Research on Coarse Aggregate Angularity Description Methods and Technical Standard for Asphalt Pavement

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ABSTRACT: The coarse aggregate particle index Iap is computed based on ASTM D3398 improved method. The computing formulas for coarse aggregate angularity index AIrm of radius method and the angularity AIgm of gradient method are proposed by the digital image processing technology(DIPT). The analysis shows that the coarse aggregate angularity index AIrm of radius method and AIgm of gradient method are linearly correlative with each other, and their regression coefficients may be used to convert the coarse aggregate particle index Iap into AIrm and AIgm respectively. Effects of the coarse aggregate angularity on asphalt concrete performance and anti-shear parameter are analyzed based on the common and dynamic triaxial tests of two types asphalt concrete, so that the correlation between the asphalt concrete performance including anti-shear parameter and the particle index Iap is established. The technical standard for the coarse aggregate angularity is proposed based on asphalt pavement performance requirements. Recommendation is provided for the revision of the technical specification for construction of highway asphalt pavements (JTG F40-2004), to improve coarse aggregate quality.

KEY WORDS: Asphalt pavement, aggregate angularity, description index, technical standard

1 INTRODUCTION

Considerable experience has been accumulated in the selection of asphalt pavement aggregate. To ensure the aggregate meet the quality requirements for the asphalt pavement, and helpful to the aggregate quality control in the construction process of asphalt pavement, the specific provisions of the stone quarry and the aggregate production including each of the indexes and test methods are made[1-2]. In 2004, the latest version technical specifications for construction of highway asphalt pavements (JTG F40-2004) is published by the Ministry of Communications of P.R. China, a fairly complete technical standard for aggregate[3].

Broadly speaking, the shape characteristics of coarse aggregate include form, angularity and texture. The elongated and flat shaped aggregates are unpopular, which are easily broken in the mixing process of asphalt mixture, the compaction rolling and under the loading of motor traffic. Due to the newly broken surfaces without asphalt binder coating and due to the changing of asphalt mixture aggregate gradation and volume index, the strength, fatigue performance and durability of the asphalt mixture are decreasing. The coarse aggregate angularity is a critical index in macroscopic terms of particle shape. When the shape is close to polyhedron with conspicuous angularity, it is more likely for the aggregates to be interlocked with each other. The round shaped aggregates like unbroken gravel and cobblestone should not be used as much as possible. Good coarse aggregate angularity plays an important role in improving high-temperature stability of HMA. The surface texture of coarse aggregate is critical in sub-microscopic terms of surface shape. Good coarse aggregate texture can not only improve high-temperature stability of HMA, but also increase asphalt-coating thickness on coarse aggregate surface, which improves durability of HMA such as fatigue and water stability performance.

ASTM D3398 has put forward the coarse aggregate particle index(Ia) that characterizes form, angularity and texture. Analysis shows that the coarse aggregate Ia is a comprehensive index of the coarse aggregate particles, which includes shape characteristics such form, angularity and texture. The mean particle index(Ia) of seven different types of coarse aggregates have measured and computed by ASTM D3398, and researched the effects of coarse aggregate mean Ia on HMA performance. The study result shows that the coarse aggregate mean Ia has different effects on high-temperature stability, low-temperature anti-cracking performance and water stability, however no recommendation is made of feasible description method and technical specification for the coarse aggregate angularity[4].

Prithvi S. Kandhal et al have investigated and evaluated the test methods of aggregate sources and processing characteristic, and researched the effect of coarse aggregate angularity on HMA performance. According to investigations on the stone materials in some states of the USA and the index tests of the crushed aggregate, the test methods and specifications have been established without unification. The effect of coarse aggregate particles form, angularity and texture on open-graded HMA performance is more obvious than that on dense-gradation HMA performance. The coarse particles which have good angularity and coarse texture are helpful to improve anti-deforming and fatigue performance of HMA, and are helpful to anti-skid performance of the friction course. The purpose of increasing the proportion of the crushed particles in gravel is to improve the particle angularity and coarse texture. As increasing proportion of crushed particles with two crushing surfaces in gravel, the coarse aggregate particle index(Ia) computed by ASTM D3398 is increasing. When the proportion of crushed particles with two crushing surfaces in gravel is more than 80%, the coarse aggregate Ia computed by ASTM D3398 reaches a peak with significant increase. The flat and round particles are not more popular than the round particles such as no-crushing gravel[5-7].

Eyad A. Masad et al. from Illinois State University capture images by the aggregate imaging analyzer with conveyor, and then make a research on the form, angularity and texture of the coarse aggregate by DIPT. The research shows that the coarse aggregate imaging characteristic indexes are closely relative with the HMA performance and can be used to characterize the shape of the coarse aggregate[8].

Based on the computation of coarse aggregate particle index Iap by improved ASTM D3398 method, we study the description methods of coarse aggregate angularity by DIPT in this paper and put forward the technical standard for the asphalt pavements coarse aggregate angularity.

2 DESCRIPTION METHOD OF COARSE AGGREGATE ANGULARITY

2.1 Description Method Based on ASTM D3398

The ASTM D3398 coarse aggregate particle index Ia is sensitive to different sources of aggregate, processing methods and aggregate specifications, but has little numerical difference. It is difficult to clearly distinguish the shape of different coarse aggregate. So the coarse aggregate air voids in natural packing state should be considered while the coarse aggregate shape characteristics are described by the air voids test and computing method. Furthermore it can reflect different combination state of coarse aggregate shape characteristic, and simulate well the process of asphalt mixture compaction. Based on the computing and analysis of ASTM D3398 coarse aggregate particle index Ia, the formula of the coarse aggregate particle index Iap is proposed by improved ASTM D3398 method as follows:

$$Iap=2.5V_0-1.25V_{10}-0.25V_{50}-32.0 \quad (1)$$

Where, V_0, V_{10} and V_{50} - the percent air voids (%) of coarse aggregate in natural packing state, 10 drops and 50 drops of the tamping rod respectively.

The packing density tests under three different conditions of natural packing, 10 drops and 50 drops of the tamping rod are carried out for limestone coarse aggregate including back-breaking + back-breaking without thin and flat particle of three crushed methods and basalt coarse aggregate including stone breaking stone without thin and flat particle of four crushed methods. Then the percent air voids of coarse aggregate are computed for the three states respectively. Furthermore the coarse aggregate particle index Iap can be computed by formula (1), as shown in Table 1 and Table 2. It is shown that the limestone coarse aggregate particle index Iap are graded according to the sizes: $E^{\#}>G^{\#}>F^{\#}>F1^{\#}$, and the basalt coarse aggregate particle index Iap are graded according to the sizes: $X^{\#}>A^{\#}>D^{\#}>C^{\#}>C1^{\#}$. The coarse aggregate particle index Iap have great numerical difference, and can clearly distinguish different shape characteristic of limestone and basalt coarse aggregate.

It is simple and practical that the coarse aggregate particle index Iap is computed by improved ASTM D3398 formula (1) used to describe coarse aggregate Angularity. However the coarse aggregate particle index Iap is a comprehensive index, which not only includes form characteristics of coarse aggregate but also angularity and texture ones.

Table 1: Limestone coarse aggregate particle index Iap

Breaking Method	Jaw+Hammer		Jaw+Back-breaking		Back-breaking + Back-breaking	
	G#	G1#	E#	E1#	F#	F1#
20~30mm	26.0	23.1	30.3	21.6	24.4	20.5
10~20mm	23.3	22.5	24.1	20.7	19.1	18.5
5~10mm	26.7	25.0	28.8	23.4	21.9	21.0

Table 2: Basalt coarse aggregate particle index Iap

Breaking Method	Jaw+Hammer		Jaw+Back-breaking		Stone-Stone		Stone-Iron	
	X#	X1#	A#	A1#	C#	C1#	D#	D1#
10~15mm	23.8	24.1	22.3	19.9	19.9	19.6	21.5	21.4
5~10mm	26.4	24.2	25.0	20.8	22.5	20.6	22.8	21.8

2.2 Description Method by DIPT

The coarse aggregate angularity can be well described by DIPT, with procedures as the following: 1）to prepare one specification of coarse aggregate and divide them into two groups, and to take 100 representative particles weighted from the two groups respectively; 2) to prepare one sheet of paper with the size of 80cm×80cm, then lightly drawing 10×10 gridlines framed with clear lines; 3) Putting the paper on a frosted glass plate, and placing the weighted coarse aggregate particles on each of the grid center; 4）Placing fluorescent light below the frosted glass, and taking photos perpendicularly to the paper with HD digital camera. The image information configuration, can be extracted from the original photos, combined with numbered tagging and image processing which include homogeneous filtering, image segmentation, miscellaneous points filtering and contour extraction. The processed photos can be used to parameters computation, as shown in Figure 1.

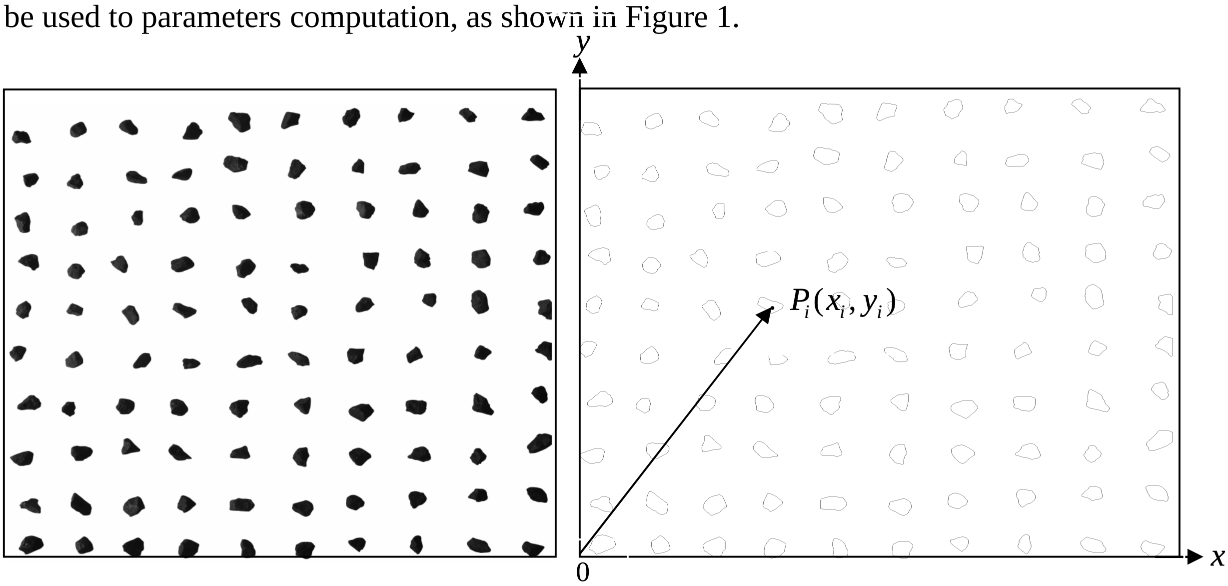

Figure 1: Original and processed photos of the coarse aggregate by DIPT

The x-y coordinate system is established with the lower-left corner as origin, the horizontal direction as horizontal coordinate, and the longitudinal coordinate as longitudinal coordinate as shown in Fig.1. The coordinate $p_{ij}(x_{ij}, y_{ij})$ can be taken on each coarse aggregate particle contour line every five degrees referenced to the centroid. The centroid location coordinate $P_i(x_i, y_i)$ can be computed for No.i coarse aggregate particle.

According to the centroid location coordinate $P_i(x_i, y_i)$ and the coordinate $p_{ij}(x_{ij}, y_{ij})$ on the coarse aggregate particle contour line every five degrees referenced to centroid, the length can be computed from the centroid location to the contour line every five degrees referenced to centroid, that is the radius R_{ij} of each point along the coarse aggregate particle contour line every five degrees referenced to centroid. The coarse aggregate angularity index AI by DIPT can be calculated by two methods, i.e. the radius method and the gradient method, and the calculating formulas are as follows:

One is the coarse aggregate angularity index AI_{rm} of radius method: After computing the centroid location coordinate of each coarse aggregate particle, an equivalent circumcircle of this particle can be drawn, and the radius R_i of the equivalent circumcircle can be computed. Which should be divided by n as follow:

$$AI_{rm} = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{72}\frac{|R_{ij} - R_i|}{R_i} \quad (2)$$

Where, AI_{rm} means the coarse aggregate angularity index of radius method by DIPT; R_{ij} means the radius of coordinate No.j on the contour line for No.i coarse aggregate particle; R_i means the radius of equivalent circumcircle for No.i coarse aggregate particle.

The other is the coarse aggregate angularity index AI_{gm} of gradient method: Taking three points coordinates on each coarse aggregate particle contour line every five degrees referenced to the centroid: $p_{ij+2}(x_{ij+2}, y_{ij+2})$, $p_{ij+1}(x_{ij+1}, y_{ij+1})$ and $p_{ij}(x_{ij}, y_{ij})$, a fitting formula of quadratic parabola function is proposed, i.e. $f(x, y) = ax^2 + bx + c - y$. Then the function $f(x, y)$ partial derivatives for x and y can be calculated respectively:

$$G_x = \frac{\partial f(x, y)}{\partial x} = 2ax + b, \quad G_y = \frac{\partial f(x, y)}{\partial y} = -1 \quad (3)$$

Where, G_x and G_y mean the function $f(x, y)$ partial derivatives for x and y respectively; a and b mean the fitting parameters.

After calculating the function $f(x, y)$ partial derivatives for x and y, the gradient azimuth angle θ can be calculated between the x axis of x-y coordinate system and the coordinate $p_{ij+1}(x_{ij+1}, y_{ij+1})$ on each coarse aggregate particle contour line every five degrees referenced to centroid as follow:

$$\theta = \arctan(\frac{G_y}{G_x}) = \arctan(\frac{-1}{G_x}) \quad (4)$$

Then the cumulative value of absolute value can be divided by n as follows:

$$AI_{gm} = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{72}|\theta_{ij+3} - \theta_{ij}| \quad (5)$$

Where, AI_{gm} means the coarse aggregate angularity index of gradient method by DIPT; θ_{ij+3} means the gradient azithum angle of the coordinate No.j+3 on the contour line for No.i coarse aggregate particle; θ_{ij} means the gradient azithum angle of the coordinate No.j on the contour line for No.i coarse aggregate particle.

For limestone coarse aggregate including back-breaking + back-breaking without thin and flat particle produced by three crushing methods and basalt coarse aggregate including stone breaking stone without thin and flat particle produced by four crushing methods, the coarse aggregate angularity index AI_{rm} of radius method and AI_{gm} gradient method can be computed by formula (2) and (5) respectively, as shown in Table 3 and Table 4. It is shown that the limestone coarse aggregate angularity index AI_{rm} and AI_{gm} are graded according to the size: E#>G#>F1#>F#, and the basalt coarse aggregate angularity index AI_{rm} and AI_{gm} are graded according to the sizes: X#>A#>D#>C1#>C#. The result is consistent with the coarse aggregate particle index Iap by formula (1). But the coarse aggregate angularity index AI_{rm} and AI_{gm} can better describe the coarse aggregate angularity, and clearly distinguish different angularity of limestone and basalt coarse aggregate.

Table 3: Limestone coarse aggregate angularity index AI_{rm} and AI_{gm}

Breaking Method	Jaw+Hammer		Jaw+Back-breaking		Back-breaking + Back-breaking			
	G#		E#		F#		F1#	
Indexs	AI_{rm}	AI_{gm}	AI_{rm}	AI_{gm}	AI_{rm}	AI_{gm}	AI_{rm}	AI_{gm}
20~30mm	12.7	15.1	14.6	16.5	11.9	13.4	12.3	14.4
10~20mm	13.2	17.8	13.6	18.4	12.6	16.3	13.0	16.5
5~10mm	17.1	18.3	17.5	18.7	13.1	15.1	13.7	15.7

Table 4: Basalt coarse aggregate angularity index AI_{rm} and AI_{gm}

Breaking Method	Jaw+Hammer		Jaw+Back -breaking		Stone-Stone				Stone-Iron	
	X#		A#		C#		C1#		D#	
Indexs	AI_{rm}	AI_{gm}	AI_{rm}	AI_{gm}	AI_{rm}	AI_{gm}	AI_{rm}	AI_{gm}	AI_{rm}	AI_{gm}
10~15mm	13.4	17.8	13.1	16.5	10.4	15.4	11.8	16.4	11.7	16.2
5~10mm	16.5	19.3	15.5	18.8	13.2	16.0	13.9	16.9	15.0	17.2

The analysis shows that the coarse aggregate angularity index AI_{rm} of radius method and AI_{gm} of gradient method are correlative well with the coarse aggregate particle index Iap. The regression coefficient can be used to convert coarse aggregate particle index Iap into angularity index AI_{rm} of radius method and AI_{gm} of gradient method. The k and b values of AI_{rm} converting coefficients are 0.4054 and 4.2021（R=0.868） respectively, and the k and b values of AI_{gm} converting coefficients are 0.3959 and 7.4671（R=0.877） respectively.

3 TECHNICAL STANDARD OF COARSE AGGREGATE ANGULARITY

Based on test study of two types of asphalt concrete for two types of rock, four aggregates gradation curves and several levels of coarse aggregate angularity index, the effect of the coarse aggregate angularity on asphalt concrete performance and anti-shear parameters is analyzed. The regression formulas and their correlative coefficient are obtained between asphalt concrete performance, anti-shear parameters and coarse aggregate particle index Iap. Based on the asphalt concrete performance requirements and the regression coefficient between coarse aggregate angularity index AI_{rm} of radius method and AI_{gm} of gradient method and particle index Iap, the technical standard of asphalt pavements coarse aggregate angularity can be proposed.

3.1 Aggregate Gradation Ranges for Asphalt Mixture Test

Limestone coarse aggregate is mainly used for dense gradation asphalt concrete AC-25/20 of the binder layer of expressway pavements and the surface layer of other classified highway pavements. In order to improve strength, high-temperature anti-deformation and anti-fatigue performance of asphalt concrete, the aggregate gradations should be designed by taking S-type skeleton-compacting structure, which is favorable to study the effect of coarse aggregate angularity on asphalt concrete performance. The aggregate gradation ranges of AC-25/20 asphalt mixtures are listed in Table 5.

Table 5: Aggregate gradation ranges of AC-25/20

Quality percentage (%) passing different sieve size(mm)												
31.5	26.5	19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
100	90~100	75~90	65~81	56~74	45~61	29~42	19~30	12~22	8~18	6~13	5~10	3~6
—	100	90~100	79~93	68~83	55~70	35~47	22~34	14~24	8~18	6~13	5~10	3~6

Basalt coarse aggregate is mainly used for the surface layer of expressway and class I highway pavements, such as SMA, AC and PA. Based on technology condition of asphalt pavements in China, the aggregate gradation range of SMA-13 asphalt mixtures is recommended under the technical specifications for construction of highway asphalt pavements（JTG F40-2004）, as shown in Table 6.

Table 6: Aggregate gradation range of SMA-13

Quality percentage (%) passing different sieve size(mm)									
16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
100	90~100	50~75	20~34	15~26	14~24	12~20	10~16	9~15	8~12

3.2 Effect of Limestone Coarse Aggregate Angularity on Asphalt Performance

Due to the difference of the effect of the coarse aggregate angularity on the asphalt concrete of different aggregate gradation, the more coarse the aggregate gradation, the better would be for the improvement of the asphalt concrete strength, anti-deformation, also for the improvement of rut-resistance performance of asphalt pavements. So the effect of limestone coarse aggregate angularity on AC-25/20 asphalt concrete performances is researched by considering three aggregates gradation curves: The first curve is the mean value of quality percentage passing key sieve size 4.75mm in Tab.5, that is C-type aggregate gradation; The second curve is the maximum value of quality percentage passing key sieve size 4.75mm in Tab.5, that is F-type aggregate gradation.

For the two aggregates gradation curves of AC-25/20 asphalt mixtures, meticulous preparation of the coarse aggregate above sieve size 4.75mm is carried out for limestone coarse aggregate including back-breaking + back-breaking clearing away thin and flat particles produced by three crushing methods, then 3~5mm fine aggregate and 0~3mm crushed sand of number $F^{\#}$ limestone, Beijing Dahongmen mineral powder and Jiadeshi 70# asphalt are used in the performance tests of all AC-25/20 asphalt mixtures. The optimum asphalt content is determined according to the technical specification for construction of highway asphalt pavements（JTG F40-2004）, before the performance test of the strength, high-temperature performances, water stability and low-temperature for the AC-25/20 asphalt concrete. The rut depth deformation of bind layer is biggest where the flowing rut occurs for the asphalt pavement with AC-20. So the dynamic triaxial tests are carried out for the third gradation curve of AC-20 asphalt mixtures (with test equipment of UTM-100 an advanced system made in Australian IPC Company).

As can be seen from the Marshall Stability（MS）, cleavage strength σ, Dynamic Stability（DS）, residual DS and low-temperature bending strain ε have significant linear correlation with the coarse aggregate particle index Iap for the two aggregate gradation curves of AC asphalt mixture. The regression formulas are proposed between AC concrete performance and the coarse aggregate particle index Iap.

Based on the asphalt concrete performance requirements, the technical standard of asphalt pavements limestone coarse aggregate particle index Iap can be proposed (as shown in Table 7). The reduction of the coarse aggregate particle index Iap for the AC-20 asphalt mixture, the cohesive strength parameter c reduces and the internal friction angle φ increases, which indicates that the improvement of particle shape and angularity characteristics of limestone coarse aggregate would result in better anti-shear performance of AC concrete, with conspicuous linear correlativity. Based on the internal friction angle φ ranging from 25° to 50°, the corresponding reasonable range for the limestone coarse aggregate particle index Iap should be from 16.8% to 23.7%.

Table 7: Upper limit of limestone coarse aggregate particle index Iap

Type	MS/KN no less than		DS/ time/mm no less than			Residual DS / time/mm no less than				ε/με no less than		
	8.0	5.0	600	800	1000	400	600	700	800	2000	2300	2600
AC-25	33.3	43.2	32.6	30.6	28.7	29.4	27.7	26.8	25.9	44.6	37.3	29.9
AC-20	35.5	47.1	32.8	30.0	27.1	27.0	25.5	24.7	24.0	52.1	42.4	32.7

3.3 Effect of Basalt Coarse Aggregate Angularity on Asphalt Performance

For the aggregate gradation the median of the three curves for the SMA-13 asphalt mixture, meticulous preparation of the coarse aggregate above sieve size 2.36mm is carried out for basalt coarse aggregate including stone breaking stone clearing away thin and flat particles produced by three crushing methods, then 0~3mm crushed sand of number $C^{\#}$ basalt, Beijing Dahongmen mineral powder and SBS modified asphalt and 0.3% wood fiber are used in the performance tests of all SMA-13 asphalt mixtures. The optimum asphalt content is determined according to technical specification for construction of highway asphalt pavements（JTG F40-2004）, before the performance test of the strength, high-temperature performances, water stability and low-temperature for the SMA-13 asphalt concrete. The dynamic triaxial tests are carried out for SMA-13 asphalt mixtures (with test equipment of UTM-100 an advanced system made in Australian IPC Company).

As can be seen from the Marshall Stability（MS）, cleavage strength σ, Dynamic Stability（DS）, residual DS and low-temperature bending strain ε have significant linear correlation with the coarse aggregate particle index Ic for the aggregate gradation middle curve SMA-13 asphalt mixture. The regression formulas are proposed between SMA-13 concrete performance and the coarse aggregate particle index Iap.

Based on the asphalt concrete performance requirements, the technical standard of asphalt pavements basalt coarse aggregate particle index Iap can be proposed (as shown in Table 8). A multiple regression formula is developed for the SMA-13 concrete performance on coarse Iap, so as to get the technical standard of limestone coarse aggregate Iap. The reduction of coarse aggregate particle index Iap for the SMA-13 asphalt mixture, the cohesive strength parameter c reduces and the internal friction angle φ increases. The improvement of particle shape and angularity characteristics of basalt coarse aggregate would result in better anti-shear performance of SMA-13 concrete, with conspicuous linear correlation. Based on the internal friction angle φ ranging from 25° to 50°, the corresponding reasonable upper limit of basalt coarse aggregate particle index Iap should be 27.1%.

Table8: Upper limit of basalt coarse aggregate particle index Iap

MS/KN no less than	DS/ time/mm no less than	Residual DS/ time/mm no less than	ε/με no less than		
6.0	3000	2400	2500	2800	3000
29.4	26.4	21.2	41.7	38.9	37.0

3.4 Technical Standard of Asphalt Pavements Coarse Aggregate Angularity

The technical standard of coarse aggregate particle index Iap (as shown in Table 9) is proposed based on the result of the study on limestone and basalt coarse aggregate angularity (as shown in Table 7 and Table 8), with the lower limit of particle index Iap for coarse aggregate without thin and flat particles.

The technical standards of asphalt pavements coarse aggregate angularity indexes AI_{rm} and AI_{gm} are proposed based on the correlation between and among coarse aggregate angularity indexes AI_{rm} of radius method and AI_{gm} of gradient method and particle index Iap, with the lower limits of angularity indexes AI_{rm} and AI_{gm} for coarse aggregate without thin and flat particles, as shown in Table 10.

Table 9: Technical standard of coarse aggregate particle index Iap

Particle index	Asphalt pavements of expressway and class I highway				Asphalt pavements of class II highway		Asphalt pavements lower than class II	
	Surface Layer		Other Layers					
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
Iap/%	30	19	31	19	35	19	40	19

Table 10: Technical standards of coarse aggregate angularity indexes AI_{rm} and AI_{gm}

Angularity	Asphalt pavements of expressway and class I highway				Asphalt pavements of class II highway		Asphalt pavements lower than class II	
	Surface Layer		Other Layers					
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
AI_{rm}/%	16	12	17	12	18	12	20	12
AI_{gm}/%	19	15	20	15	21	15	23	15

4 CONCLUSIONS

1) The coarse aggregate particle index Iap calculated by improved ASTM D3398 formula (1) can distinguish different shape characteristics obviously. However the coarse aggregate particle index Iap is a comprehensive index, which not only includes form characteristics of coarse aggregate, but also includes angularity and texture ones.

2) The calculation formulas (2) and (5) of coarse aggregate angularity index AI_{rm} of radius method and AI_{gm} of gradient method are proposed by DIPT which can describe coarse aggregate angularity better. The analysis shows that the coarse aggregate angularity index AI_{rm} of radius method and AI_{gm} of gradient method are correlative well with the coarse aggregate particle index Iap. The regression coefficient can be used to convert coarse aggregate particle index Iap into angularity index AI_{rm} of radius method and AI_{gm} of gradient method. The k and b values of AI_{rm} converting coefficients are 0.4054 and 4.2021（R=0.868） respectively, and the k and b values of AI_{gm} converting coefficients are 0.3959 and 7.4671（R=0.877） respectively.

3）The technical standards of coarse aggregate particle index Iap over 19～30% are for surface layer, and 19～31% for bind layer of expressway and class I highway asphalt pavements; The technical standards of coarse aggregate particle index Iap over 19～35% are for class II highway asphalt pavements; The technical standards of coarse aggregate particle index Iap over 19～40% are for asphalt pavements lower than class II.

4）The technical standards of coarse aggregate angularity index AI_{rm} and AI_{gm} over 12～16% and 15～19% are for surface layer, and 12～17% and 15～20% for binder layer of expressway and class I highway asphalt pavements; The technical standards of coarse aggregate angularity index AI_{rm} and AI_{gm} over 12%～18% and 15%～21% are for class II highway asphalt pavements; The technical standard of coarse aggregate angularity index AI_{rm} and AI_{gm} over 12～20% and 15～23% are for asphalt pavements lower than class II.

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