TENTATIVE RESEARCH PROPOSAL FOR THE REFINEMENT AND FIELD VALIDATION OF MIX DESIGN CRITERIA FOR 4.75 MM SUPERPAVE MIXES

BACKGROUND

Within the Superpave mix design system there are design criteria for 9.5 to 37.5 mm nominal maximum aggregate size (NMAS) mixes. Many agencies have expressed an interest in using a 4.75 mm NMAS mix because such a mix could result in an easy riding surface, be used for thin lift applications, correct surface defects (leveling), decrease construction time, provide a use for manufactured screening stockpiles, provide a very economical surface mix for low traffic volume facilities, and be used for thin lift maintenance.

In February of 2002, the National Center for Asphalt Technology completed a study to develop Superpave mix design criteria for a 4.75 mm NMAS mix (Cooley et al, 2002). NCAT's research was used, in part, by the Superpave Mixture/Aggregate Expert Task Group to recommend to AASHTO the addition of 4.75 mm NMAS mixes to the Superpave mix design system. Based upon the findings in NCAT's study, the following design criteria were recommended:

- Gradations for 4.75 mm NMAS mixes should be controlled on the 1.18 mm (No. 16) and 0.075 mm (No. 200) sieves. On the 1.18 mm sieve, the gradation control points were recommended as 30 to 54 percent. On the 0.075 mm sieve, the control points were recommended as 6 to 12 percent.
- An air void content of 4 percent should be used during mix design.
- A minimum VMA limit of 16 percent should be utilized.
- For mixes designed at 75 gyrations and above, a maximum VMA criteria of 18 percent should be utilized to prevent excessive optimum binder contents.
- For mixes designed at 50 gyrations, no maximum VMA criteria should be utilized.
- For mixes designed at 75 gyrations and above, VFA criteria should be 75 to 78 percent.
- For mixes designed at 50 gyrations, VFA criteria should be 75 to 80 percent.
- $\%G_{mm}@N_{ini}$ values currently specified in AASHTO MP2-01 for the different traffic levels were recommended.
- Criteria for dust-to-effective binder ratio were recommended as 0.9 to 2.2.

Based on NCAT's research, it was also recommended that the mix design criteria be refined in the laboratory and then field validated. Laboratory refinement of the procedure was recommended in the following areas:

1. Minimum VMA criteria and $P_{0.075}/P_{be}$-Ratio Requirements: Laboratory work is needed to evaluate the aging characteristics of 4.75 mm NMAS mixes designed with the proposed mix design criteria. The minimum VMA criterion of 16 percent was selected based upon minimum binder contents and gradation specifications on similar mixes from Maryland and Georgia. Included within this work should be an evaluation of the maximum $P_{0.075}/P_{be}$ ratio requirement.
2. Maximum VMA criteria: High optimum binder contents were identified as the primary cause of excessive laboratory rutting during development of the mix design criteria. For this reason, a maximum VMA criterion of 18 percent was recommended. This value needs to be validated in the laboratory by designing numerous mixes with a wide range of aggregate types to further evaluate the relationship between VMA and stability.

3. $\%G_{mm}@N_{ini}$ criteria: Within NCAT's study, two high quality aggregates were utilized. None of the 36 mixes designed failed the $\%G_{mm}@N_{ini}$ criteria for a 75 gyration design (90.5 percent). Additional work needs to be conducted that incorporates various percentages of natural, rounded sand to evaluate the applicability of $\%G_{mm}@N_{ini}$ requirements within the mix design system.
4. Aggregate Properties: Both of the aggregates used in this study had fine aggregate angularity values in excess of 45 percent. Additional refinement needs to be conducted to evaluate the desired FAA values for different traffic levels.
5. To avoid excessive binder contents, work should be conducted to verify if 4.75 mm NMAS mixes can be designed at a single air void level (e.g., 4 percent) and result in satisfactory performance or if a design air void range criteria is needed.
6. Use of Polymer Modified Binders: Within a refinement study, some polymer-modified binders should be included to evaluate any enhanced performance for thin maintenance applications on higher volume roadways.

Field validation of the refined mix design criteria would entail working with agencies to construct a number of test pavements. Selected projects should encompass a number of different applications and traffic conditions to determine where 4.75 mm NMAS mixtures are applicable. Also, the performance of these mixtures should be monitored over a time period to provide data on overall performance. Based upon the results of the laboratory refinement and field validation, guidelines should be developed on the design, production, construction, and allowable applications of a 4.75 mm NMAS Superpave mix.

OBJECTIVES

The objective of this study will be to refine and field validate design criteria for 4.75 mm NMAS Superpave mixes. Additionally, guidelines for the production, construction, and use of this mix type will be developed.

WORK PLAN

As illustrated in Figure 1, the tentative work plan will have three main phases. Initially, a laboratory phase will be needed to refine the mix design criteria developed for the 4.75 mm NMAS Superpave mixes. The second phase will include a field validation of the refined mix design criteria through the construction of experimental test sections utilizing mixes designed with the refined mix design criteria. The third phase will entail monitoring the performance of each test section for three years. After three years, the mix design criteria will be further refined, if needed, considering construction and performance experiences. Following are detailed descriptions of the work planned in each phase of work.

Phase I – Laboratory Refinement of Mix Design Procedure

The experimental plan for the laboratory refinement of the mix design criteria is illustrated in Figure 2. As shown on this figure, the first step will be to obtain the materials necessary to accomplish the project objectives. A total of four to six aggregate sources are proposed and will be obtained from states participating in the research study. Multiple fine aggregates will be obtained from each source. The exact number of aggregate sources will depend upon the number of states that participate. In addition to the four to six aggregate sources, another fine aggregate utilized in this study will be a rounded, natural sand. As stated previously, one of the issues needing refinement is aggregate quality (fine aggregate angularity and $\%G_{mm}@N_{ini}$). Two different binders will be used in the study. All of the mix designs and performance testing will be conducted with an unmodified binder (PG 64-22). For some limited testing, a polymer-modified binder will also be utilized (PG 76-22).

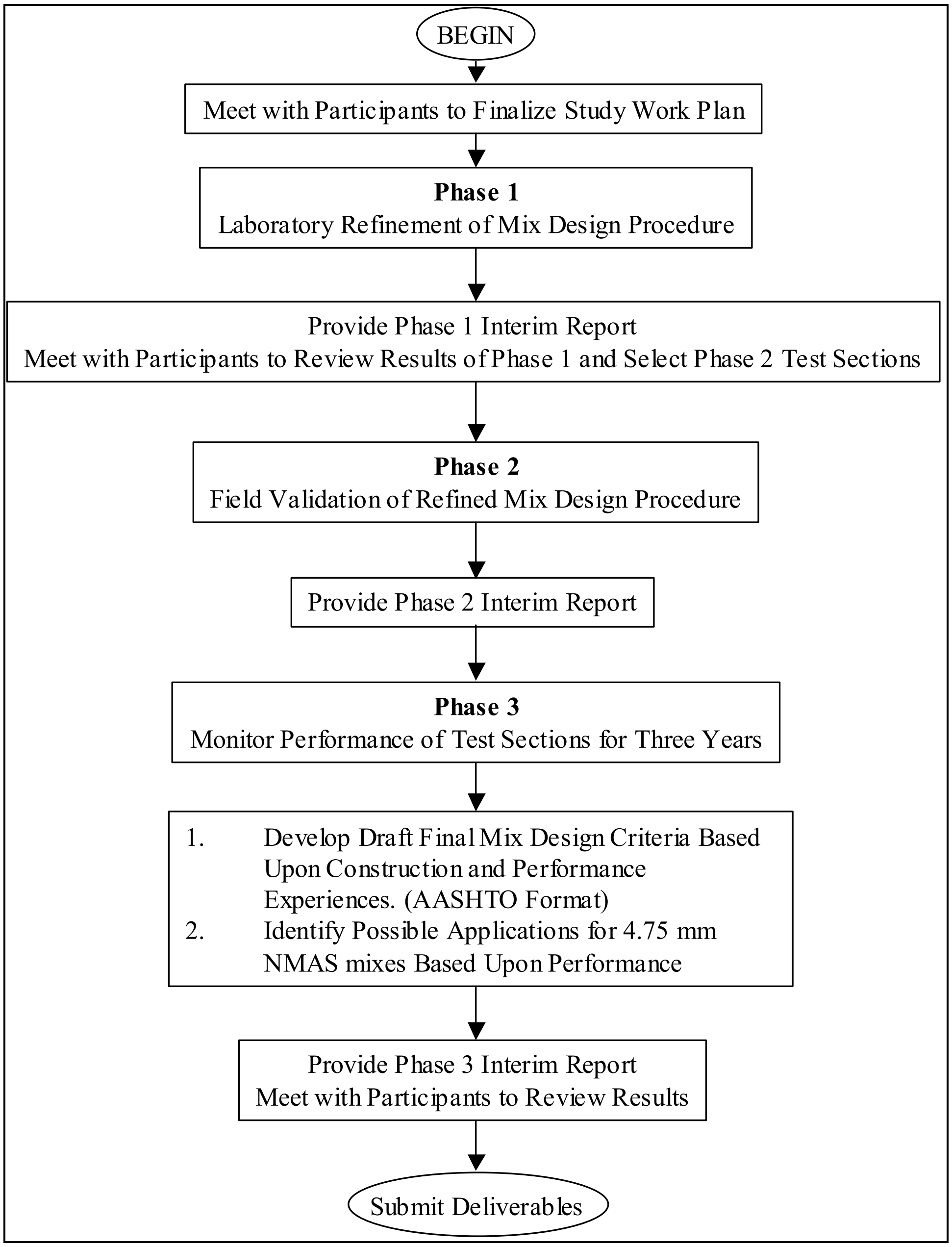

Figure 1: Overall Research Approach

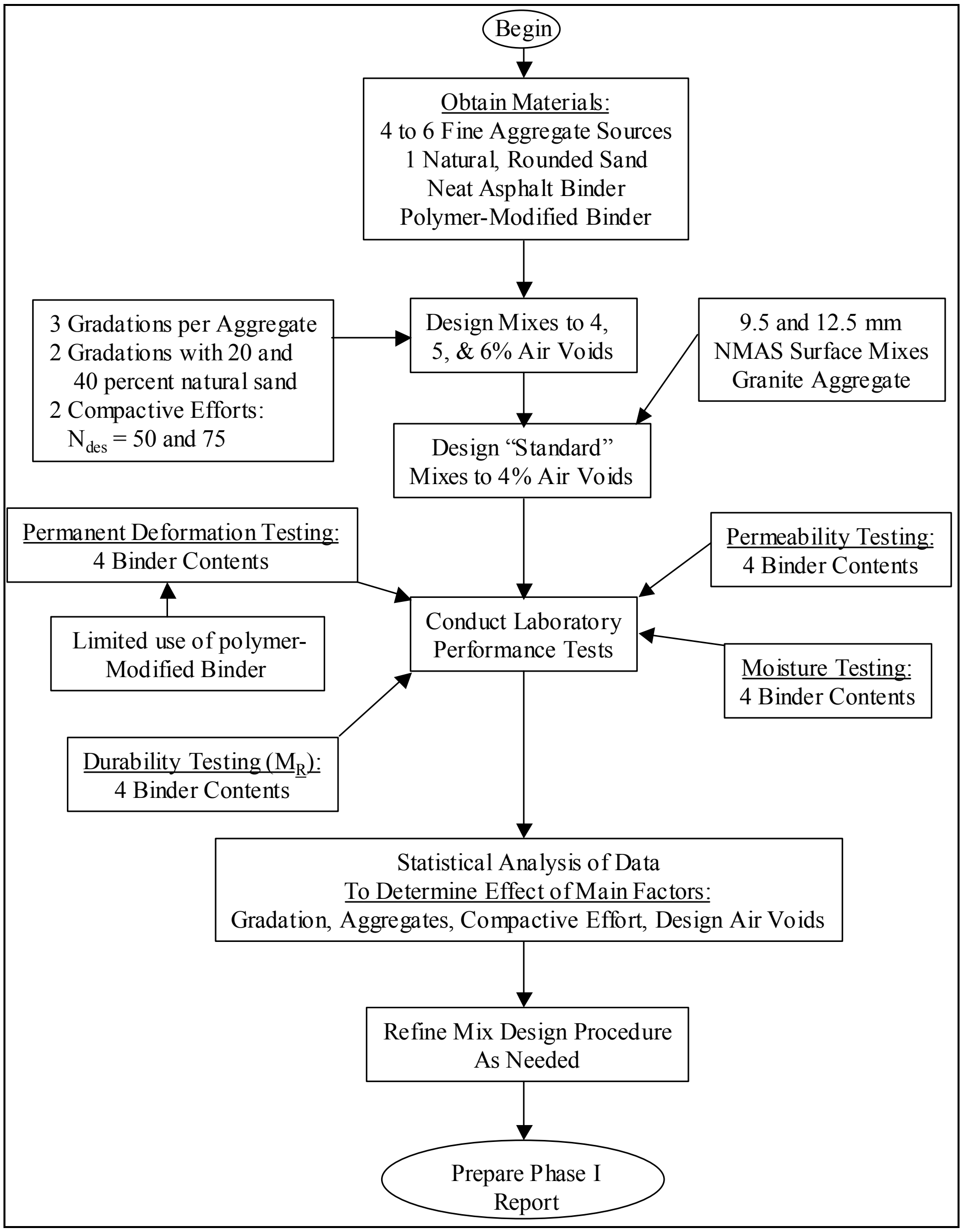

Figure 2: Experimental Plan for Laboratory Refinement

Once all of the materials are obtained, aggregates from a given source will be blended to meet three general gradation shapes. Instead of testing manufactured gradations, the aggregates will be blended to meet three general gradation shapes: fine, medium, and coarse. In preparation of this tentative proposal, a number of fine aggregate stockpiles were evaluated to determine the range of potential gradations that could be encountered. This range is illustrated in Figure 3. Also included on Figure 3 are the recommended gradation control points from the NCAT research study. Based on this figure, the lower control point appears to be in approximately the right location. However, there are a number of aggregates that would allow for gradations finer than the upper control point recommended in the NCAT research of 4.75 mm NMAS mixes.

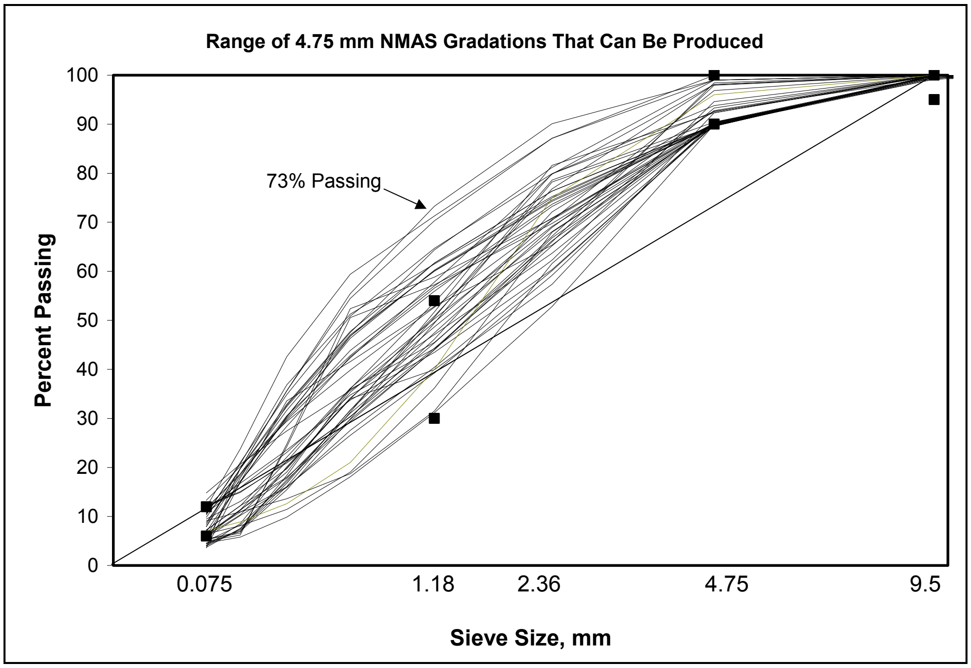

Figure 3: Range of 4.75 mm NMAS Gradations

The definition of the general gradation shapes (fine, medium, and coarse) will involve the 1.18 mm (No. 16) sieve. Fine gradations will pass at or above the upper control limit at the 1.18 mm sieve. Medium gradations will pass between the upper control limit and maximum density line and coarse gradations will pass below the maximum density line at the 1.18 mm sieve. These definitions are based upon the potential gradations illustrated in Figure 3. These three general gradation shapes will be included to verify the gradation control points recommended in NCAT's original study.

For each of the four to six aggregate sources, the natural sand aggregate will be added at 20 and 40 percent in addition to the three general gradation shapes described above. The natural sand will have a fine aggregate angularity value between 37 and 40 percent. Inclusion of the natural sand in the experiment will be required to verify the recommended aggregate and volumetric criteria.

The next step of the research study will be to conduct mix designs. Each of the aggregates/gradations will be designed using two different compactive efforts: 50 and 75 gyrations. These two gyration levels were selected because 4.75 mm NMAS mixtures will likely be used for lower traffic volume applications. This will result in a total of 40 to 60 mixes (4 to 6 aggregates * 5 gradations [including the two natural sand percentages] * 2 compactive efforts). Each of these mixes will be designed to 4, 5, and 6 percent air voids. The purpose of the differing air void contents is the concern of some mixes being over-asphalted due to high VMA values. A possible solution to mixes with high asphalt binder contents would be to increase the design air void content. Realistically, the six optimum binder contents (2 compactive efforts * 3 design void levels) will result in only four asphalt contents. Based upon the research NCAT conducted during NCHRP 9-9 (Brown et al., 1998), the difference between design compactive efforts of 50 and 75 gyrations for a given aggregate/gradation combination is approximately 1 percent VMA. Additionally, for a given compactive effort/mix the difference in 1 percent design air voids is also 1 percent VMA. A given mix designed with 50 gyrations at 5 percent air voids should have the same optimum binder content as a mix designed with 75 gyrations at 4 percent air voids. Therefore, results of the mix designs should result in four optimum binder contents per aggregate/gradation combination. This will result in a total of 80 to 120 total mixes (4 to 6 aggregates * 5 gradations * 4 optimum binder contents).

For comparison purposes, two "standard" surface mixes will also be included in the research: 9.5 and 12.5 mm NMAS surface mixes. These mixes will be fabricated from a granite aggregate and designed with both compactive efforts to 4 percent air voids. These two mixes will also be subjected to the different performance tests to provide comparisons in performance between the 4.75 mm NMAS mixes and more traditionally used mixes.

As shown on Figure 3, the next step in the research will be to conduct laboratory performance tests. Included within the performance tests will be permanent deformation testing, durability testing, permeability testing, and moisture sensitivity testing. Generally, rutting is not a concern with thin lift mixes; however, the permanent deformation testing will be included to evaluate how stable the 4.75 mm mixes will be in the field. Also, this testing will be related to the needed aggregate properties for a 4.75 mm NMAS mix. Durability testing will be conducted to verify volumetric criteria related to durability (e.g., VMA and VFA). The permeability tests will be utilized to evaluate the needed density in the field. It is tentatively proposed to conduct all performance tests on a one-half fractional basis. Therefore, 40 to 60 (depending upon the number of aggregates) mixes will be subjected to the performance tests instead of the 80 to 120 mixes. The fractional factorial will be statistically based.

For the permanent deformation testing, the Asphalt Pavement Analyzer (APA) will be the main test used to evaluate the stability of 4.75 mm NMAS mixes. The test procedure recommended by NCHRP Project 9-17, "Accelerated Laboratory Rutting Tests: Asphalt Pavement Analyzer," will be utilized for this testing. Some limited testing will also be conducted with the Simple Performance Test for validation of the APA testing. On a limited number of mixes, a polymer-modified binder will be utilized instead of the neat asphalt binder and permanent deformation tests conducted. This should provide an indication of the ability of 4.75 mm NMAS mixes to be used as thin maintenance applications on higher volume roadways.

The next performance test to be conducted is durability testing. This testing will be conducted to evaluate the minimum VMA criteria for 4.75 mm NMAS mixes. During SHRP A-003A (Bell et. al, 1994), the diametral resilient modulus test (M_R) was found to be able to differentiate between mixtures having various states of laboratory aging. It is proposed to conduct resilient modulus testing on compacted HMA mixtures after various states of laboratory aging to evaluate durability. Samples compacted after short-term aging will be considered as time equal to zero (t_0). Three replicates will be tested for M_R at t_0. Three replicates will also be aged for 3, 5, 7, and 10 days at 85ºC in a forced draft oven. After aging the appropriate time each replicate will be tested for M_R.

Results of this testing should provide a relationship between asphalt binder aging and modulus for each mixture (aggregate-gradation-VMA) combination. It is planned to develop modulus ratios, which would include the modulus at any given time (t_i) divided by the modulus at t_0. This modulus ratio (M_R-ratio) would be plotted versus aging time. Figure 4 illustrates the anticipated relationship, which is representative of the results obtained from SHRP A-003A (Bell et. al, 1994). Figure 4 shows that initially the modulus (M_R-ratio) of a mixture should increase rapidly as the asphalt binder ages. At some point, the modulus should begin to level off as the binder has aged to near its fullest extent.

Two properties will be derived for each mixture from the M_R-ratio versus aging time plot. First, the slope of the line within the initial linear range will be determined. It is anticipated that mixtures having lower VMA values (hence smaller film thicknesses) will age quicker than mixes with larger film thicknesses. This should be indicated with steeper initial slopes. The other property to be evaluated is the magnitude of the M_R-ratio after 10 days of long-term oven aging, which will define the total amount of binder aging. Slopes and magnitudes of aging for the 4.75 mm NMAS mixes will be compared to the two more conventional mixes (9.5 and 12.5 mm NMAS mixes) to compare the durability characteristics. The data will be analyzed to determine the VMA, VFA, and/or film thickness needed to resist excessive aging of the asphalt binder.

Research is currently being conducted through NCHRP to evaluate the proper VMA, VFA, or film thickness of Superpave designed mixes (NCHRP Project 9-25, "Requirements for Voids in Mineral Aggregate for Superpave Mixtures"). Results from the NCHRP study on the proper measure of durability will be compared to the research results from the this study.

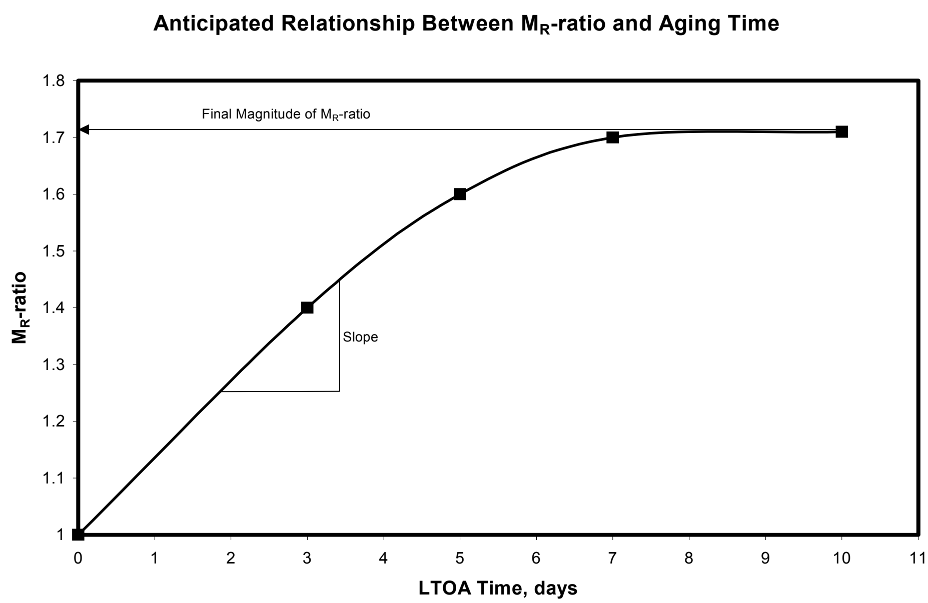

Figure 4: Anticipated Relationship Between M_R-ratio and Aging Time

The next laboratory performance testing to be conducted will be laboratory permeability testing. This testing will be conducted to evaluate the proper density required for 4.75 mm NMAS mixes in the field to prevent permeable pavements. Samples will be prepared in the Superpave gyratory compactor to a range of air void contents. These samples will be compacted to a height of 25 mm (1 in.) to represent a typical layer thickness in the field. Samples will then be tested to determine laboratory permeability. NCAT is currently using this methodology within NCHRP 9-27, "Relationships of HMA In-Place Air Voids, Lift Thickness, and Permeability," with success. This testing should provide an indication of the critical in-place density needed to prevent water from infiltrating a 4.75 mm NMAS mix on the roadway.

The final performance test conducted as part of the laboratory refinement of the 4.75 mm NMAS mix design criteria will be to evaluate the moisture susceptibility of the mixes. Because of the relative fineness of 4.75 mm NMAS mixes, traditional methods of calculating asphalt film thickness indicate relatively small film thicknesses (on the order of 5 to 6 μm). Therefore, moisture susceptibility testing needs to be conducted to evaluate the relative resistance to moisture induced damage for 4.75 mm NMAS mixes. For this testing, AASHTO T283 will be utilized. A single freeze/thaw cycle will be included to make the test harsher. However, to validate these results, a limited number of Hamburg Wheel Tracking Device tests will also be conducted.

At the conclusion of mix designs and laboratory performance testing, the proposed mix design criteria for 4.75 mm NMAS mixes will be refined. A draft report will be provided to the participating states for review. A project panel meeting will be held at NCAT approximately two months after the draft report is submitted. Expenses for one person per participating state will be paid through the project funds to attend the meeting. Results of Phase I along with the refined mix design criteria will be presented and discussed. Also at this meeting, work to be conducted in Phase 2 will be discussed.

PHASE II – FIELD VALIDATION OF REFINED MIX DESIGN CRITERIA

Based upon the Phase I project panel meeting, a minimum of four states will be selected for the field validation of the refined mix design criteria. Selection will likely be based upon having test sections in the four SHRP climatic zones and the use of different traffic applications. Traffic applications infer different traffic volumes and speeds. Possible applications include residential streets, leveling, low volume rural highways, and thin maintenance treatments. It will also be requested that the states place their typical mix for the selected application along with a 4.75 mm NMAS mix. This will provide comparisons in performance between the 4.75 mm NMAS mixes and the state’s typical mixes.

For each of the test sections, NCAT will work with the participating states to design the mix, if requested. Either NCAT can conduct the designs or just provide assistance with the design. NCAT will also work with the states to develop supplemental specifications or special provisions, if needed.

During construction, NCAT personnel will travel to the construction site with a mobile laboratory. This mobile laboratory is equipped to conduct numerous types of quality control tests on plant produced HMA. At each project, NCAT will collect data and obtain the raw materials used to produce the 4.75 mm NMAS mix. Figure 5 illustrates the activities at each project.

Figure 5 shows that testing will be conducted on plant produced mix, field compacted mix, and the raw materials used for the 4.75 mm NMAS mix. Similar testing will also be conducted on the “typical” mix if placed by the participating state. For the plant-produced mix, a minimum of two samples will be obtained per day. Enough mix will be obtained to compact three replicates in the SGC to the design number of gyrations. Samples from each project will also be fabricated for testing in the Asphalt Pavement Analyzer. Additionally, enough mix will be obtained to conduct two Rice gravity tests on the plant-produced mix. Also, loose plant produced mix will be saved and brought back to the NCAT laboratory.

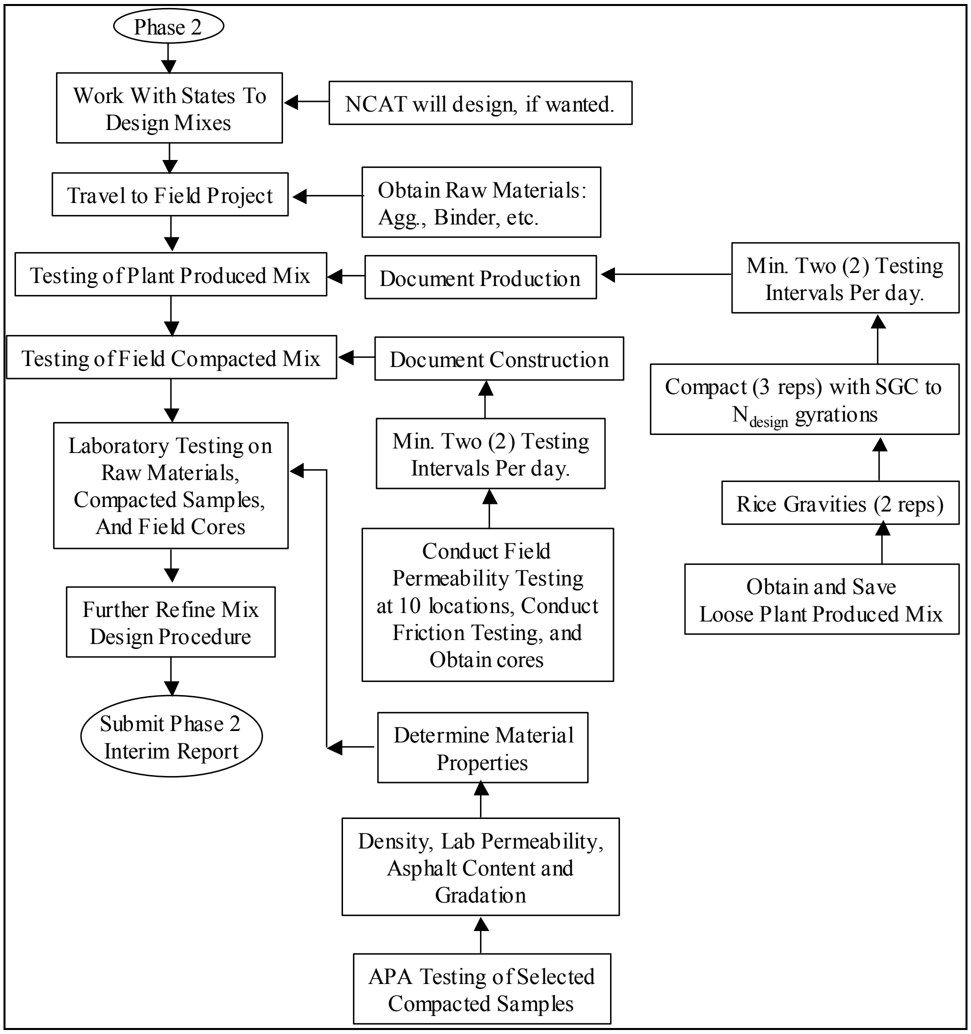

Figure 2: Research Approach for Field Validation

For the field compacted mix, field permeability tests will be conducted on the newly placed pavement, prior to any traffic. Cores will also be obtained from the pavement to determine in-place air void contents. These cores will also be used to determine asphalt content and gradation. NCAT will also evaluate the frictional characteristics of the compacted pavement using two portable devices that are correlated to the International Friction Number.

At the conclusion of the field projects, NCAT will analyze all of the data and further refine the 4.75 mm NMAS mix design criteria, if needed. A draft report will be provided to the participating states that document production and construction of the projects, results of all testing, conclusions, recommendations, and the refined mix design criteria.

PHASE III – PERFORMANCE EVALUATION

After the completion of all projects, NCAT will evaluate the performance of the 4.75 mm NMAS mixes at one and three years. Included within the performance evaluation of each test section will be a distress survey and an evaluation of frictional properties. At the conclusion of three years, the mix design criteria will be further refined based upon actual performance in the field, if needed. A draft final report will be prepared that documents the entire study and provides the final mix design criteria. Approximately two months after submitting the draft final report, the researchers will meet with the participating states to present and discuss the final deliverables. The draft final report will be revised as needed based upon the comments of the project panel and a final report submitted to the participating states.

DURATION

The time needed for this study will be approximately five years. Initial laboratory refinement of the mix design procedure will take approximately one year. Construction and monitoring of the pavement sections will take four years. Table 1 illustrates the anticipated progress for the study.

Table 1: Anticipated Progress

Phase	Year 1	Year 2	Year 3	Year 4	Year 5
Laboratory Refinement					
Construction of Test Sections					
Performance Evaluations					

COST

It is anticipated that the funding needed to complete this research study would be fourteen states participating at a total contribution of $30,000. This contribution could be made in two contributions of $15,000 over the first two years of the project.

REFERENCES

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