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Experimental Study on Performance of Asphalt Mixture Designed by Different Method

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Abstract

In order to explore the Marshall, Superpave and GTM methods, the similarities and differences of the three design methods are detail studied. Experimental study on performance of asphalt mixture AC-13、AC-20 and AC-25 designed by different method were executed in this paper. Test results show that, GTM method gives lower void and lower bitumen aggregate ratio than other two methods, it have very better water stability and high-temperature stability. The DS value is 3256 / mm by GTM design method, is 1.91 times of the Marshall and 1.33 times of the Superpave. Superpave method gives lower bitumen aggregate ratio than Marshall method. The asphalt mixture designed by Superpave method has longer fatigue life than the mixture designed by other two methods. The volume parameters of asphalt mixture designed by Marshall can conform specification very well, but the performance of asphalt mixture seems to be worse than other two methods.

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Keywords: Road engineer; asphalt mixture; proportion design method; volume parameter; performance

1. Introduction

In recent three decades, together with the rapid development of road transportation, the mileage of asphalt pavement grows fast, which has promoted the economic and social development of China. However, due to the increase of the traffic volume and axle loads, especially the influence of overloaded traffic, the early damage of asphalt pavement occurs frequently and becomes the restraining factor of the development of the road transportation

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in China. The early damage of asphalt pavement is generally caused by several factors, such as the material's properties, construction method, construction quality, harsh environment, traffic volume and loads [1], the unsuitable design method of asphalt mixture is also considered as main reason causing the early damage of asphalt mixture [2].

The Marshall design method (called Marshall in after) is the standard design method of asphalt mixture in China, and the related technical index of asphalt mixture is usually used as inspecting technical index in project acceptance [3]. In order to improve the durability of asphalt pavement, Gyratory Testing Machine design method (called GTM in after) and Superior Performing Asphalt Pavement design method (called Superpave in after) are adopted in some pavement projects, and the performance of asphalt mixture designed by GTM and Superpave has also been studied. However, the difference in properties of asphalt mixture designed by three methods has not systematically been studied by now. In the paper, AC-13、AC-20 and AC-25 asphalt mixtures were executed based on Marshall, GTM and Superpave separately, and the performances of asphalt mixture designed by different method were determined and compared.

In Marshall, asphalt mixture specimen is obtained by heavy hammer compaction and the volume parameter of the specimen is used to decide the optimum asphalt content, in which, some differences exist in the compaction process of experimental specimens and the actual pavement. Both Superpave and GTM adopt gyratory compactor to mold specimens [3, 4]. Superpave adopts SGC (Superpave Gyratory Compactor) to mold the asphalt mixture specimen. GTM adopts the similar method as Superpave to mold specimen by compacting and kneading the asphalt mixture to simulate the influence of compacting equipment at the worksite and follow-up traffic condition. The purpose of the GTM molding method is to simulate the final compacted state, under the impact of road traffic load, and analyze and test the shear strength and plastic deformation in order to know whether the proportion of the asphalt mixture is reasonable or not.

Both Marshall and Superpave are volume design methods. Superpave mixture design system is the most important part of outcome of SHRP plan. Superpave mixture design includes three design levels: level I, level II and level III [5]. Basically volume design is the Level I, in which the asphalt content and aggregate gradation were decided based on performance of asphalt and aggregate, and volume index of asphalt mixture is also considered. The resistance to water damage of asphalt mixture is performed in level I. Level II and III are mixture design process related to the mechanical properties and pavement performance of asphalt mixture [3, 5].

2. Experimental materials

The materials in tests, AC-13 use asphalt of SBS, basalt aggregate and limestone mineral powder. AC-20 and AC-25 use 70# asphalt, limestone aggregate and limestone mineral powder. The properties of the materials conform to the requirements of "Technical Specification for Construction of Highway Asphalt Pavement" (JTG F40-2004) [6]. Asphalt of SBS is Grade I-D , and the density in 15℃ is 1.020g/cm^3. 70# Asphalt is Grade A, and the density in 15℃ is 1.037g/cm^3. The apparent density of limestone mineral powder is 2.785 g/cm^3. The densities of aggregate are shown in Table1 and Table 2 (JTG E42-2005) [7].

Table 1. Density of aggregate test results of AC13.

Aggregate group	13.2~16(g/cm3)	9.5~13.2(g/cm3)	4.75~9.5(g/cm3)	2.36~4.75(g/cm3)	1.18~2.36(g/cm3)
Apparent density	2.904	2.871	2.828	2.793	2.773
Bulk density	2.889	2.829	2.787	2.701	2.689
Aggregate group	0.6~1.18(g/cm3)	0.3~0.6(g/cm3)	1.15~0.3(g/cm3)	0.075~0.15(g/cm3)	0~0.075(g/cm3)
Apparent density	2.765	2.758	2.749	2.736	2.765
Bulk density	---	---	---	---	---

Table 2. Density of aggregate test results of AC20、AC25.

Aggregate group	26.5~31.5(g/cm3)	19~26.5(g/cm3)	9.5~19(g/cm3)	4.75~9.5(g/cm3)	2.36~4.75(g/cm3)	0~2.36(g/cm3)
Apparent density	2.798	2.793	2.771	2.778	2.784	2.703
Bulk density	2.791	2.792	2.751	2.742	2.743	2.662

3. Results and discussion

3.1. Mixture proportion Design

(1) Aggregate gradation design.

According to the requirements of aggregate gradation scope of AC-13, AC-20, AC-25 asphalt mixtures in JTG F40-2004, the mineral aggregate gradation is designed and shown in Figure1.

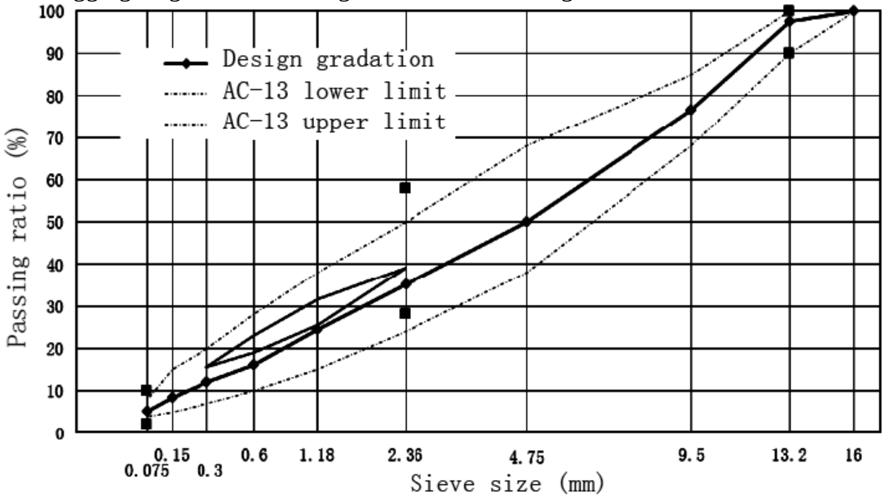

Fig. 1. Aggregate gradation curves of the asphalt mixtures (a) AC13;

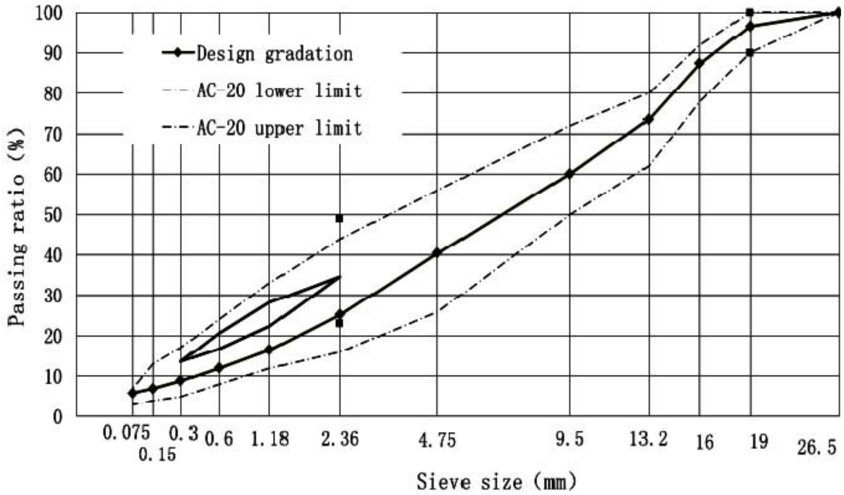

Fig. 1. Aggregate gradation curves of the asphalt mixtures (b) AC20;

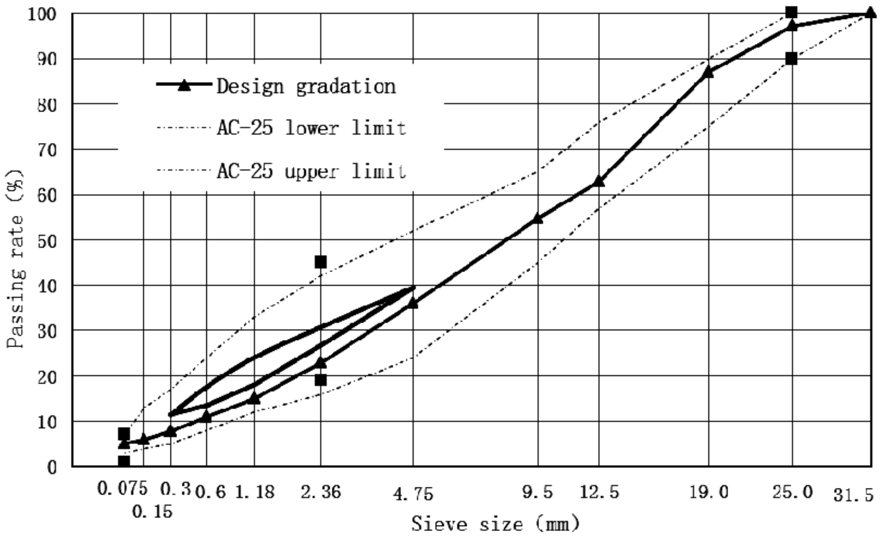

Fig. 1. Aggregate gradation curves of the asphalt mixtures (c) AC25.

Mineral aggregate gradation should be determined through control point and restrictive area in Superpave. The mineral aggregate gradation in Superpave has to choose three different gradations for optimizing. However, considering the purpose of this paper is to make the results comparable, this study choose the same mineral aggregate gradation as used in Marshall and GTM, as shown in Figure 1. This aggregate gradation can also meet the requirements about the control points and restrictive area of gradation in Superpave.

(2)The Optimum asphalt content

The optimum asphalt content of three kind of asphalt mixture is obtained according to different tests procedure stipulated in Specification of Marshall, GTM and Superpave respectively. The optimum aggregate asphalt ratio and volume parameters are shown in Table 3.

Table 3. Design results by different design methods.

Types	Methods	Optimum asphalt aggregate ratio（%）	Bulk density (g/cm3)	VV (%)	VMA (%)	VFA (%)
AC-13	GTM	4.6	2.526	2.6	12.2	78.5
	Superpave	4.7	2.488	4.0	13.6	71.0
	Marshall	5.0	2.468	4.2	14.6	71.3
AC-20	GTM	4.0	2.516	2.1	11.5	81.5
	Superpave	4.1	2.469	4.0	13.1	70.0
	Marshall	4.5	2.438	4.4	14.5	69.9
AC-25	GTM	3.8	2.494	2.2	11.0	81.2
	Superpave	3.9	2.479	4.1	13.0	68.5
	Marshall	4.1	2.453	4.8	13.8	60.5

It can be seen that there are certain differences on the optimum asphalt content and volume parameters in three design methods. The bulk density and VFA in GTM are biggest. In Superpave, the bulk density and VFA take the second place, and the bulk density and VFA are smallest in Marshall. For the optimum proportion asphalt, porosity and VMA, the order of three methods are GTM<Superpave<Marshall. Because the compacting method and theory

is different in different design method of asphalt mixture, the volume parameters is also different, which will cause some impact on pavement performance of asphalt mixture.

3.2. Performance test

(1) High temperature stability

The indoor rutting experiments are performed according to the requirements of “Standard Methods of Asphalt and Asphalt Mixture for Highway Engineering” (JTG E20-2011) [8]. The dynamic stability of asphalt mixtures in different methods are shown in Figure 2.

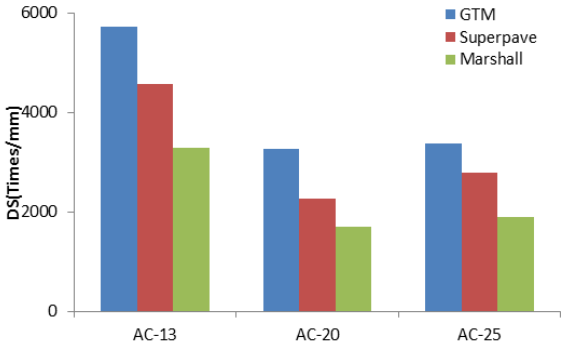

Fig. 2. High temperature stability of Asphalt mixtures designed.

The molding method of Marshall is heavy hammer compaction and the compaction work is relatively small, which is different from the real pavement compaction method in worksite and also different from the molding method of rutting test specimen. Although the volume parameter of the mixture meets the requirements of specification, the arrangement of aggregate in asphalt mixture has been changed under the effect of wheel load, which results in dislocation and deformation in asphalt mixture. Therefore, the high temperature stability is relative low in Marshall. Meanwhile, the optimum asphalt content of Marshall is higher. The higher asphalt content will induce the reduction on high temperature stability of asphalt mixture. GTM specimen has higher density and lower asphalt content, which reduce the lubrication between the asphalt and aggregates and the pavement deformation caused by the compaction of wheel. Meanwhile, some mechanical index, such as shearing strength has been taken into consideration in the GTM. Therefore, the ability to resist shear deformation is better in GTM.

As a volume design method, the Superpave design method controlled strictly the porosity at 4.0% level. At same time, the SGC compaction method is adopted, which can stimulate the stress state of pavement very well. Therefore, the Superpave specimen also shows better high temperature stability performance.

(2) Anti stripping performance

The residual stability test and freeze-thaw splitting test are carried out in order to evaluate anti stripping performance according to the requirements of “Standard Methods of Asphalt and Asphalt Mixture for Highway Engineering” (JTG E20-2011) [8]. The test results of remained stability (MS_0) and TSR of asphalt mixture is shown in Figure3.

It can be seen that, the remained stability of GTM specimen is higher than Superpave specimen, and the remained stability of the Marshall specimen is lowest. The TSR results are as the same as remained stability results. It can be said that the anti-stripping performance of GTM specimen is best and that of Marshall specimen is worst.

As shown in Table 3, GTM specimen is better than Superpave and Marshall in the technical index of density or porosity. The larger density and smaller porosity can decrease the water permeability of asphalt mixture, which will reduce the infiltration and impact of water on the inside structure of asphalt mixture. Even the experimental materials are totally same in these three methods, the asphalt mixture in GTM method has better performance of resistance to water damage.

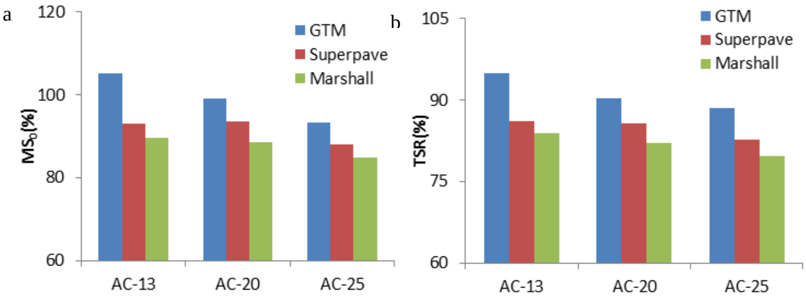

Fig. 3. (a) Test results of MS_0; (b) Test results of TSR.

(3) The Anti-fatigue performance

The fatigue test is an assessment on anti-fatigue performance of asphalt mixture, which reflects the service life of asphalt mixture to some extent. In some asphalt pavement design methods, the anti-fatigue performance of asphalt mixture is regarded as a key design indicator. The service life of asphalt pavement can be approximately estimated according to the fatigue curve.

In order to indirectly discuss the impact of design methods on anti-fatigue performance of asphalt mixture, the simple fatigue performance tests of asphalt mixture specimens are carried out for different design method by using MTS-810 material fatigue testing equipment.

The specimen of asphalt mixture for simple fatigue test is a 40mm×40mm×250mm beam cutting from rutting test specimens. The test carried out at 15℃ and 10 Hz frequency, the load is half sine wave. The test adopts three points loading way, and easy fatigue test with stress level control mode is used. The total break of beam specimen is recognized as the fatigue damage standard of asphalt mixture specimen. For instance, in AC-20, the maximum flexural-tensile strength of specimens in GTM, Superpave and Marshall method are 7.83MPa, 7.07MPa and 6.84MPa respectively.

The fatigue test result of asphalt mixture designed by different methods is shown in Figure 4, in which, S is stress level defined as the ratio of load stress to the maximum splitting tensile strength of asphalt mixture, and N is the total number of the load when the specimen is failure.

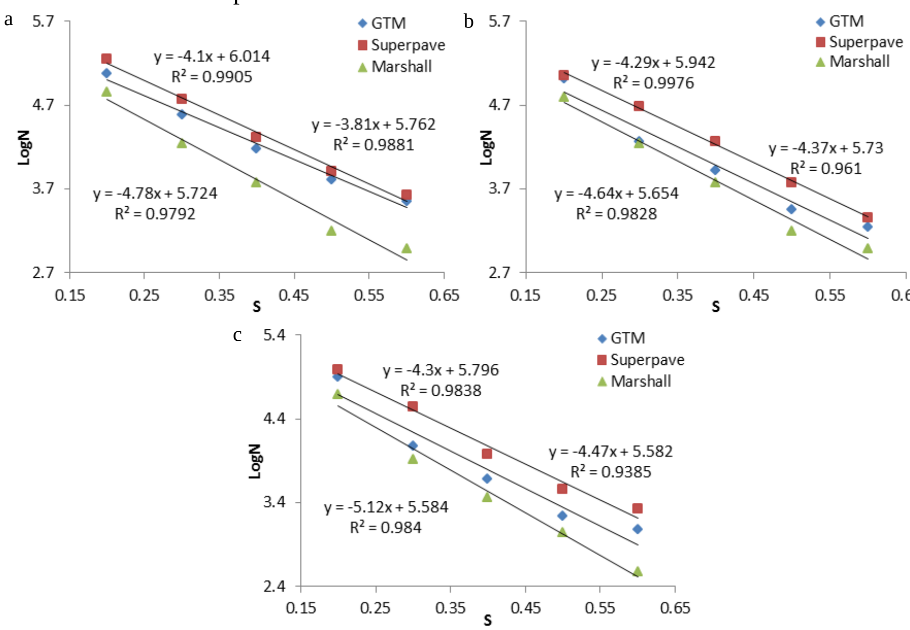

Fig. 4. S-N curve of asphalt mixture (a) AC-13; (b) AC-20; (c) AC-25.

As it shows in above experiments, the porosity of Superpave specimen and GTM specimen are low, but the asphalt content of Superpave specimen is higher than GTM specimen. Larger density and lower porosity ensure that the specimen has higher strength and abilities to resist all kinds of damages. Moreover, the larger asphalt content enables asphalt mixture to have higher bonding strength, which improves the anti-fatigue performance and the abilities to resist the fracture damage.

The air voids of Marshall specimen is largest, the asphalt content is highest and the VFA is the lowest, which results that its anti-fatigue performance is lower than the specimens in the other design methods.

3.3. Analysis

Test results mentioned above shows that, although the raw materials and experimental conditions are the same, there are still differences among the performance of asphalt mixture designed by different methods. Firstly, in Marshall, asphalt content and porosity of asphalt mixture is high, but the high temperature stability, anti-stripping performance and anti-fatigue performance are low. Secondly, in GTM design method, the asphalt content and porosity of asphalt mixture are lower and the high-temperature stability and anti-stripping performance are higher. Thirdly, the basic performances of the asphalt mixture designed by Superpave method are just between Marshall and GTM method, excepting the excellent anti-fatigue performance.

The design principles of three methods are different, and the producing methods of specimens are also different. Marshall method adopts hammer compaction to mold specimen, and the combination of the aggregates is not close, which will cause dislocation and movement under the external forces, such as automobile load, and also result in lower high temperature stability and anti-fatigue performance. The other two methods, GTM and Superpave, adopt the molding methods which are similar or close to the actual construction roller compaction. Therefore, the combination of the aggregates is close. Moreover, the design emphases in these three design methods are different. For instance, GTM design method adopts reasoning method related to stress to design and analyze asphalt mixture mechanically. GTM specimen is to simulate the final compacted state, namely equilibrium state, under the impact of road traffic load, and analyze and test the shear strength and plastic deformation. Therefore, the asphalt mixture has better resistance to traffic load.

Currently, according to the related regulation, Marshall is the standard design method and construction quality inspection method in China. The performance of asphalt mixture designed by other methods should meet the requirements of experimental index of Marshall. The above experimental results show that, within the scope of this paper, the results of GTM and Superpave design methods are better than Marshall's results. Consequently, it is necessary to reconsider and revise the design method of asphalt mixture and test indicators of asphalt pavement quality, in order to enable the results of asphalt mixture design method to be more suitable for the actual situation and improve the quality of asphalt pavement.

4. Conclusions

The paper briefly analyzed and compared the design principles of three design methods of asphalt mixture and experimental explored the results of Marshall, GTM and Superpave design methods. The results show that there are differences on the volume parameter of asphalt mixture and pavement performance. The asphalt mixture has better technical performance in GTM; the technical performance in the currently used Marshall method is relatively lower.

The reasons why the above differences exist are mainly due to the differences on molding method, emphases and principle of asphalt mixture design method. The asphalt mixture designed method which is close to the actual conditions and also considers the real stress state of pavement has better technical performance. Such design method is worth of further promoting.

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