test data at different temperatures were fitted to the exponential decay function, which proved that the recycled hot mix asphalt conformed to the generalized Maxwell model, and provided parameters for the establishment and analysis of the viscoelastic mechanical model of the recycled hot mix asphalt.

1 Introduction

In recent years, in order to save resources and protect the environment, the recycling of asphalt mixtures has become a hot topic. Many literatures have pointed out that the performance of recycled hot mix asphalt (RHMA) is optimal when the recycled asphalt pavement (RAP) content ranges from 20%~30% [1] [2]. In this paper, the performance of recycled hot mix asphalt with 30% RAP content is evaluated by splitting test, freeze-thaw splitting test and dynamic modulus test.

As a viscoelastic material, the mechanical properties of asphalt mixture are significantly affected by the loading temperature and time. Therefore, it is very important to describe the viscoelastic model correctly and quantitatively. For this reason, many scholars have carried out a lot of experimental research and established a variety of viscoelastic models of asphalt mixture, in order to grasp the viscoelastic characteristics of asphalt mixture more accurately [3] ~ [6]. However, these studies are based on hot mix asphalt (HMA), and there is no relevant research on viscoelastic model of recycled hot mix asphalt. In this paper, the viscoelasticity of recycled hot mix asphalt is studied based on fitting the bending creep test data at different temperatures with an exponential decay function.

2 Mix design

In this paper, the gradation type of asphalt mixture is AC-16 dense. In order to verify the performance of RHMA, HMA with the same raw materials and conditions was used as a comparison. All technical indexes of raw materials meet the requirements of "Technical Specifications For Construction Of Highway Asphalt Pavement" (JTG F40-2004). According to the aging of the asphalt in the old material, it is determined that the mixing ratio of the rejuvenating agent is 8% of the old asphalt. According to the Marshall Design method in "Technical Specifications for Construction of Highway Asphalt Pavement" (JTG F40-2004), the optimum asphalt content was determined to be 4.7%. The gradation curve of HMA AC-16 and RHMA AC-16 is shown in Fig. 1.

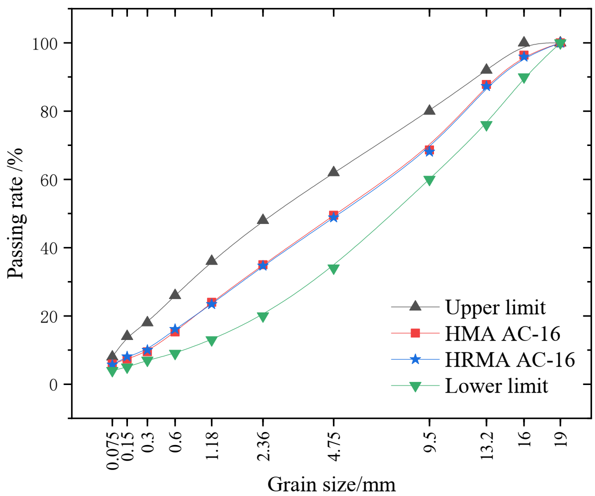

Fig.1. Mineral aggregate graduation curve

*Corresponding author: [b] hellotai@163.com;
Author E-mail address: [a] yangyanhai168@126.com;
[c] yangye138@126.com; [d] 865061854@qq.com;

https://doi.org/10.1051/e3sconf/202016504054

3 Road performance test

3.1 splitting test

Marshall Test specimens were made for the split test. The test temperatures were -20℃, -10 ℃, 0℃, 10℃, and 20℃. When testing at -20℃, -10℃ and 0℃, the loading rate is 1mm / min; when testing at 10℃ and 20℃, the loading rate is 50mm / min [7].

Table 1. Splitting testing result

Types	Temperature /℃	Maximum load/N	Split tensile strength /MPa	Breaking tensile strain /×10^{-3}
RHMA AC-16	20	8800	0.87	4.41
	10	14600	1.45	3.60
	0	20330	2.05	3.45
	-10	28690	2.86	3.54
	-20	24700	2.47	2.73
HMA AC-16	20	8340	0.82	4.59
	10	12980	1.29	3.54
	0	20600	2.07	3.42
	-10	27600	2.75	3.63
	-20	24450	2.44	2.64

Table 1 data shows that (1) The splitting tensile strength of RHMA and HMA increases with the decrease of temperature at first, and then decreases after the peaking. At high temperature, the splitting tensile strength of RHMA AC-16 is 6.1% higher than that of HMA AC-16, and 1.2% lower than that of low temperature. This shows that the high temperature deformation resistance of RHMA AC-16 is strong, and the low temperature performance is slightly poor; (2) According to the relationship between the failure strain and temperature, the failure strain of RHMA and HMA gradually decreases with the decrease of temperature, and there is a cross phenomenon, and the failure strain of the two is not much different;

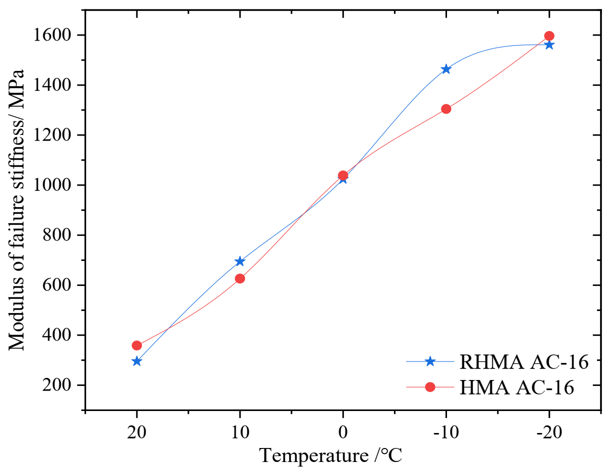

Fig.2. Relationship between modulus of failure stiffness and temperature

It can be known from Fig. 2 that the failure stiffness modulus of both RHMA AC-16 and HMA AC-16 increases with decreasing temperature.

3.2 freeze-thaw splitting test

The test is to concentrate and strengthen the impact of water on the actual road surface, so that the impact of the road surface can be simulated in a shorter period of time. Table 2 for freeze-thaw splitting strength test results.

Table 2. Testing result of freeze-thaw splitting strength

Types	RHMA AC-16	HMA AC-16
Splitting tensile strength of specimens without freeze -thaw /MPa	0.136	0.0976
Splitting tensile strength of specimens after freeze-thaw in vacuum /MPa	0.117	0.0868
Tensile strength ratio of freeze-thaw splitting /%	85.7	88.9

According to the data in Table 2, the splitting tensile strength of RHMA AC-16 without freeze-thaw is greater than that of HMA AC-16. This is because the splitting strength is mainly composed of the internal friction resistance of the mineral and the cohesive force of the asphalt. Due to RHMA AC-16 contain 30% RAP content, the old asphalt in the old material has a higher viscosity after being regenerated by the rejuvenating agent, which makes the splitting strength relatively high. However, it decreased rapidly after freeze-thaw cycles. Compared with the HMA AC-16, the freeze-thaw splitting strength of the RHMA AC-16 is reduced by 3.2%, and the change is not great, which proves that the water stability of RHMA AC-16 is the same as that of HMA AC-16 basically.

3.3 Dynamic modulus test

The simple performance tester (SPT) is used for the dynamic modulus test. At the specified temperature, the sinusoidal compressive stress test of 0.01 ~ 25Hz is applied to the test specimens [7]. Table 3 is the average value of three groups of dynamic modulus test results under the same temperature (15℃), the same load and different frequency.

Table 3. Dynamic moduli at different frequencies at 15℃ /MPa

Types		RHMA AC-16	HMA AC-16
Frequency /Hz (Loading stress 0.7MPa)	25	15364	14308
	20	14781	13718
	10	12618	12079
	5	10687	10482
	2	8808	8282
	1	7420	6598
	0.5	6247	5108
	0.2	4843	3516
	0.1	3950	2595
	0.01	1701	980

It can be known from Table 3 that the dynamic modulus of the two asphalt mixtures increases with increasing load frequency. The dynamic modulus of RHMA AC-16 is greater than that of HMA AC-16, which indicates that the deformation resistance of RHMA AC-16 is stronger than that of HMA AC-16.

Table 4 shows three groups of dynamic modulus test results under the same frequency (10Hz), same load and different temperature.

Table 4. Dynamic moduli at different temperature at 10Hz

Types		RHMA AC-16	HMA AC-16
Temperature /℃	55	981.3	316.7
	45	2100	1001
	35	5068	3820
	25	8709	6960
	15	12618	12079

It can be known from Table 4 that the dynamic modulus of the two asphalt mixtures decreases with the increase of temperature. At the same temperature, the dynamic modulus of RHAM AC-16 is higher than that of HAM AC-16, especially at higher temperature. It shows that the deformation resistance of RHAM AC-16 is better than that of HAM AC-16 at high temperature.

4 Viscoelastic model establish

The establishment of viscoelastic model could reflect the mechanical properties of materials better, and the model should be as simple and intuitive as possible. The mechanical parameters in the model are determined by experimental simulation. The test simulation uses the theoretical solution of the mechanical model to fit the test results. By adjusting the values of the mechanical parameters, the two results can achieve the best fit effect. On the one hand, the rationality of the selected mechanical model can be verified. On the other hand, it can determine the mechanical parameters of the material. The research on the viscoelastic mechanics model of RHMA AC-16 is based on the above methods. And the creep test is carried out at - 20℃, 0℃ and 25℃. The experimental data are sorted out and simulated by the generalized Maxwell model. Therefore, it is studied whether the viscoelasticity of RHMA AC-16 conforms to the generalized Maxwell model.

$$\varepsilon(t) = \varepsilon_0 + A_1\exp(-t/\tau_1) + A_2\exp(-t/\tau_2) \quad (1)$$

The second-order exponential decay function (1) is used to fit the test data of three groups (9 specimens) at -20℃, 0℃ and 25℃ each temperature. Before fitting the data, the unreasonable negative strain and the falling section of the post creep section are deleted.

The average value is shown in Table 5 and the fitting curve of fitting parameters is shown in Fig. 3~ Fig. 5. It can be known from Table 5 and Fig. 3~Fig.5 that the fitting result of -20℃ is poor, and the correlation coefficient is only 0.7755. However, the fitting effect of 0℃ and 25℃ is good, and the correlation coefficient reaches above 0.9985.

Table 5. Fitting parameters

Temperature	-20℃	0℃	25℃
ε_0	0.1156	0.0117	0.1285
A_1	-3.9528	-0.0093	-0.0219
τ_1	46.8307	3638.2974	147.3898
A_2	-0.0431	-0.0018	-0.1034
τ_2	1047.5129	178.8844	3328.1624
R	0.7755	0.9987	0.9985

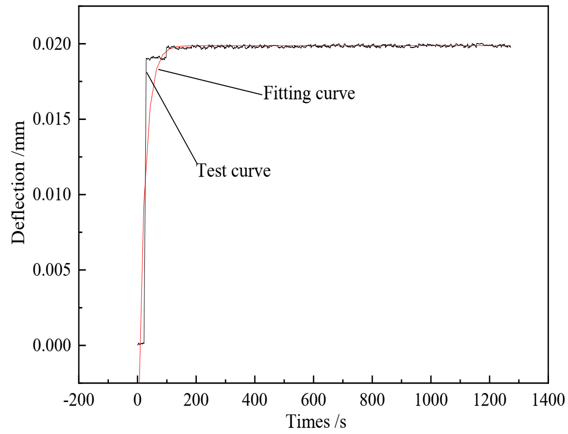

Fig.3. Contrast on the fitting curve and test curve at the temperature -20℃

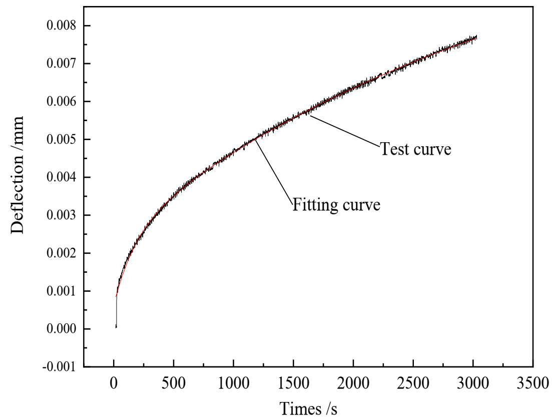

Fig.4. Contrast on the fitting curve and test curve at the temperature 0℃

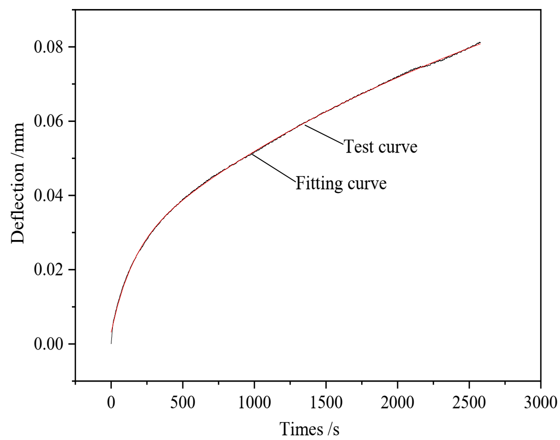

Fig.5. Contrast on the fitting curve and test curve at the temperature 25℃

Because the creep effect is not obvious at -20℃, this article only analyzes the two cases of 0℃ and 25℃. The stiffness modulus can be obtained by substituting the vertical force concentration applied in the span of the test specimens at 0℃ and 25℃ into equation $S(t)=\sigma_0/\varepsilon(t)$, as shown in Fig.6.

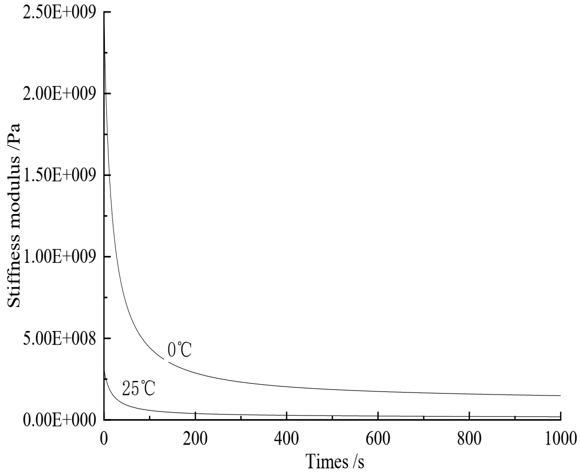

Fig.6. Curve between stiffness modulus and time at the temperature 0℃ and 25℃

The third-order exponential decay function is used to fit the two curves in Fig.6 The general equation of the fitting curve is as follows:

$$E(t)= E_0+A_1\exp(-t/\tau_1)+ A_2\exp(-t/\tau_2)+ A_3\exp(-t/\tau_3) \quad (2)$$

The coefficients in equation (2) at 0 ℃ and 25 ℃ are shown in Table 6.

By fitting the correlation coefficients in Table 6, it can be known that the generalized Maxwell model $E\left(t\right)=E_0\sum_{i=1}^{n}w_i\exp(-t/\tau_i)$ can simulate the test results better. Therefore, according to specific test conditions, multiple Maxwell unit models in parallel can well characterize the viscoelastic state of RHMA AC-16, that is, increasing the number of parallel unit models to improve the accuracy of curve fitting [4] [5].

Table 6. Fitting parameters of third order exponential decay function

Temperature	0℃	25℃
E_0	1.468E8	1.794E7
A_1	9.488E8	3.511E7
τ_1	44.870	329.255
A_2	2.893E8	1.164E8
τ_2	247.851	48.093
A_3	1.084E9	1.389E8
τ_3	10.557	10.950
R	0.9985	0.9988

5 Conclusions

(1) The high temperature performance of RHMA with 30% RAP content is better than that of HMA. Low temperature performance is slightly worse than HMA.

(2) The water stability of RHMA with 30% RAP content is similar to that of HMA.

(3) RHMA with 30% RAP content has the same road performance as HMA, which can be widely used.

(4) The fitting results of the creep data of the test specimens at -20℃, 0℃, and 25℃ with theoretical calculations show that the viscoelastic characteristics of RHAM AC-16 conform to the generalized Maxwell model.

(5) According to the fitting results of the test data and the generalized Maxwell model, the parameters are provided for the establishment of the mechanical model of the RHMA.

Acknowledgments

We sincerely thank Weizhe Xu, Wei Ren, Changyu Wu and others for their support and help in the experiment. This research was funded by Liaoning Distinguished Professor Program [grant numbers tpjs2017003].

References

1. Yihua Nie, Ping Liu, Xu Dai, Wangguo Xu. Study on Pavement Performance of Plant-mix Hot Reclaiming Asphalt Mixture (PHRAM). Applied Mechanics and Materials, **174-177**,1257-1264(2012)
2. Rodrigo Miró, Gonzalo Valdés, Adriana Martínez, et al. Evaluation of high modulus mixture behaviour with high reclaimed asphalt pavement (RAP) percentages for sustainable road construction. Construction and Building Materials, **25**,3854–3862(2011)
3. Hoki B., Soohyok I., Yong-Rak K.Nonlinear Viscoelastic Approach to Model Damage associated Performance Behavior of Asphaltic Mixture and Pavement Structure. Canadian Journal of Civil Engineering, **40(4)**,313-323(2013)
4. Chien-Wei H., Rashid K. Abu A., et al. Three-Dimensional Simulations of Asphalt Pavement Permanent Deformation Using a Nonlinear Viscoelastic and Viscoplastic Model. Journal of Materials in Civil Engineering, **23(1)**,56-68(2011)
5. Haoran Z.,Lu S.Mechanistic Rutting Prediction Using a Two-Stage Viscoelastic Damage Constitutive Model of Asphalt Mixtures. Journal of Engineering Mechanics, **139(11)**,1577-1591(2013)
6. Fares B., Sesh C., Musharaf Z., et al. Viscoelastic-Plastic Model of Asphalt-Roller Interaction. International Journal of Geomechanics, **13(5),**581-594(2013)
7. *Standard Test Methods Of Bitumen And Bitumen Mixture Of Highway Engineering*. JTG E20-2011. Beijing: China Communications Press, (2011)