Refinement and Field Validation of 4.75 mm Superpave Asphalt Mixtures

RESEARCH SYNOPSIS–NCAT REPORT 11-01

Background

In 2002, the National Center for Asphalt Technology (NCAT) completed a study to develop Superpave mix design criteria for 4.75 mm nominal maximum aggregate size (NMAS) mixes. AASHTO ultimately added these mixes to the Superpave mix design system, and several state highway agencies began using them for projects such as thin-lift application and maintenance, leveling courses to decrease construction time, and to provide an economical surface mix for low-volume roads.

While the original study provided initial criteria for 4.75 mm NMAS Superpave mixes, these criteria needed to be further refined in the laboratory and field validated. A pooled-fund study including nine states — Florida, Virginia, Missouri, Minnesota, Alabama, Tennessee, Wisconsin, New Hampshire and Connecticut — was initiated in 2004 to refine the mix design criteria for 4.75 mm NMAS mixes.

Objective

The main objective of this study was to refine the design procedures and criteria for 4.75 mm NMAS Superpave mixtures. Specifically, the following criteria needed refinement:

- Minimum voids in the mineral aggregate (VMA) requirements and a workable range for voids filled with asphalt (VFA)
- Percent of mixture theoretical maximum specific gravity at number of gyrations at initial compaction (%G_{mm} @N_{ini}) requirements
- Aggregate properties such as sand equivalent (SE) and fine aggregate angularity (FAA) of mixtures
- Appropriate design air void content for a given compaction effort
- Dust-to-binder ratio (D:B) requirements
- Recommendation on the use of modified binders to enhance performance of 4.75 mm NMAS asphalt mixtures

Description of Study

A literature review was first completed in order to understand the history and previous use of 4.75 mm NMAS Superpave mixtures. Next, a laboratory test plan was developed that created numerous Superpave mix designs using materials from each of the nine states participating in the study. A 4.75 mm mix design was developed for each state, using 50 gyrations and a design air void content (V_a) of 4 percent. Variations of those mix designs were created by changing the design gyrations and design V_a. Additional variations were created to evaluate changes in mix factors such as dust content and binder grade. Aggregate properties were measured for each material and mix design, and optimum asphalt contents were determined for a given compaction effort and design V_a.

Also included in this study were four plant-produced baseline 4.75 mm mixtures from Mississippi, Maryland, Georgia and Michigan that had proven field performance.

A series of performance tests were conducted for each mix design and baseline mixture to determine how well the mixtures performed for a given set of properties. Permanent deformation testing was completed using a mixture verification tester (MVT), a compact version of the Asphalt Pavement Analyzer (APA). This testing followed AASHTO TP63-03, *Rutting Susceptibility of Asphalt Pavements Using the Asphalt Pavement Analyze*r. Moisture susceptibility testing was performed according to AASHTO T-238, *Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage*. However, although AASHTO T-238 states that test specimens should be compacted to 7 +/-1% V_a, it was decided that specimens molded for moisture susceptibility in this particular study should be compacted to 9 +/-0.5 percent V_a to be more representative of in-place air void contents for 4.75 mm pavement layers.

Permeability of the mixtures in this study was assessed using a falling-head test (ASTM PS 121). Previous NCAT studies showed permeability decreases with smaller NMAS, which means pavements with smaller NMAS could be less susceptible to moisture damage and rapid aging. Figure 1 shows that 4.75 mm mixes remain impermeable up to about 10 percent V_a.

Finally, cracking resistance of the mixtures was evaluated through fracture energy (FE) testing on an indirect tension tester (IDT). FE, the sum of strain energy and damage energy, has been shown to be a good indicator of cracking resistance of asphalt concrete.

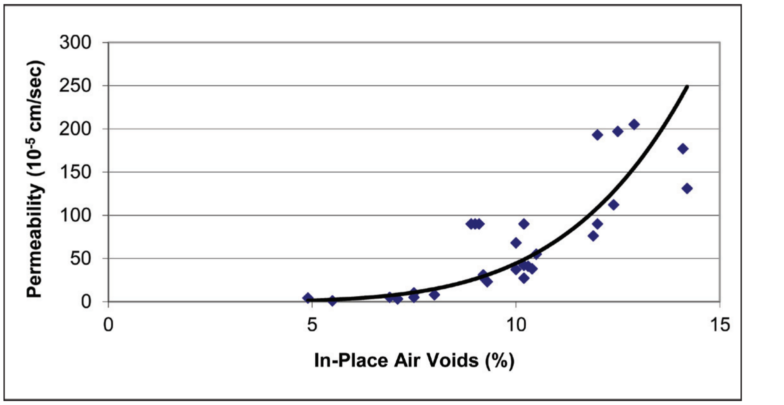

Figure 1 In-place air voids versus permeability of 4.75 mm mixtures.

Conclusions

The design of 4.75 mm NMAS mixtures is largely dependent on the characteristics of available fine aggregates. In general, aggregates used for these mixtures should be drawn from at least three stockpiles to develop a blend that can be adequately controlled during plant production. Most blends of available materials tend to result in very fine gradations, which generally have excessive VMA. As a result, 4.75 mm mixtures often have high asphalt contents and tend to be susceptible to permanent deformation. These challenges can be solved by adjusting some of the mix design criteria and following practical guidelines as follows.

1) VMA and design asphalt contents of 4.75 mm mixtures can be reduced by using coarser gradations and increasing the dust content.
2) The compactive effort used during mix design should be consistent with the design traffic level. Fifty gyrations are generally suitable for low-traffic applications where rutting is not a concern, and 75 gyrations should be suitable for most other 4.75 mm mixture applications.
3) Using a design V_a of 4.0 to 6.0 percent has little effect on VMA but allows mix designers to reduce the asphalt content for an aggregate blend when the VMA is above 16.0 percent. This makes 4.75 mm mixtures more resistant to permanent deformation.
4) Mixtures with less than 13.5 percent volume of effective binder (V_{be}) have better rutting resistance than mixtures with more than 13.5 percent V_{be}.
5) Resistance of 4.75 mm mixtures to permanent deformation can be improved by increasing dust content, using aggregates with high angularity and using stiffer binders.
6) Moisture damage susceptibility increases slightly with decreasing effective asphalt content. A natural sand content over 15 percent appears to adversely affect moisture and rutting susceptibility as well as permeability.
7) Fine-graded 4.75 mm NMAS mixtures are practically impermeable, even with high in-place air voids.
8) Higher asphalt contents tend to increase fracture energy ratio. A 4.75 mm mixture's ability to sustain cracking resistance is a function of both asphalt content and dust content. Therefore, criteria for a 4.75 mm mix should include a minimum V_{be} and a maximum dust-to-binder ratio to assure good durability.

Recommendations

Following the laboratory study, four of the nine participating state highway agencies constructed projects to validate the proposed mix design criteria and establish field construction criteria. Based on this research, the following recommendations were made regarding 4.75 mm mixtures:

1) Gradation limits placed on percent passing the 1.18 sieve should be adjusted to 30 to 55 percent. Limits placed on percent passing the 0.075 mm sieve should be 6.0 to 13.0 percent.
2) For mixes designed for over 0.3 million equivalent single-axle loads (ESALs), the aggregate blend should contain no more than 15 percent natural sand and have a minimum fine-aggregate angularity of 45 for improved rut resistance, moisture damage resistance and low permeability.
3) The target air void content for selecting the design binder content should be changed to a range of 4.0 to 6.0 percent
4) Criteria for VMA and VFA should be replaced with minimum and maximum V_{be} requirements. This is a more sensible approach when working with a range of design air voids. For less than 3.0 million design ESALs, a V_{be} range of 12.0 to 15.0 percent is recommended. For 4.75 mm mixtures designed for projects more than 3.0 million ESALs, a minimum V_{be} of 11.5 percent and a maximum V_{be} of 13.5 percent is recommended.
5) The maximum $\%G_{mm}$ @ N_{ini} requirement for both 4.0 and 6.0 percent design air voids should be maintained.
6) The minimum dust-to-binder ratio should be increased slightly from 0.9 to 1.0. The maximum dust-to-binder ratio should be maintained at 2.0.
7) At this time, the minimum sand equivalent criteria should be maintained.

Table 1 Proposed design criteria for 4.75 mm NMAS Superpave-designed mixtures

Design ESAL Range (Millions)	N_{des}	Minimum FAA	Minimum Sand Equivalent	Minimum V_{be}	Maximum V_{be}	$\%G_{mm}@N_{ini}$	Dust-to-Binder Ratio
<0.3	50	40	40	12.0	15.0	$\leq$ 91.5	1.0 to 2.0
0.3 to $\leq$ 3.0	75	45	40	11.5	13.5	$\leq$ 90.5	1.0 to 2.0
3.0 to $\leq$ 30	100	45	45	11.5	13.5	$\leq$89.0	1.0 to 2.0

Gradation Limits		
Sieve Size	Maximum	Minimum
12.5 mm	—	100
9.5 mm	100	95
4.75 mm	100	90
1.18 mm	30	55
0.075 mm	13	6

Design Air Void Range = 4.0 to 6.0 percent

Acknowledgements and Disclaimer

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