The Critical Designing Problems of SMA-10 Bridge Deck Pavement

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Abstract. This paper mainly discusses the volume characteristic change trend of SMA-10 as ultra thin friction course under different gradation design conditions. Marshall compaction results shows that air void is relevant to 2.36mm-4.75mm gravel content. Skeleton structure analysis indicates that 2.36-4.75mm gravel content below 15% is suitable. We can choose designing gradation with 2.36mm or 4.75mm as control point. 1.18mm aggregate interference effects apparently for 2.36mm sieve pore as break point (BP). Road performance of SMA-10 meets the demands when gradation is designed according to the research conclusions.

KeyWords: Thin friction course, Air void, Gravel content, Interference, Break point.

1. Background

As a gap gradation type asphalt mixture with good rutting resistance and skipping resistance performance, SMA(Stone Matrix Asphalt) has been widely spread especially in China since American innovation and improvement in 1991. Nominal maximum aggregate size(NMAS) of traditional SMA mixtures is 12.5mm and 19mm, fine SMA of 9.5mm and 4.75mm(NMAS) is ideal gradation for thin friction course with dense, noise reduction, durable and economical advantages. Several province highway agencies began using them for projects such as thin-lift application and maintenance to provide an effective surface mix. This paper mainly researches the volume characteristic change trend of SMA-10 as ultra thin friction course under different gradation design conditions.

2. Gradation Selecting Study

Skeleton structure and dense characteristic are the premise and base of good surface service function (skipping resistance, wearing resistance, noise reduction and waterproof). In contrast with SAC(Stone Asphalt Concrete, developed by Sha Qinglin, academician of the Engineering Academy), SMA has better workability and construction reliability, however, China recommended gradation scope need further research and optimization. In 2002-2003, the National Center for Asphalt Technology(NCAT) completed the series study to develop mix design criteria for Superpave-5, SMA-5 and SMA-10.
China introduced SMA technology and made Chinese SMA technical criteria in the mid-twentieth century. The comparison results of gradation scope between China (“Technical specification for construction of highway asphalt pavement” (JTG F40-2004)) and other countries such as America shows that, Chinese recommended gradation scope is similar with Australian, both of them consider the 2.36mm sieve pore as break point, rather than 4.75mm sieve pore.

However, Australian recommended gradation scope is far more ‘narrower’ than Chinese recommended gradation scope. The latter mainly adapted from America and Germany, gradation scope of 2.36mm sieve pore is relatively narrower while scope of 4.75mm sieve pore is relatively wider. In Chinese SMA-10 gradation scope, coarse gravel content over 4.75mm sieve pore reaches from 40% to 72%, 2.36mm-4.75mm gravel content is approximately changes from 0%~40%. According Chinese gravel sieve analysis test, both 4.75mm and 2.36mm are suited to being the break point among the gradation scope, which increase the design difficulty since the indefinite gap selection. NCAT completed the series study to analyze the performance difference of SMA-10 with 2.36mm BP or 4.75mm BP, several Chinese research institute tried to research the relationship between volume index and gravel content using gyration compaction method[1][2][3]. According to similar thought about research, this paper has done the following tentative research:

(1) Seventeen types of mixtures within the Chinese specification recommended SMA-10 gradation scope (Table 2) are selected to make specimens using Marshall compaction;

(2) The relationship between gravel content (2.36-4.75mm, 1.18-2.36mm) and critical volume index of mixture (air void, VMA) are studied to determine the critical sieve pore and passing rate for mixture structure interference.

(3) After these researches, some conclusions would be valuable for the engineering application of SMA-10.

### Table 1. SMA-10 gradation Scope of different countries

|                  | Chinese Specification | American Criteria | Australian Criteria | German Criteria | Recommended Gradation Scope (Some Chinese Research Institute) |
|------------------|-----------------------|-------------------|---------------------|----------------|---------------------------------------------------------------|
|                  | 13.2                  | 9.5               | 4.75                | 2.36           | 1.18             | 0.6             | 0.3              | 0.15              | 0.075             | 200~100 | 90~100 | 28~60 | 20~32 | 14~26 | 12~22 | 10~18 | 9~16 | 8~13 |
| 100~100          |                       |                   |                     | 100~100        | 90~100           | 26~60           | 20~28           | 13~21           | 12~18             | 12~15             | -      |
|                   |                       |                   |                     | 100~100        | 90~100           | 30~50           | 21~31           | 16~25           | 14~22             | 12~20             | 10~17   | 8~12  |
| 100              |                       |                   |                     |                |                  | 30~40           | 20~27           | -               | -                 | -                 |        | 9~13  |
|                  | 100~100               |                   |                     |                |                  | 32~48           | 20~30           | 17~25           | 14~20             | 12~18             | 10~16   | 8~13  |

2.1. Raw Material
(1) Binder: SBS modified asphalt, testing technical indexes conforms to I-D standard.
(2) Aggregate: Basalt, basic volcanic rocks, produced by Zhangqiu material yard.
(3) Filler: limestone dust.
(4) Stabilizer: lignin fiber.

All the testing indexes of above materials meet the relevant regulations of “Technical specification for construction of highway asphalt pavement” (JTG F40-2004).

2.2. Testing Method
Considering the engineering maneuverability and instructive characteristic of laboratory test method. This research adopts Marshall compaction to make specimens, 75 hitting times for each side, asphalt content is 6.3%. This method is easy to operate and widely accepted by most Chinese laboratories.
Table 2. SMA-10 gradation

| Gradation | Sieve Pore(mm) |
|-----------|----------------|
| 1#        | 13.2 9.5 4.75 2.36 1.18 0.6 0.3 0.15 0.075 |
| 2#        | 100 96.1 40.1 33.6 25.2 18.7 14.7 12.5 9.4 |
| 3#        | 100 96 37.7 31.5 23.8 17.9 14.2 12.2 9.3 |
| 4#        | 100 95.8 34.9 29.1 22.8 17.8 14.8 13.1 10.4 |
| 5#        | 100 95.6 32 26.5 21.1 16.8 14.2 12.7 10.2 |
| 6#        | 100 95.4 29.2 24 19.4 15.8 13.6 12.4 10 |
| 7#        | 100 96.3 43.2 25.1 20.4 16.9 14.7 13.4 10.9 |
| 8#        | 100 96.2 40.4 25.1 20.4 16.8 14.7 13.4 10.9 |
| 9#        | 100 96 37.6 25 20.4 16.8 14.6 13.4 10.9 |
| 10#       | 100 96.6 46.5 28 22 17.4 14.6 12.9 10.3 |
| 11#       | 100 95.7 33.3 20.2 16.9 14.3 12.8 11.9 9.8 |
| 12#       | 100 96.2 40.4 26.8 21.5 17.5 15 13.6 11 |
| 13#       | 100 96.1 39.4 22.9 19 16 14.2 13.1 10.8 |
| 14#       | 100 95.8 34.8 25 20.4 16.8 14.6 13.4 10.9 |
| 15#       | 100 95.9 36.2 25 20.4 16.8 14.6 13.4 10.9 |
| 16#       | 100 96.4 43.9 37 27.3 19.7 15.1 12.5 9.3 |
| 17#       | 100 95.1 24.9 20 16.4 13.7 12 11 9 |

Table 2 shows 17 types of mixtures within the Chinese specification recommended SMA-10 gradation scope (Table 2).

2.36~4.75mm gravel content of gradation(1#-7#,15#,16#)is 4~7%,while break point is 4.75mm, which means there is a gradation gap between 2.36mm and 4.75mm.

2.36~4.75mm gravel content of gradation 8#-14# is 11~19%,while break point is 2.36mm, which means there is a gradation gap between 1.18mm and 2.36mm.

2.3. Influential factors analysis of volume index

Since the high portion of coarse aggregate for wearing course, enough attention should be paid to volume design for ensuring the mixture road performance. If mixture air voids slanted low, rutting and upheaval would be easily produced. Conversely, if mixture air voids slanted high, water and air would easily accelerate the asphalt membrane aging and mixture moisture. All the above factors maybe shorten pavement service life, which means target air void should be cautiously designed while considering field compaction situation.

When mixture is designed using traditional Marshall testing method, Germany regulates that suggesting air void for 0/8 and 0/5 SMA is 2%~4% while for 0/8 and 0/11 SMA is 3%~5%. AASHTO regulates that air void for SMA(NMAS4.75mm to 25mm)is 3%~4%. European SMA standard (draft) preliminarily suggests air void (NMAS4mm to 22mm) is 2%~6%. Air void for fine and gap gradation mixture that’s widely used in English is 2%~4%. French thin asphalt concrete such as BBM is a total gap gradation, target design air void is 2%~8% in accordance with 98% compactness control. <Specification for Design of Highway Asphalt Pavement>(JTG D50-2006)suggests designing air void for UTAC(Ultra-thin wearing course) is 4%~5%(4%~6%).

Some domestic researchers suggest adopting VCA(Percent Air Voids in Coarse Aggregate) and AV (Air void) as critical design indexes for the formation of skeleton and dense structure. Moreover, they consider that target AV with 2%~4% while VMA no less than 17% is suitable for expected compactness. On the basis of above recommendations, AV and VFA (Voids Filled with Asphalt) of gradation(1#,5#,9#,10#,12#,14# and 15#) meet the technical requirements, however, individual WMA are slightly lower. VMA and VFA of gradation 7# and 8# meet requirements while AV are slightly higher. Combined with Table 2 and Table 3 data, the following figures demonstrate the relevance
between AV and gravel content (2.36mm–4.75mm, 1.18mm–2.36mm), R2.36-4.75-9.5, R1.18-2.36-4.75 (formula 1.3-1, 1.3-2), on a separate note, there is a similar change tendency between VMA and above factors.

Table 3. Volume indexes of SMA-10 Mixture under different designing conditions

| Gradation | Bulk Density (g/cm³) | Maximum Theoretical Density (g/cm³) | AV (%) | VMA (%) | VFA (%) |
|-----------|----------------------|-------------------------------------|--------|---------|---------|
| 1#        | 2.485                | 2.535                               | 2.00   | 16.07   | 87.6    |
| 2#        | 2.479                | 2.536                               | 2.25   | 16.27   | 86.18   |
| 3#        | 2.466                | 2.536                               | 2.74   | 16.68   | 83.6    |
| 4#        | 2.472                | 2.537                               | 2.55   | 16.64   | 84.68   |
| 5#        | 2.438                | 2.537                               | 3.9    | 17.79   | 78.09   |
| 6#        | 2.413                | 2.538                               | 4.91   | 18.62   | 73.65   |
| 7#        | 2.431                | 2.537                               | 4.18   | 18.06   | 76.84   |
| 8#        | 2.433                | 2.537                               | 4.11   | 17.99   | 77.23   |
| 9#        | 2.454                | 2.537                               | 3.27   | 17.28   | 81.11   |
| 10#       | 2.536                | 2.536                               | 3.25   | 17.21   | 81.13   |
| 11#       | 2.367                | 2.539                               | 6.77   | 20.14   | 66.39   |
| 12#       | 2.457                | 2.536                               | 3.13   | 17.10   | 81.74   |
| 13#       | 2.398                | 2.538                               | 5.5    | 19.22   | 71.43   |
| 14#       | 2.457                | 2.537                               | 3.17   | 17.21   | 81.65   |
| 15#       | 2.441                | 2.537                               | 3.76   | 17.72   | 78.78   |
| 16#       | 2.500                | 2.534                               | 1.35   | 15.47   | 91.27   |
| 17#       | 2.370                | 2.540                               | 6.6    | 19.85   | 66.47   |

\[
R_{2.36-4.75-9.5} = \frac{m_{(4.75mm-9.5mm)}}{m_{(2.36mm-4.75mm)}} \quad (1)
\]

\[
R_{1.18-2.36-4.75} = \frac{m_{(2.36mm-4.75mm)}}{m_{(1.18mm-2.36mm)}} \quad (2)
\]

Where,
m(4.75mm-9.5mm)=Gravel content of 4.75mm-9.5mm, %
m(2.36mm-4.75mm)=Gravel content of 2.36mm-4.75mm, %
m(1.18mm-2.36mm)=Gravel content of 1.18mm-2.36mm, %
R2.36-4.75-9.5=Gravel content Ratio while break point is 4.75mm
R1.18-2.36-4.75=Gravel content Ratio while break point is 2.36mm
When gravel content of 2.36mm-4.75mm is relatively lower(such as 4-7%), air voids decrease with the increase of gravel content, which means 2.36-4.75mm gravel maybe helpful in skeleton structure formation. In this case, a majority of 2.36-4.75mm gravel content produced by S12 (5-10) gravel size. Filler and fine aggregate contribute more to air void. Therefore, there is good correlation between air void and R2.36-4.75-9.5.

When gravel content of 2.36mm-4.75mm increases to 11-18%, air voids and VMA increase first and then decrease. The reason is that, on the one hand, when 2.36-4.75mm gravel increase to certain degree (such as 11-15%), aggregates approaching 4.75mm increase to formulate skeleton structure and residue approaching 2.36mm fill the void as sub-level aggregate. On the other hand, while 2.36mm-4.75mm gravel content increasing as higher proportion of S14 (3-5) in mix, 1.18mm-2.36mm gravel content increases relatively, which play a role in aggregate interference. Based on these analysis, this
paper deduce that both 2.35mm-4.75mm gravel content and 1.18mm aggregate interference should cause enough attention during SMA-10 design, which is also the difference with previous research[4]. Feature points of S style curve in figure1 are selected to analyze interlocking conditions.

**Figure 4** The Relationship between gradation and air void

**Figure 5** Relationship between VCA and VCAmix (gradation 3#, gradation 16#)

**Figure 6** Relationship between VCA and VCAmix (gradation 9#, gradation 10#)
Figure 7 Relationship between VCA and VCAmix (gradation 13#)

VCADRC, VCAmix are highly sensitive barometer of skeleton structure formation. Suitable air voids and VCAmix≤VCADRC are a prerequisite to formulate interlocking condition.

Above figures demonstrate that, all gradation are skeleton structures except for gradation 9#, that means target air void should be more than 3.0%, when break point is 4.75mm. As figure 3 shows, R2.36-4.75-9.5 should be more than 10. When break point is 2.36mm, there is a extreme point where interlocking condition of mixture would be destroyed by 1.18mm particles with 2.36mm-4.75mm gravel content increases. In that case, volume index maybe suitable but road performance would descend. From this perspective, 2.36mm-4.75mm gravel content should be no more than 15%. Air voids and VMA of gradation (7#, 8#) both meet technical requirements while VCAmix/VCADRC<1,that means higher air void such as 4.5% maybe suitable if field compactness is satisfied.

3. Road Performance Study

Based on the above analysis, this paper select 1#(NMAS 4.75mm)and 2#(NMAS 2.36mm) to verify high temperature stability, moisture resistance and skid resistance of both mixtures.

Table 4. Comparative gradation of SMA-10

| Gradation | Test Content | Sieve Size |
|-----------|--------------|------------|
| 1#        | Passing Rate (%) | 13.2 9.5 4.75 2.36 1.18 0.6 0.3 0.15 0.075 |
| 2#        |              | 100 95.8 35.8 30.0 23.3 18.2 15.0 13.2 10.4 |

Table 5. Volume index results of SMA-10

| Gradation | Asphalt Content (%) | Bulk Density (g/cm³) | Theoretical Maximum Density of Bituminous Mixtures (g/cm³) | AV (%) | VMA (%) | VFA (%) |
|-----------|---------------------|----------------------|----------------------------------------------------------|-------|--------|--------|
| 1#        | 6.2                 | 2.460                | 2.540                                                     | 3.16  | 16.92  | 81.35  |
| 2#        | 6.3                 | 2.458                | 2.548                                                     | 3.52  | 17.69  | 80.11  |

Table 6. Test results of road performance

| Gradation | Surface Texture Depth (mm) | Dynamic Stability for Wheel Rutting Test (60℃) (Times/mm) | Relative Deformation Rate (%) | TSR (%) | Mass Loss for Cantabro Test (%) |
|-----------|-----------------------------|-------------------------------------------------------------|--------------------------------|---------|--------------------------------|
| 1#        | 0.91                        | 8895                                                        | 3.3                            | 94.19   | 1.85                           |
| 2#        | 0.73                        | 6005                                                        | 3.5                            | 93.08   | 2.16                           |

As shown in the above tables, Road performance of SMA-10 mixtures designed meet technical requirements.
4. Conclusion

Based upon the findings in this study, SMA mix design requirements are recommended for 9.5mm NMAS mixture.

(1) Both 2.36mm and 4.75mm sieve pore could be used as break point under the gradation scope of specification.

(2) There is good correlation between air void and R2.36-4.75-9.5, when break point is 4.75mm. R2.36-4.75-9.5 should be more than 10.

(3) 2.36mm-4.75mm gravel content should be no more than 15%. Higher air void such as 4.5% and lower VMA such as 16.5% maybe suitable if field compactness is satisfied.

(4) Cubic shape of S12 (5-10mm) is helpful to surface texture depth, content of needle-like particles and soft particles should be strictly controlled.

(5) 1.18-2.36mm particles content of S14 (3-5mm) has remarkable influence on mix air void, which should be controlled during gravel manufacturing.

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