World Journal of Applied Physics
2022; 7(3): 43-47
http://www.sciencepublishinggroup.com/j/wjap
doi: 10.11648/j.wjap.20220703.12
ISSN: 2637-5990 (Print); ISSN: 2637-6008 (Online)

Study on the Compaction Temperature of Warm Mix Asphalt Mixture Based on Different Test Equipment

Xiaosen Wang[1, 2], Gang Li[3, *], Jie Li[3]

[1]Research and Development Center of Transport Industry of Technologies, Materials and Equipments of Highway Construction and Maintenance, Shijiazhuang, China

[2]Hebei Provincial Communications Planning, Design and Research Institute CO. LTD, Shijiazhuang, China

[3]China Construction Port Group CO. LTD, Qingdao, China

Email address:

399310432@qq.com (Xiaosen Wang)

[*]Corresponding author

To cite this article:

Xiaosen Wang, Gang Li, Jie Li. Study on the Compaction Temperature of Warm Mix Asphalt Mixture Based on Different Test Equipment. *World Journal of Applied Physics*. Vol. 7, No. 3, 2022, pp. 43-47. doi: 10.11648/j.wjap.20220703.12

Received: October 10, 2022; **Accepted**: November 7, 2022; **Published**: November 22, 2022

Abstract: Warm mix asphalt has special viscosity characteristics, and the compaction mechanism is different from that of hot mix asphalt**.** It is necessary to investigate the compaction characteristics of warm mix asphalt by laboratory test. The compaction characteristics of surface active warm mix SMA mixture were determined by viscosive-temperature curve, rotational compaction and Marshall compaction. The experimental results show that the surface active warm mix has little effect on the viscosity of asphalt, it changes the interface characteristics between asphalt and aggregate, and makes the mixture more easily compacted. The viscosity-temperature curve is not suitable for determining the mixing and rolling temperature of surface active warm mix asphalt mixture; In the process of Marshall compaction, the relative movement between aggregates was limited, and the test itself could not fully reflect the cooling effect of surface active warm mix. The forming temperature can not be determined according to the cooling experience of warm mixing agent in engineering application. It should be shaped according to the temperature of the hot mix; Using rotary compaction molding SMA mixture, under the condition of 140°C~155°C, 120 times of rotary compaction can ensure that the mixture can achieve a better compacting state, surface active warm mixing agent can reduce the molding temperature by 10~20°C.

Keywords: Surface Activity, Warm Mix, Compaction Characteristics, Viscosity Curve, Compaction Temperature

1. Introduction

The viscosity of asphalt binder varies with temperature, the compacting characteristics of mixtures are greatly affected by temperature [1]. Reasonable compaction temperature should ensure that the mixture reaches the required volume parameters under certain compaction work [2]. At present, the mixing and rolling temperatures of surface active warm mix asphalt are determined according to experience. It is reduced by 20~30°C on the basis of ordinary asphalt mixture [3]. Because the compaction principle is different, the compactness degree of the mixture compacted by different molding methods under the same temperature condition is different. In this paper, the reasonable molding temperature of warm mix SMA based on different molding methods was determined by PCG rotary compaction and Marshall compaction tests [4-7].

2. Viscosity Temperature Curve of Warm Mix Asphalt

It is generally believed that the degree of compaction difficulty of asphalt mixture with the same grade is related to the viscosity of asphalt binder. The method of determining mixing and compaction temperature of mixture by asphalt viscosity-temperature curve has been proposed at home and abroad. For ordinary bitumen, the mixing temperature is 0.17 Pa·s±0.02Pa·s, and the compaction temperature is 0.28 Pa·s±0.03 Pa·s [8-10]. The viscosity characteristics of SBS (i-D) modified asphalt and cementing material with different dosage of warm mixing agent were determined by test as shown in Table 1. The viscosity and temperature curve is shown in figure 1.

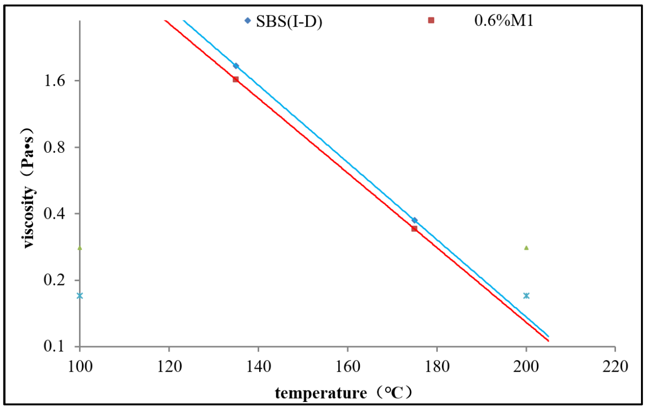

Figure 1. *Viscosity-temperature curves of two kinds of asphalt.*

Table 1. *Viscosity characteristics of asphalt with different amounts of Evotherm M1.*

Test temperature (°C)	Viscosity (Pa•s)			
	SBS (I-D)	**0.3%M1**	**0.6%M1**	**0.9%M1**
125	3.28	3.23	2.89	2.65
135	1.87	1.76	1.62	1.57
145	1.18	1.19	1.06	1.02
155	0.84	0.88	0.68	0.66
165	0.62	0.69	0.46	0.47
175	0.373	0.38	0.341	0.35

According to Table 1, when 0.3% M1 was added, the viscosity of SBS (I-D) asphalt almost did not change at different temperatures. When the content is above 0.6%, the viscosity of asphalt decreases obviously in the range of 125°C~135°C. When the temperature is above 145°C, the viscosity decreases slightly. It can be seen that, according to engineering experience, the viscosity of binder will not change greatly under the condition of reducing the construction temperature of 20°C~30°C (145°C~155°C) by using 0.6% warm mixing agent.

According to the viscosity and temperature curve, the mixing temperature of the mixture needs to be above 190°C, and the rolling temperature needs to be about 180°C. According to the engineering experience, the construction temperature determined by this method is obviously too high, and is more adverse to the short-term aging of asphalt. Evotherm M1 improving the compaction characteristics of mixtures is based on changing the lubrication characteristics between asphalt and aggregate interface. Evotherm M1 does not significantly change the viscosity characteristics of asphalt, especially at high temperature. Therefore, the cooling effect can hardly be seen from the viscosity and temperature curve.

When modifier and warm mixing agent are added to asphalt, the factors affecting the compaction of the mixture increase, the compaction mechanism of the mixture is more complex. At the same time, surface active warm mix can improve workability by changing interface characteristics between binder and aggregate, it does not change the viscosity of asphalt [11]. Therefore, the viscosity and temperature curve is no longer suitable for determining the mixing and compaction temperature of warm mix modified asphalt mixture. In this section, the equal void fraction method is used to determine the reasonable compaction temperature for different compaction methods.

3. Analysis of Compacting Characteristics of Mixtures Based on PCG3

Rotary compaction is a method of mixture forming that is closer to field construction. At present, the most commonly used rotary compaction methods are SGC (Superpave), PCG3 (France) and GTM (USA). The working parameters of three kinds of rotary compaction equipment are shown in Table 2 [12-15].

Table 2. *Different working parameters of rotary compaction equipment.*

Parameter		PCG3	SGC	GTM
Rotation Angle	Internal	0.82±0.02	1.16±0.02	
	External	1.0±0.02	1.25±0.02	0.8
Vertical pressure		0.6±0.018MPa	0.6±0.018MPa	Set as needed
Speed		30±0.5r/min	30±0.5r/min	12~18
Specimen diameter		150±0.1mm	150±0.1mm	101.6mm
End condition		Specify number of rotations	Specifies the number of rotations or specimen height	State of equilibrium

The compaction characteristics of asphalt mixture were analyzed by PCG3 test of French rotary compactor. The compaction principle of PCG3 is shown in figure 2. The mixture is subjected to both vertical pressure and shear due to rotation. The axis trajectory of the specimen is conical. PCG3 recorded the height of the specimen after each turn during compaction. The volumetric voids (including open and closed voids) were calculated according to the height to evaluate the compaction characteristics of the mixture. The calculated voids are larger than the actual voids of the specimens.

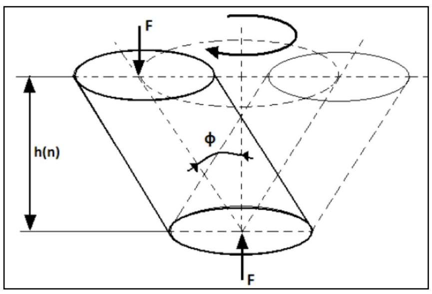

Figure 2. *PCG3 rotational compaction principle.*

Rotational compaction test was carried out at different temperatures for two kinds of mixtures with and without Evotherm M1 warm mixing agent. Set 120 times as the end condition of rotary compaction. The compaction characteristic curves of the two mixtures are shown in Figure 3 and Figure 4.

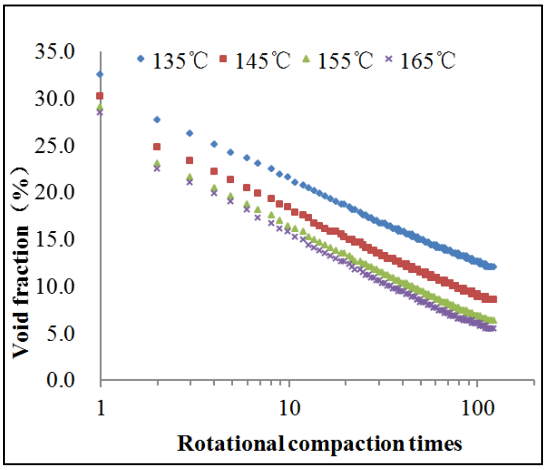

Figure 3. *Compaction curve of hot mix asphalt mixture.*

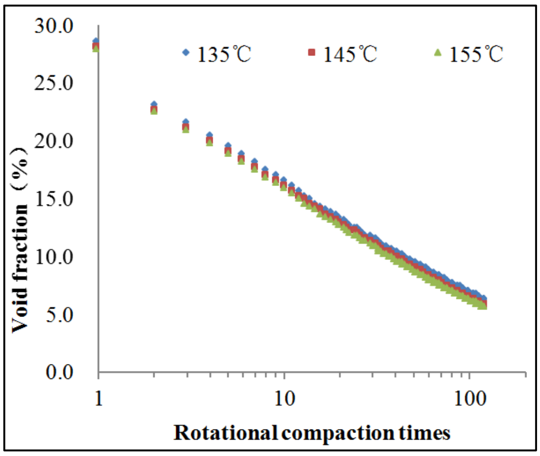

Figure 4. *Compacting curve of warm mix asphalt mixture.*

It can be seen from figure 3 and figure 4 that:

1) The two mixtures at different temperatures show similar compaction laws with compaction times. In logarithmic coordinates, the void fraction decreases linearly with the number of times of compaction. The compaction curves of the same mixture at different temperatures are basically parallel.
2) The compacting effect of the mixture without temperature mixing agent is greatly affected by temperature. At each stage of the compaction process, the lower the temperature, the larger the void fraction. The difference of compactness of mixture at different temperatures increases with the decrease of temperature.
3) After adding the warm mixture, the effect of temperature on the compacting characteristics of the mixture is obviously reduced. There is little difference in compaction voids between 145°C and 155°C mixtures at each stage, and the specimen collapsed after the mixture molding and demoulding at 165°C. This is due to the change of interface characteristics between asphalt and aggregate after adding warm mixing agent.

The compaction curve reflects the internal structure characteristics of the mixture during compaction. In the process of rotating compaction, the compaction times N and the void fraction of the mixture can be fitted as a logarithmic function as shown in Equation (1). The curve intercept represents the compacting degree of the mixture at the initial stage of rolling. The slope K of the curve represents the change rate of void fraction with the number of compaction, a higher value of K indicates that the mixture is more easily compacted. It reflects the molding ability of the mixture. The compaction curve equation of asphalt mixture at different temperatures is shown in Table 3.

$$V = C - K\ln(N) \tag{1}$$

In the formula: V—void fraction;
C—curve intercept;
K—the curve slope;
N—compaction number;

Table 3. *Equation of compacting curve of mixture at different compacting temperature.*

Mixture	The mixing temperature (°C)	Equation of compaction curve	R^2
Hot mix asphalt mixture	135	V=30.41-3.91ln (N)	0.995
	145	V=27.65-4.08ln (N)	0.993
	155	V=26.36-4.29ln (N)	0.994
	165	V=25.65-4.34ln (N)	0.995
Warm mix asphalt mixture	135	V=26.17-4.22ln (N)	0.995
	145	V=25.91-4.27ln (N)	0.992
	155	V=25.53-4.231ln (N)	0.993

It can be seen from Table 3:

1) The intercept C of the compaction curve of the two mixtures decreased with the increase of temperature, it reflects the degree of precompaction difficulty of pavers in construction. The C value of warm mix is lower than that of hot mix at the same temperature, the slope of the curve at 135°C~155°C is similar to that of hot mix mixture at 155°C~165°C.
2) After adding M1, the K value of the mixture is basically the same under the three temperature conditions. The degree of compaction is less affected by temperature. The K value of the mixture without M1 decreases obviously with the decrease of compaction temperature, the compaction rate is obviously affected by temperature. The temperature mixture of 135°C~155°C has the same K value as the hot mixture of 155°C.

Table 4. *Volume index of mixture under different compaction times and temperatures.*

Mixture	The mixing temperature (°C)	Void fraction (%)		
		80 Times	100 Times	120 Times
Hot mix asphalt mixture	165	7.6	5.9	5.3
	155	8.6	6.7	6.1
	145	10.7	9.0	8.4
	135	14.2	12.5	11.9
Warm mix asphalt mixture	155	8.0	6.2	5.6
	145	8.3	6.4	5.7
	135	9.2	7.1	6.0

The voids of the two mixtures at different times of compaction and at different temperatures are shown in Table 4:

1) The rate at which the void fraction of the mixture decreases with the increase of compaction times gradually decreases. The change of void fraction is very small after 120 times of rotary compaction. Therefore, it is reasonable to set 120 times as the end condition of compaction.
2) Compared with hot mix asphalt mixture, the influence of temperature on the compaction of warm mix asphalt mixture is significantly reduced, the void fraction of the mixture at 135°C~155°C is similar to that of the hot mix mixture at 155°C~165°C. It can be seen that surface active warm mixing agent can reduce the molding temperature of the mixture by 10~20°C.

According to the PCG3 test, it is reasonable to adopt the rotary compaction chamber to form warm mix asphalt mixture specimens, and adopt the rotary compaction 120 times under the conditions of 155°C~145°C.

4. Analysis of Compacting Characteristics of Mixtures Based on Marshall Test

Marshall design method is the most mature and popular design method of asphalt mixture. Some engineering projects do not have the conditions to use rotary compaction for mix design. Therefore, Marshall compaction method was used to compare and analyze the volume parameters of two kinds of asphalt mixtures at different forming temperatures. Both sides of the specimen were hammered 75 times. The volume parameters of the specimens under different temperature compaction of the two asphalt mixtures are shown in Table 5.

Table 5. *Volume index of Marshall forming specimen under different temperature conditions.*

Mixture	Indicators	The mixing temperature (°C)			
		165	155	145	135
Hot mix asphalt mixture	Viscosity (Pa•s)	0.62	0.84	1.18	1.87
	Void fraction (%)	3.6	4.1	4.7	5.9
	Mineral clearance ratio (%)	16.1	16.6	17.0	18.1
	Saturation (%)	77.8	75.0	72.6	67.5
Warm mix asphalt mixture	Viscosity (Pa•s)	0.46	0.68	1.06	1.62
	Void fraction (%)	3.5	3.9	4.4	5.5
	Mineral clearance ratio (%)	16.0	16.4	16.8	17.8
	Saturation (%)	78.4	76.3	73.8	69.0

As can be seen from Table 5, the voids of the two mixtures showed an obvious trend of increasing with the decrease of the compaction temperature. Warm mix asphalt mixture does not show obvious advantages in compaction characteristics. The Marshall test mold is small, which limits the relative movement between aggregates in the compaction process of the mixture. At the same time, warm mixing agent has little effect on asphalt viscosity. Therefore, surface active warm mix can not reflect the cooling effect in Marshall compaction test.

The Marshall method was used to design the mix ratio of hot mix asphalt, The forming temperature can not be determined according to the cooling experience of warm mixing agent in engineering application. It is recommended that the forming temperature of 160°C~155°C be used for 75 times of double-sided compaction. Compared with rotary compaction, it can be seen that the temperature range of Marshall forming warm mix asphalt mixture is smaller. It is necessary to strictly control the compaction temperature of the mixture to prevent the temperature from falling too fast to affect the compaction effect.

5. Conclusion

1) The viscosity-temperature curve is not suitable for determining the mixing and rolling temperature of surface active warm mix modified asphalt mixture.
2) Using PCG3 rotary compaction temperature to mix asphalt mixture specimens, taking 6% voids as the control standard, 120 times of rotary compaction under the conditions of 140°C~155°C can ensure the mixture to achieve a good compaction state.
3) Surface active warm mix can not fully reflect the cooling effect in Marshall compaction test. The forming

temperature can not be determined according to the cooling experience of warm mixing agent in engineering application. It should be shaped according to the temperature of the hot mix.

References

[1] Li X, Song X Y, Zhang W Z 2013 Study on compaction characteristics of warm mix asphalt mixture based on surface active technology Journal of Highway (4): 103~106.

[2] Cheng L, Zhou W, Zhang Sh Ch 2009 Study on compaction performance of warm mix asphalt mixture Journal of Modern transportation technology 6 (6): 4~6.

[3] Wang S Y, Yu J, Zhang G T, Li L P 2013 Experimental study on compaction characteristics of warm mix asphalt mixture Journal of Highway (5): 143~147.

[4] Guo P, Tang B M, Cheng Z Q, Li J K 2012. Compaction characteristics of warm mix reclaimed asphalt mixture Journal of Wuhan University of Technology 34 (7) 42~45.

[5] Zuo Q Y 2014 Determination of compaction temperature and performance evaluation of warm mix SBS asphalt mixture Journal of Modern transportation technology 11 (1): 1~3.

[6] Jiang Y, Ma H B, Meng H L, Zhou X Y 2020 Research on rotary compaction characteristics of GB4 asphalt mixture based on PCG Journal of China and Foreign Highway 40 (5): 301~305.

[7] Yang B 2017 High temperature performance of AC-13 based on GTM rotary compaction parameters Study on Evaluation Index Journal of Hunan Communication Science and Technology 42 (2): 68~71.

[8] Feng X J, Kang Q 2020 Laboratory compaction method on hot mix asphalt mixture Effect of void fraction and mechanical properties Journal of China and Foreign Highway 40 (3): 291~297.

[9] Sukhija M, Wagh V P, Saboo N 2021 Development of workability based approach for assessment of production temperatures of warm mix asphalt mixtures Construction and Building Materials 305: 10.1016.

[10] Wang C, Hao P W, Ran F 2020 Method for determining the mixing and compaction temperature of warm mix asphalt mixture Journal of Wuhan University of Technology (Transportation Science & Engineering) 44 (4): 640~643.

[11] Nan Q C 2019 Influencing Factors of Compaction Characteristics of Warm Mix Asphalt Mixture Journal of Chongqing Jiantong University (Natural Science) 38 (12): 63~68.

[12] Cai L Z, Li G, Li X, He Z Y, Xu X X, Chen M H 2022 Study on Stability State of Asphalt Mixture Skeleton: Compaction Power and Contact Point Analysis Journal of Basic Science and Engineering 30 (02): 341~350.

[13] Xiong S H, Zheng Y B, Wang H T, Jiang Y J, Yi Y 2022 Performance evaluation of asphalt mixture with different forming methods for long life pavement Journal of Highway 67 (10): 112~118.

[14] Lai Y Q, Wang J, Chen H R, Huang Y H 2020 Study on temperature sensitivity of asphalt mixture Journal of Western Transportation Science and Technology 2020 (12): 23~26.

[15] Li Y Y 2021 Experimental analysis of splitting tensile strength of asphalt mixture based on rotary compaction method Journal of Fujian Transportation Science and Technology 2021 (05): 39~42.