The Bulk Specific Gravity Measurements of the Coarse Gap-Graded Mixture

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ABSTRACT: To improve the high-temperature stability of the asphalt mixes, the coarse gap-graded mixes are used extensively, such as SMA, the stone asphalt concrete (SAC), that invented by Chinese Engineering academician Sha Qinglin. Because the surface texture of this mixes is larger than one of the traditional continue-graded mixes, there is strong influence for measurements of the bulk specific gravity. The volumetric method of mixture design is used in the world, and the bulk specific gravity of mixes is a basic parameter in this method. So its accuracy and reasonableness is the base of volumetric design method. There are several methods for measuring the bulk specific gravity of mixes, such as SSD， automatic vacuum sealing method (ASTM PS 132-01), wax-enveloped method, etc. The results of measurement are different for the different methods. And it is influence on the volumetric characters of mixture and results of mixture design. In this paper, the bulk specific gravity of the mixture under the different asphalt-stone ratios is measured by the different methods to the several coarse gap-graded mixtures. From these testing results, the automatic vacuum sealing method and the improved wax-enveloped method are rather than SSD method to measure the bulk specific gravity of the coarse gap-graded mixtures. And for the bulk specific gravity measured by two kinds of methods, the different of the calculated air voids of mixtures is about 1%~2%.

KEYWORDS: Bulk specific gravity, coarse aggregate gap-graded, asphalt mixture

1 BACKGROUND

The volume index design is primarily applied for current asphalt mix design, like the design method of SUPERPAVE^{TM}. The bulk specific gravity of mix is the basis of all mix volume index, and the calculation of neither the design air voids, void in mineral aggregate (VMA) nor void in coarse aggregate(VCA) and the saturation could be independent from the bulk specific gravity of mix. As a result, the accuracy of bulk specific gravity measurement will be critical for the evaluation of density of mixes and mineral aggregates. In conclusion, the measurement of bulk specific gravity of mix is one of essentials for volume design of mix.

However, it is not easy to accurately measure the bulk specific gravity of mix. The bulk specific gravity refers to the quantity of mix under unit bulk volume. Here comes the question "what is the bulk volume?", and "how to measure the bulk volume?". Which deserves our further discussion. According to the different understandings, different test methods for mix bulk specific gravity arise, and they are the diameter/height method (AASHTO T269), SSD (ASTM D2726, AASHTO T166), and automatic vacuum sealing method (ASTM D 1188, AASHTO T275) and wax-enveloped method or like. They have different operation methods and principles for various applications and uses.

For general bulk specific gravity, it will face two main problems during measuring the actual density: 1. the water absorption of specimen; 2. the difference between texture depth and open void of specimen. The first problem sees latency during the test, that is to say that it is unable to determine the water absorption of mix before the measurement of mix gravity, nor to determine the applicability of SSD. For the second problem, this condition is more obvious for the determination of density of coarse dense mix, typically the SMA and SAC. This is because these two mixes both have ideal texture depth, facing the technical difficulty to differentiate the texture depth and open void. This is also the difficulty for the large void and open graded mixes like PAC and OGFC need to be overcome.

This document is comprised of the test and analysis for the bulk specific gravity measurement of coarse gap-graded mixes with five density levels. According to these tests and analysis, it is found that the selection of density measurement method and of mineral aggregate grade of mix is actually correlated, and the density measurement method for continuous dense mix that is generally used may not be applicable for the coarse gap-graded mix (including the dense mix). As a result, the automatic vacuum sealing method is finally adopted for the measurement of coarse gap-graded mix. Such method is applicable for the measurement of mix density with different air voids so that the bulk specific gravity of open-graded mix and dense graded mix could reach efficient uniformity.

2 DISCUSSION OF DEFINITION OF BULK SPECIFIC GRAVITY MEASUREMENT

2.1 Brief Description for Some Bulk Specific Gravity Measurement

The bulk specific gravity of asphalt mix refers to the dense condition of a limited size solid formed under certain compaction against some mineral aggregate graded mix. According to the physical concept description of density, the determination of bulk specific gravity is subject to the determination of the bulk volume of this limited size solid. Generally, the bulk volume of mix consists of the volume of mineral aggregate and asphalt, internal close voids of specimen and external open voids of specimen or like.

Actually, some defects exist on the surface of specimen, equivalent to the surface texture depth occurred from the pavement of these materials on the road surface. This is especially for the coarse gap-graded mixes and non-dense mix, which has higher surface texture depth than it of continuous dense mix, and therefore causes severer surface defects of specimen.

It should be pointed out that these surface defects are not equal to the open voids of specimen. During measuring the bulk volume, it is a technical problem that how to differentiate the surface texture depth and open voids of specimen. This feature is seen obviously for coarse gap-graded mixes.

The height/diameter method is to measure the overall dimension of the specimen, including all open voids, close voids and all surface texture depth. It takes actually the surface texture depth as the open void of specimen, and the measurement result of air voids of mix will be therefore high. However, this method is still the main one for measurement with volumetric method of open-graded mixes.

The weight in water method is a simple mix density measurement method, and on the contrary, this method will nearly exclude all open voids from the bulk volume of mix (in addition to few small open voids that are free from water immersing due to the surface tension of water), that is to say that it will consider mostly open voids as surface texture depth of specimen so that the bulk volume of mix under measurement will be slightly low with relatively low air voids. Accordingly, it is such specified in Chinese test method that this method is only applicable for the air voids measurement of continuous dense-graded mixes with less than 3% air voids.(Ministry of Communications China Standard JTJ 052-2000, 2000)

The SSD is the most extensively used measurement method for bulk specific gravity of mixes in the world now, which actually takes all volume covered by the surface profile water film under saturated surface dry condition as the bulk volume of mixes, and then calculate the bulk specific gravity of mixes on this basis. It should be noted that the “water film profile” could not be used to directly differentiate the open voids and texture depth of mix specimen. Especially for the coarse gap-graded and open graded mixes with high texture depth, most open voids are excluded from the “water film profile”, so the bulk volume of mix actually measured will be slightly lower than the actual bulk volume. This result in high bulk specific volume of mixes and low air voids in some sort. Consequently, this method is only applicable for the measurement of bulk specific volume of continuous dense graded mixes.

The wax-enveloped method is also a general used measurement method for bulk specific gravity of mixes. Similar with the SSD, it determines the surface profile of mix with “wax film’ instead of the “water film”. Since the wax is amorphous material, the surface profile of specimen will be greatly affected by the wax melted temperature during wax sealing. When the wax is under high temperature, the wax has ideal fluidity, and the bulk volume of wax film of specimen is equivalent to it of the water film, or even smaller; when the wax is under low temperature, the bulk volume of specimen under wax film measurement will be obviously larger than it of water film measurement. For this reason, the wax temperature under wax sealing is controlled within 60~70℃ temperature.

The automatic vacuum sealing method is proposed by the US SUPERPAVE, which measures the bulk specific gravity of mixes by means of vacuum the wax-enveloped method. It actually replaces the “water film” under SSD and “wax film’ under wax sealing method with the “plastic film” to describe the bulk volume of specimen. It has the advantages to avoid the fluid water and wax immersing the surface open voids of specimen, and should theoretically come near to or be same with the improved wax-sealing test result, and achieve reasonable test result. But the disadvantage is that it has high test cost, and sometimes the plastic packaging film broken may lead to the test failure.

2.2 Improvement of The W**ax-enveloped Method**

For the wax-enveloped test, there is an operational problem need to be considered. Under melting condition, the wax will keep fluid, and when the specimen is immersed into, the wax will always try to enter into some open voids that are inevitable for coarse gap-graded and open graded mixes. This makes it face the same problem with the SSD—unable to distinguish the open voids and texture depth of specimen, and the bulk volume of mixes under measurement will be slightly smaller than the actual value.

For this reason, the improved wax sealing method is proposed, i.e. implementing the wax sealing with brush, which means to coat wax on surface of specimen with ink brush slightly when the wax is under 55~60℃ temperature (to be freezing) so that it could maximally prevent the wax entering into the open voids of specimen and keep the bulk volume measurement accurate as much as possible and therefore get the true bulk specific gravity of mixes to the best. Actually, this method has replaced the former “wax dipping” with the “wax brushing”.

This method is applicable for the measurement of bulk specific gravity of different graded mixes. But it has such difficulty that requires the test staff to be skillful, careful and serious enough (Wang Xudong, Zhang lei, 2009).

3 EXPLANATION FOR COMPARISON TEST OF BULK SPECIFIC GRAVITY

This study uses a group of coarse gap-graded mixes (i.e. five level graded mixes: SAC16-21, SAC16-24, SAC16-27, SAC16-30 and SAC16-33), and the related graded curve may see table 1 below. This gradation was put forward by the Chinese highway researchers in the beginning of 1990s (Q. Sha, 2005). According to the data, the coarse aggregate contents (gravel with above 4.75mm size) of them are relative high and they are 67%, 70%, 73%, 76% and 79% respectively. For this reason, the compactness of mixes transits from the dense mix to open graded mix.

Table 1: Mineral aggregate gradation with different gravel contents

Sieve size (mm)		19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
SAC16-33	The Passing In Percentage (%)	100	95	80	60	33	26	20	16	13	10	8
SAC16-30		100	95	79	58	30	23	18	15	11	9	7
SAC16-27		100	95	78	56	27	21	17	13	10	8	6
SAC16-24		100	95	77	54	24	19	15	12	9	7	6
SAC16-21		100	94	76	53	21	16	13	10	8	6	5

The mixes for any gradation are all shaped by means of rotating compaction. Every graded mix is shaped with 5 asphalt-stone rates. The asphalt-stone rate under test of SAC16-33 mix is 3.8%, 4.2%, 4.6%, 5.0% and 5.4%; of SAC16-30, SAC16-27 and SAC16-24 mix is 3.4%, 3.8%, 4.2%, 4.6% and 5.0%; and of SAC16-21 mix is 3.0%, 3.4%, 3.8%, 4.2% and 4.6%. For ensuring the reliability of test, each asphalt-stone rate is prepared with four samples, and each graded mix will be given two parallel tests.

For the analysis on properness of bulk specific gravity measurement, it should follow two basic laws, and when these laws are violated, the density measurement will be considered unreliable:

1）With the rise of asphalt-stone rate, the bulk specific gravity of mix will gradually increase, and when it reaches certain level, it will gradually decrease. So, the general shape of curve looks like the upper convex conic curve model.

2）With the rise of asphalt-stone rate, the void in mineral aggregate of mixes and of coarse aggregate will gradually decrease, and when it reaches certain level, it will gradually increase. So, the general shape of curve looks like the upper concave conic curve model.

4 TEST DATA ANALYSIS

4.1 Analysis with Same Gradation and Different Gravity Measurement Method

Table 2 shows SAC16-30 asphalt concrete and the 100 times SGC rolling shaped specimen, it will separately measure the bulk specific gravity of mixes with volumetric method, weight in water method, SSD, improved wax sealing method and the wax-enveloped method, while calculating the corresponding air voids and void in mineral aggregate. According to the data in the Table below, the difference of bulk specific gravity of mix got from five different density measurement methods is relative high. Regarding to the density data, the density under weight in water measurement method is the highest, and then under the SSD, the automatic vacuum sealing method and the wax-enveloped method, and volumetric method successively. Among which, the density result from weight in water method and SSD is relative close, and the result from wax-sealing and the wax-enveloped method is comparatively approximate. The corresponding test curve may see Figure 1. According to the curve, except the weight in water method, the bulk specific gravity of mixes got from other measurement methods will gradually increase with the rise of asphalt-stone rate. The density curve of weight in water method violates the fundamental law 1 and this also proves the limitedness of this method.

Generally, the weight in water method is applicable for density measurement for the mix with less than 3% air voids. The air voids of mix will vary with the change of asphalt-stone rate and it will also be different under different asphalt-stone rates. As for the test, the air voids of mix, within asphalt-stone rate of 3.8%~5%, is 4.36%~1.84%; and when the asphalt-stone rate is higher than 4.6%, the air voids of mix will meet the requirement of less than 3%. But the problem is that the testers are unable to accurately estimate the air voids range of mix before the test and accordingly choose proper test method.

Table 2: Summary of Test Result with Different Bulk Specific Gravity Measurement Methods

Parameter	Asphalt aggregate Ratio (%)	Volumetric method	Weight in water method	SSD	Wax sealing method	The wax-enveloped method
Bulk	3.4	2.3503	2.5534	2.5051	2.421	2.3912

specific gravity (g/cm^3)	3.8	2.3943	2.5459	2.5244	2.4622	2.4478
	4.2	2.4226	2.5443	2.5383	2.4834	2.4613
	4.6	2.4442	2.5526	2.5491	2.5003	2.4879
	5	2.4534	2.5585	2.5552	2.5149	2.5014
	3.4	11.97%	4.36%	6.17%	9.32%	10.43%
	3.8	9.77%	4.06%	4.86%	7.21%	7.75%
VV	4.2	8.15%	3.53%	3.76%	5.84%	6.68%
	4.6	6.78%	2.64%	2.77%	4.64%	5.11%
	5	5.87%	1.84%	1.97%	3.52%	4.03%
	3.4	18.79%	11.77%	13.44%	16.35%	17.38%
	3.8	17.59%	12.37%	13.11%	15.25%	15.75%
VMA	4.2	16.94%	12.76%	12.97%	14.85%	15.61%
	4.6	16.52%	12.81%	12.93%	14.60%	15.02%
	5	16.52%	12.94%	13.06%	14.43%	14.89%

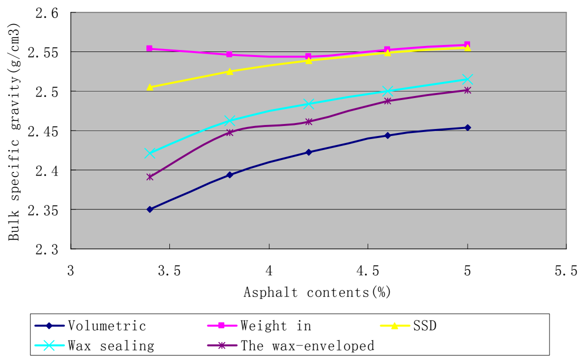


Figure 1: Gravity curve with different bulk specific gravity test method

Also, for the test with SSD, according to the bulk specific gravity test result, it has large difference with the automatic vacuum sealing method and the wax-enveloped method. On the view of calculating the air voids, within the asphalt-stone rate of test, when the air voids of mix are 6.17%~1.97%, it will be basically classified into the dense mix. According to the current test requirement, this method is applicable. But, are these test results proper and correct? Nobody could know it. With reference to the analysis on SSD regarding to the test principal, the bulk specific gravity of mix is slightly high and its air voids is slightly low.

The measurement for above gravity with volumetric method features simple operation and wide applicability, but due to the inherent defect of bulk volume of mixes, the test result will definitely not the true bulk specific gravity of mixes, which provides the low limit for such gravity.

As a result, this study has the opinion that the true bulk specific gravity and air voids of mixes should lie between the volumetric method measurement result the SSD (bulk specific gravity) measurement result; while the said gravity mixes should remain between the automatic vacuum sealing method and the wax-enveloped method measurement results.

Within the asphalt-stone rate range of test, the bulk specific gravity of mixes under the automatic vacuum sealing method is averagely 2.3% lower than the result from SSD measurement, which also results in average increase of 2.89% (absolute value) of air voids; the said gravity under the wax-enveloped method measurement averagely decreases 3.0% that leads to average rise of 4.60% (absolute value) in terms of air voids.

The more important is that: after the mix gravity measuring with the automatic vacuum sealing method and the wax-enveloped method, the air voids of mix has basically exceeded the technical requirement of bulk specific gravity. The air voids under the automatic vacuum sealing method within the asphalt-stone rate range is 9.32%~3.52%, and it under the wax-enveloped method is 10.43%~4.03%, the air voids level lying between the dense mix and open graded mixes. This will greatly affect the performance evaluation of mixes.

In accordance with the further analysis of void in mineral aggregate, the nominal max. particle size in this study is the 16mm coarse gap-graded mix. As the technical requirement, the min. void in mineral aggregate should be higher than 13.5%. For the gravel content with more than 4.75mm size in the gradation of this test, it has reached up to 70%, and when the VMA mixes are measured with SSD, the values are all lower than this standard value and this is improper. This is resulted from slightly high bulk specific gravity of mix. The mixes with automatic vacuum sealing method and wax-enveloped method all exceed the technical requirement. In this respect, the bulk specific gravity from these two measurement methods is basically proper.

4.2 Comparison of Different Mineral Aggregate Gradations

For further comparing the properness of SSD and the automatic vacuum sealing method, the comparison test is made between SAC16-33 and SAC16-27. In this test, the gravel content of SAC16-33 is 3% reduced from it of SAC16-30, i.e. 67%; the gravel content of SAC16-27 is 3% rise than it of SAC16-30, i.e. reaching 73%. The relevant test result may see Table 3.

For SAC16-33, due to the increase of fine aggregate in mix, the compactness of mix is therefore improved, and within the testing asphalt-stone rate range, the air voids of SSD is 4.72%~0.93%, and the air voids of the automatic vacuum sealing method is 7.24%~1.83%; for SAC16-27, due to the decrease of fine aggregate in mix, the compactness of mix is therefore reduced, and within the testing asphalt-stone rate range, the air voids of SSD is 6.53%~3.57%, and air voids of the automatic vacuum sealing method is 10.34%~5.74%.

In combination with the above SAC16-30 test result, when the SSD is applied for gravity test, these three mixes may be taken as the bulk specific gravity; when the automatic vacuum sealing method is used, the compactness of these mixes will have high difference. This further reveals that due to the variation of gradation and density measurement methods, the determination of compactness of mixes will be affect.

Table 3: Data summary of two different mix bulk specific gravity test methods

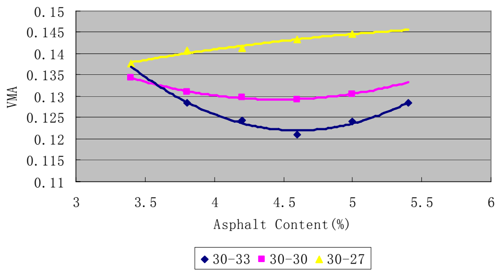
Method	Volumetric method	SSD	The automatic vacuum sealing method

Asphalt aggregate ratio	bulk specific gravity (g/cm^3)	Air voids	VMA	bulk specific gravity (g/cm^3)	Air voids	VMA	bulk specific gravity (g/cm^3)	Air voids	VMA
	SAC16-33								
3.8	2.4242	8.57%	16.37%	2.5263	4.72%	12.85%	2.4594	7.24%	15.16%
4.2	2.4498	7.05%	15.82%	2.5482	3.32%	12.43%	2.491	5.49%	14.40%
4.6	2.4845	5.17%	14.95%	2.5674	2.01%	12.11%	2.5217	3.75%	13.68%
5	2.5	4.01%	14.74%	2.5682	1.40%	12.42%	2.5362	2.63%	13.51%
5.4	2.5039	3.31%	14.93%	2.5654	0.93%	12.84%	2.5423	1.83%	13.63%
	SAC16-27								
3.4	2.3438	12.28%	19.08%	2.4976	6.53%	13.77%	2.3956	10.34%	17.29%
3.8	2.3592	11.17%	18.86%	2.4982	5.93%	14.08%	2.4185	8.93%	16.82%
4.2	2.3697	10.23%	18.81%	2.5065	5.05%	14.13%	2.4398	7.57%	16.41%
4.6	2.383	9.19%	18.67%	2.5099	4.35%	14.34%	2.452	6.56%	16.31%
5	2.3892	8.41%	18.77%	2.5156	3.57%	14.47%	2.4589	5.74%	16.40%

In addition, as for the air voids of mineral aggregate, the VAM mix variation curve drawn on the basis of different asphalt-stone rate may see Figure 2 and 3. The Figure 2 shows the result of gravity test with the SSD. According to the curve, the curve of two mixes of SAC16-33 and SAC16-30 appears upper concave, while the SAC16-27 shows upper convex. On the basis with the compactness principle of mix, and same compaction effort, with the rise of asphalt-stone rate, the VMA of mix should show upper convave curve variation. When the SAC16-27 mix appears upper convex, it will be abnormal, this represents incorrect mix gravity measurement. The Figure 3 shows the test result of the automatic vacuum sealing method. From the curve in Figure, the VMA of three mixes show upper concave curve variation. This indicates, the gravity result gained from the automatic vacuum sealing method measurement is more reliable and has extensive applicability. It’s funny, the analysis like VCA mix index may get the same conclusion.

For the open graded SAC16-24 and SAC16-21 mixes with more coarse aggregate content and high air voids, it is obviously inapplicable to measure the mix gravity with SSD. It directly measured the geometrical size of mix specimen with volumetric method in the past to calculate the bulk specific gravity of mix. This is because that first, the article has explained the improperness of gravity measurement with volumetric method, and second, the volume index of mix and it of dense mix is not comparable.

Table 4 shows the summary of volume parameters summary for SAC16-24 mix and SAC16-21 mix with the automatic vacuum sealing method and volumetric method. In terms of the air voids, the air voids for such open graded mix with the automatic vacuum sealing method measurement will generally 2% less than it measured with volumetric method. From the changing trend of VMA and VCA mix index, due to the high air voids of mix, the accuracy of volumetric method measurement is such affected that result in the short of the regularity for the variation of two indices; while for the automatic vacuum sealing method, these two indices show ideal regularity along with asphalt-stone rate variation form. For this reason, the mix gravity measurement with the automatic vacuum sealing method and relevant volume index is more reliable for the measurement of open graded mix.



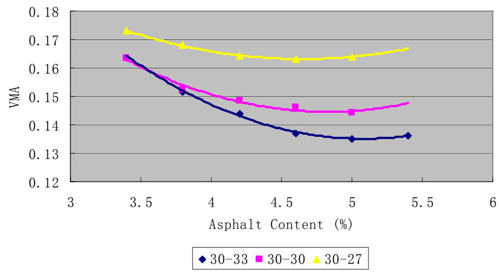


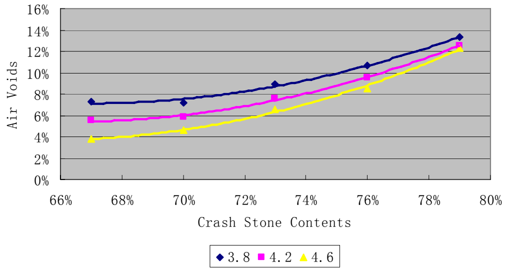
Figure 2: The VMA versus asphalt contents (SSD)
Figure 3: The VMA versus asphalt contents (The automatic vacuum sealing method)

Table 4: Test result summary of open graded mix gravity

Asphalt aggregate ratio	bulk specific Gravity (g/cm^3)	VCA	Air voids	VMA	bulk specific gravity (g/cm^3)	VCA	Air voids	VMA
	Volumetric method				Wax sealing method			
	SAC16-24							
3.4	2.3017	39.96%	13.92%	20.53%	2.3489	38.73%	12.15%	18.95%
3.8	2.3050	40.10%	13.26%	20.72%	2.3728	38.34%	10.71%	18.44%
4.2	2.3095	40.21%	12.57%	20.87%	2.3890	38.16%	9.56%	18.20%
4.6	2.3274	39.98%	11.36%	20.57%	2.4022	38.05%	8.52%	18.06%
5.0	2.3268	40.23%	10.86%	20.89%	2.3997	38.35%	8.07%	18.46%
	SAC16-21							
3.0	2.1963	40.21%	18.43%	23.96%	2.2590	38.51%	16.10%	21.79%
3.4	2.2149	39.94%	17.22%	23.62%	2.2816	38.13%	14.73%	21.32%
3.8	2.2222	39.98%	16.44%	23.66%	2.3056	37.72%	13.30%	20.79%
4.2	2.2287	40.03%	15.68%	23.73%	2.3121	37.78%	12.53%	20.87%
4.6	2.2466	39.78%	14.50%	23.41%	2.3048	38.22%	12.28%	21.43%

At last, with reference to the above testing data, a Figure is drawn with two methods for these five mixes of SAC16-33, SAC16-30, SAC16-27, SAC16-24 and SAC16-21 with the air voids variation under the asphalt-stone rate of 3.8%, 4.2% and 4.6% to show the influence of variation of graded gravel content on air voids. The first method is to measure the mix gravity with the automatic vacuum sealing method (see Figure 4); and the other method is to show the mix gravity of SAC16-33, SAC16-30, and SAC16-27 with SSD, and of SAC16-24 and SAC16-21 with volumetric method (see Figure 5).

According to the above Figures, it is obvious that when the second method is used, due to the inconformity of mix gravity measurement, the influence due to the change of mix gravel content on the air voids is discontinuous, while the first method could show an ideal and continuous variation trend. Consequently, it is proper to measure the bulk specific gravity of mix by means of the automatic vacuum sealing method, and then analyze the variation of mix volume index.



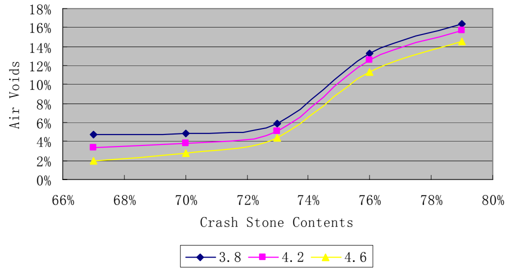


Figure 4: Air voids versus crush stone contents (SSD)

Figure 5: Air voids versus crush stone contents (Volumetric method)

5 CONCLUSIONS

The measurement of bulk specific gravity is an essential sector for asphalt mix design and critical for the density and skeleton structure of mix. Different with the traditional continuous gradation, the coarse gap-graded mix has ideal texture depth, which however causes a new problem for such measurement—how to correctly distinguish the surface texture depth and open void of mix. According to a serious test analysis and research in this article, it makes following conclusions:

1）The SSD is not applicable for the measurement of coarse gap-graded mixture, and the test result of this method shows apparently higher than the actual bulk specific gravity.

2）Generally, the value between bulk specific gravity of mix lies in the measurement results between SSD and volumetric method.

3）Such measurement with improved wax-enveloped method is proved to be an efficient way and also the one that could get the most accurate value.

4）The improved wax-enveloped method is not only applicable for the dense coarse gap-graded mix gravity measurement, but also for the measurement of open graded mix gravity. The combination of gravity measurement for two different types graded mix is absolutely helpful for the future research.

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