WHITE PAPER ON SUPERPAVE ISSUES OF CONCERN TO THE AGGREGATES INDUSTRY

INTRODUCTORY COMMENTS

This White Paper was prepared at the request of the TRB ETG on Superpave Mixtures and Aggregates. Its intent is to frame aggregate-related issues that currently present challenges to the implementation and use of the Superpave mix design system. There are a number of issues with certain criteria and test methods adopted for use in the Superpave system. Research that has been performed subsequent to The Strategic Highway Research Program (SHRP)is showing that many of the concerns that have been expressed by the aggregate industry are valid. This research shows that changes are necessary to aggregate specifications, acceptance criteria, and test methods. The changes are needed 1) to improve the Superpave system, 2) to allow use of quality aggregates from sources that may not meet the original criteria adopted for use, 3) to match aggregate quality requirements with the application, and 4) to provide high performing, long-lasting hot-mix asphalt pavements.

The Superpave mixture design system is a product of the five years of research developed during the Strategic Highway Research Program that was completed in 1993. New concepts emerged from the research to ensure mixture performance. However, very little work/research was performed on aggregates, which comprise approximately 95 percent by mass of an asphalt concrete mixture.

Departments of Transportation (DOTs) throughout the United States are now implementing the Superpave mixture design system and constructing Superpave projects. Many projects have successfully met all Superpave requirements. However, significant problems have been encountered on some projects, and this has caused considerable concern for materials suppliers, paving contractors, and even personnel of the state DOTs.

The aggregate supplier is concerned because problems have been encountered meeting the specified consensus properties or the source properties or both with certain types of aggregates, including aggregates that are 100 percent crushed. Some aggregate sources are producing a product having particles that are “too cubical” in shape. This results in low fine aggregate angularity (FAA). It may also adversely impact the voids in the mineral aggregate (VMA) for the asphalt mixture. However, the profession determined years ago that cubically shaped particles are desired to produce high performing hot mix asphalt (HMA) mixtures.

A wide variety of mineral aggregate is used to produce HMA. Sand and gravel from river or glacial deposits is processed and used. Crushed stone is also used, and is produced by crushing, sizing, and washing into distinct size fractions or products. All

aggregates are not alike, but most can be used to produce high quality, long lasting HMA pavements. Regardless of the aggregate source, processing method, or mineralogy, the aggregate must provide enough shear resistance to resist repeated load applications, and must result in pavements that are resistant to rutting and cracking.

Results of current research, and engineering judgment applied to local conditions, must be considered and permitted, to modify current Superpave criteria and test methods as necessary. Use of an aggregate that has a history of good performance should not be prohibited because the aggregate does not meet all currently specified Superpave criteria.

The proliferation of test procedures is one of the most contentious issues facing the aggregate and contracting industries. Proliferation, and also modification of standard test methods, by state DOTs needs to end. ASTM/AASHTO test methods should be adopted by state DOTs without modification whenever possible.

The aggregate and contracting industries believe that Superpave is a step forward for the hot mix asphalt (HMA) industry. The aggregate industry continues to work on methods and plant modifications, when necessary, to permit production of the specified/ needed products. Large capital investments for hardware, and time, are required to implement a change once it is determined that the change is necessary. The industry cannot make changes overnight. Industry personnel are active at the national and regional level in various associations, with asphalt user/producer groups, with researchers, and with expert task groups (ETGs) and state DOTs to focus on pertinent issues and to develop rational approaches to implementing Superpave.

At the September, 1999 meeting of the Transportation Research Board (TRB) ETG on Mixtures and Aggregates, the aggregate industry was asked to develop a "white paper" that would 1) identify on-going aggregate research, 2) identify areas where additional aggregate research is needed, and 3) identify activities the ETG could undertake to address areas of concern.

The aggregate industry has been given an opportunity to identify their concerns relative to the Superpave design system and Superpave aggregate test methods and acceptance criteria. They have been asked to identify and to recommend activities to be undertaken by the Superpave ETG or by the main TRB Superpave (Oversight) Committee, or both, and to identify/recommend research projects that should be developed for approval and funding through AASHTO and others.

PERTINENT INFORMATION FROM MINUTES OF ETG MEETING (SEPTEMBER, 1999)

The minutes of the Superpave Mixture and Aggregate ETG for the first meeting of the newly formed ETG that was held on September 21-22 contain the following:

"Chuck Marek, a member of the TRB Superpave Committee, was asked to frame the issues currently facing the aggregate industry relative to Superpave which need to be

resolved. The following areas of concern were identified by Marek in a presentation given to the ETG at this meeting:

1) Aggregate test procedures, standards and definitions are not being applied uniformly by state agencies throughout the U.S. For example, differences exist in how states measure and implement flat and elongated (F&E) and fine aggregate angularity (FAA) test procedures. Use of the restricted zone varies. Where to draw the maximum density line and control points is different in some states. The concept of promoting the use of variable criteria among states, while still utilizing the same definitions and procedures, needs to be explored.

2) The aggregate industry is concerned with potential problems with the Superpave criteria regarding the restricted zone, FAA, dust-to-binder ratio, VMA (specific gravity values are critical to VMA), tighter grading control (variability in grading). Aggregate producers need to continue to develop test data for each aggregate product. Also of concern is the need to increase the level of competence and understanding of the technicians running these tests.

3) Improvements in the test procedure used to determine FAA are needed. There is significant variability in test results.

4) Excess crusher fine material is being generated at many quarries, and there is less demand to use these materials in coarse graded Superpave mixtures.

5) Some aggregate production operations have experienced difficulty making aggregate to the specific sizes needed in Superpave. Operational and equipment changes in aggregate production at many facilities have resulted in fractionalization of coarse aggregate sizes to meet grading requirements, production of more aggregate fines, more wear on plants, reduced production rates, and increased quality control efforts.

6) Available local materials should be used to the greatest possible extent to minimize transportation costs. The aggregate industry wants to ensure that good materials are used and bad materials are rejected. Valid performance measures need to be developed, the economic impacts of Superpave requirements fully understood, and aggregate research continued.

7) The aggregate industry questions whether or not the equipment changes that have been necessary for production of Superpave aggregates are truly needed, that the aggregate criteria may not be related to HMA performance, and that the requirements are not going to change dramatically again. The industry does not want to incur significant cost to meet current aggregate criteria, and then learn that the acceptance criteria are not valid nor related to mixture performance.

Based on Marek's presentation and subsequent discussion, ETG members associated with the aggregate industry, and "friends" of the ETG in attendance at the

September meeting, summarized several key aggregate issues that need to be addressed as:

1) Recommend test procedure standardization among states (allow variable criteria).

2) Evaluate the VMA criteria (need different requirements for fine and coarse mixture gradings).

3) Eliminate the restricted zone.

4) Conduct ruggedness testing of consensus aggregate test procedures and criteria, and develop precision statements to identify inherent testing variability.

5) Design and use fine-graded aggregate mixtures that meet criteria for Superpave mixture volumetrics, and perform well.

6) Evaluate current fine aggregate angularity (FAA) test procedures (bulk specific gravity, sample grading, and other) and resolve problems being experienced with this test method. Recommend testing of blends, and development and use of acceptance criteria based on relation to mixture application and desired performance.

7) Reexamine F&E criteria, and recommend that acceptance criteria be related to mixture performance.

SUMMARY OF RESEARCH

The **National Center for Asphalt Technology** (NCAT) periodically compiles information on research projects that are currently in progress pertaining to hot mix asphalt pavements. The listing of projects as of April, 2000 is contained in Appendix A of this White Paper. Projects that include aggregate research are denoted by a "bullet" in the left-hand margin. This listing by NCAT is probably the most complete listing of research projects that is available. Input is obtained from many sources, including TRB, ICAR, NAPA, and others. The most current listing can be obtained by visiting the NCAT website at the following address: **www.eng.auburn.edu/center/ncat** and clicking on *Information*, and then clicking on *Research in Progress.*

Research has been performed on various aggregate tests since the conclusion of the Strategic Highway Research Program (SHRP). One recent project was **NCHRP Project 4-19**, *Aggregate Tests Related to Asphalt Concrete performance in Pavements.* This research project evaluated many aggregate tests, and identified a set of nine aggregate tests that the researchers believe relate to performance of HMA. The project did not assess the validity of the identified tests by in-service performance or accelerated load tests. **Validation** is needed, **and adoption and use** of valid tests and acceptance criteria for each test in the Superpave system is critical to the success of Superpave.

NCHRP Project 4-19(2), FY'99 entitled *Validation of Performance-Related Tests of Aggregates for Use in Hot mix Asphalt Pavements* has recently been defined and awarded. The objective of this research project is to evaluate the validity of the aggregate tests identified in NCHRP project 4-19. The Research Project Statement developed by TRB for this project contains the following statements."The properties of coarse and fine aggregates used in hot mix asphalt (HMA) mixtures are very important to the performance of the asphalt concrete pavements in which used. Many currently used aggregate tests were developed empirically (in Project 4-19) to characterize an aggregate without, necessarily, understanding the direct relationship to the performance of the final product."

Although Project 4-19(2) will provide information on specific tests to evaluate aggregates, it will not address all of the issues of concern to the aggregate producers and contractors pertaining to the current Superpave mix design system. Additional research is needed, and a recommendation by the TRB ETG for inclusion of some of the needed research in future FHWA and TRB research programs has been made. Recommendations for additional research should be reinforced by the ETG on Superpave Mixtures and Aggregates.

Some states use mathematically combined aggregate properties for aggregate blends because Superpave criteria are based on the total blend of the aggregates. If a given aggregate fails a particular requirement, its use is permitted in the mixture as long as the entire blend does not fail the requirement. In reality, an individual aggregate component that fails to meet the criteria is typically rejected from use. Research recently performed by **Carter and Prowell** in Virginia shows that significant differences exist between the physically and mathematically combined aggregate properties. Tests were performed to determine: bulk specific gravity of coarse and fine aggregate, flat and elongated, fine aggregate angularity, sand equivalent, and sieve analysis. This research showed that the fine aggregate properties are affected most significantly. The authors concluded:"agencies may need to reevaluate the manner in which they calculate aggregate properties for Superpave design".

Additional studies have been performed by several researchers on issues of concern and importance to the Aggregates Industry. Four pertinent presentations were made at the Transportation Research Board (TRB) 79th Annual Meeting held in January, 2000.

Fernandes and Roque, et. al. (Paper No.1397) reported that although fine aggregate angularity (FAA) contributes to shear strength, other factors such as toughness, grading, and packing characteristics of the fine aggregate overshadow FAA. The FAA criteria rejected some aggregates with high shear strength and accepted aggregates with low shear strength. Aggregate toughness and grading have a dominant effect on shear strength that overwhelms the effect of FAA.
These researchers concluded: "continued use of FAA as a tool for screening or accepting fine aggregates for use in asphalt mixtures must be seriously questioned".

In a study by **Khosla and Kawaguchi** (Paper No.1061), asphalt concrete mixtures prepared with aggregate gradings that pass through and above the restricted zone met all of the current Superpave system requirements. The authors concluded "that these gradings with crushed and angular aggregates can be expected to perform adequately in the field".

A study reported by **Epps and Hand** (Paper No.1269) stressed the need for a performance-related test to prevent catastrophic rutting failures in asphalt pavements. They concluded that based on "their study and the observed performance of Superpave mixtures at WesTrack, experimentation with fine graded, rather than coarse graded, Superpave mixtures should be considered and performed".

Mallick, et.al. (Paper No.1105) reported that the researchers observed that substantial differences in VMA exist among different permissible gradings of mix made with aggregate of the same nominal maximum size. The average difference in VMA for a five percent increase in percent passing the 2.36mm sieve was found to be 0.4 percent. The authors concluded "a more rational way of specifying the minimum design VMA will be to specify VMA on the basis of percent passing the 2.36mm sieve rather than the nominal maximum size".

Additional research has been conducted and is contained in the literature. This author did not attempt to conduct an exhaustive review of all of the research that has been performed and as a result, this White Paper does not include reference to all of the research that may have been conducted. However, some of this additional research is summarized below.

McRae has reported that the currently used Superpave criteria of fixed compaction at 0.6 M Pa and fixed air voids at 4 percent will result in serious problems with some Superpave mixtures. This conclusion is based on work performed at the U.S. Army Engineer Waterways Experiment Station (WES), and subsequent WES investigations pertaining to adoption and use of empirical voids criteria. McRae stated that the optimum asphalt content and density is a function of aggregate grading and stress related compaction effort. "The air voids content of a mixture at optimum asphalt content will vary with aggregate grading and porosity as well as with the required amount of compaction". McRae concluded that the current Superpave mixture criteria fail to take this into account. Some, but not all, aggregate industry engineers believe that McRae's position has merit. Additional research of the Superpave mixture criteria should be supported and recommended by the Superpave Mixtures and Aggregates ETG.

Jahn recently reported the results of a research effort at Martin Marietta pertaining to measurement of aggregate particle shape. He believes that Multiple Ratio Analysis (MRA) of the aggregate is an improved method for categorizing the various particle shapes present in an aggregate sample. He reports that "the current Superpave procedure for determining and describing a sample's particle shape provides very limited detail about the variety of particle shapes present in a given sample. Further, the currently accepted measurement method does not give a true representation of a three dimensional

particle. Describing the flat and elongated particles present using the percent of particles found at one ratio (e.g. 5 to 1) does not give a true representation of the various ratios in the sample. Jahn believes that Multiple Ratio Analysis may give a more accurate representation of an aggregate sample's particle shape by evaluating the sample on five different ratios instead of just one. Further, Jahn reports that MRA appears to be a sensitive analysis technique that can provide information to allow Superpave mix designers to optimize the combined aggregate grading that best fits the particle shapes present in the aggregate. Rather than force uniform particle shapes across all geologic aggregate types, MRA analysis may identify the particle shapes and the appropriate combined grading suitable for each aggregate material. Further research on this analysis technique (MRA) appears to be warranted, and should be supported by and recommended by the Superpave Mixtures and Aggregates ETG. Also, research to characterize particle shape by three dimensional analysis techniques should be continued.

Dukatz reported on practical factors influencing Superpave performance at an 6th Annual Symposium of ICAR in 1998. He expressed concern for both the FAA and the flat and elongated test methods and current specification requirements, and also reported on *squirrelly mixes* that may occur due to the grading of some mixtures, based on his field experience in producing Superpave mixtures. **Dukatz** stated that "Superpave is still a design method in development. There will be, must be, changes as more is learned from the performance of pavements built and being built. The Superpave mix design procedure must be allowed to grow. The philosophy is sound."

Weingart reported that the mid-Atlantic states have more difficulty than other areas of the country with the Superpave F&E specification "due to the nature of and the greater use of igneous stone and use of older compression cone crushers to manufacture the stone products. He also stated that current work to date with video imaging systems to analyze aggregate shape and grading changes has demonstrated the capacity to readily distinguish shape and grading changes in a reasonably fast time frame. One imaging system that was recently evaluated "provided output that is more discrete and precise than either the current F&E test or a Gilson grading test." **Weingart** believes that a good optical system for measurement of these aggregate properties may be the best bet for the long term, and recommends that additional research be defined and conducted in this direction.

At the 8th Annual International Center for Aggregate Research (ICAR) Symposium in April, 2000 **Hanf** reported his concern and the difficulty that sand and gravel producers are having in meeting Fine Aggregate Angularity (FAA) and Coarse Aggregate Angularity (CAA) consensus requirements for aggregates for asphalt mixtures designed for high traffic volume pavements. He stated that the coarse aggregate crush count of most gravels can be as high as 98 percent, but that a 100 percent two-faced crushed gravel is very difficult (if not impossible) to achieve. Aggregate industry representatives from Indiana, and elsewhere, have reported similar issues in their state. (**Yzenas** commented that the Coarse Aggregate Angularity issue is on the horizon.) Sand and gravel producers are challenged to produce higher quality aggregates and to remain competitive in supplying aggregates for HMA. **Hanf** concludes by stating that "industry is spending millions of dollars to achieve a 100 percent crushed gravel as opposed to a 98

percent crushed gravel." He recommends that research be performed to evaluate the significance of a 2 or 3 percent difference in coarse aggregate crush count (change from 97% to 100%) on the performance of Superpave mixtures designed for high traffic levels.

Hanf also reported that another potential concern of aggregate producers is the moisture sensitivity test, AASHTO T 283. Many producers believe this test is inaccurate, experience different results when the test is performed on 4 in. versus 6 in. specimens, and believe that some anti-strip agents reduce the tensile strength of dry specimens (rather than increase the tensile strength of the moisture conditioned specimens).

Lastly, **Hanf** reported that the bulk specific gravity of the fine aggregate that is used to calculate the FAA can significantly change the uncompacted void content (and consequently, the FAA). A change in bulk gravity of $\pm$ 0.100 can result in a change in FAA of 2 or more points, i.e., from 44 to 46.

Discussion of Some Current Issues/ Problems

Differences exist in the definitions used by various state DOTs relative to the Superpave mixture being specified. For example, 12.5mm Superpave mixtures defined by the MsDOT, by the LaDOTD, and by the AlDOT are all different. This leads to confusion, and potential problems for contractors performing work in multiple states.

In Mississippi, the maximum density line is a straight line on the FHWA 0.45 power grading chart which extends from the zero origin point of the chart through **the plotted point of the combined aggregate grading curve on the nominal maximum sieve size.**

In Louisiana, the maximum density line is a straight line plot on the FHWA 0.45 power grading chart which extends from the zero origin point of the chart through **the nominal maximum sieve size.**

In Alabama, the maximum density line is a straight line on the FHWA 0.45 power grading chart which extends from the zero origin point through the **maximum particle size**. The maximum particle size is defined as the sieve size that is two sizes larger than the first sieve to retain more than 10 percent of the material. Alabama designates the mix by maximum particle size rather than nominal maximum size. Therefore, a 12.5mm mix in Alabama is a 9.5mm mix elsewhere.

Some aggregate sources have problems with the criteria that have been established for aggregate consensus standards. A simple performance test is needed to properly evaluate acceptance criteria for each consensus property. This will help ensure that the criteria are not arbitrary, but rather are related to mixture performance.

Development and implementation of a aggregate testing plan to provide current test data for each aggregate source is recommended. Frequent testing of aggregates for specific gravity is necessary for valid volumetric analysis of Superpave mixtures. Testing each aggregate product on an annual basis is not adequate to properly characterize the

aggregate. Since the contractor normally gets paid on compacted mixture volumetrics, more frequent data, and control of aggregate specific gravity, are essential.

Most aggregate production plants are not currently designed to produce fractionated aggregate sizes. Others do not currently have the types of crushers and screens that may be necessary to permit production of the specified aggregate products. Consequently, some producers can not adequately produce the specific sizes currently needed in Superpave. Major plant changes, at substantial cost to the producer, and new permits will be required to change crushers, add screens and conveyors, etc. to enable production of individual sizes necessary for specified aggregate blends. The industry wants to improve the quality of hot mixed asphalt concrete, but may not be able to make all needed changes. The industry is moving towards fractionalization, but slowly, and not at all production facilities. Fractionalization also requires an increase in the number of bins at asphalt plants to handle the greater number of aggregate products used in a given mixture.

The aggregate and contracting industry continues to review what can be done operationally to increase production of aggregate products that meet Superpave requirements and to produce Superpave designed mixtures. Significant upgrades may be required at many aggregate production plants and at some older asphalt plants.

There must be better recognition of appropriate use of available materials that accounts for both performance and economics. Engineers should utilize locally available materials whenever possible to minimize transportation costs, and should utilize these materials to their best technical advantage in each application. This will also maximize the benefit to the taxpayer and to the driving public. Economics must be considered in the design of the pavement, particularly in this time of limited funds available for construction and maintenance and increasing fuel costs.

The industry has placed asphalt concrete mixtures for years that have performed well in both low and high traffic volume situations. This can continue within the Superpave mix design system. However, the same Superpave mix should not be required or used on a rural two-lane road with 50 vehicles per day and on an Interstate highway carrying thousands of vehicles per day. This is a major missing link with implementation of the current Superpave design system. It is causing a great deal of concern within the industry. Different materials and mixture design requirements should be required based on traffic volumes. The highest quality aggregates and Superpave mixtures should be required and used only on some high volume roads of strategic importance.

The restricted zone is intended to eliminate poor performing humped gradings that contain too much round natural sand in relation to total sand. Unfortunately, the restricted zone also eliminates many successful heavy duty, rut resistant mixtures produced with 100 percent crushed aggregate from sources that have been used successfully for many years. Many states prohibit gradings that pass through the restricted zone. At least ten states (Co, Cn, Ga, Ms, NH, Tn, Ut, Vt, Wi, and Va) do not have a restricted zone requirement in their Superpave specifications. States (e.g. Ga) that have granite sources

typically have very high performance mixtures that pass through the restricted zone. Best economy is also achieved with these mixes due to the balanced aggregate skeleton that these blends create. Use of all particle sizes produced at an aggregate source is important to keeping extra production and inventory costs at a minimum. Research currently being performed at NCAT, and elsewhere, suggests that asphalt mixtures made with aggregate gradings that pass through the restricted zone exhibit performance qualities equal to and even better than mixtures made with other gradings of aggregate. The restricted zone is not needed, and its use in Superpave specifications should be eliminated.

Differences often exist for certain geologic types of aggregates between the grading of aggregate used in laboratory design and the grading of the same aggregate products and proportions used in the field mixture. As a consequence, aggregates obtained from the aggregate production plant may need to be 5 to 10 percent coarser (to account for grading changes that occur during transport, handling, and mixing) in order to meet mixture design volumetric requirements in the field. However, an aggregate product that is 5 to 10 percent coarser at the aggregate production facility may not meet Superpave grading requirements (and may be rejected from consideration). Mixture designers, specifiers, and field plant personnel should become knowledgeable in the properties of aggregates obtained from specific sources, and should permit adjustment of aggregate gradings during laboratory mixture design to be representative of the aggregate gradings that will be received and used at the asphalt plant.

RECOMMENDED ACTIONS TO BE TAKEN BY THE ETG

The issues set-forth and discussed herein are Superpave issues, and not issues currently facing only the aggregate industry. Some elements of the Superpave system are not correct, and should be changed or corrected. Aggregate producers, paving contractors, and government agency personnel must all do a better job than what we have done in the past. Efforts to partner and to learn together, and to improve the Superpave System must continue in order to achieve the greatest benefit. The Mixtures and Aggregates ETG should take appropriate actions to address and correct significant issues that have been identified herein.

The Recommended Actions identified below have been grouped, per request of the Superpave Mixtures and Aggregates ETG Chairman Ron Sines, into one of four categories. These categories include: Informational, Regional Issues, Standards Changes, and Needed Research. The Recommended Actions have also been prioritized within each category.

INFORMATIONAL

1) The ETG should request an immediate, fast track effort by TRB to synthesize all published and currently on-going research on aggregate properties and aggregate

acceptance criteria for use in Superpave. This review and compilation should be performed by an *independent* source.

2) Aggregate producers must perform more frequent tests on aggregate products produced for Superpave mixtures. Properties such as fine aggregate and coarse aggregate specific gravity must correctly reflect the properties actually used in the mixture. The ETG should encourage aggregate producers to develop appropriate testing and quality control plans to provide accurate information for use in Superpave mixture design.

REGIONAL ISSUES

3) Some source properties, such as L.A. degradation, have not been related to the performance of a Superpave mixture, and therefore, the validity of state DOT acceptance criteria is questioned. Research on source properties for various geologic aggregate types used in HMA should be supported and recommended by the ETG. In particular, the influence of L.A degradation loss on asphalt mixture performance should be evaluated, and current guidelines and/or acceptance criteria should be validated, or revised.
4) The use of locally available aggregates should be encouraged if they will not adversely impact the performance of the Superpave mixture. Engineering judgment should be permitted in Superpave mixture design to avoid excessive transportation costs for materials that will be incurred when the local materials are not within the acceptance criteria.

STANDARDS CHANGES

5) The ETG should recommend to AASHTO SOM that the basic definitions used by all state DOTs in the Superpave mix design system be standardized. (For example, a 12.5 mm design should have the same maximum density line and control points in each state). In addition, the proliferation of aggregate test procedures by state DOTs should be discouraged. The ETG should support and recommend that the *best test methods* (ASTM or AASHTO methods if good, or some other method if better than ASTM/AASHTO) for aggregate properties be adopted and used by all state DOTs without modification and without tweaking.
6) The ETG should recommend consideration and acceptance of aggregate blends that meet Superpave requirements that are anywhere within the grading control points. The Restricted Zone should be eliminated. The ETG should encourage State DOTs to consider blends that are on the fine side as well as on the coarse side of the band. Experience with fine-graded Superpave mixtures at WesTrack supports this recommendation. Forcing the use of gradings that only go below the maximum density line should be eliminated. Consideration and use of fine-graded Superpave mixtures and mixtures having gradings that pass through the restricted zone should be encouraged.
7) The ETG should encourage development of proper corrections and adjustments to aggregate gradings used in the laboratory design process (to account for changes that

may occur during handling, transport, and mixing), and encourage state DOTs to permit use of the adjusted gradings in the design process.

8) The significance of test method precision should be recognized, and the inherent variability of each test should be properly reflected in Superpave mixture acceptance criteria. The ETG should recommend that state DOTs incorporate test method precision into their specifications and acceptance criteria.
9) Differences will be experienced between the grading of the aggregate components used in the laboratory design of Superpave mixtures and the grading of each aggregate in stockpiles at the asphalt plant. These differences should may be significant. Specifying agencies should allow the contractor to modify the mixture design (adjustment to the aggregate blends) in the field to account for these differences. The ETG should encourage field verification of a mix and adjustment as necessary, and without penalty, to ensure that the mix will perform as designed.

NEEDED RESEARCH

10) The ETG should recommend and promote development of valid performance measures and related tests. A performance measure and test will allow the mix designer to use available aggregates to their best technical advantage to achieve cost-effective HMA pavements for each application.
11) The use of the fine aggregate angularity (FAA) test and current FAA acceptance criteria should be reexamined. Many aggregate suppliers question the validity of the test method. The ETG should recommend that research be performed on the test method a) to establish the validity and applicability of the method, b) to establish the sensitivity of the method and the results to specific test parameters (size of sample, size of orifice, height of free fall, size of collection cylinder, etc.), and c) to validate current acceptance criteria. Since 100 percent crushed sands perform well in asphalt mixtures, the ETG should support and recommend acceptance of use of 100 percent crushed, angular, sharp edged aggregate products in Superpave mixtures **without** a FAA requirement.
12) The ETG should recommend that the minimum VMA required for a given Superpave design should be a function of aggregate grading, not just the nominal maximum size of the aggregate. The need for a maximum (or upper) VMA limit should also be thoroughly researched. Further, the influence of variability of aggregate grading on mixture volumetrics has not been adequately researched. Mixture volumetrics may change dramatically with a small change in grading for some geologic types of aggregate. The ETG should recommend that research be performed to determine the amount of variation that may be experienced in aggregate grading at the HMA plant, and to evaluate the significance of this variability on the volumetric properties of a Superpave mixture. Acceptable and realistic tolerance limits for grading should then be established and recommended.
13) Proposed limits for flat and elongated particles at 3 to 1 should be thoroughly researched, and the impact of F&E on mixture performance should be determined, prior to a change of Superpave acceptance criteria. Research by NCAT, and more

recently by the Asphalt Institute, shows that the percent F&E in the mix has little to no adverse impact on mixture performance in the laboratory.

14) The significance of a 2 or 3 percent difference in coarse aggregate crush count (change from 97% to 100%) on the performance of Superpave mixtures designed for high traffic levels using a crushed gravel aggregate should be researched. This research will determine the effect that this change may have on the performance of Superpave mixtures. The ETG should support and recommend that this research be performed.
15) The use of the Superpave criteria of fixed air voids at 4 percent should be carefully reexamined. The ETG should recommend that research be performed on the validity of use of the empirical voids criteria, and that future Superpave criteria should consider the influence of aggregate grading and porosity and compaction.
16) The tests for aggregates identified in NCHRP 4-19 should be validated, and the ETG should support and recommend adoption and use of those tests that are valid and relate to pavement performance.
17) The validity of the moisture sensitivity test, AASHTO T 283, is of concern to aggregate producers and others. The ETG should continue its efforts to support research of this test, or to develop an alternate test that more accurately relates to mixture performance.
18) The ETG should recommend research pertaining to Multiple Ratio Analysis for characterizing aggregate shape. It should also encourage determination of particle shape and then optimum grading, rather than vice versa, to minimize the requirement of a uniform particle shape for all geologic aggregate types. Further, video imaging systems have demonstrated a capacity to readily distinguish aggregate shape and grading changes quickly and accurately. These systems permit separation of an aggregate into separate individual sizes, and then classification as desired for shape or size distribution or both. The ETG should support and recommend continuing research in this area.

Disclaimer

This White Paper was written and reviewed by a limited number of individuals from the aggregate industry, and consensus was achieved amongst this group. The ideas and thoughts expressed in the White Paper have not received review by the entire industry. Additional review should be performed, and comments and input from others within the aggregate industry should be solicited. Therefore, this White Paper should be considered by the Superpave Mixtures and Aggregates ETG members as a document in progress, subject to change as additional information becomes available.

LIST OF REFERENCES

1) National Center for Asphalt Technology, 211 Ramsey Hall, Auburn University, Alabama 36849-5354. 334-844-NCAT.

2) NCHRP Project 4-19(2),FY'99, National Cooperative Highway Research Program , Research Project Statement for Project 4-19(2) entitled *Validation of Performance-Related tests of Aggregates for Use in Hot-Mix Asphalt Pavements*, Transportation Research Board, 2001 Wisconsin Avenue, NW, Washington, D.C. 20007.

3) Carter, Chester B., and Prowell, Brian D., *Comparison of Mathematically and Physically Blended Aggregate Properties*, Paper submitted to TRB Committee A2J03 for consideration for presentation at the Transportation Research Board (TRB) 79th Annual Meeting, January 9-13, 2000 in Washington, D.C.

4) Fernandes and Roque, et. al., *Paper No.1397* presented at the Transportation Research Board (TRB) 79th Annual Meeting, January 9-13, 2000 in Washington, D.C.

5) Khosla and Kawaguchi, *Paper No.1061* presented at the Transportation Research Board (TRB) 79th Annual Meeting, January 9-13, 2000 in Washington, D.C.

6) Epps and Hand, *Paper No.1269* presented at the Transportation Research Board (TRB) 79th Annual Meeting, January 9-13, 2000 in Washington, D.C.

7) Mallick, et. al. , *Paper No.1105* presented at the Transportation Research Board (TRB) 79th Annual Meeting, January 9-13, 2000 in Washington, D.C.

8) McRae, John L., Engineering Developments Company, Inc., Vicksburg, Mississippi, *Correspondence* dated March 1, 2000 with T. Paul Teng (Director of Office of Infrastructure, Research and Development, FHWA, Mclean, Va.), pertaining to "issues related to mixture design for flexible pavements of our nation".

9) Jahn, David W., CSR American Aggregates, (now with Martin Marietta Technologies), Cincinnatti, Ohio, *A Closer Look at Superpave Aggregate Specifications*, A paper presented at the 4th Annual Symposium of the International Center for Aggregate Research (ICAR), Atlanta, Georgia, April, 1996.

10) Jahn, David W., Martin Marietta Technologies, Cincinnati, Ohio, Preprint of a paper entitled *Evaluation of Aggregate Particle Shapes Through Multiple Ratio Analysis* presented at the 8th Annual Symposium of the International Center for Aggregates Research (ICAR), April 12-14, 2000, Denver, Colorado.

11) Dukatz, Ervin L., Vulcan Materials Company-SWD, (now with Mathy Construction), *Practical Factors Influencing Superpave Performance*, A paper presented at the 6th Annual Symposium of the International Center for Aggregate Research (ICAR), St. Louis, Missouri, April, 1998.

12) Weingart, Randy, *personal correspondence* with the writer of this White Paper dated February 23, 2000.

13) Hanf, Kurt, Hanson Aggregates East, Easton, Pennsylvania, *Using Sands and Gravels in Superpave Mixtures,* A paper presented at the 8th Annual Symposium of the International Center for Aggregate Research (ICAR), Denver, Colorado, April, 2000.