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Adjustment to Asphalt Mixtures to Meet Performance Testing Requirements and Allow Innovations

NATIONAL ACADEMIES *Sciences Engineering Medicine*

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Adjustment to Asphalt Mixtures to Meet Performance Testing Requirements and Allow Innovations

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Introduction

Tim Aschenbrener
Federal Highway Administration

Asphalt mixture mechanical tests [e.g., Hamburg wheel-track (HWT), asphalt pavement analyzer, indirect tensile cracking] are growing in use by numerous state departments of transportation (DOTs) as part of their standard material specifications to complement volumetric properties and help ensure satisfactory asphalt mixture performance. These mechanical tests have been used by state DOTs as part of their balanced mix design (BMD) process on pilot, shadow, or standard asphalt pavement projects. Efforts are also being made by some state DOTs to advance mechanical tests within their long-life asphalt pavement program or their mechanistic-empirical pavement design process. Thus, with well-developed asphalt mixture mechanical test methods and practices, state DOTs, contractors and consultants have valuable experiences and lessons learned in designing mixtures and adjusting those mix designs to meet mechanical test requirements.

Workshop 1059 on Adjustment to Asphalt Mixtures to Meet Performance Testing Requirements and Allow Innovations was held at the 103rd Annual Meeting of the Transportation Research Board (TRB) in January 2024. With the increased focus on using mixture performance tests for mix design and in some cases acceptance, questions have arisen on how to adjust mix designs. The takeaways for

- State DOTs: understand options needed to create flexibility within specifications to allow for appropriate adjustments to meet performance test requirements to allow innovation. In other words, in current specifications, what requirements can be relaxed? What requirements should be kept?
- Contractors: understand options on improving mix designs to meet mixture performance tests using fundamentals and innovation. What changes in aggregates, aggregate gradation, volumetric properties, binder properties, etc. can be used to improve performance test results?

The workshop objective was to have an improved understanding of options for state DOTs to specify BMD and for contractors to adjust mixtures to meet performance test requirements and determine what techniques are effective. More than 200 participants attended the workshop in person.

The workshop was moderated by Tim Aschenbrener from the Federal Highway Administration (FHWA) and Jhony Habbouche from the Virginia Transportation Research Council (VTRC). Part of the workshop interaction was to allow the participants to share their opinions in real time using Mentimeter. The Mentimeter polling was managed by Derek Nener-Plante of FHWA. The first speaker was Elie Hajj of University of Nevada, Reno, who set the stage with BMD, approaches and overview of each presenter. The next speaker, Tom Bennert of Rutgers University Center for Advanced Infrastructure and Transportation (CAIT) presented an overview of various techniques to adjust asphalt mixtures being used currently by several experienced mix designers. This was followed by a presentation by Anas Jamrah of Marathon Petroleum Company LP discussing the impacts of binder source and how mix adjustments could be made to meet performance tests. The next speaker, Randy West of Auburn University, presented the four BMD approaches with the motivation of moving towards Approach D. The final presentation of the session was by Nathan Moore of the National Center for Asphalt Technology (NCAT) offering four real-life case studies of mix adjustments made by contractors with options for the participants to select.

This E-Circular provides a synopsis of the session by including key figures along with a synthesis of the points delivered by each of the five presenters. The material included in this E-Circular provides a valuable reference for moving forward with implementation of BMD.

ACKNOWLEDGMENTS

Standing Committee on Asphalt Materials Selection and Mix Design (AKM30) thanks Thomas Bennert, Elie Hajj, Anas Jamrah, Nathan Moore, and Randy West, presenters; Tim Aschenbrener and Jhony Habbouche, moderators; and Derek Nener-Plante for managing the Mentimeter polling. The committee also thanks all the participants at the session for sharing their valuable insight, experience, and knowledge.

The following TRB Standing Committees were cosponsors of the workshop, and their contribution has been key to the event success.

- Standing Committee on Production and Use of Asphalt (AKM10),
- Standing Committee on Binders for Flexible Pavement (AKM20), and
- Standing Committee on Asphalt Mixture Evaluation and Performance (AKM40).

A special recognition goes to the people that planned and organized the workshop and prepared this document.

- Tim Aschenbrener, FHWA, AKM30 Committee Member;
- Thomas Bennert, Rutgers University, CAIT, AKM10 Committee Member;
- Jenna Bowers, Ingevity, AKM30 Committee Chair;
- Stormy Brewster, Marathon Petroleum Company LP, AKM30 Committee Friend;
- Cristian S. Clopotel, Ph.D., Marathon Petroleum Company LP;
- Lora C. Collins, Marathon Petroleum Company LP;
- Mohab El-Hakim, Manhattan College, AKM30 Committee Member;
- Jhony Habbouche, VTRC, AKM20 Member;
- Elie Hajj, University of Nevada, Reno, AKM10 Committee Member;
- Anas Jamrah, Marathon Petroleum Company LP, AKM30 Committee Friend;
- Nathan Moore, NCAT, AKM30 Committee Friend;
- Derek Nener-Plante, FHWA, AKM10 Committee Member;
- Jo Sias, University of New Hampshire, AKM30 Committee Member;
- Randy West, Auburn University, AKC60 Committee Member; and
- Fan Yin, NCAT, AKM30 Committee Research Coordinator.

Mix Design Versus Acceptance

Setting the Stage

ELIE HAJJ
University of Nevada Reno

A workshop on “Adjustment to Asphalt Mixtures to Meet Performance Testing Requirements and Allow Innovations” was held on Sunday, January 7, during the 2024 TRB Annual Meeting (Figure 1). The workshop spanned 3 h, with five speakers and one overall question-and-answer session. The workshop aimed to address challenges often faced with adjusting mix designs to meet performance testing requirements for BMD of asphalt mixtures. Key takeaways from the workshop included:

- Provide state DOTs with potential options for modifying specifications to allow for appropriate adjustments to meet performance test requirements using fundamentals and innovation.
- Offer examples to contractors on ways to improve and adjust mix designs to meet performance testing criteria through both traditional methods and innovative approaches.

FIGURE 1 Title slide for the TRB Workshop 1059.

The workshop sought to enhance participants' understanding of available strategies for adjusting asphalt mixtures to meet performance test requirements and identify effective techniques for achieving desired outcomes.

Figure 2 summarizes the five presenters for the workshop and their respective topics. The workshop was moderated by Tim Aschenbrener from FHWA and Jhony Habbouche from VTRC.

Several Mentimeter polls were created and implemented throughout the presentation. The Mentimeter polling was managed by Derek Nener-Plante from FHWA. Figure 3 summarizes sectors represented by the workshop participants. More than 200 participants attended the workshop. A total of 65 participants responded to the poll and were distributed as follows:

The concept of BMD for asphalt mixtures, as outlined in the American Association of State Highway and Transportation Officials' (AASHTO's) Standard Practice for Balanced Design of Asphalt Mixtures [PP 105-20 (2022)], represents a comprehensive framework aimed at achieving optimal asphalt mixture performance (*1*, *2*). This approach is defined as utilizing mechanical tests that are correlated to field performance, conducted on appropriately conditioned specimens. These tests address various modes of distress experienced by an asphalt concrete (AC) layer, while considering factors such as mixture aging, traffic patterns, climate conditions, and the specific location within the pavement structure.

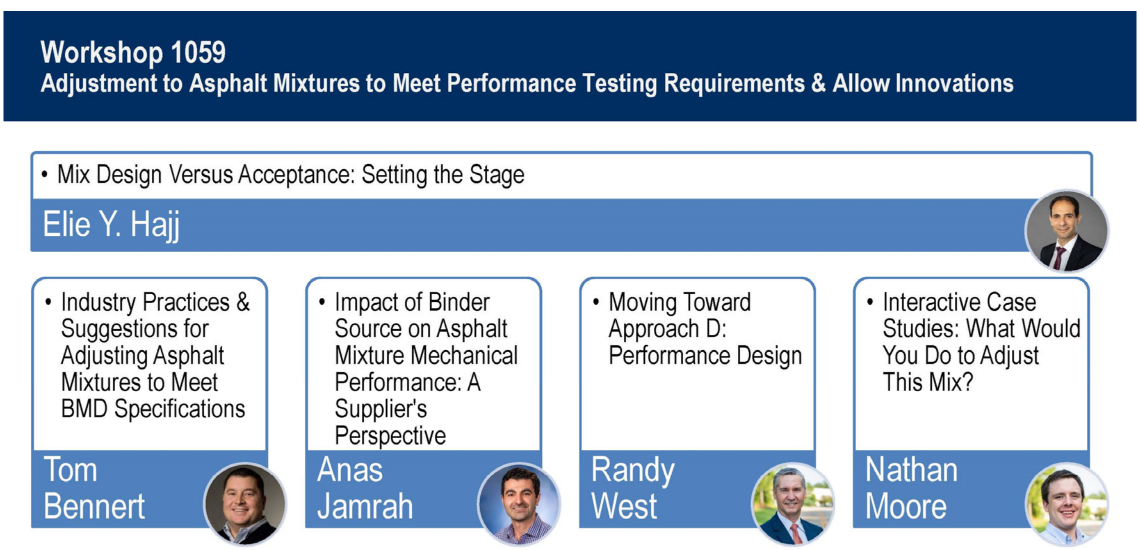


FIGURE 2 Workshop presenters and their respective topics.

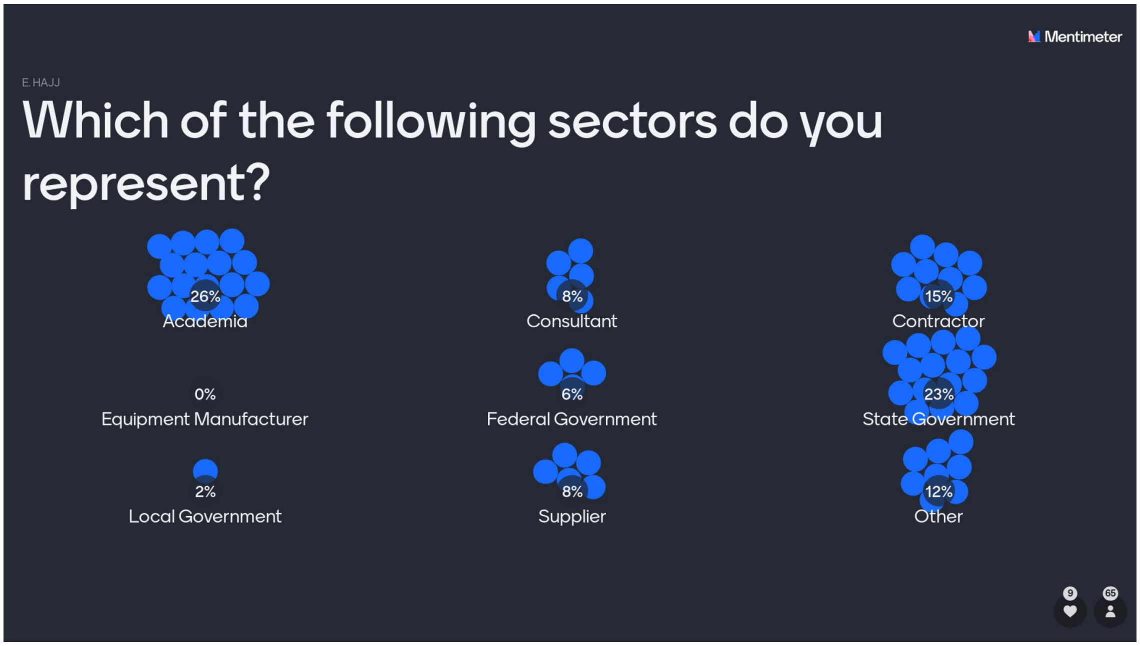


FIGURE 3 Voting results indicating the sectors represented by workshop participants.

In other words, BMD serves as a design “philosophy” that focuses on tailoring asphalt mixtures to address the range of key distresses pertinent to the climate and traffic conditions at the project. The BMD underscores the importance of aligning mix design with the unique environmental and structural requirements for each project to enhance the longevity and durability of asphalt pavements.

Figure 4 shows the traditional volumetric mix design approach, which involves the selection and design of aggregate gradation and determination of mixture proportions based on volumetric requirements. Whether a mix design is developed through a Marshall, Hveem, or Superpave mix design process there are basic volumetric requirements that the asphalt mixture must be designed to meet. In these traditional methods the process of air voids (AV), voids in mineral aggregate (VMA), and voids filled with asphalt (VFA) must fall within a specified range to meet the design requirements specific to the method. The process involves determining the optimum asphalt binder content (OBC) to achieve 4% AV in compacted specimens under a specified compaction effort. Subsequently, the remaining volumetric properties are evaluated at the selected OBC to ensure compliance with respective criteria.

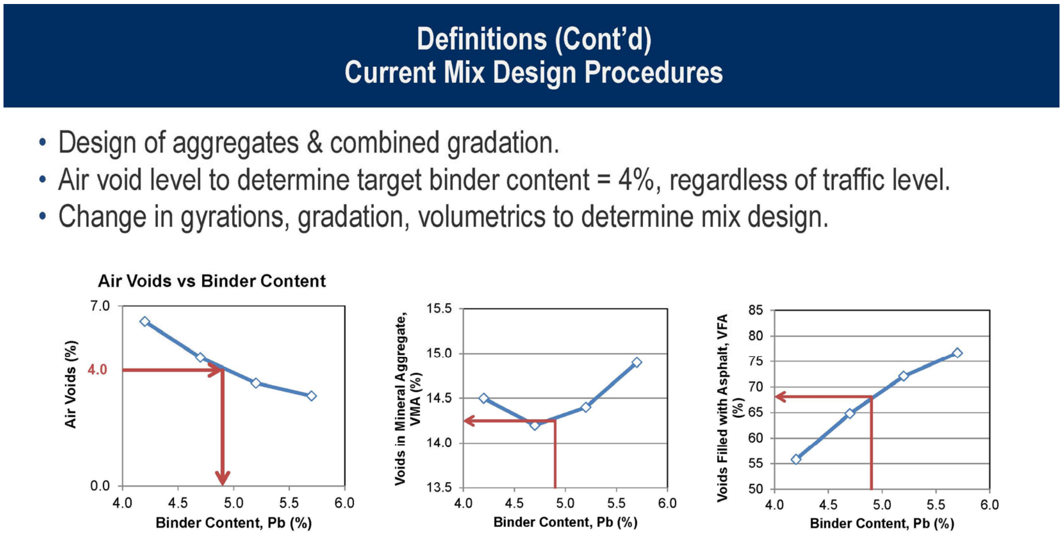


FIGURE 4 Traditional volumetric-based mix design.

The initial concept of BMD for asphalt mixtures is illustrated in Figure 5. The focus was mainly on increasing asphalt binder content in asphalt mixtures to improve their cracking resistance without jeopardizing rutting resistance. The range of acceptable asphalt binder contents is then limited by a minimum value to meet cracking resistance and maximum value to meet rutting resistance.

Figure 6 shows an example of mechanical testing diagram for BMD. The red and blue dashed lines represent the criterion for each of the BMD test parameters for cracking and rutting, respectively. Four quadrants are presented in the diagram: a red quadrant representing the zone for asphalt mixtures failing both rutting and cracking tests criteria, a green quadrant representing the zone for asphalt mixtures passing both rutting and cracking tests criteria, and two purple quadrants representing the zone for asphalt mixtures passing either the rutting or the cracking tests criteria. Multiple strategies for adjusting asphalt mixtures proportions and components, besides increasing asphalt binder content, are available for shifting an asphalt mixture to the green quadrant from any of the other three quadrants. Examples and case studies will be provided by the workshop speakers.

Mechanical tests are the basis of the BMD process. They allow for the assessment of potential performance issues with an asphalt mix design. A variety of mechanical tests are available to evaluate the performance of asphalt mixtures against specific types of distress (e.g., rutting, cracking, moisture damage) (Figure 7). While several factors can influence the selection and adoption of BMD tests, it is essential to ensure that the tests align with the specific failure

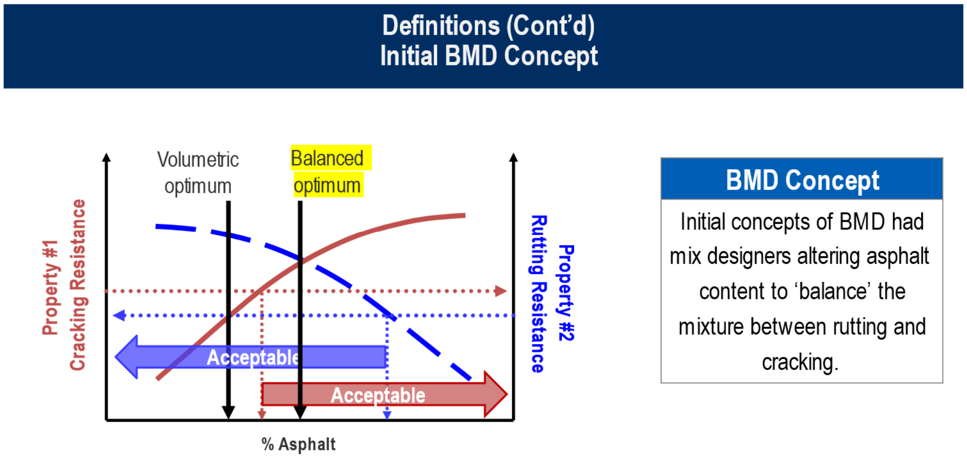


FIGURE 5 Illustration of initial concept of BMD.

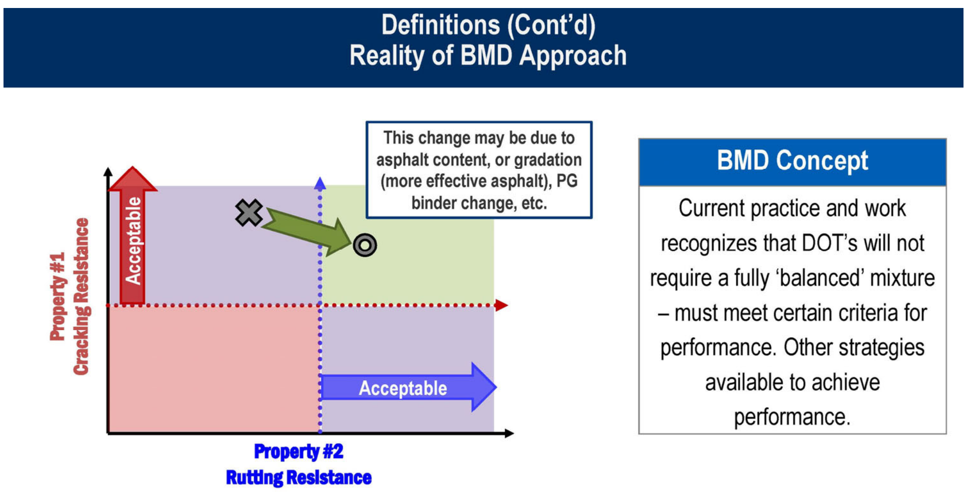


FIGURE 6 Mechanical testing diagram for BMD.

FIGURE 7 BMD mechanical tests.

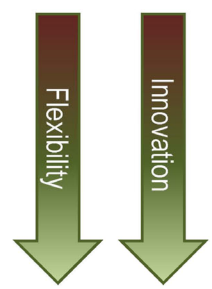
mechanisms associated with the distresses they are intended to address. Previous efforts presented key factors to be considered when selecting a BMD test for mix design and acceptance (*3*, *4*). These evaluation factors were presented as part of an approach for screening and assessing the overall appropriateness of specific mechanical tests for use in a BMD process. It should be noted that the selection of BMD tests will depend on the agencies' specific needs, goals, and internal resources.

The different approaches of BMD are outlined in the AASHTO PP105-20 (2022) Standard Practice (*1*, *2*). The four approaches aim to provide different levels of flexibility and adaptability in achieving an optimized asphalt mix design that meet the BMD mechanical tests criteria (Figure 8).

- **Approach A—Volumetric Design with BMD Verification**. This approach starts with the traditional volumetric mix design method (i.e., Superpave, Marshall, or Hveem) to determine the OBC. The asphalt mixture at the OBC is then subjected to additional mechanical tests to assess its resistance to common distresses such as rutting, cracking, and moisture damage. If the mix design meets the test criteria, the job mix formula (JMF) is established and production can start. If not, the mix design process is repeated by adjusting either mixture proportions or materials until all volumetric properties and BMD test criteria are met.

Standard Practice for Balanced Design of Asphalt Mixtures
AASHTO PP 105-20 (2022)

APPROACH	VOL. REQUIREMENTS (e.g., Va, VMA, VFA, Pbe, DP)	PERF. REQUIREMENTS
A—Vol. Design with Perf. Verification	Full compliance at OBC.	Full compliance.
B—Vol. Design with Perf. Optimization	Full compliance at preliminary OBC. Adjust specific parameters at final OBC (e.g., VMA relaxed).	Performance optimization through moderate changes in binder content.
C—Performance-Modified Vol. Design	Some requirements relaxed or eliminated (e.g., no Va limit or Va range)	Performance optimization by adjusting initial binder content or mixture component properties or proportions.
D—Perf. Design	Limited or no requirements.	Performance optimization by adjusting mixture components and proportions.[a]



OBC=optimum binder content.

[a]State DOT may set minimum requirements for binder quality & aggregate properties.
Once lab test results meet performance criteria, mixture vol. properties may be checked for use in production.

FIGURE 8 Summary of BMD approaches and their volumetric and performance requirements.

- **Approach B—Volumetric Design with BMD Optimization**. Like Approach A, this approach starts with the traditional volumetric mix design method to determine a preliminary OBC. The asphalt mixture at the preliminary OBC and two or more additional contents is then subjected to mechanical tests. The final OBC that meets all BMD test criteria is determined. If not, the mix design process is repeated by adjusting either mixture proportions or materials until BMD test criteria are met. This approach necessitates relaxation of some volumetric properties such AV content (e.g., allow for a lower target AV) or VMA.
- **Approach C—BMD-Modified Volumetric Design.** This approach starts with the traditional volumetric mix design method (i.e., Superpave, Marshall, or Hveem) to establish preliminary component material properties, proportions, and preliminary asphalt binder content. The mechanical test results are then used to adjust either the preliminary asphalt binder content or the mixture component properties or proportions until the tests criteria are met. For this approach, the final design is optimized based on the mechanical tests and may not necessarily meet all mix design volumetric criteria. This approach allows for greater flexibility in modifying certain volumetric properties to meet BMD tests criteria. For instance, some of the properties that may be relaxed or adjusted under Approach C include AV, VMA, VFA, and aggregate consensus properties.
- **Approach D—BMD Design Only**. This approach focuses primarily on mechanical tests criteria to determine and adjust mixture components and proportions with limited or no requirements for volumetric properties. It offers the highest level of flexibility and innovation potential. The agency may set minimum requirements for asphalt binder quality and aggregate properties. Examples of requirements that can be relaxed or eliminated during mix design include volumetric criteria (AV, VMA, VFA); aggregate gradation bands; aggregate consensus properties; recycled materials content; asphalt binder performance grade; additives (e.g., warm mix additives, liquid anti-strip) and modifiers (e.g., polymer modification) usage. Once the mechanical test results meet the BMD criteria at the mix design and verification stages, the mixture volumetric properties may be checked for use in production.

Figure 9 summarizes the typical procedure to verify that plant-produced asphalt mixtures meet the BMD requirements. It starts with contractors developing the laboratory mix design and agencies approving the JMF. This is followed by contractors developing a quality control plan outlining procedures for monitoring and controlling mix production, including sampling and testing

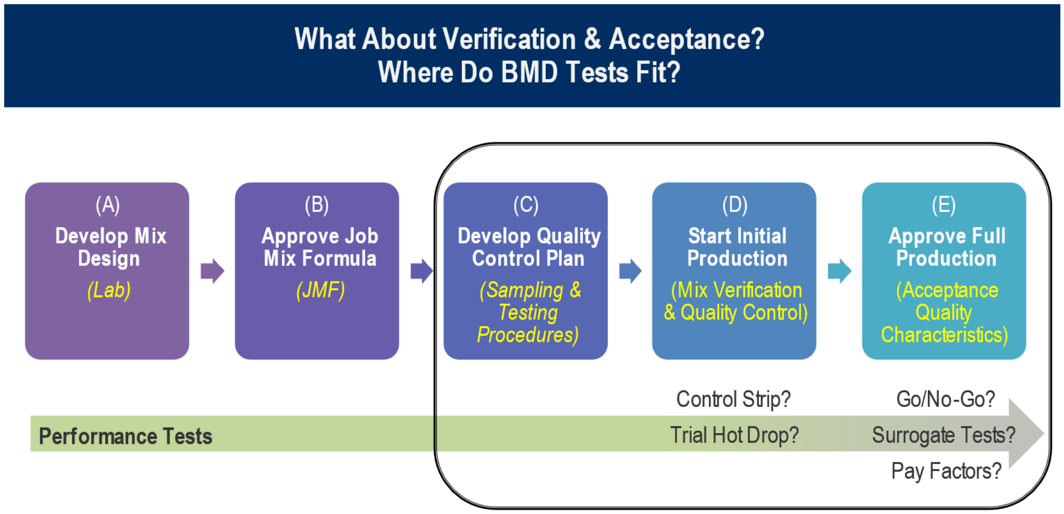


FIGURE 9 Typical steps for asphalt mix design, verification, and production.

procedures. Subsequently, the mix design verification is conducted on plant-produced asphalt mixtures using the actual hot-mix asphalt plant facility and actual project materials. The mix design verification, which is considered a critical step with BMD, is typically done on the first day of production, as part of a control strip or a trial hot drop. If deemed necessary, the contractor needs to adjust the asphalt mixture to bring the characteristics into compliance with JMF target tolerances. In case of changes in mixture proportions or components, a new JMF or a full redesign may be necessary. When approved for full production, the mechanical tests may be used as go/no-go, surrogate tests, or for pay factors. The challenge with implementing BMD tests during production lies in the quick turnaround time and the frequency of testing during production.

The adoption of BMD involves a shift from traditional volumetric-based design towards a mix design method that focuses on the performance of asphalt mixtures under applied traffic and environmental conditions. This shift necessitates a re-evaluation of the traditional acceptance quality characteristics (AQCs) to ensure that the asphalt mixtures delivered in the field meet the intended performance requirements. Thus, additional considerations for defining AQCs when implementing BMD include, but not limited to (Figure 10):

- BMD test methods precision and bias.
- Understanding and quantifying production variability.
- Supporting and maintaining personnel training or certification and laboratory accreditation for BMD tests.
- Selecting traditional AQCs that may be eliminated to allow for the use of BMD tests during for acceptance without jeopardizing quality.

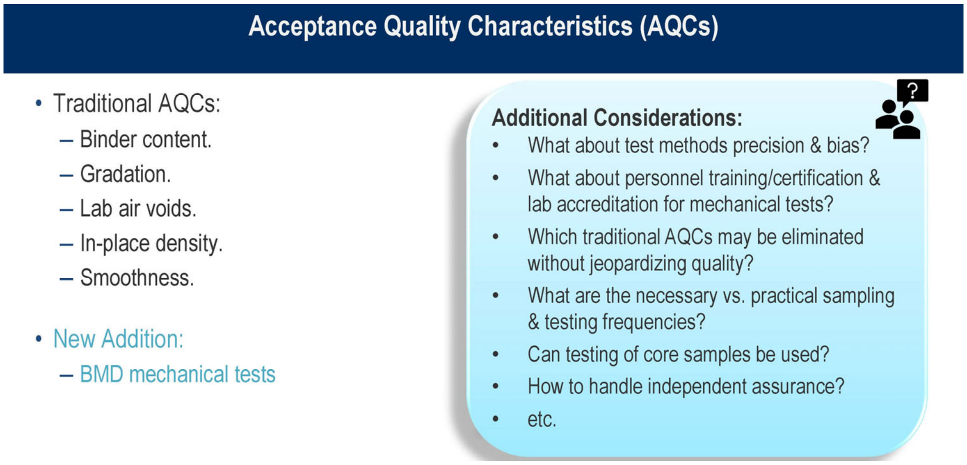


FIGURE 10 Additional considerations for AQCs with BMD.

- Identifying the necessary versus the practical sampling and testing frequencies and quantifying associated risks.
- Defining methods to handle independent assurance.

Figure 11 summarizes the Mentimeter poll results for the workshop participants with the BMD concept and mix adjustments to meet BMD tests criteria. A total of 75 responses were received. In general, most respondents had a level of familiarity with the BMD concept, with only a few indicating no competence in this area. On the other hand, the responses ranged across the spectrum when it came to the participants' proficiency in adjusting to meet BMD test criteria, ranging from no competence to high competence levels. Thus, supporting the need and timing of this workshop to bridge the gap in knowledge by proving the attendees with real-world examples and effective means in adjusting asphalt mixtures.

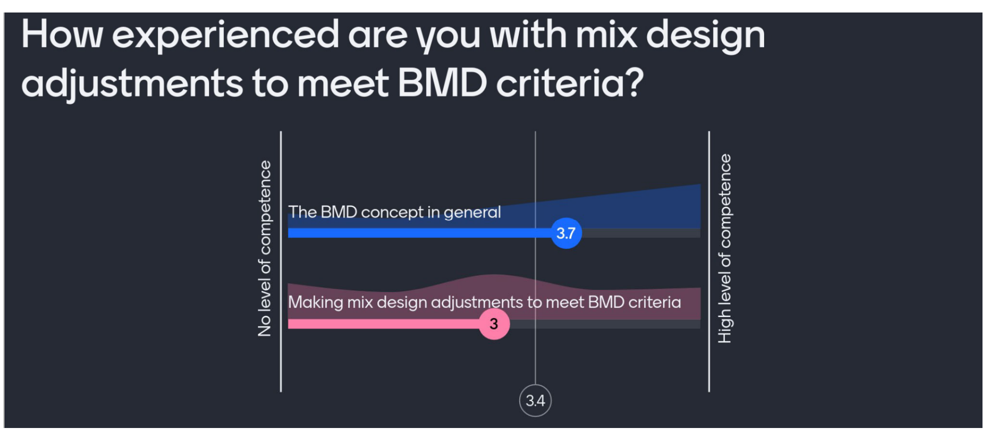


FIGURE 11 Voting results for workshop participants' experience with BMD concept and mix design adjustments.

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Industry Practices and Suggestions for Adjusting Asphalt Mixtures to Meet Balanced Mix Design Specifications

THOMAS BENNERT

Rutgers University, Center for Advanced Infrastructure and Transportation

The general approach of the study was to interview seven industry personnel of diverse regionality and organizationally backgrounds to get their experiences and thoughts on BMD. The interviews spanned over 2 days along with a post interview session to ensure accuracy of the information collected during the interviews (Figure 1).

The presentation organization was broken down into five sections:

1. The interviewees and their respective backgrounds;
2. The BMD approaches the interviewees have experience in, why they chose to use them, and the mechanical performance tests they used;
3. The adjustments to asphalt mixtures the interviewees recommended to meet BMD performance criteria;
4. Suggestions the interviewees provided to help improve the implementation of BMD; and
5. The final conclusions and takeaways from the interviews.

FIGURE 1 Study methodology: Interviews with seven diverse industry personnel on BMD were conducted over 2 days, with a follow-up session to confirm accuracy..

The interviewees have a combined experience of almost 200 years working on asphalt related research and projects. Their backgrounds ranged from previous positions at FHWA and research institutions to asphalt production and construction facilities (Figure 2; Table 1).

The interviewees noted that a majority of their work in BMD has been utilized through Approach A (Figure 3; Table 2). This approach utilizes volumetrically designed asphalt mixtures that must meet performance test criteria. While some worked with Approaches B and C, it was

TABLE 1 Interviewees and Their Combined Experience Working on Asphalt-Related Research and Projects

Interviewee	Current Position and Organization	Number of Years in Current Position / Industry	Position/Experience with Other Organizations
Ramon Bonaquist	Chief Operating Officer, Advanced Asphalt Technologies	24 / 36 years	Research engineer, FHWA (10 years)
Andrew Hanz	Vice President of Technology and Research, Mathy Construction	8 / 23 years	Graduate student/ postdoctoral associate at University of Wisconsin, Madison
Brian Prowell	Principal Engineer, Advanced Material Services	15 / 31 Years	Assistant director, NCAT; VTRC; instructor, Virginia Tech
Michael Kleames and Marty McNamara	Quality Manager III and Director of Quality Control, Granite Construction	7 / 21 years 21 / 25 years	Geotechnical consultant for private consultants and consultants focusing on pavement management systems and pavement design
Philip Blankenship	Owner and CEO, Blankenship Asphalt Tech and Training	4 / 30 years	Asphalt Institute; Kentucky Transportation Cabinet; Koch Industries
Greg Rose	Quality Manager, Barre Stone Products	6 / 37 years	Material producer for private firms (30 years)
Pat Koester	Vice President of Production, Howell Paving Inc.	17 / 42 years	Illinois DOT, District 7 (10 years)

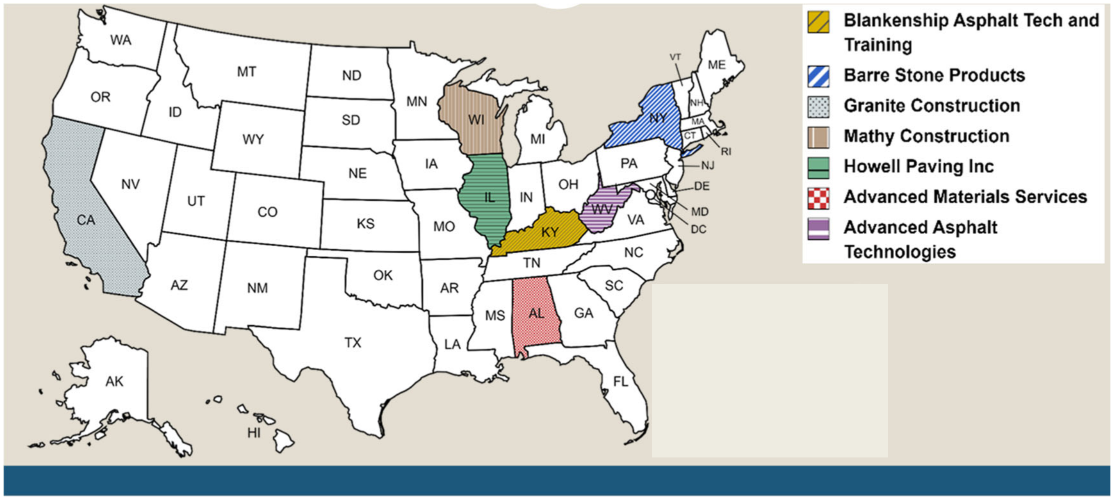

FIGURE 2 Interviewees experiences at FHWA, research institutions, and asphalt production and construction facilities around the country.

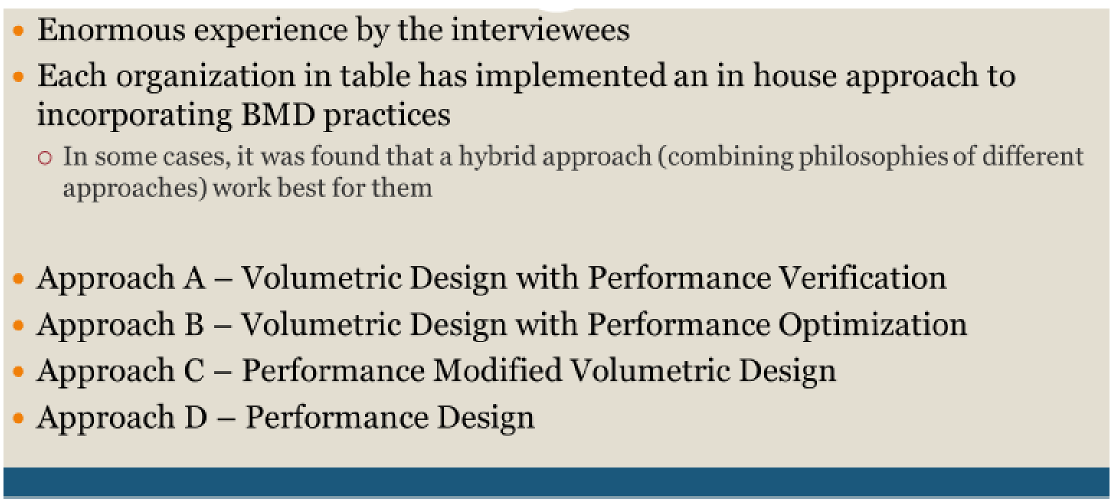

FIGURE 3 Interviewee and organization experience with BMD approaches.

mostly utilizing state specifications that had modifications applied to volumetric and gradation tolerances to commonly allow more asphalt binder in the mixtures. However, California DOT (CalTrans) did utilize an Approach D in a large Interstate project that Granite Construction was involved in the production and construction of the asphalt materials.

When asked what volumetric criteria the interviewees thought was critical in meeting BMD performance criteria, the common responses from the interviewees were generally around volumetric parameters that increased the effective asphalt binder content of the asphalt mixtures (Figure 4). VMA and VFA were the predominant volumetric parameters mentioned. In addition, the interviewees all agreed that state agencies may need to modify existing air void

TABLE 2 Interviewee and Organization Experience With BMD Approaches

Organization	States Worked with on BMD Projects	BMD Approach	Number of Annual Projects/ Asphalt Mixture Tonnage
Advanced Asphalt Technologies	Pennsylvania	Approach A	Research and development projects
Mathy Construction	Wisconsin, Minnesota, Iowa	Approach A	30 to 40 projects
Advanced Materials Services	Alabama, New Jersey, Florida, California, Arizona	Approach A Approach B Approach C for 50% reclaimed asphalt pavement	15 to 20 projects. Multiple projects for high-performance racetracks and port facilities
Granite Construction	California	Approach D	238,300 tons (2020 and 2021 paving seasons)
Blankenship Asphalt Tech and Training	Kentucky	Approach A Kentucky still in BMD implementation	10 to 20 projects
Barre Stone Products	New York	Approach A	25,000 to 100,000 tons a year
Howell Paving Inc.	Illinois	Approach A Approach B	Varies

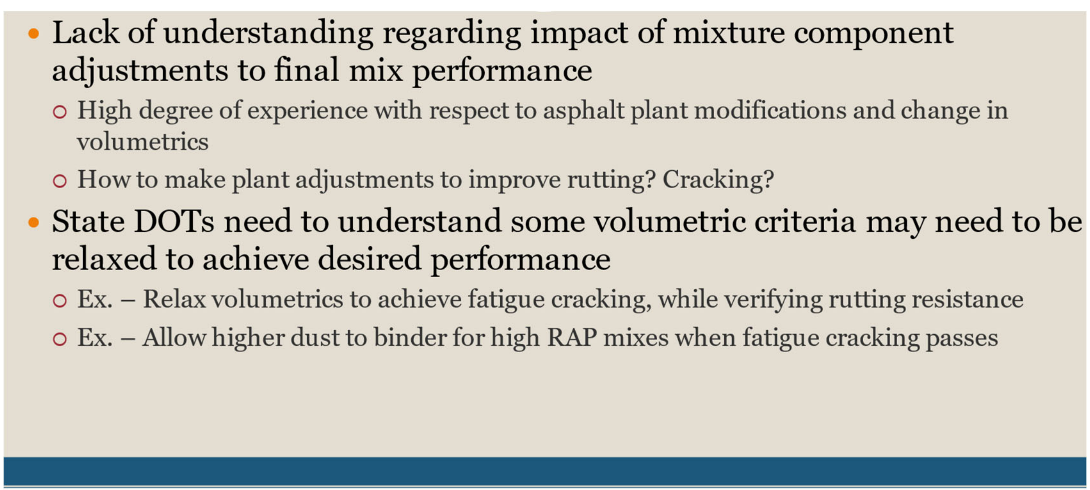

FIGURE 4 BMD approach considerations: volumetric properties versus mechanical testing.

tolerances to allow more asphalt binder in the mixtures. The consensus was that if the state agency is going to verify rutting and cracking performance, existing criteria like AV could be modified without the fear of the asphalt mixture having performance issues.

Interviewees were also asked about their experience and preference in use of mechanical performance tests (Table 3). Most of the interviewees appreciated and trusted some of the more simple performance tests, such as the high temperature indirect tension test (HT-IDT), IDEAL-CT cracking index, and IDEAL-RT rutting index tests, especially during production. However, the HWT test was a test that interviewees had experience with, most likely due to the state agency specification(s) that were accustomed to working with.

TABLE 3 Interviewees' Experience and Preference in Use of Mechanical Performance Tests

Organization	Volumetric Properties	Mechanical Tests for Mix Design	Mechanical Tests for Production or Quality Control
Advanced Asphalt Technologies	AV Binder Content by Volume	HT-IDT IDEAL-CT	HT-IDT IDEAL-CT
Advanced Materials Services	AV VMA VFA	HWT IDEAL-CT	HWT
Granite Construction	VMA AV OBC DPe	Flow Number (FN) HWT SCB	FN HWT SCB
Blankenship Asphalt Tech and Training	VMA Air Voids	HWT IDEAL-RT IDEAL-CT	HWT IDEAL-RT IDEAL-CT
Barre Stone Products	VMA AV VFA	HT-IDT IDEAL-RT SCB IDEAL-CT	N/A
Howell Paving Inc.	VMA AV VFA Asphalt Content	HWT SCB I-FIT TSR	HWT SCB I-FIT

NOTE: N/A = not available.

The interviewees voiced their concerns with respect to state agencies moving directly from a volumetrically based mix design and acceptance approach to a purely performance-based approach (BMD Approach D). The interviewees felt there is a lack of understanding regarding how volumetric and mixture component adjustments impacted final mixture performance. Most mix designers and asphalt plant operators are well versed with making adjustments to meet volumetric parameters such as target AV and VMA, but the interviewees were concerned with a plant operator making appropriate adjustments to improve the rutting and/or cracking performance of an asphalt mixture during production. The interviewees were also concerned that if state agencies were not willing to relax current volumetrics and mixture constituents, it would be quite difficult to meet the minimum performance requirements desired by the agency.

To be implemented confidently, the interviewees did agree that proper asphalt mixture conditioning to represent aged conditions in the field were important for proper cracking evaluations (Figure 5). However, this will be very difficult to implement in a time effective manner for quality control (QC) testing during plant production. There are some research initiatives that have begun or planned to begin on both a state and national level that may provide a better understanding on how to properly implement a conditioning protocol within BMD. Unfortunately, some of the interviewees thought that the real benefit may only be witnessed during the design phase and QC testing may need to be simplified and conducted without additional conditioning. Work conducted by Ramon Bonaquist during a Wisconsin DOT research project noted that the best predictor of long-term conditioned asphalt mixture cracking performance was the short-term conditioned cracking performance. This illustrates that perhaps a “correction factor” can be developed during mixture design which relates short-term aged cracking performance to long-term aged cracking performance that could be implemented during QC performance testing.

Each Interviewee’s preference and recommendations on how to adjust asphalt mixtures to meet performance testing was noted and presented. Ramon Bonaquist of Advanced Asphalt Technologies (AAT) noted that to help meet cracking tests, increasing effective asphalt binder content was critical (Figure 6).

Mix designers should also pay close attention to the recycled asphalt amount and quality as this greatly impacts mixture cracking. In addition, if low-temperature cracking is a concern, a majority of issues can be resolved as long as the appropriate low-temperature asphalt binder grade is selected and used. Meanwhile, to help address rutting issues, reducing effective asphalt content and incorporating an asphalt binder with a higher stiffness at high temperatures

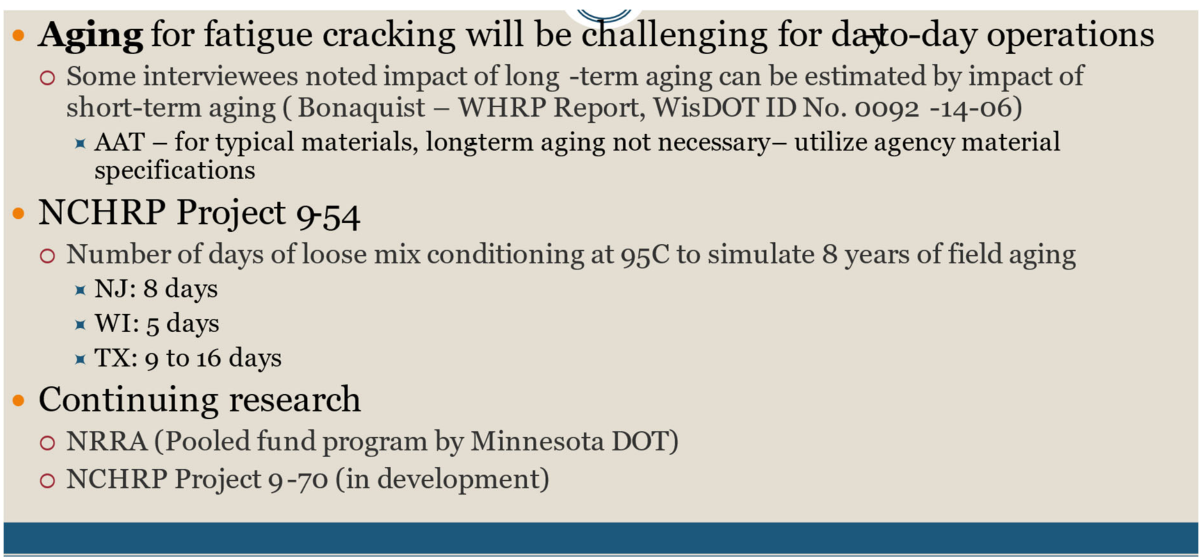

FIGURE 5 Asphalt mixture conditioning to represent aged conditions in the field.

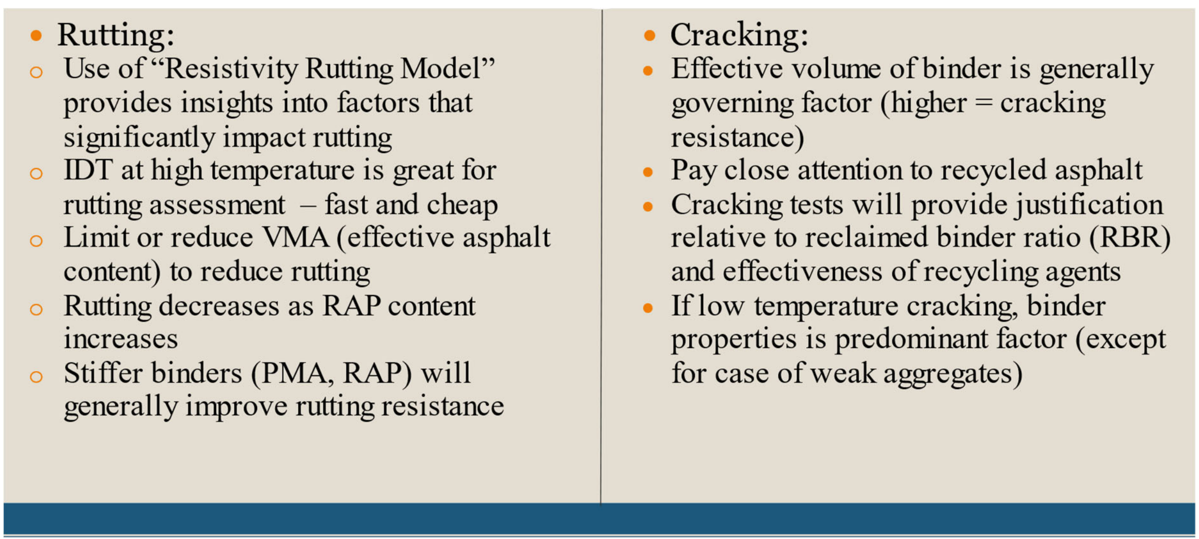

FIGURE 6 Interviewee's preference and recommendations on how to adjust asphalt mixtures to meet performance testing.

was recommended. Bonaquist noted that he has found rutting potential decreases as reclaimed asphalt pavement (RAP) content increases and that the HT-IDT test is a simple, easy method to quickly evaluate rutting potential of asphalt mixtures.

Last, Bonaquist recommended the use of regression-based models to help practitioners, consultants and researchers evaluate the key factors that impact mixture performance. Bonaquist recommended looking that resistivity rutting model developed by AAT during their work on NCHRP Projects 9-25 and 9-31 (Figure 7).

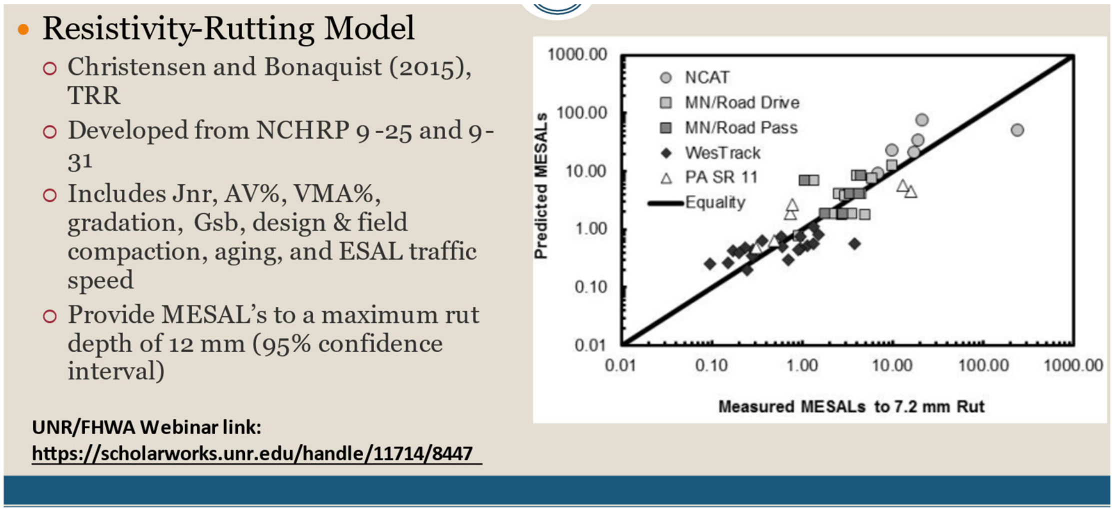

FIGURE 7 Use of regression-based models to help practitioners, consultants, and researchers evaluate the key factors that impact mixture performance: Bonaquist's recommendation.

The resistivity rutting model uses critical asphalt mixture constituents and volumetric parameters to predict rutting in the field (Figure 7). The model can be adjusted for regional temperature effects and time in the field (i.e., field aging). Mix designers can conduct parametric studies with their materials to help determine which material factors can be the most cost-effective to utilize, meanwhile, state agencies can utilize the model to make better decisions regarding modifying specifications to better adapt existing volumetric specifications into BMD-based specifications. For more details, a webinar on "Adjusting Asphalt Concrete Mix Designs to Optimize Laboratory Performance" is available at https://scholarworks.unr.edu/handle/11714/8447.

Brian Prowell of Advanced Material Services (AMS) recommended to utilize a polymer-modified asphalt binder to help meet rutting requirements while also ensuring fine aggregates had good angularity and texture properties (Figure 8). Meanwhile, to meet cracking performance, Prowell recommended that state agencies reduce the target AV requirements in order to increase the effective asphalt binder content of the mixture. Prowell recommended that lower AV and increasing VFA would aid in designing asphalt mixtures with higher VMA, especially when higher RAP contents and/or polymer-modified asphalt binders are to be used. Prowell also noted that AMS prefers to use mechanical performance tests that mirror specific cracking mechanisms for specific pavement structures. For example, for composite pavements, AMS prefers to use the overlay tester to design asphalt mixtures, while for flexible pavements, the bending flexural beam fatigue test is preferred and used.

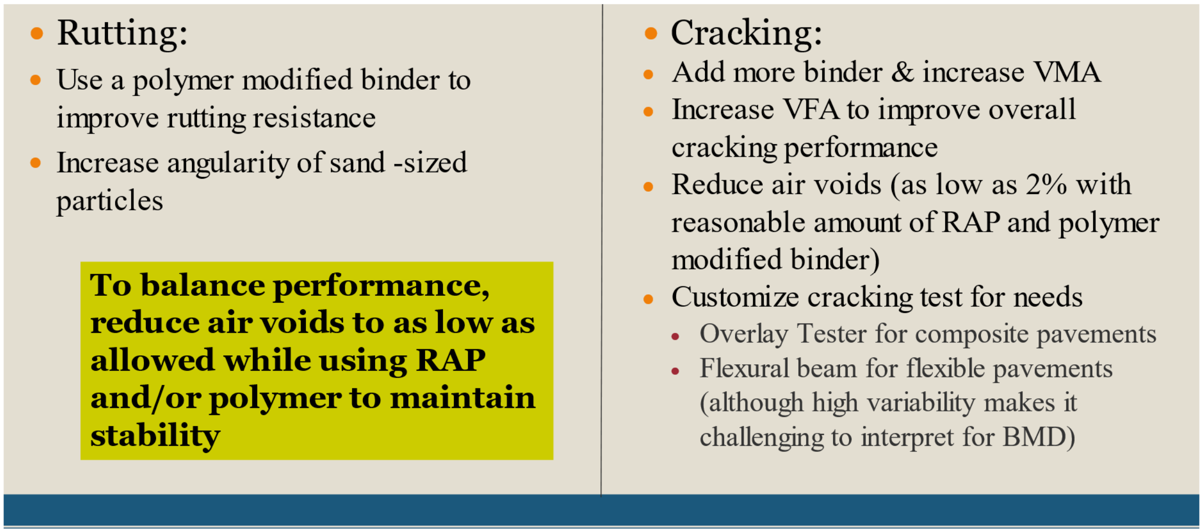

FIGURE 8 Adjustments to asphalt mixture components to satisfy BMD: Prowell' s recommendation.

Phil Blankenship of Blankenship Asphalt Technology and Training (BATT) also noted that fine aggregate angularity and texture were important in developing a rut resistant asphalt mixture and lower levels of natural sand are required if polymer-modified asphalts are not used (Figure 9). Blanksenship mentioned that it is helpful to evaluate different gradation combinations to accommodate both rutting resistance and VMA for durability. In addition, dust quantity and type of dust, matters. With respect to meeting fatigue cracking tests, BATT focuses on apshalt binder quantity and quality, noting that additional asphalt binder may be necessary and softer performance grade (PG) grades have also helped achieving cracking performance. But Blankenship warned that the selection of an appropriate cracking test is important, as BATT have found from personal experience that the IDEAL-CT test may not be as sensitive to polymer modification as other tests.

CalTrans, through a research agreement with University of California–Davis, developed a flowchart methodology to help their mix producers and contractors meet their mechanical performance test requirements. Marty McNamara and Michael Kleames of Granite Construction noted that flowchart methodology has been quite helpful. Based on their personal experience, Granite Construction has found that volumetrics are not impacted by stiffness changes the same way as mechanical performance tests. Therefore, procedures on handling or reheating asphalt materials are critical and found high levels of variability when not consistently followed.

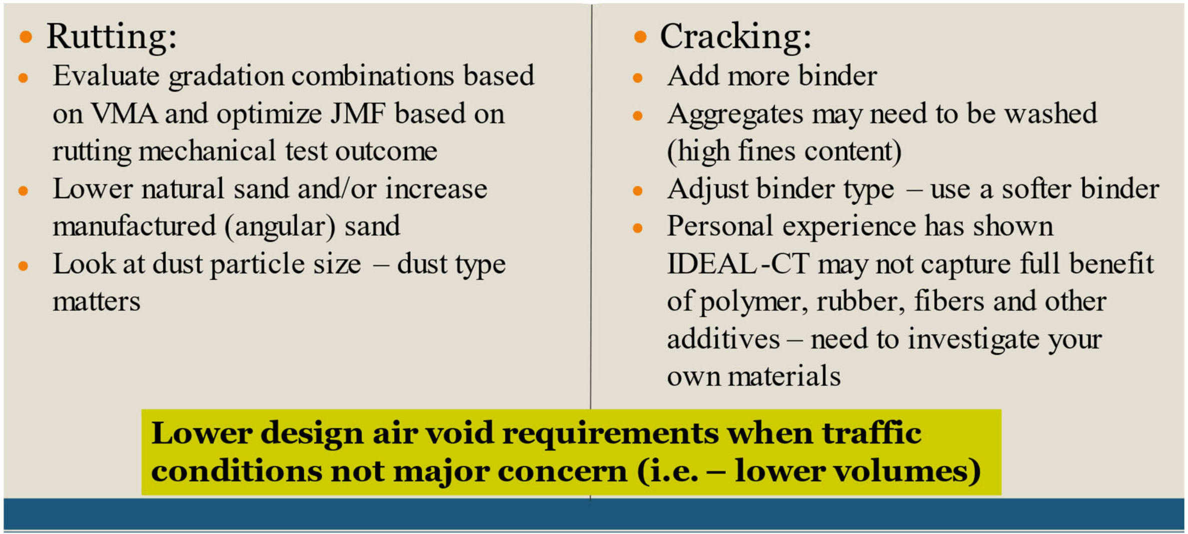

FIGURE 9 Adjustments to asphalt mixture components to satisfy BMD: Blankenship's recommendation.

Some commonalities among the responses of the interviewees were when making any changes, follow a systematic approach and only make one change at a time in order to properly understand the impact of that respective change (Figure 10). For example, if trying to improve fatigue resistance, the following orderly steps could be followed:

1. Adjust gradation off the 0.45-power curve.
2. Reduce natural sand.
3. Adjust dust content if too low.
4. Examine coarse aggregate for crushing.
5. Increase binder content.
6. Decrease RAP content.
7. Change RAP source.
8. Change binger source.
9. Use polymer-modified binder.

And if conducted during plant production, make sure to produce sufficient asphalt mixture through the plant for the change to fully take into effect. For example, if producing through a drum plant, allow 50 to 100 tons of asphalt mixture to be produced before taking a sample for evaluation. Additionally, the interviewees thought that mix design procedures that follow a Bailey

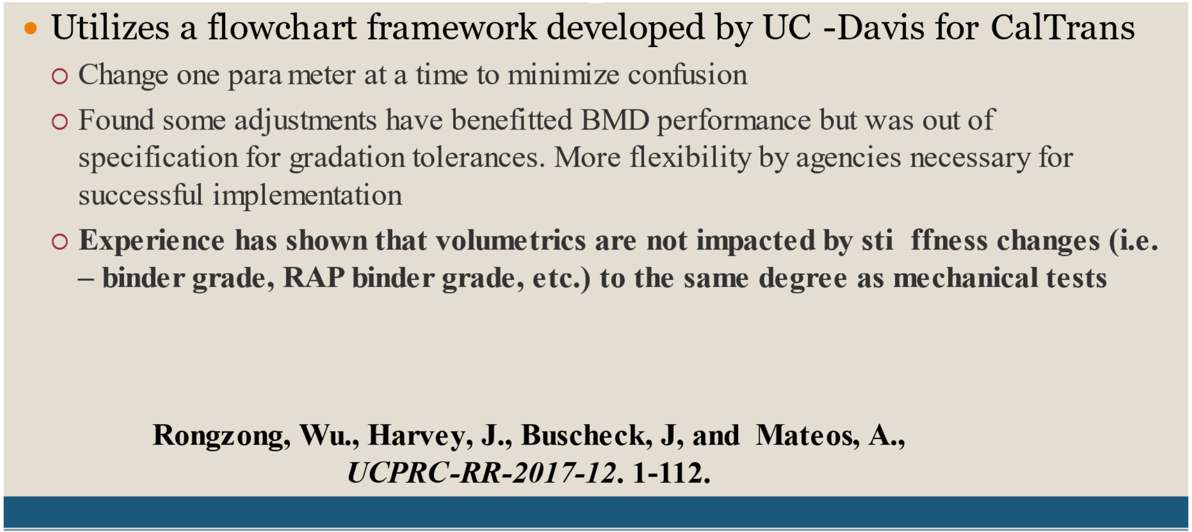

FIGURE 10 A summary flowchart methodology developed by the University of California–Davis to help mix producers and contractors meet mechanical performance test requirements..

method approach can help mix designers design and produce asphalt mixture with sufficient effective asphalt content (Figure 11). The Bailey method also requires the designer to take into consideration the impact of aggregate quality, angularity, and general packing more so than conventional Superpave mix design. These factors can greatly improve mixture performance while being cost-effective.

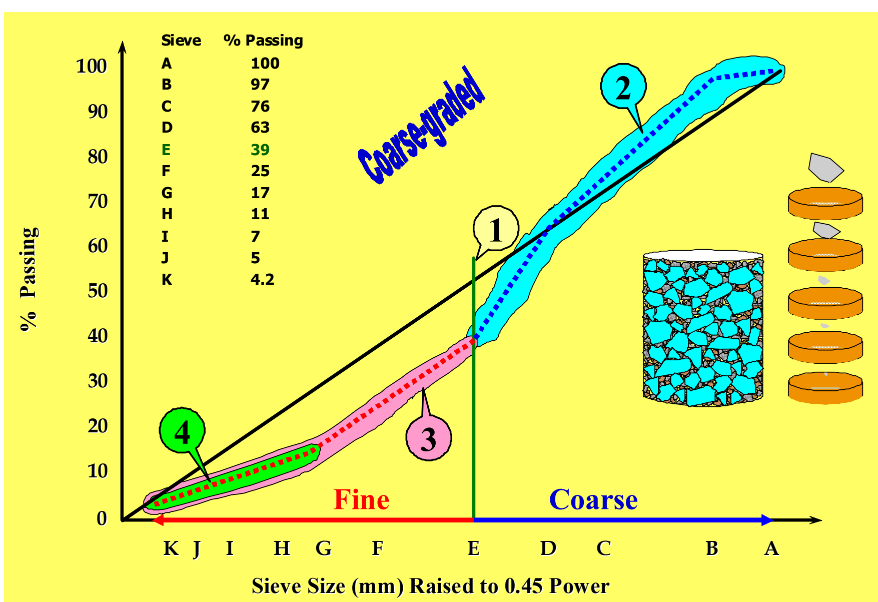

FIGURE 11 Combined blend gradation.

The interviewees all agreed that with the incorporation of performance testing, state agencies need to consider relaxing some of the volumetric design and production parameters, especially AV (Figure 12). Utilize the general methodology by Hveem, which was to try to get as much asphalt binder into the mix until there is a stability concern. BMD allows for this same general approach. The interviewees also stated that mix designers should not solely rely on the mechanical performance tests when adjusting, and that a lot of history exists regarding volumetric impacts on mixture performance, so proper design and adjustments should be a combined approach between good volumetric changes and mechanical performance testing verification.

As the concept of BMD gains greater popularity, the interviewees cautioned there is still work to be done and suggested some improvements as BMD moves forward (Figure 13). One of the biggest issues perceived by the interviewees was the current lack of training regarding BMD. Many state asphalt associations have current training programs for their respective asphalt mix designer and plant operators, but these are volumetric and constituent based. How should a plant operator make adjustments during plant production when the asphalt mixture does not meet a fatigue cracking criterion? Rutting? And although there are some organizations developing programs, such as NCAT, the National Asphalt Pavement Association (NAPA), and even the Virginia DOT in conjunction with the Virginia Education Center for Asphalt Technology, these are exceptions to the norm.

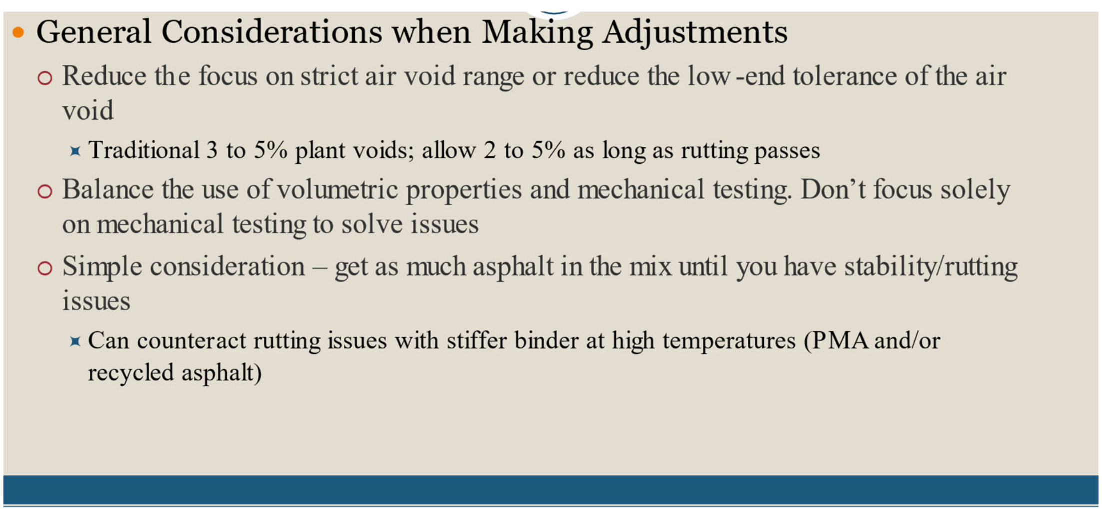

FIGURE 12 General considerations for relaxing some volumetric design and production parameters when incorporating performance testing.

FIGURE 13 Suggestions for improvements moving forward.

Along with proper training and education, there must also be considerations to accreditation (Figure 14). Laboratories are going to be inundated with mechanical performance testing with BMD and the equipment and technicians conducting the testing must be properly assessed and determined whether they meet the minimum requirements and standards. In a similar fashion to what AASHTO Resource currently has for asphalt binder PG testing. Currently, AASHTO only accredits a very small number of mechanical performance tests and does not require proficiency sample program testing for those tests either. An established accreditation program would greatly improve the confidence in moving forward with BMD. State agencies and asphalt user groups need to consider the multiple test methods required in a regional area and determine if this can be simplified to help those asphalt suppliers–contractors supplying in more than one state. Like the prior issues asphalt binder suppliers needing to conduct multiple tests for Superpave Plus specifications for polymer-modified binders had prior to the adoption of the multiple stress creep recovery test.

The interviewees noted that like current volumetric-based Superpave mix design practice, BMD criteria should be tied back to structural design approaches (Figure 15). The same asphalt mixture at the base of the low-volume road should not require the same level of mechanical test performance as the surface course of an Interstate highway. An example is shown how the New Jersey DOT handles this approach with their high RAP asphalt mixture BMD Approach B specification. In addition, if an asphalt producer provides an asphalt mixture that far exceeds the required mechanical test performance requirements, should a pay adjustment be provided?

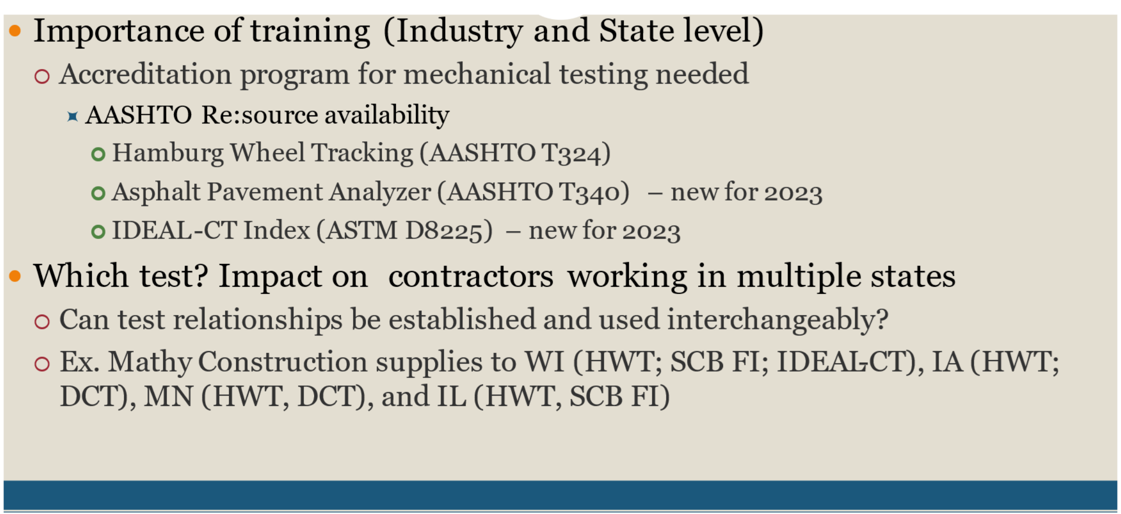

FIGURE 14 Suggestions for improvements moving forward, continued.

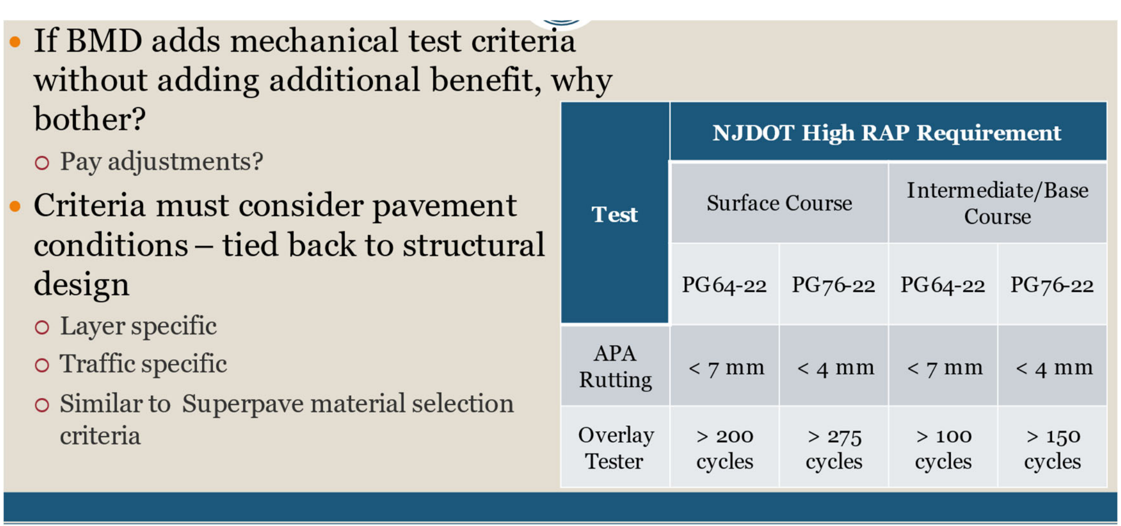

FIGURE 15 Suggestions for improvements moving forward, continued.

What is the current incentive of an asphalt mixture supplier to provide a product above the criteria as opposed to barely meeting spec?

In summary, although the interviewees believe moving towards BMD will improve asphalt material and pavement performance, there are several areas that still needs to be considered and protocols developed for (Figure 16). These include, but not limited to

- How will a state agency handle variability in performance results between the contractor and the state agency test labs?

- Can the same performance criteria be used for both lab-produced/mix design and asphalt mixtures produced at the plant?
- Ensure that proper training on specimen preparation, specimen handling, mechanical testing practices and how to make proper mixture adjustments when not meeting criteria is provided.
- Encourage accreditation when available, but until implemented, utilize round robin testing to gain testing experience and help identify poor equipment and testing practices.

Last, when designing and producing asphalt mixtures to achieve BMD mechanical test performance criteria, there are several methods and adjustments the interviewees recommended an asphalt mix designer and producer can conduct (Figure 17). To meet rutting requirements, the interviewees suggest designing towards the low end of the VMA specification, increase the high temperature stiffness of the asphalt binder—either using a polymer-modified binder or the addition for more recycled asphalt—and ensure that quality aggregates of high angularity and texture be used. Meanwhile, to ensure fatigue cracking performance is met, the interviewees noted that higher effective asphalt content will be necessary

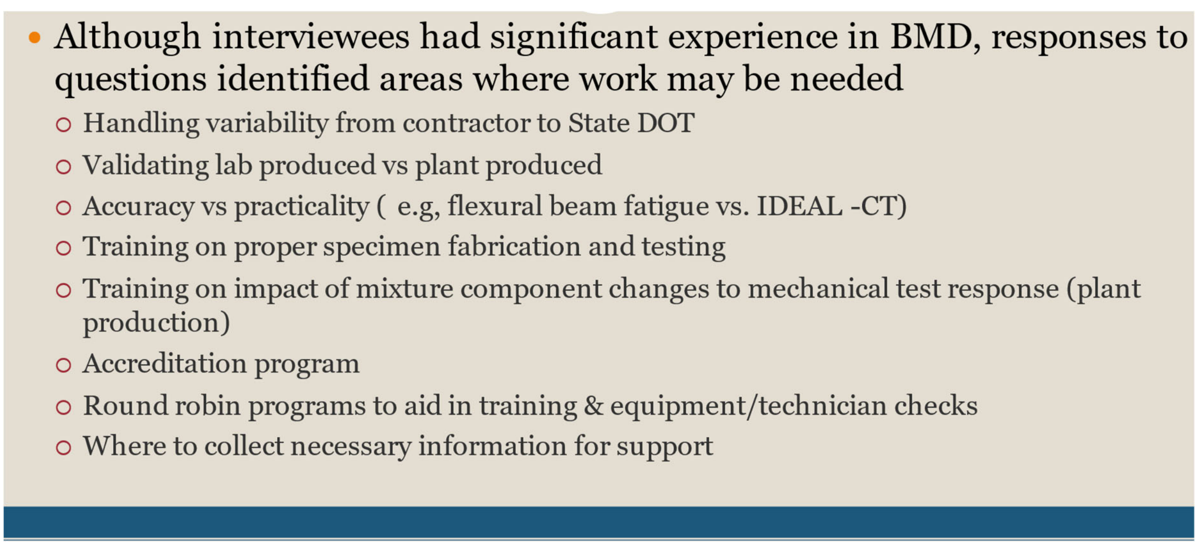

FIGURE 16 Areas that still need to be addressed and protocols that need to be developed.

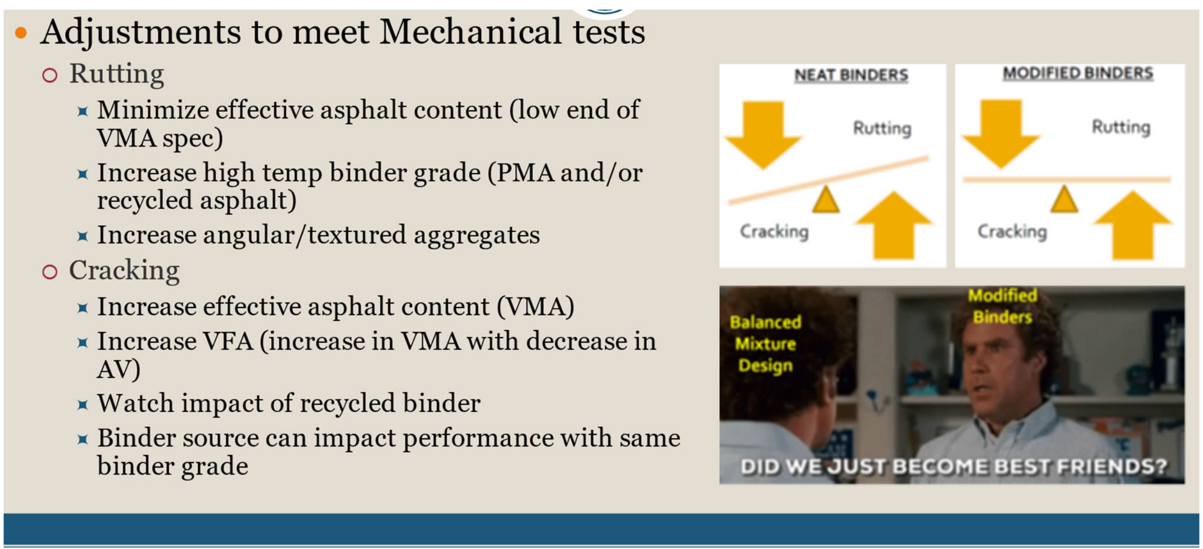

FIGURE 17 Methods and adjustments the interviewees recommended an asphalt mix designer and producer can conduct.

and that state agencies should consider reducing air void tolerances to help increase the VFA. In addition, the asphalt binder properties will have a great impact on the cracking resistance, and therefore, paying close attention to the quality and amount of the recycled asphalt binder while ensuring the source of the virgin asphalt binder does not change from design.

Impact of Binder Source on Hot-Mix Asphalt Mechanical Performance

A Supplier's Perspective

ANAS A. JAMRAH

Marathon Petroleum Company LP

This presentation offers insight, from a supplier's perspective (Figure 1), on the impacts of different asphalt binder sources on the mechanical performance of hot-mix asphalt (HMA). In addition, the data presented herein, which was developed as part of a larger study, will utilize industry knowledge and published literature to demonstrate innovative mixture adjustment options that can be successfully employed to improve mechanical performance.

As agencies and industry continue to evaluate BMD for asphalt mixtures, it has become increasingly important to understand the impact of material properties on finished mixture performance. Asphalt mixtures are complex, heterogeneous materials, and their performance can change significantly depending on the quality of the constituent materials (Figure 2).

FIGURE 1 Cover from presentation by Anas A. Jamrah, Marathon Petroleum Company.

- Besides asphalt **binder source**, what adjustment options do we have to improve performance of asphalt mixtures, in a **Balanced Mix Design** framework?
- What do **published literature** and state-of-practice suggest?
- Experimental plan designed to address that
- **Phase 1:**
  - Used a common Midwest mix design: **20% Recycled Asphalt Pavement**
  - **100% credit to recycled binder** as allowed by many DOTs in the Midwest
  - Evaluated Hot Mix Asphalt for **rutting and cracking**
  - Studied the impact of **three different refinery sourced PG 64-22 binders**
- **Phase 2:**
  - Investigate **adjustment options** to improving performance and allow **innovation**

FIGURE 2 Impacts of binder source on HMA performance.

In a BMD framework, permanent deformation (rutting) and a prevalent mode of cracking in the region/ climate of interest are evaluated. As industry continues to move towards increased RAP usage, and mixtures tend to become drier and more prone to cracking. Several modes of cracking can be observed in the field, depending on the different climatic and loading conditions. This has resulted in a variety of different mixture cracking tests being introduced in the industry. In addition, agency implementation approaches vary significantly. This study presents a detailed analysis and a controlled laboratory experiment to identify several mixture adjustment options, besides asphalt binder source, to improve mechanical performance. The laboratory evaluation involved two phases. In the first phase, a common HMA mix design from the Midwest was used to provide a performance benchmark for PG 64-22 asphalt binder from three different refinery sources. Rutting and three different cracking tests were evaluated on this mixture. In the second phase, the mixture utilizing the PG 64-22 source binder with improvement potential on one of the cracking tests was further optimized by varying other mixture factors, resulting in significant impact to mechanical performance.

Figure 3 provides more details related to the mixture design. A limestone aggregate surface mixture, with 9.5-mm nominal maximum aggregate size (NMAS) was chosen in this experimental program. The agency requirement for this mixture was a PG 64-22 binder, and the volumetric mix design resulted in a 5.6% binder content.

- Limestone Surface Mixture; 9.5mm NMAS, 20% RAP
- AADT Class 3; 600-2999
- N_{design} = 65 gyrations
- PG 64-22 asphalt binder
- Total binder content 5.6%
  - Full credit to recycled binder allowed
  - ~15% of total binder content (0.85%)
- Used the same mix design with asphalt binder from three different sources
  - With one point verification
- Mix Performance Requirements:
  - Minimum 10,000 Hamburg passes for critical rut depth of 12.5 mm
  - Minimum 95 IDEAL -CT index

FIGURE 3 Mix design details.

As currently allowed by many agencies in the Midwest, RAP binder contribution was assumed at 100%, which equates to 0.85% of the total binder content. The main variable investigated was binder source. During execution of Phase 1, an agency specification requiring a minimum of 10,000 HWT passes before a critical rut depth of 12.5 mm was considered. In addition, the specification included a minimum cracking requirement measured through the IDEAL-Cracking Test (IDEAL-CT). IDEAL-CT has become increasingly popular, given the easy and quick nature of the test.

Figure 4 shows the experimental testing plan for the asphalt binders used in this study. The data shown in this presentation is highlighted with a red outline. Binder testing included the material in its original unaged condition, and several short- and long-term aging conditions. Physical and mechanical properties, as well as chemical composition analyses, were performed. The PG 64-22 Source B and C were the same as Source A.

Figure 5 shows the experimental plan for mixture testing. The HWT test was used to evaluate rutting. For cracking, the disc-shaped compact tension (DCT) test was used to assess

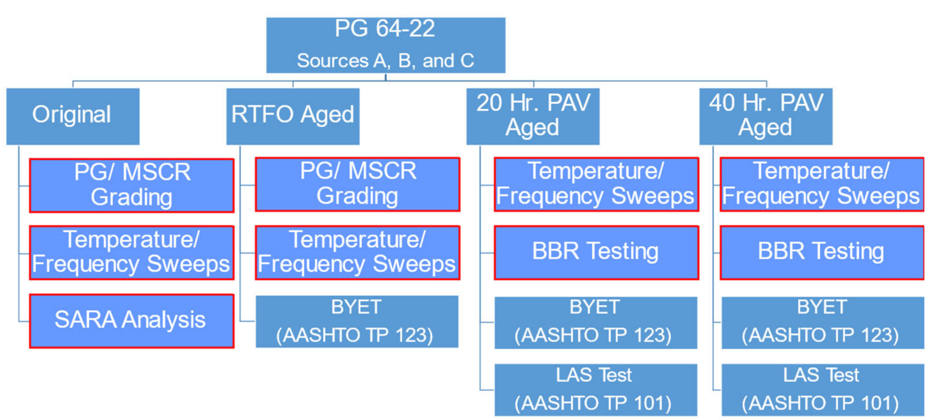

FIGURE 4 Experimental plan: binder testing.

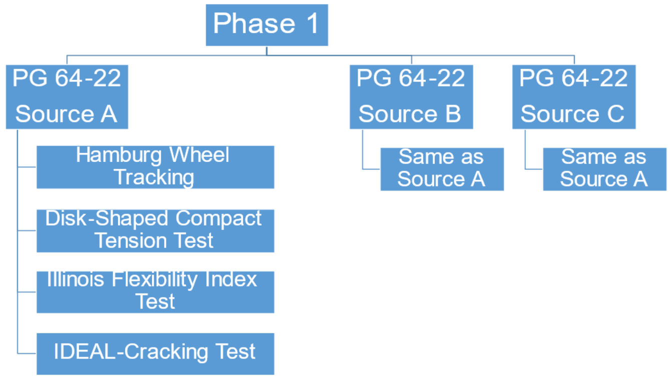

FIGURE 5 Experimental plan: mixture testing.

thermal cracking, while the Illinois Flexibility Index Test (I-FIT) and IDEAL-CT were used to assess fatigue cracking.

Table 1 shows a summary of the asphalt binder characteristics. Although the three binders used in this study meet the AASHTO M320 specification for PG 64-22, they were diverse in quality, with a wide range of properties as shown in the figure.

In addition, |G*| master curves and Colloidal Instability Index shown in Figure 6 demonstrate the differences in rheology and chemical composition. The next figures will highlight mixture performance results.

TABLE 1 Asphalt Binder Characteristics.

Binder Property	Range
Vacuum viscosity at 60°C (Poise)	2,000–3,000
Penetration at 25°C (dmm)	50–80
Original DSR at 64°C (kPa)	1.10–1.70
MSCR JNR at 64°C, 3.2 kPa (1/kPa)	2.00–4.00
PAVE DSR at 25°C (kPa)	3,500–4,800
BBR *m*-value at –12°C	0.308–0.365
BBR stiffness at –12°C (MPa)	150–250
20-h Delta T_c, °C	–3.0–+2.0
40-h Delta T_c, °C	–9.0–0.0
Glover–Rowe parameter at 25 C°(kPa)	2,500–5,000
BBR *R*-value at –12°C	1.75–2.50

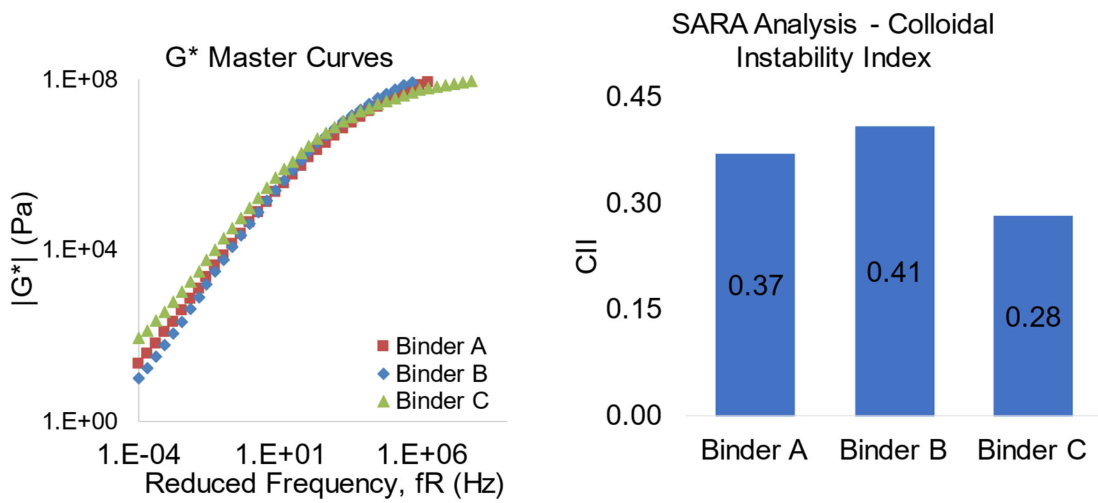

FIGURE 6 Asphalt binder characteristics.

Figure 7 shows HWT testing at 50°C. Rut depth, in millimeters, after 10,000 wheel passes shows little to no differences between binder sources, and that all binders met the agency specification of less than 12.5 mm. Stripping inflection point varied slightly but is not part of the agency specification.

DCT results for thermal cracking are shown on Figure 8. Reminder that bending beam rheometer (BBR) *m*-value was measured on the three binders used in this study, at the same temperature as DCT (–12°C) and varied significantly (between 0.308 and 0.365) as shown on Figure 6. However, DCT shows that these three PG 64-22 binders performed equivalently in the mixture when test variability is included.

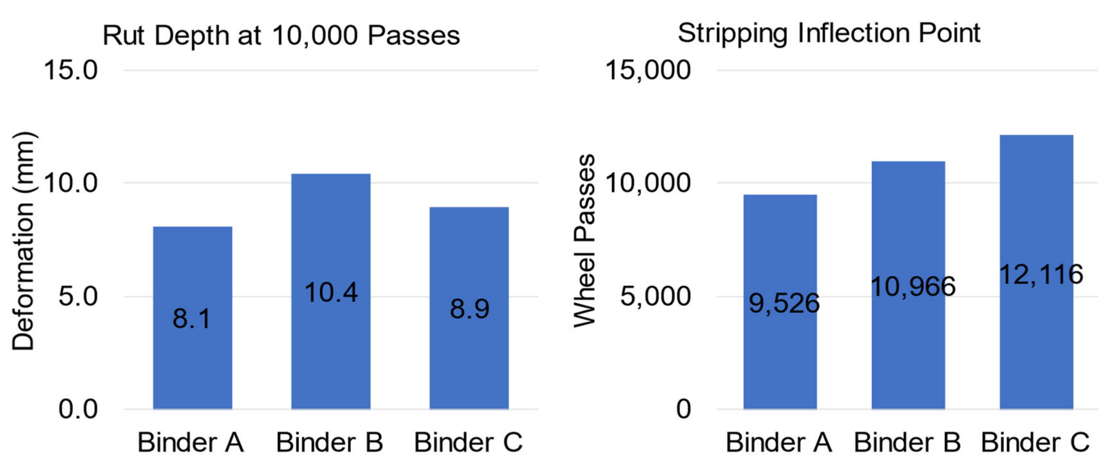

FIGURE 7 Rutting and stripping inflection points for different mixtures produced with various binders.

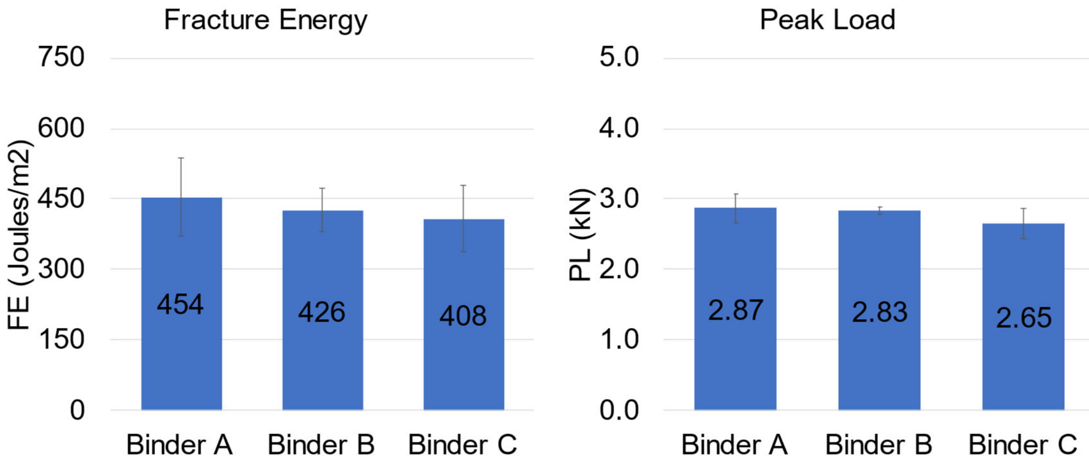

FIGURE 8 Thermal cracking results for different mixtures produced with various binders.

For fatigue cracking performance at intermediate test temperatures, the Illinois Flexibility Index Test (I-FIT) and IDEAL-CT tests were chosen to evaluate performance. Figure 9 shows results from I-FIT data, consistent with findings from DCT testing. While fracture energy shows slight differences, the three binders were statistically equivalent. The same applies to flexibility index.

Figure 10 shows IDEAL-CT performance. CT index, required at a minimum of 95, was the most sensitive to binder source. In this context, Binder A falls slightly below this expectation at 86 CT index.

Given the monotonic nature of IDEAL-CT, an index calculated from the slope of the post-fracture curve, as is the case with CT index, is not the most appropriate way to interpret this data (Figure 11). A recent study by NCAT published in Transportation Research Record (Yin et

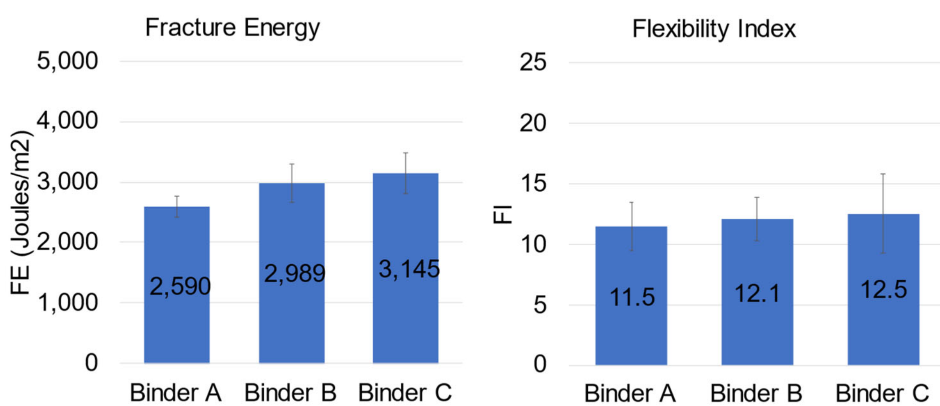

FIGURE 9 Illinois I-FIT: fatigue cracking results for different mixtures produced with various binders (25°C).

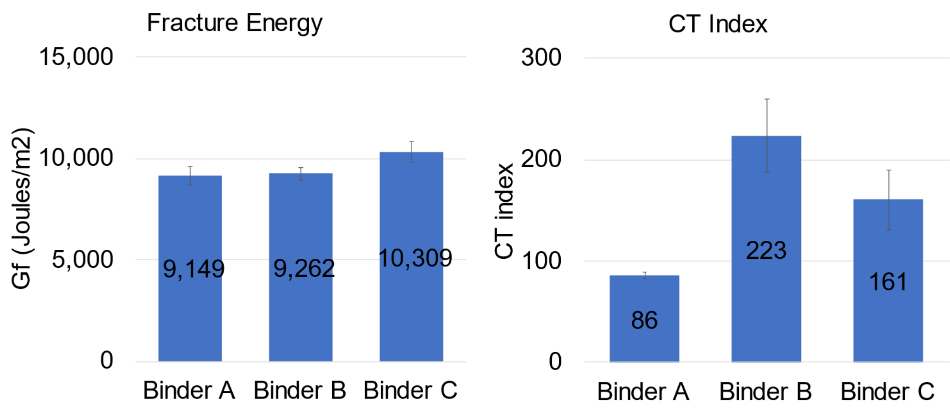

FIGURE 10 IDEAL cracking test: fatigue cracking results for different mixtures produced with various binders (25°C).

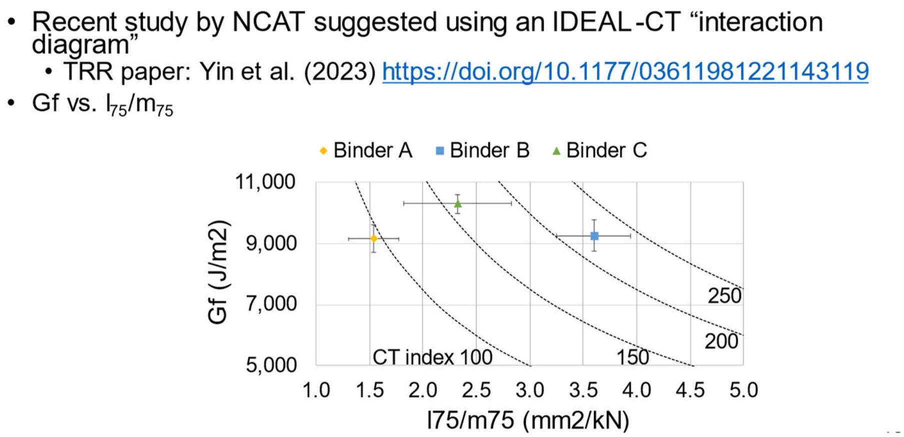

FIGURE 11 IDEAL-CT interaction diagram.

al., 2023) suggested the use of an IDEAL-CT interaction diagram. In this alternative approach to interpreting the results, a more holistic view of the fracture resistance of mixtures can be presented by capturing fracture energy, as well as the slope of the post-fracture mechanics. This is especially true with polymer-modified asphalt materials. An index-based classification of materials can be misleading and can become a roadblock to implementation if performance tests do not align with proven field performance of superior materials with tens of years of experience.

In Phase 2 of this study, Binder A was further investigated, given the CT index performance (Figure 12). To identify the most promising mixture factors that could be adjusted to improve mechanical performance, a recent Tech Brief published by the Western Regional Superpave Center at the University of Nevada, Reno, was reviewed. This report provides an excellent resource for practitioners summarizing state of the practice and industry experience with mix

- Significant industry experience with mixture adjustment options
- Hurdles include specifications vs. innovation
- Hajj, E., et al. (2023) Tech Brief: Adjustment of Asphalt Mix Design/Job Mix Formula to Satisfy Mechanical Test Properties.
  - https://scholarworks.unr.edu/handle/11714/8436
- Most promising variables identified:
  - Proper assessment of RAP binder availability
  - Passing #200 sieve and binder absorption
  - Use of commercially available additives
- Phase 2:
  - Focused on Binder A
  - Re-evaluate key mix performance measures : Rutting (Hamburg) and Cracking (IDEAL-CT)

FIGURE 12 Summary of the tech brief published by the Western Regional Superpave Center at the University of Nevada, Reno.

performance adjustment options. However, the hurdle today in practice becomes balancing agency specifications and innovation. The three most promising variables identified in Phase 2 were: (1) proper assessment of RAP binder availability and contribution, (2) reducing passing #200 sieve, or dust content by 0.40%, and (3) the use of commercially available warm-mix asphalt (WMA) additive at a rate of 0.50% by weight of the asphalt binder. These three variables were adjusted, one at a time, and mixture performance measures were reevaluated.

A recent study completed by Texas A&M and Texas Transportation Institute presented a comprehensive assessment of RAP binder availability in recycled materials collected from various sources and climates around the United States (Figure 13). The study established correlations between RAP binder availability and extracted binder stiffness, as measured by performance grading in the DSR. The RAP binder utilized in this analysis was extracted and tested in the DSR and had a continuous PG grading of 101°C. Based on recommendations from Kaseer et al. (2019), this would suggest 75% RAP binder availability, rather than 100% as currently allowed by several state DOTs in the Midwest. This equated to an additional 0.20% of virgin PG 64-22 binder in the mixture.

Figure 14 summarizes HWT results on the mixture designed with Binder A and adjusted with one of the three options described on Figure 12. Although the primary goal of these mix adjustments was to improve cracking, rutting was evaluated to confirm that no unintended consequences were observed in mechanical performance. The analysis showed no negative impact on permanent deformation measured in millimeters at 10,000 wheel passes. The commercially available WMA additive slightly improved rutting. In addition, stripping inflection point improved with these mixture adjustments.

- Recent study by Dr. Amy Epps Martin's team at Texas A&M and TTI
  - TRR paper: Kaseer et al. (2019) https://doi.org/10.1177/0361198118821366
  - Quantified RAP binder availability in recycled materials from different sources
  - Established correlations between RAP binder availability and high temperature PG of extracted binder
- In this study, the extracted RAP binder had a high temperature continuous DSR grade of 101 degrees C
  - This would suggest 75% RAP binder availability, rather than 100%!

FIGURE 13 Study on the availability of RAP binders in recycled materials.

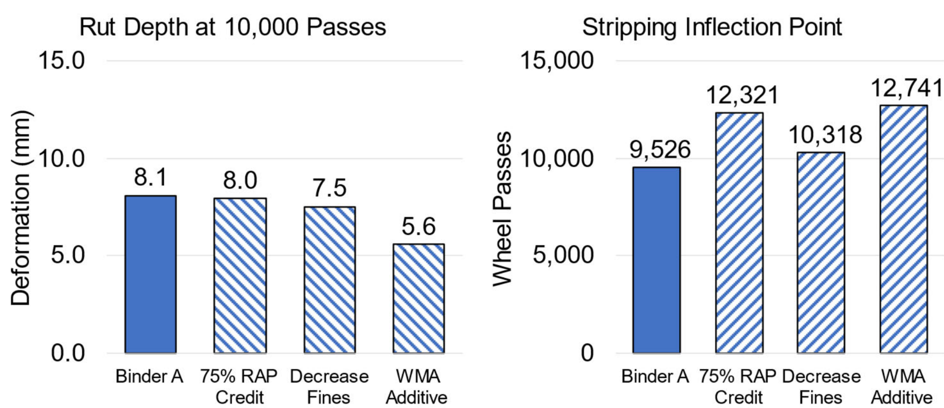

FIGURE 14 Rutting and stripping inflection points for different mixtures (50°C).

Figure 15 summarizes cracking performance measured through IDEAL-CT. As shown, fracture energy was not significantly impacted by the mixture adjustment options. CT index, however, changed significantly when RAP binder was properly characterized and resulted in an increase in virgin PG 64-22 binder content. In addition, decreasing fines and using a commercially available WMA additive also improved CT index.

A summary is shown in Figure 16. Based on the preceding analysis, it can be concluded that all refinery source binders performed well against rutting, as measured by Hamburg. In terms of cracking, there were statistically insignificant differences in performance as measured by DCT and I-FIT. Fundamental engineering properties derived from fracture tests, such as fracture energy, show less variability in the results and should be considered by agencies for

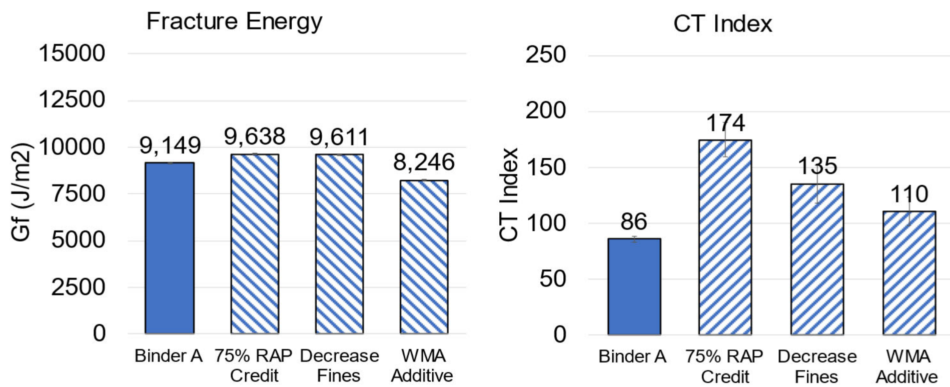

FIGURE 15 IDEAL cracking test: Fatigue cracking results for different mixtures (25°C).

- All refinery sourced binders performed well in Hamburg testing
- Cracking performance measured by DCT, and I-FIT showed statistically equivalent performance in the three binders
- Although IDEAL-CT Fracture Energy was statistically equivalent, CT Index showed most sensitivity to binder source
- Properly assessing RAP binder availability and allowing innovation in asphalt mix design adjustments can help meet BMD expectations

FIGURE 16 Summary and conclusions.

proper assessment of mixture performance. This also applies to IDEAL-CT, which showed the most sensitivity to binder source, through CT index. Additionally, although mixture DCT results for thermal cracking shown on Figure 8 were measured at the same temperature as BBR*m*-value on asphalt binder (–12°C), no difference was observed in mix performance between the three different sources of PG 64-22 binders. BBR testing is a very well-established test with relatively low repeatability. This is a perfect example that asphalt binder, although critical, is not the sole factor that impacts mixture performance.

Agencies and industry should conduct thorough vetting when new binder testing parameters are proposed for aged materials. Phase 2 of this study showed that there are several factors other than binder source that could be adjusted to improve mixture performance. Good mechanical performance can be achieved through several mixture adjustment factors without the need to completely change refinery binder sources or implement overly restrictive asphalt binder specifications.

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Approaches to Balanced Mix Design and Moving Towards Approach D

Randy West
Auburn University

INTRODUCTION: WHY CHANGE?

BMD is one of the most talked about topics in the field of asphalt pavements. As the state DOTs consider BMD implementation, an early decision must be made on how to approach BMD for mix design approval. This presentation discusses the pros and cons of different approaches in AASHTO PP 105.

There are two recognized deficiencies of mix design systems based on volumetric properties: (1) the reliability and accuracy of VMA are questionable because of the difficulties in accurately determining the bulk specific gravity (G_{sb}) of aggregates, and (2) there is no way to determine the interaction effects of virgin binders, recycled binders, and other additives such as recycling agents. These issues are further discussed below (Figure 1).

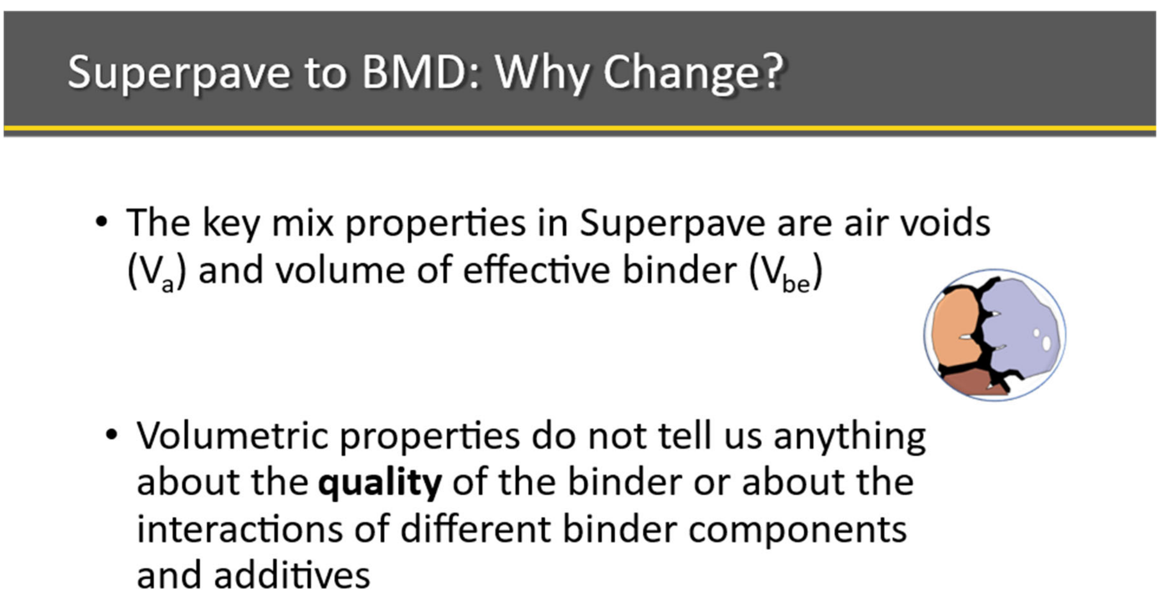
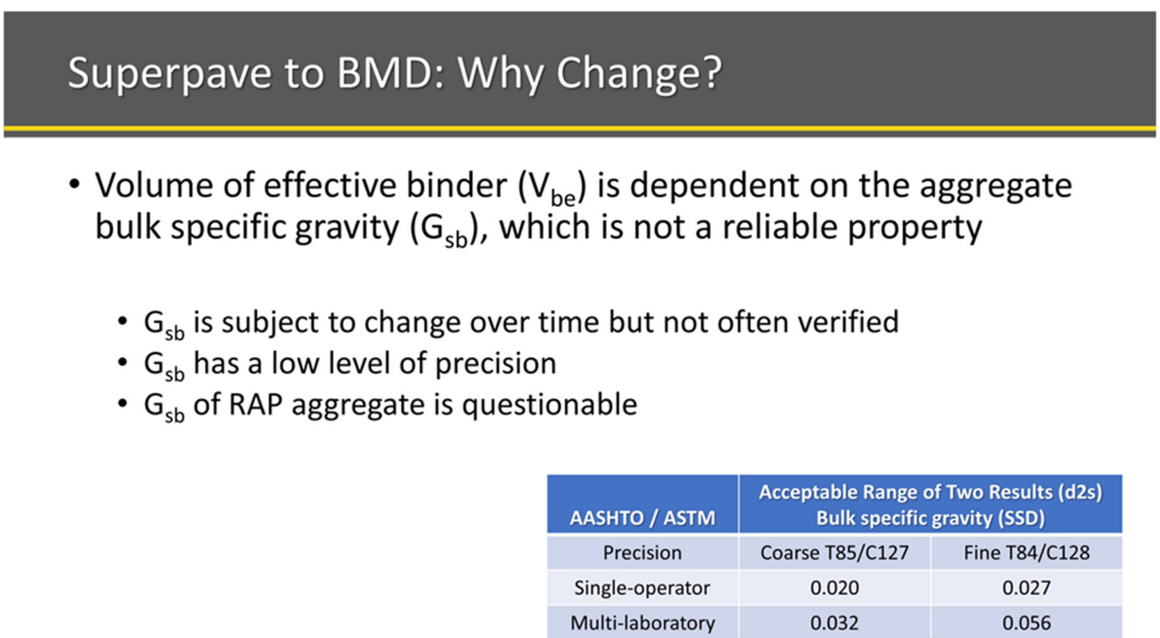


FIGURE 1 Two recognized deficiencies of mix design systems based on volumetric properties.

CONCERNS REGARDING VOIDS IN MINERAL AGGREGATE

The two primary volumetric properties used in asphalt mix design and Quality Assurance specifications are air voids (*Va*) and voids in the mineral aggregate (VMA). Air voids represent the volume of void space within a compacted specimen at a specific compactive effort (e.g., N_{design}), which has been related to rutting resistance (Brown and Cross, 1992). VMA is defined as the volume of the intergranular void space between the aggregate particles of a compacted asphalt mixture that includes the air voids and the volume of effective binder. A minimum VMA is considered important to ensure that a mixture contains an adequate effective asphalt content. The minimum VMA criteria were established by Norman McLeod in the late 1950s, however no mix performance data were provided to support the criteria (Kandhal et al., 1998, Coree and Hislop, 2000).

An accurate calculation of VMA requires the combined G_{sb} of aggregates, including RAP aggregates. Unfortunately, G_{sb} is not a reliable property as evident from the precision information in the AASHTO standards for fine and coarse aggregate specific gravity determinations, AASHTO T 84 and T 85, respectively (Figure 2). A difference in an aggregate blend's G_{sb} of 0.030 (a difference that is well within the repeatability of G_{sb} determinations) can change the mixture's calculated VMA by 1.0%.



AASHTO / ASTM	Acceptable Range of Two Results (d2s) Bulk specific gravity (SSD)	
Precision	Coarse T85/C127	Fine T84/C128
Single-operator	0.020	0.027
Multi-laboratory	0.032	0.056

FIGURE 2 AASHTO standards for fine and coarse aggregate specific gravity determinations, AASHTO T 84 and T 85, respectively.

Furthermore, there is no national standard for determining the specific gravity of RAP aggregate. Although different test methods have been adopted by state DOTs for determining RAP aggregate G_{sb}, they often yield inconsistent results, and their accuracy varies greatly depending on the type of aggregate. As RAP contents continue to increase year to year due to growing interest in sustainability, the impact of uncertainty of RAP aggregate G_{sb} increases. Most DOTs lack the resources to verify RAP aggregate G_{sb} values provided by contractors.

It is also important to recognize that the G_{sb} of a virgin aggregate source may change over time due to the site's geology and mining operations. Likewise, RAP G_{sb} values can change over time as the sources of millings change from project to project. However, many state DOTs allow mix designs to remain effective for several years without verifying the G_{sb} used in the original VMA calculations. If the actual G_{sb} values are subject to change over time but are not often verified, the resultant mix designs will have inaccurate VMA values.

UNKNOWN INTERACTIONS OF BINDERS

The second major deficiency of volumetric properties is that they tell us nothing about the quality of the composite binder. Even if we were able to overcome the issues with G_{sb} and correctly determine VMA, basing mix quality solely on volumetric properties would only ensure that mixtures contained the specified volume (quantity) of a binder. What is lacking is an indication of the quality of the binder and how it will impact mix performance. For example, consider a virgin Superpave mix design with an unmodified binder and the same mix with a polymer-modified binder. The two mixes may have nearly identical volumetric properties but the mix containing the polymer-modified binder is expected to have superior rutting and cracking resistance over the one with the unmodified binder.

Most asphalt mixtures in the United States contain RAP, and there is growing interest in increasing RAP contents as we work to decarbonize pavements. For decades, asphalt technologists have debated how much of the RAP binder is active as a glue within a mixture, and researchers have continued to explore ways to quantify the "activity" or "contribution" of RAP binder. Likewise, the same arguments and questions occur for mixtures containing recycled asphalt shingles (RAS). There is likely a wide range of "activity" for recycled binders depending on their stiffness, compatibility with virgin binders and recycling agents (if used), and mixing conditions (i.e., time and temperature) that differ from plant to plant, project to project, and even within a single day of production.

VOLUMETRIC PROPERTIES PROVIDE NO INDICATION OF THE IMPACTS OF ADDITIVES

Another limitation of volumetric properties is that they do not provide any indication of how innovative additives such as recycling agents, fibers, dry-process ground tire rubber, recycled plastics, graphene, etc., affect the rutting resistance or cracking resistance of mixtures (Figure 3).

Until a mix design system and an acceptance program that evaluates the resistance of a mixture to the common asphalt pavement distresses is implemented, innovations will be stymied. Those performance tests must be simple enough for use in everyday practice by mix designers and quality assurance (QA) technicians.

THE FOUR APPROACHES TO BALANCED MIX DESIGN

The AASHTO provisional standard for BMD, AASHTO PP 105, describes four alternate approaches summarized as follows (Figure 4).

FIGURE 3 Limitation of volumetric properties.

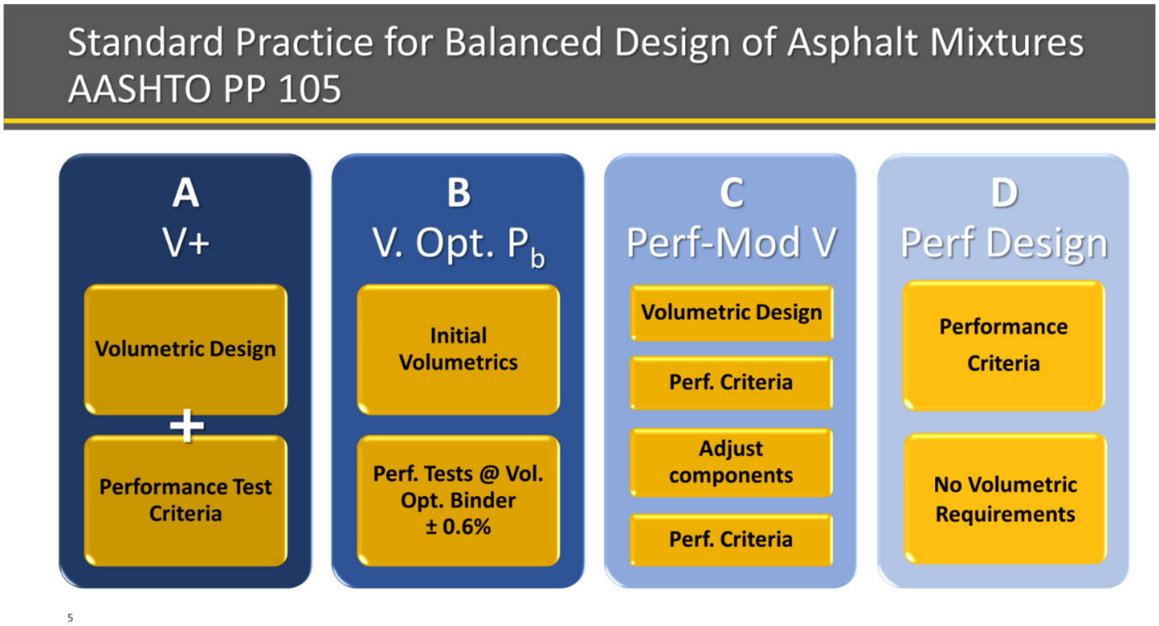


FIGURE 4 Four alternate approaches to BMD.

Approach A: Volumetric Mix Design with Performance Verification

This approach starts with the current volumetric mixture design method (i.e., AASHTO M323) to determine an OBC that meets the existing volumetric requirements. The mix design is then tested with the selected performance tests to assess its resistance to distresses of interest at the OBC. If the mix meets the performance test criteria, the JMF can be established; otherwise, the entire mix design process (including the volumetric analysis) needs to be repeated using different component materials or proportions until all the volumetric and BMD performance test criteria are satisfied.

Approach A may appear to be a simple approach for DOTs to implement BMD because it only requires adding the performance test criteria to the existing volumetric specifications (Figure 5).

However, this approach has significant drawbacks because the OBC is selected purely based on volumetric analysis, which cannot assure optimum mixture performance. Another limitation is that many mix design strategies for improving mixture performance will affect volumetric properties, which makes it very challenging, if not impossible, to develop a mix design that can meet the BMD performance test criteria at the volumetric OBC (Figure 6).

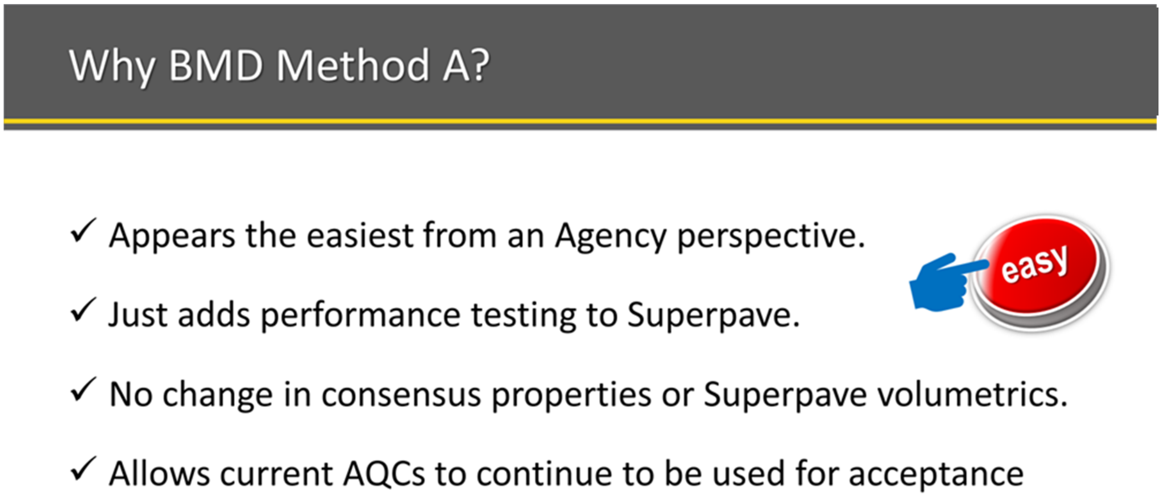


FIGURE 5 BMD Approach A Advantages.

FIGURE 6 Drawbacks of Approach A.

Experience with BMD performance tests has shown that many existing Superpave mix designs with inadequate cracking resistance could be easily modified to meet the BMD requirements by adding 0.1 to 0.3% more asphalt binder without making other changes. However, Approach A does not allow this modification because the modified mix design would deviate from the “optimum” volumetric condition. Because Approach A requires a mix design to meet the volumetric and BMD performance criteria simultaneously, it provides very limited innovation potential, preventing asphalt contractors from using locally available materials, recycled asphalt materials, and asphalt additives for economic and sustainability benefits.

Approach B: Volumetric Mix Design with Performance Optimization

This approach starts with the current volumetric mixture design method to determine a preliminary OBC that meets the existing volumetric requirements (Figure 7). The mix design is then tested with the selected performance tests to assess its resistance to distresses of interest at the preliminary OBC and two or more additional asphalt binder contents. The range of the additional asphalt binder contents recommended in AASHTO PP 105 is 0.3% to 0.6% above or below the preliminary OBC. The asphalt binder content that meets the BMD performance test criteria is selected as the final OBC. The mix design is then tested to determine its volumetrics at the final OBC, which will be used as production targets for the JMF. In cases where the final OBC does not exist, the entire mix design process (including the volumetric analysis) must be repeated using different component materials or proportions until a final OBC that meets the BMD performance test requirements can be found.

Approach B is an expanded version of Approach A, as it allows performance testing of the mix design at additional asphalt binder contents besides the OBC from the volumetric analysis.

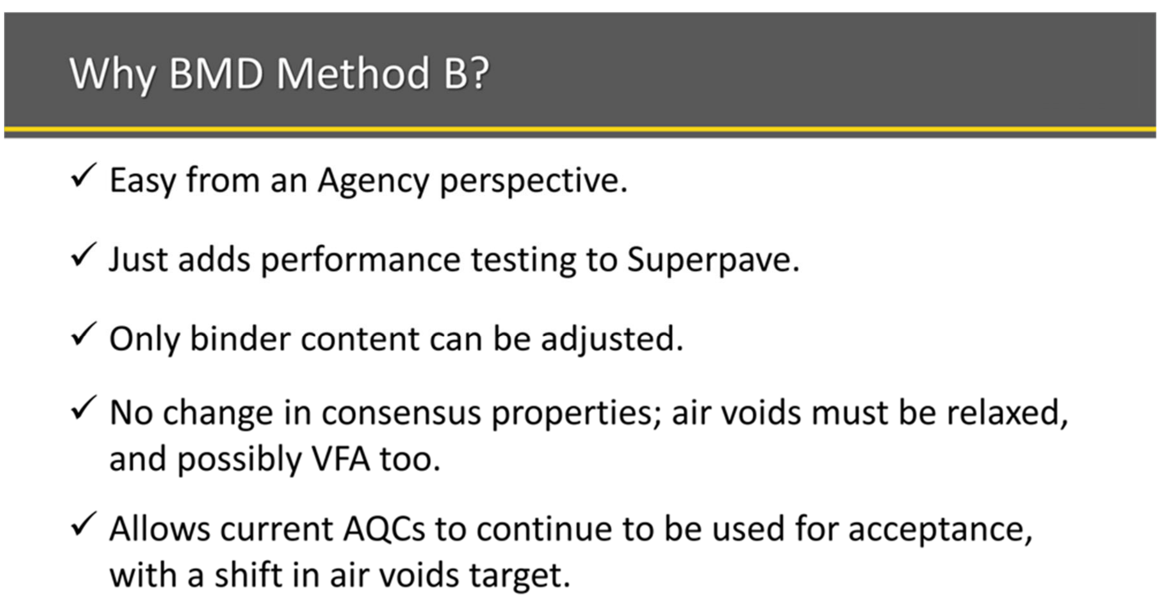


FIGURE 7 BMD Approach B Advantages.

Therefore, it offers more flexibility to asphalt contractors to meet the BMD performance test requirements by changing asphalt binder content. The final OBC is determined by meeting the BMD performance test requirements with relaxed volumetrics to accommodate changes in asphalt binder content from the preliminary OBC. Despite the improved flexibility, performance optimization for Approach B is limited to changing asphalt binder content; in other words, asphalt binder content is the only variable that can be adjusted from the volumetric analysis to meet the BMD performance test requirements. Although changing asphalt binder content is very effective in improving mixture performance, it is not necessarily always the most cost-effective and environmentally friendly method.

Approach C: Performance Modified Volumetric Design

This approach starts with the volumetric mixture design framework to select preliminary component materials and proportions and a trial asphalt binder content (Figure 8). The mix design at the trial asphalt binder content is not required to meet the full volumetric requirements. The mix design is then tested with the selected performance tests to assess its resistance to distresses of interest. If the mix design fails the performance test criteria, it will need to be modified by adjusting the asphalt binder content or changing the component materials (e.g., aggregates, asphalt binders, recycled asphalt materials, and additives) or their proportions

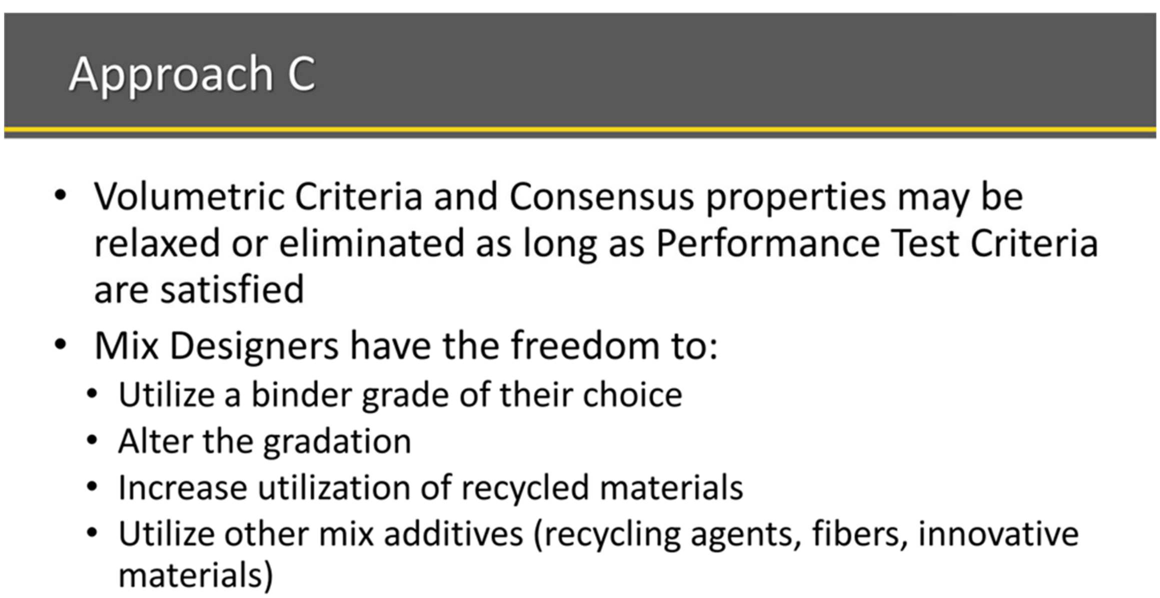


FIGURE 8 BMD Approach C Advantages.

within the mixture, until the performance test criteria are met. After that, the volumetric properties of the mix design will be determined and compared against the DOT's requirements on the selected properties for mix design approval.

This approach puts the primary focus of mix design on meeting the BMD performance test criteria instead of the volumetric criteria. It is suggested that the Superpave $N_{initial}$, N_{max}, and dust proportion (D/P) requirements in AASHTO M 323 be eliminated, as existing research has shown that they have a very limited correlation to pavement field performance. It is also recommended that AV, VMA, and VFA requirements in AASHTO M 323 be relaxed to allow the use of locally available materials, recycled asphalt materials, and additives, provided that the mix design can meet the BMD performance test requirements. Furthermore, DOTs are encouraged to use raw material property criteria only for guidance instead of using them as mix design requirements, except for aggregate friction properties due to safety reasons. Because of the relaxed volumetric requirements, Approach C offers greater opportunities to innovate compared to Approaches A and B.

As BMD confidence grows in a state, progression from Approach B to C or D should be part of the implementation plan. DOTs and contractors will learn that other mix design changes besides increased asphalt contents can be used to meet the BMD criteria. Approach C will give mix designers greater flexibility to meet the BMD criteria by exploring other aggregate sources, gradations, recycled materials, and additives. Thus, Approach C is where the opportunity exists to make a significant impact on sustainability and ensure good field performance.

Approach D: Performance Design

This approach establishes and adjusts the mixture components and proportions based on performance test results with limited or no requirements for volumetric properties (Figure 9). The DOT may recommend raw material properties for guidance only, except for aggregate friction properties due to safety reasons. Because mix design approval is purely based on meeting the BMD performance test requirements, volumetric analysis is not required. However, asphalt contractors may opt to measure the volumetric properties of the final mix design for production QC purposes.

Compared to the other three approaches, Approach D offers the highest innovation potential because it allows asphalt contractors to explore using locally available materials, recycled

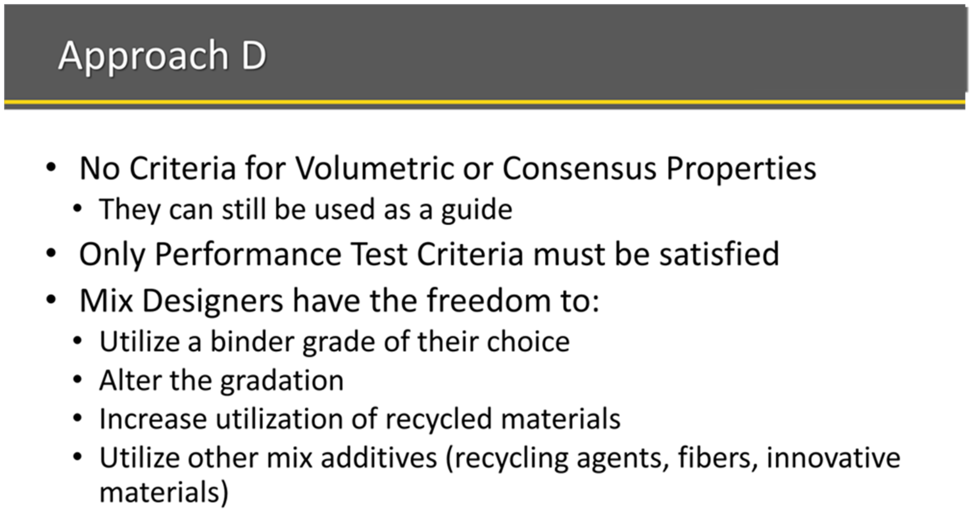


FIGURE 9 BMD Approach D Advantages

asphalt materials, and additives to develop mix designs with satisfactory performance while optimizing economics and sustainability. Like Approach C, production acceptance of BMD mixtures designed using Approach D can be determined based on asphalt binder content, aggregate gradation, and in-place density. DOT are also encouraged to conduct rapid BMD tests to check the performance properties of plant-produced mixes during production, and possibly use the test results as alternative AQCs to asphalt binder content and aggregate gradation for acceptance. When a DOT selects a rapid test, the DOT should balance the need for practicality vs. accuracy.

WHERE TO START WITH BMD

The NAPA BMD Resource Guide at https://www.asphaltpavement.org/expertise/engineering/resources/bmd-resource-guide has information on the approaches and test methods each state is considering. Although it may be easy for a DOT to simply add performance test criteria to their existing mix design requirements, doing so can make mix design a very challenging task and not achieve the full performance improvement or sustainability goals possible with BMD.

For decades, we taught people the importance of volumetric properties without discussing their limitations. As DOTs work with stakeholders in the plan for BMD implementation, early discussions should start with the motivations for making the change. Starting with the issues that need to be solved and keeping those concerns in mind throughout the process are important to achieving the goals. Part of the early discussions should address the deficiencies of volumetric criteria and how input properties, such as G_{sb}, are determined and checked in the state's policies and specifications.

Furthermore, the discussions should also address the opportunities and challenges associated with BMD for asphalt contractors to reduce carbon emissions for pavement sustainability while improving the quality and longevity of asphalt mixtures.

Keep in mind that Approach A does not allow a mix designer to adjust anything about an existing mix design that meets all volumetric criteria. Even if a mix design meets all Superpave criteria but barely fails the cracking test criteria, the asphalt content cannot be increased to improve cracking resistance since the adjusted asphalt content would yield a lower air void content at N_{design}.

Beginning with Approach B is a slightly better starting point since it gives mix designers the opportunity to increase optimum asphalt contents, if needed, to meet the DOT's cracking test and moisture damage test criteria without creating a problem with rutting resistance. However, the only mix design adjustment allowed with Approach B is to increase the virgin binder content.

This will increase the material cost and carbon emissions of the mix. DOTs that use Approach B will have to allow either a lower mix design air void target or a lower the N_{design} to maintain a specific air void target. For the lower air void target option, Table 1 provides suggested "relaxed" volumetric criteria to allow more asphalt in the mix to pass the new performance test criteria. In this table, the minimum mix design VMA criteria do not change, but the maximum VFA also has to increase. This scenario would also necessitate an adjusted production acceptance range for AV to accommodate moving the design target from 4.0% because of the additional asphalt binder added to the mix.

PROGRESSING TOWARD APPROACH D

As DOTs and contractors gain confidence that BMD tests will lead to better cracking resistance without sacrificing rutting resistance, dependence will wane on the traditional properties that have often yielded unsatisfactory performance. The best way to gain experience with BMD is with shadow projects and field validation test sections and closely monitoring their performance. Within 3 to 5 years (in some cases longer), DOTs should be ready to move from Approach B or C to Approach D, eliminating volumetric criteria for mix design and acceptance.

Ultimately, Approach D will simplify the mix design process by eliminating the need to determine aggregate specific gravities and the need to compact specimens to 115-mm height to check volumetric properties for mix design approval or QA. N_{design} will be a relic of Superpave and mix designers will be able to truly evaluate the potential benefits of any additive with mix performance tests.

TABLE 1 Suggested Relaxed Volumetric Criteria Compared to Current Superpave M 323 Volumetric Criteria for the Lower Air Void Target Option with Approach B

	AASHTO M323 Superpave Criteria			Suggested Relaxed Volumetric Criteria		
NMAS	Air Voids (%)	Min. VMA (%)	VFA Range (%)	Air Voids (%)	Min. VMA (%)	VFA Range (%)
37.0 mm	4.0	11.0	64–69	2.5–4.0	11.0	64–81
25.0 mm	4.0	12.0	67–71	2.5–4.0	12.0	67–82
19.0 mm	4.0	13.0	69–73	2.5–4.0	13.0	69–83
12.5 mm	4.0	14.0	71–75	2.5–4.0	14.0	71–84
9.5 mm	4.0	15.0	73–76	2.5–4.0	15.0	73–85
4.75 mm	4.0–6.0	16.0	63–78	3.0–6.0	16.0	63–84

HOW TO DETERMINE ACCEPTABILITY OF MIXES WITH DIFFERENT BALANCED MIX DESIGN APPROACHES?

Some DOTs choose to start with Approach A or B so they can continue to use volumetrics for acceptance quality characteristics (AQCs). Some DOTs and contractors are reluctant to implement BMD tests for acceptance because of the equipment costs, the longer turnaround time for BMD tests, and the higher variability in BMD test results compared to existing AQCs. Several options can be considered for QA with a BMD Approach B or C mix design approval process without using volumetric properties for mix acceptance.

Option 1: Old School

This option goes back to the practice of accepting asphalt mixtures based on asphalt content, gradation, and in-place density, as was done in most states in the early 1990s. Asphalt content and in-place density have proven their value as parameters that relate to performance and are easy to determine. Some DOTs still use the percent passing certain sieves as acceptance criteria for all or some mix types. Tolerances for the percent passing those sieves and the asphalt content target are based on the mixture's approved JMF. Dropping AV and VMA will greatly simplify acceptance testing. The perceived disadvantage of this option is that there is no assessment of the mixture's rutting or cracking resistance during production. However, even with field-based volumetric properties, that is also the case.

Option 2: Balanced Mix Design for Quality Assurance, Light

Option 2: Balanced Mix Design for Quality Assurance, Light

To overcome the deficiency in Option 1of not testing the rutting and cracking resistance of the produced mix, this option would require verification of the initial production lot with the selected BMD tests or their faster surrogate tests (i.e., performance tests that have simple sample preparation and testing procedures and quick results) (Figure 10). Full production of the mix would not proceed until the initial production is verified to pass the BMD criteria. After verification, acceptance testing would revert to Option 1 unless any source material (such as asphalt binder source or RAP) is changed. This QA option could be used with Approach B or C for mix design approval.

Option 3: Full Balanced Mix Design for Quality Assurance

This option is applicable to Approaches C and D, where mix designs are primarily or completely based on BMD performance tests. Acceptance would still include in-place density as an AQC and add a BMD rutting test and cracking test suitable for daily QA testing. The contractor may. choose to conduct many of the traditional tests for process control, but the results would not be used for acceptance

As we consider the different approaches for BMD mix design approval and the options for mixture acceptance during construction, it is important to keep in mind three simple characteristics of AQCs. First, they must provide a good indication of pavement performance. Second, the characteristics should be easy to measure with a quick turnaround time, and third, the variabilities of the tests must be reasonable so we can discern acceptable quality from unacceptable quality.

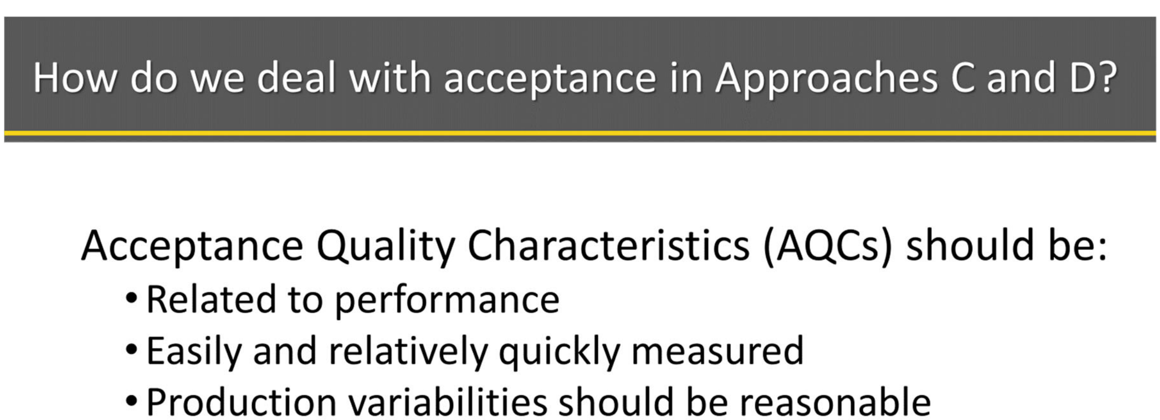


FIGURE 10 Dealing with acceptance in approaches C and D.

What Would You Do to Adjust This Mix?

Balanced Mix Design Case Studies

NATHAN MOORE

National Center for Asphalt Technology

Many in the asphalt industry are conceptually aware of the challenges of designing a mix in the lab under a BMD specification but practically inexperienced. To solve the problem of a failing mix, mix designers can be tempted to jump to extreme mix adjustments that may be unnecessary and costly. Thus, the purpose of this session was to present real-world BMD case studies to an audience with a variety of experience, interest, and knowledge of BMD. Each case study was presented with a description of the problem and numerous potential solutions, and the audience was asked to vote on which mix adjustment they would try first to improve the BMD result. Finally, the specific adjustment selected by the contractor was shared, along with an explanation for why it was chosen over the others. In every case, more than one adjustment would have worked to achieve the desired effect. The intent behind the multiple-choice style of soliciting audience feedback was to encourage the audience to consider which adjustment would be the simplest approach and, therefore, the best place to start. Borrowing from the concept of Occam's Razor, the guiding principle for this workshop presentation was "When faced with a problem with multiple solutions, begin with the simplest approach first."

There is a long list of factors that affect asphalt pavement performance. Variables like pavement thickness, temperature, haul distance, silo storage time, asphalt plant operations, loading rate, etc., all influence the performance of the pavement but cannot be influenced by the mix designer. A mix designer only has control over materials. Furthermore, neither the plant operator nor the mix designer can simply adjust a dial controlling the fatigue cracking moisture or damage resistance. Thus, thought must be given to what exactly a mix designer can control inside of a BMD specification and which variables interact with one another. A list of materials-related variables is shown in Figure 1. For example, one can vary the binder content or additive dosage in a blend or choose a different binder grade or source. Aggregate gradations can be adjusted by screening or washing, and the overall blend gradation can be manipulated by changing stockpile proportions. Aggregates with higher angularity or strength can be selected to improve aggregate structure. Recycled products such as RAP, RAS, plastic, or rubber can be

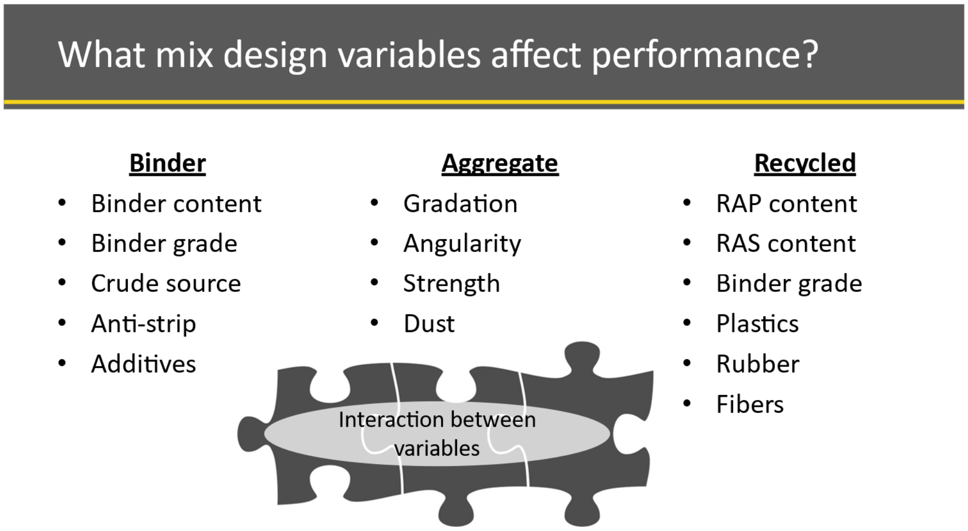


FIGURE 1 Mix design variables influencing pavement performance.

introduced into a mix to achieve a variety of effects. However, none of these adjustments are made in a vacuum. Often a change in a single variable affects others.

With this as the background, four case studies were then presented. The audience was reminded of the guiding principle of the session, "When faced with a problem with multiple solutions, begin with the simplest approach first." For the purpose of this workshop, the simplest approach was assumed to also be the most cost-effective. The idea was that extreme mixture adjustments would probably work but would cost more, and thus the need was to identify the mixture adjustment that was the simplest while also providing a good probability of success.

CASE STUDY #1

Case Study #1 (Figure 2) involved a mix designed using BMD Approach A. The mix was a 12.5mm NMAS coarse-graded design with a PG 70-22 binder. The recycled binder replacement percentage (RBR) was 20%, and the total asphalt content was 4.7%. The mix was comprised of a blend of limestone and granite aggregates and had passing volumetrics. However, the mix was too stiff and needed an improved cracking result while maintaining passing volumetrics. Five options were presented to the audience as potential mix adjustments to improve the cracking result while maintaining typical volumetrics. Those options, and the results of the audience voting, are shown in Figure 3. Many participants correctly thought that increasing binder content would improve the cracking result. However, by changing only the binder content, the AV would decrease, thus failing a volumetric specification. To increase binder content, the

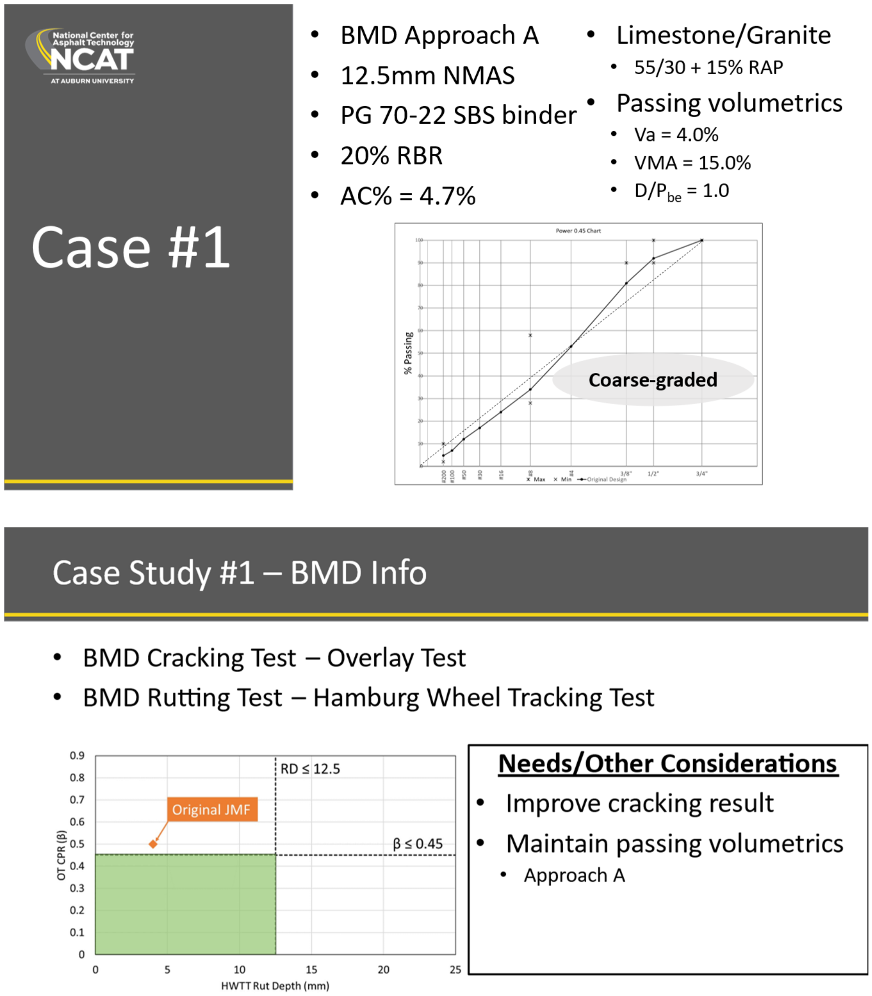


FIGURE 2 Case Study #1: mix designed using BMD Approach A.

FIGURE 3 Case Study #1 mix adjustment options and voting results.

gradation must first be altered to make room for the additional asphalt. The other options would have also improved cracking resistance but would have resulted in a more costly adjustment.

Figure 4 shows the final BMD result and the comments from the mix designer. Moving the gradation coarser and changing aggregate blend properties allowed for an increase in AC% of 0.6%, which then resulted in improved cracking resistance. This case study highlights the fact that traditional volumetrics may still be useful tools for mix designers, even as they cease being targets.

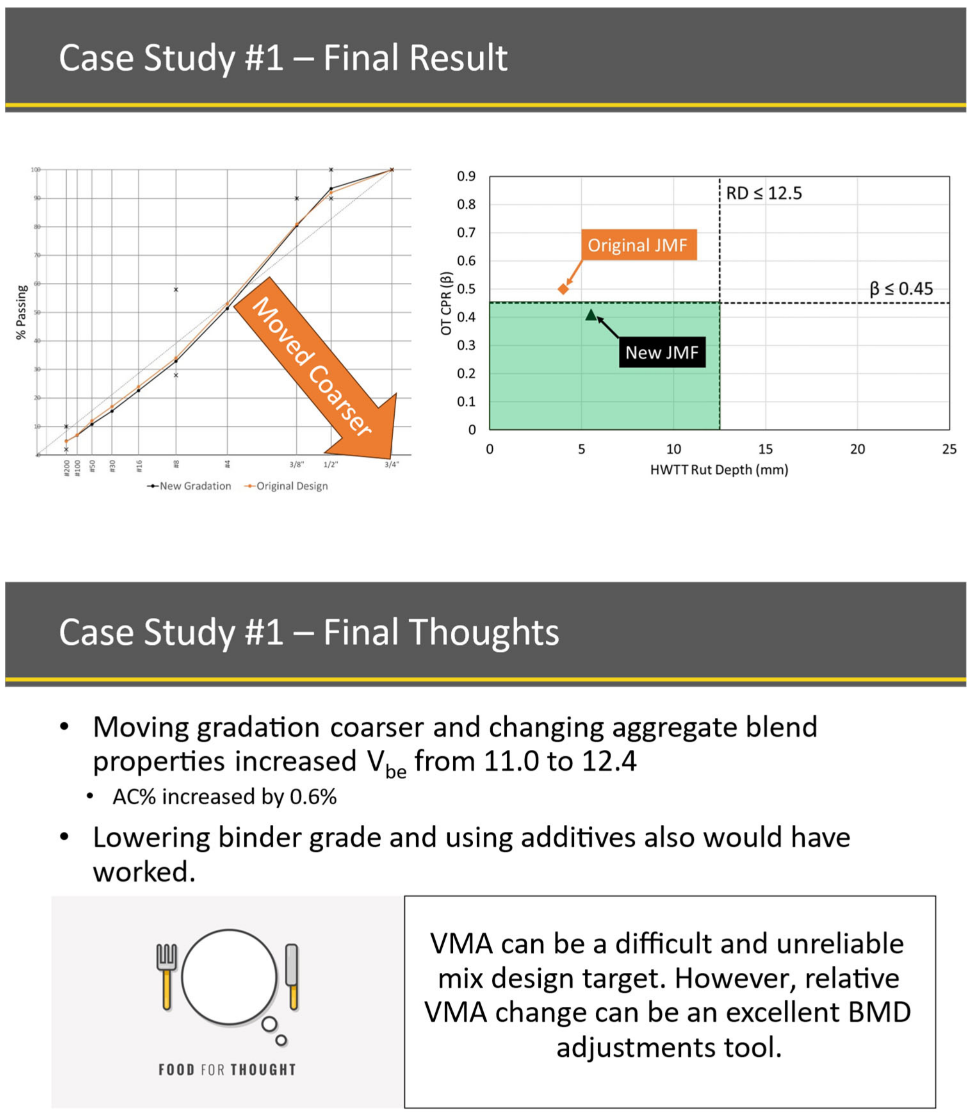


FIGURE 4 Case Study #1 final result and comments.

CASE STUDY #2

Case Study #2 (Figure 5) involved a mix designed using BMD Approach D. The mix was a 9.5-mm NMAS fine-graded design with a PG 58-22 binder. The RBR was 35% (45% RAP total), and the total asphalt content was 5.9%. The mix was comprised of a blend of gravel, limestone, and sand. No volumetric information was given. The mix needed an improved rutting result while maximizing RAP usage.

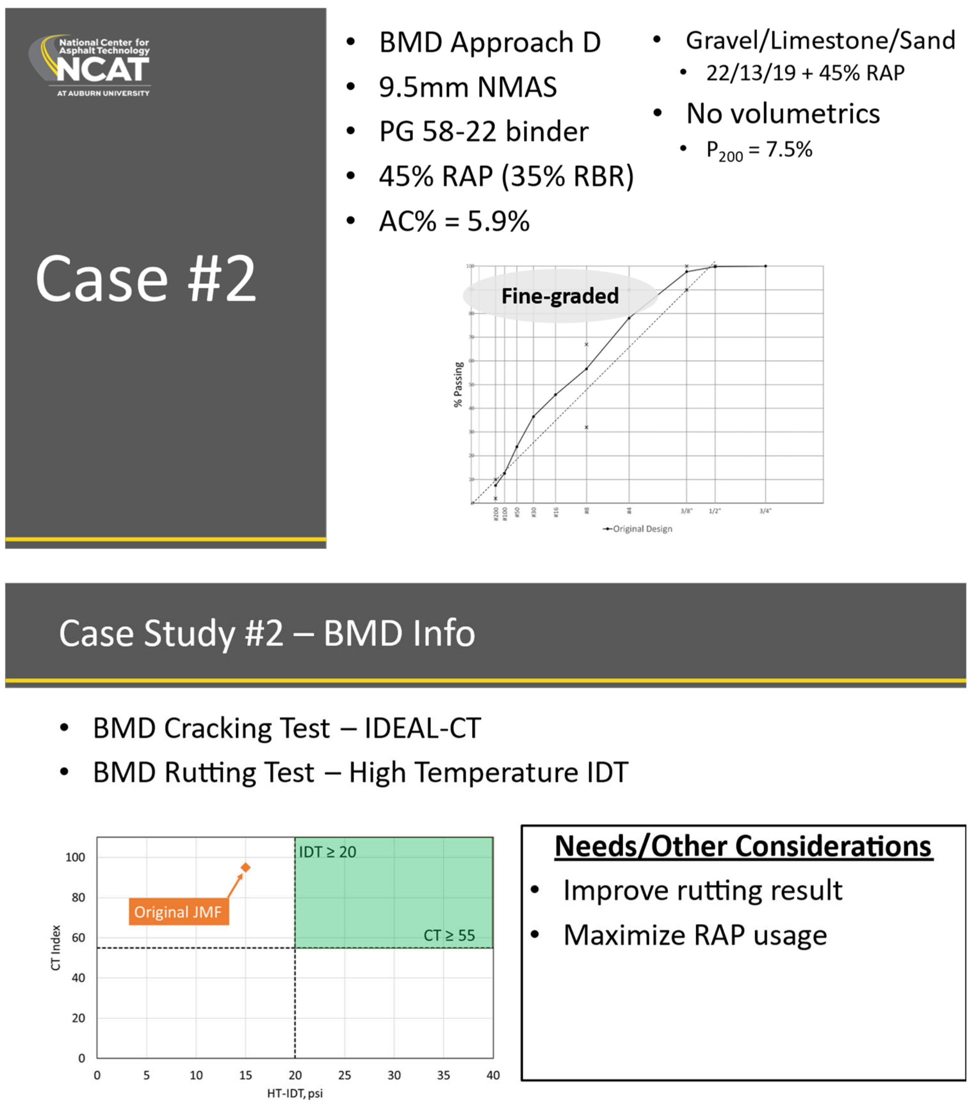


FIGURE 5 Case Study #2 mix designed using BMD Approach D.

Figure 6 shows the options as ranked by the workshop audience. Because the volumetric requirements were removed, no attention needed to be given to the downstream effects of the adjustments to the mixture volumetrics. Thus, many people responded that they would decrease binder content. Increasing the binder grade or making the gradation coarser (e.g. closer to the maximum density line) also seemed like good choices.

Decreasing the binder content and adjusting the gradation were the simplest approaches for the contractor. However, the contractor noted that despite their attempts to decrease asphalt content, the mix was extremely sensitive and would too easily result in a failing result on the cracking requirement. Therefore, the contractor opted to change RAP stockpiles. This had a similar effect as a combination of increasing the binder grade and making the gradation coarser. The new RAP had more recycled AC%, which increased the stiffness of the blend, and was also coarser, which allowed the gradation to move closer to the method detection limit. Although volumetrics were not measured, this certainly had the effect of collapsing the voids in the mix.

Figure 7 shows the results of these changes and also notes the simplicity of this particular adjustment. Despite having a wide open specification and numerous options to adjust the mix, the contractor utilized their knowledge of asphalt mixture basics to develop a durable and cost-effective mix.

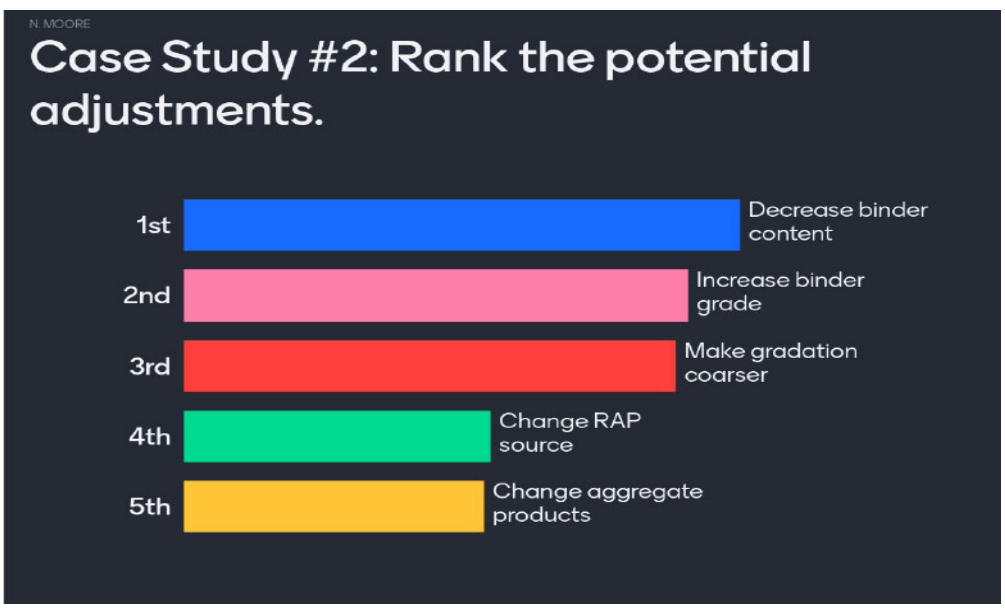
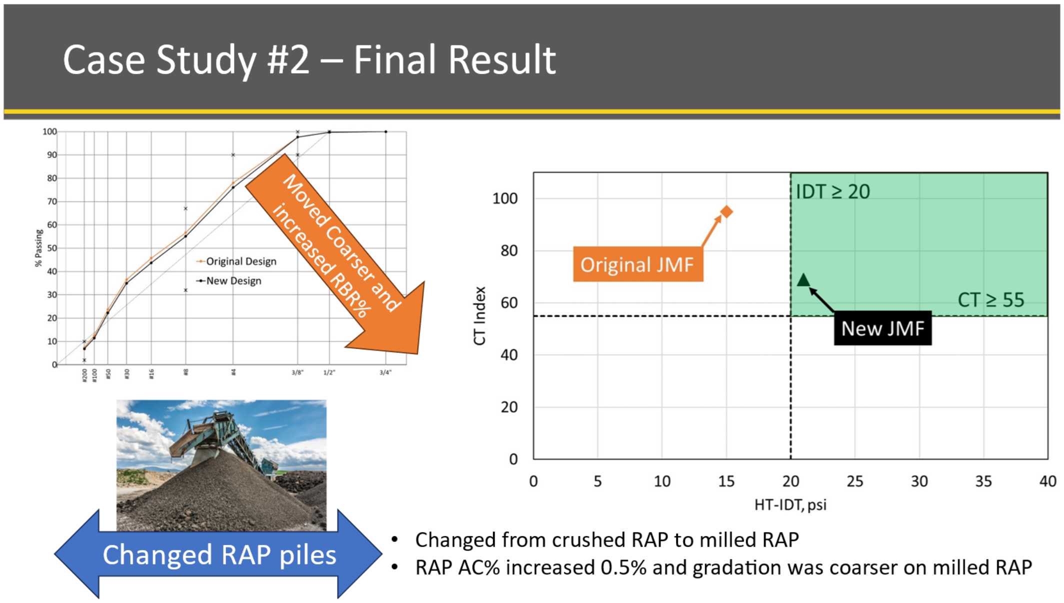


FIGURE 6 Case Study #2 mix adjustment options and voting results.



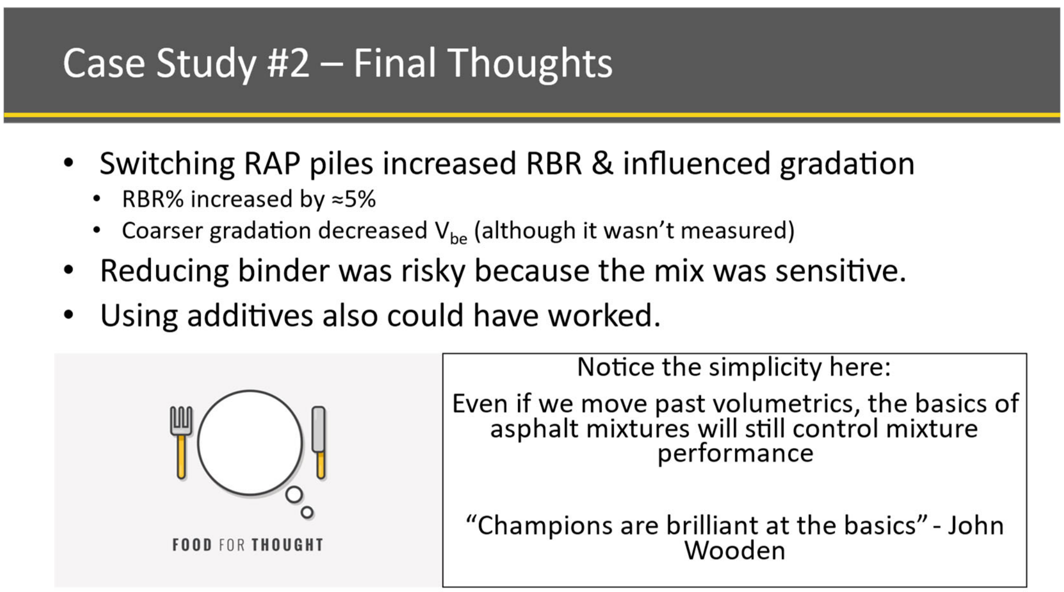


FIGURE 7 Case Study #2 final result and comments.

CASE STUDY #3

Case Study #3 (Figure 8) was a mix designed using BMD Approach A. The mix was a 9.5mm NMAS design with a PG 64-22 binder. It contained 30% RAP, and the total asphalt content was 5.8%. The mix was predominately granite with a smaller proportion of siltstone. The mix had passing volumetrics and needed a significantly improved cracking result.

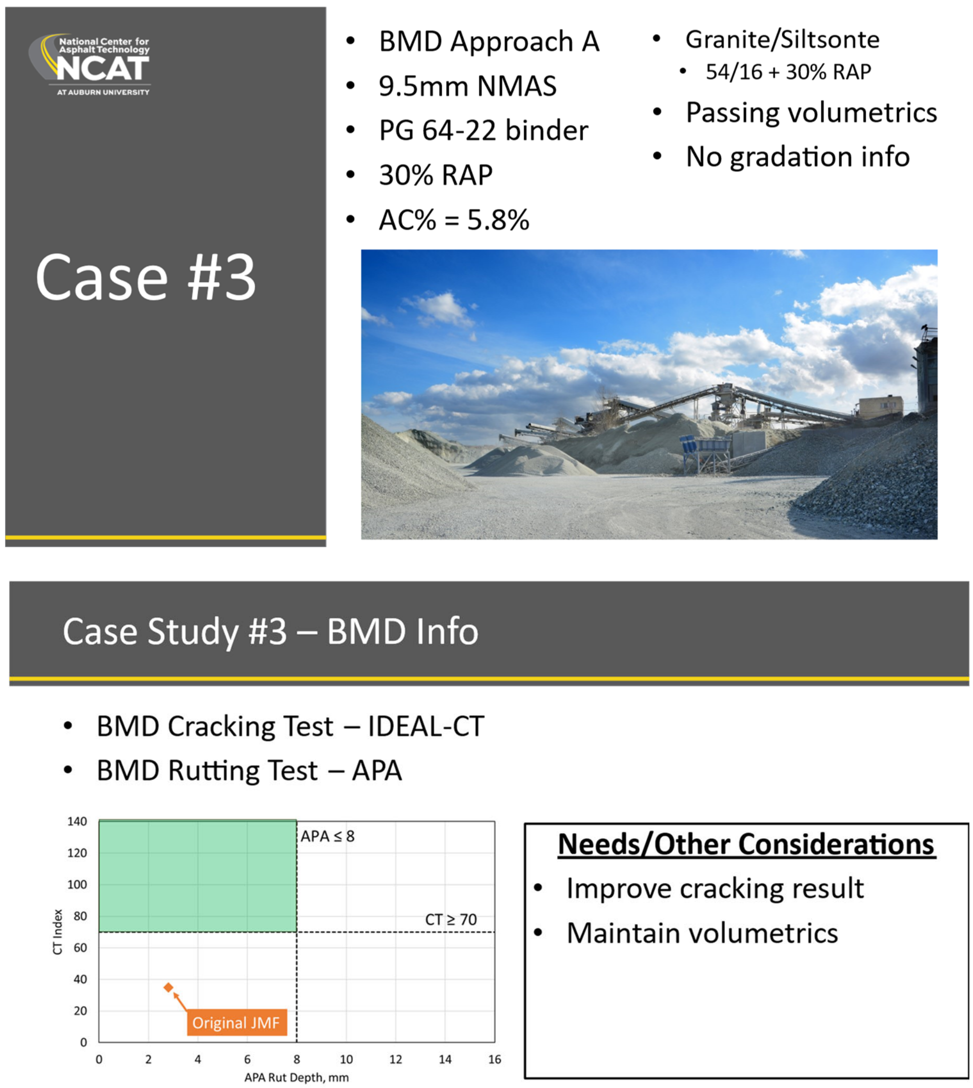


FIGURE 8 Case Study #3 mix designed using BMD Approach A.

Figure 9 shows the options as ranked by the workshop audience. Although presented as an option, increasing the binder content alone would have resulted in a failing volumetric mix design, like Case Study #1. Two of the other options, decreasing RAP content and adjusting gradation, would have worked, but the contractor did not want to decrease RAP, and any additional binder added by adjusting the gradation was not enough to improve such a failing result.

Therefore, as shown in Figure 10, the only other option this contractor had was to change aggregate products. Interestingly, the new aggregate product was an inferior aggregate with higher LA Abrasion loss. However, for reasons unknown to the contractor at the time, using this aggregate improved the BMD cracking result of the mix without compromising the volumetrics. It is assumed that the weaker aggregate resulted in lower loads and more gradual curves in the IDEAL-CT test, which are typically rewarded by that test with a higher CT_{Index}.

The contractor commented that the new mix with the inferior aggregate, but improved BMD results created an inferior asphalt mix. This case study was the cause of much discussion in the workshop because it seemed to contradict the consensus that BMD testing should supplant typical material requirements and volumetric specifications. However, this case study highlights the fact that with any change, there is the risk of unintended consequences and that agencies should be thoughtful about the potential methods that contractors may end up using to develop passing mixes that are no better than their predecessors.

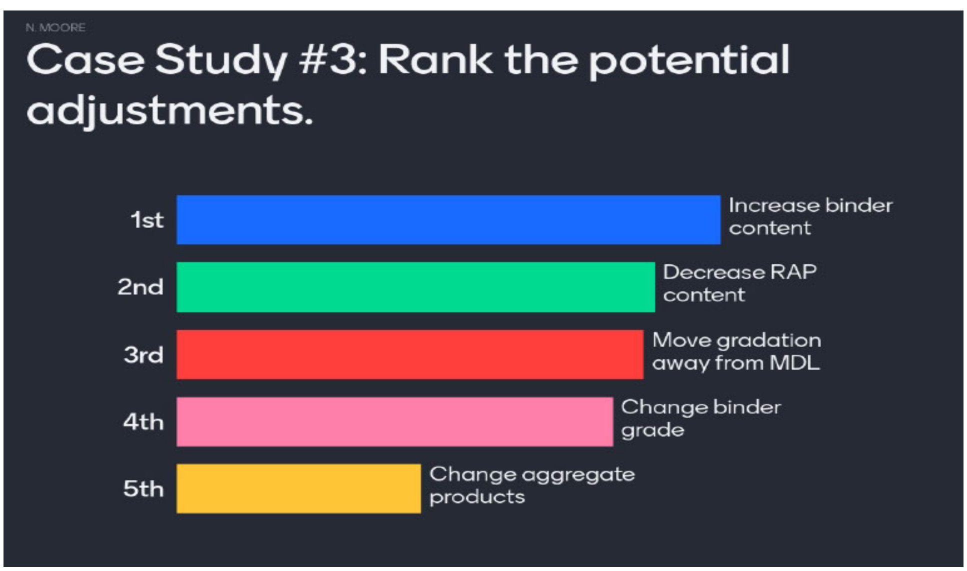


FIGURE 9 Case Study #3 mix adjustment options and voting results.

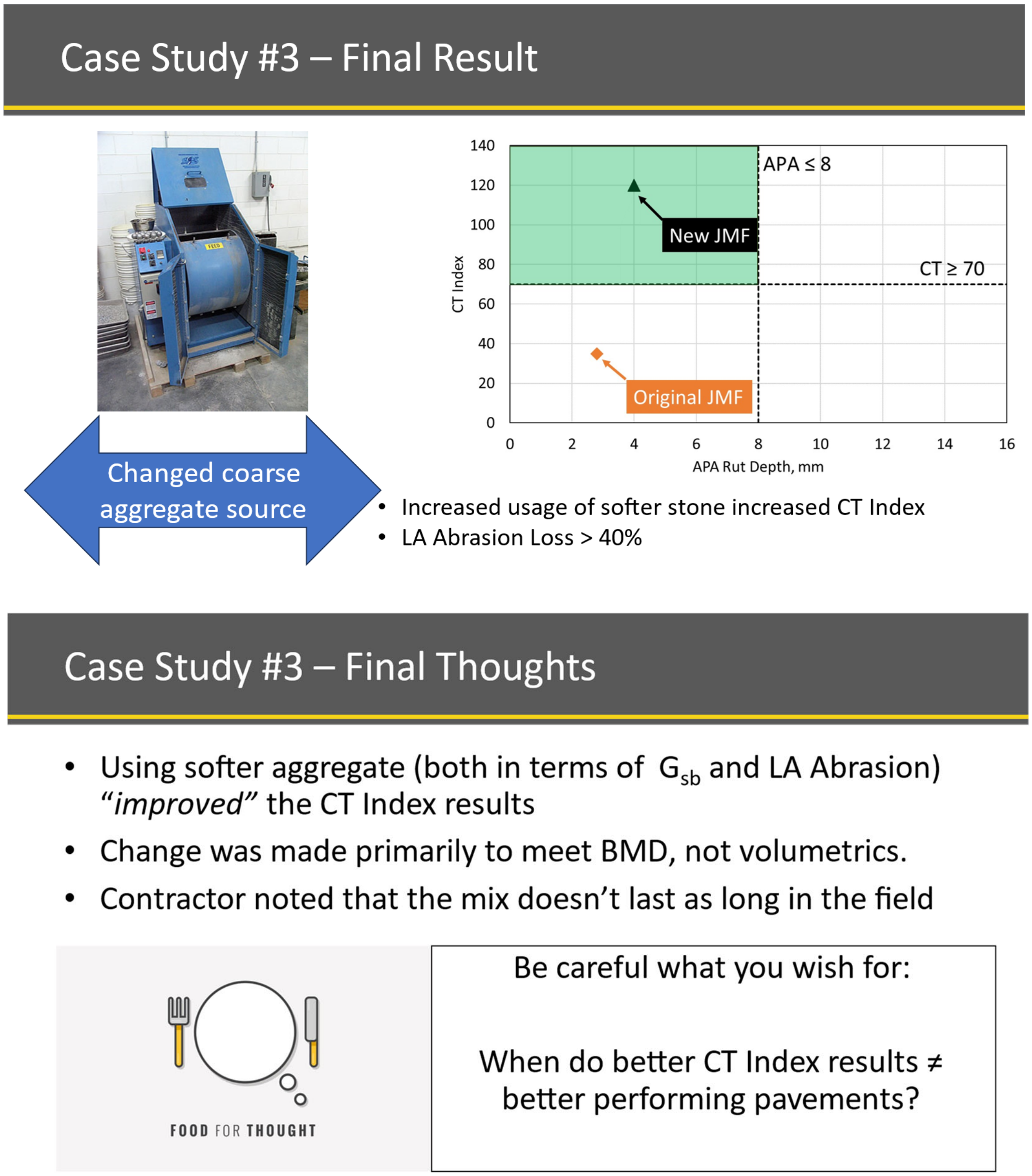


FIGURE 10 Case Study #3 final results and comments.

CASE STUDY #4

Case Study #4 (Figure 11) was a mix designed using BMD Approach A, although it was not technically a BMD design at the time. The mix was a 19-mm NMAS design for a base layer with a PG 64-22 binder. It contained 25% RAP, and the total asphalt content was 6.0%. The mix was being designed as a base layer for a perpetual pavement and needed to pass fatigue cracking criteria from the bending beam fatigue test. Furthermore, the mix was to be placed in a location

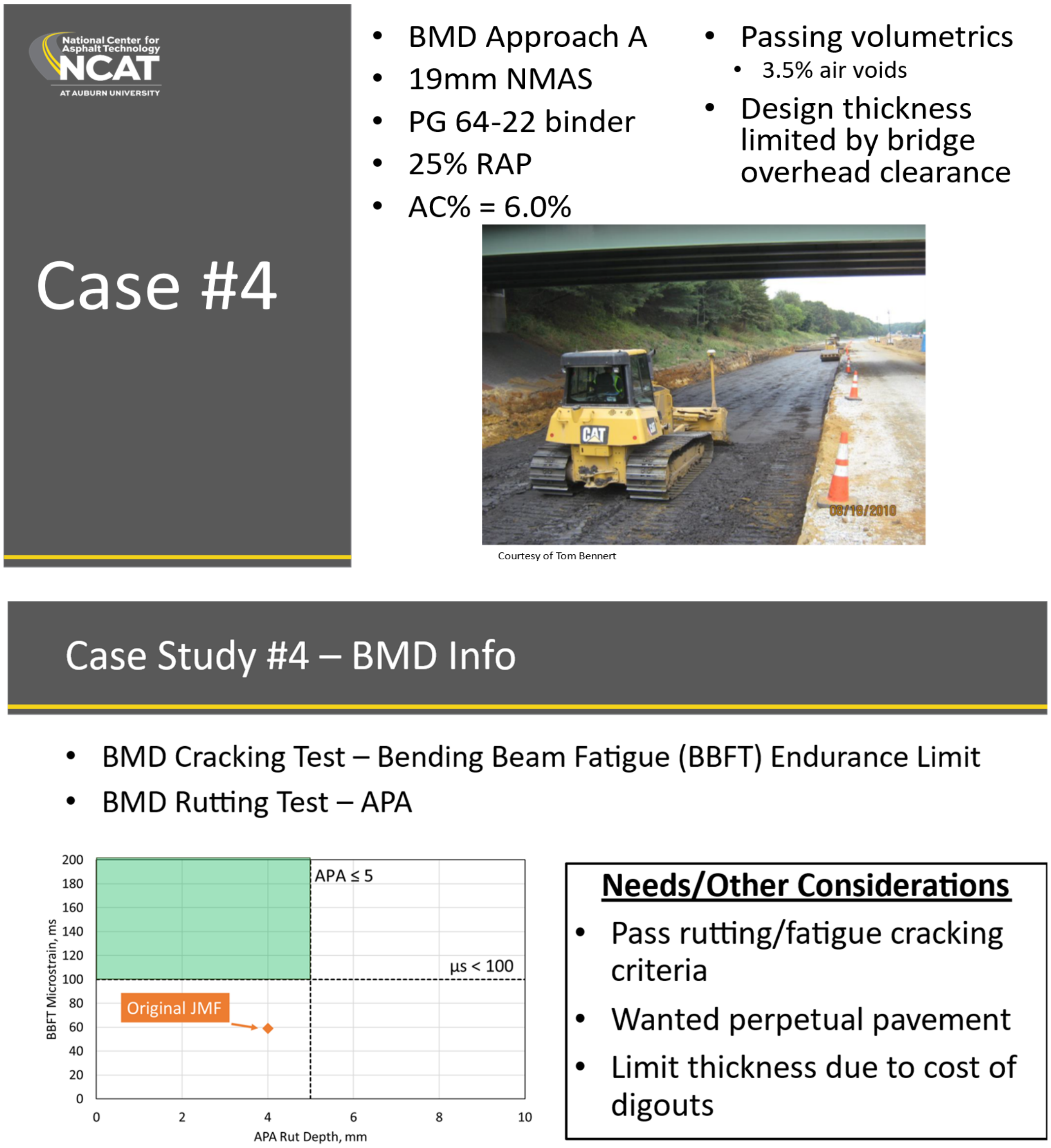


FIGURE 11 Case Study #4 mix designed using BMD Approach A.

where the design thickness was limited by an overpass. The existing pavement was a concrete pavement. If the contractor could develop a mix with an extremely high fatigue endurance limit that could be placed thinner than conventional asphalt mix, they would be able to rubblize the concrete instead of digging it out. This necessitated a pavement 4 inches thinner than what was possible with typical asphalt mix for that state.

Figure 12 displays the options, as ranked by attendees at the workshop. Although all of the five options presented would have helped improve the elasticity and flexibility of the mix, changing the binder grade had the highest potential for the extreme modification that was required.

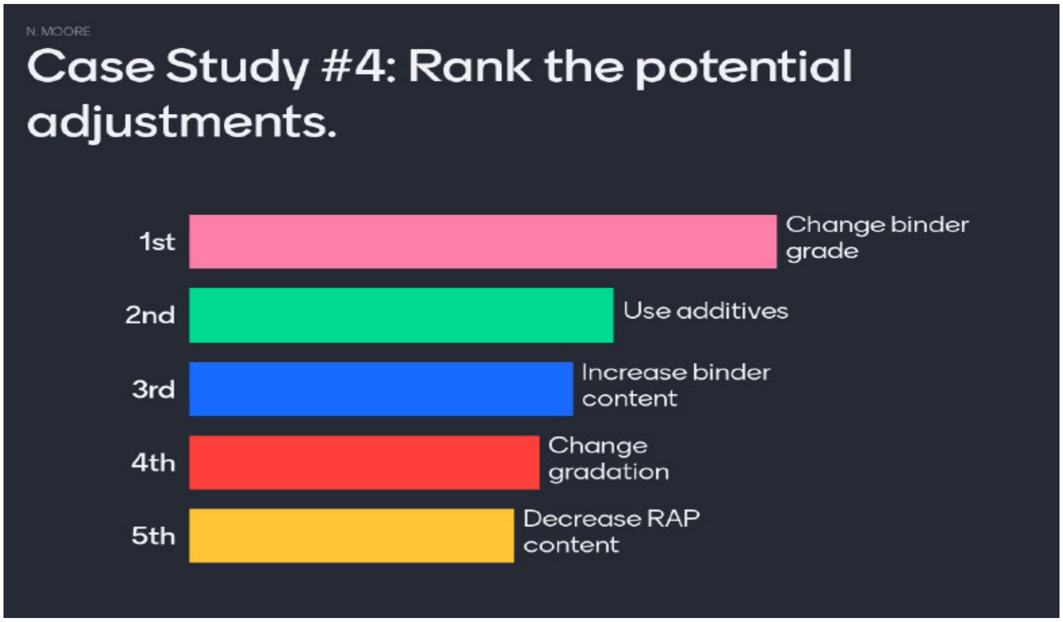


FIGURE 12 Case Study #4 mix adjustment options and voting results.

Ultimately, changing the binder grade to a high polymer-modified binder to create a binder-rich base course and removing the RAP provided the necessary material quality required to eliminate the need for concrete dig-outs. This is displayed in Figure 13. The success of this mix was further punctuated by the fact that it saved 170,000 tons of material. Although not technically BMD, this project was a good example of BMD-style, out-of-the-box innovation.

In summary, four case studies were presented in which the initial mixture design did not meet the BMD requirements. In all cases, the contractor was able to adjust the mixture to meet the BMD requirements. These contractors understood all the details of the specification as well as the cost and availability of their materials. When provided with limited information on each case study, the audience made their best estimate as to the adjustment the contractor selected. Table 1 shows the comparison of the contractor's actual selection and the audience's ranking of that selection.

In Case Studies #1, #2, and #3, there was a large difference between the actual adjustment and the audience's ranking. In Case Study #1, the contractor's knowledge of the cost and availability of their materials created a key difference. Case Study #2 appeared simple, but the sensitivity of the mix to asphalt content forced the contractor to advance beyond the simplest options. In Case Study #3 the limitations of Approach A were on display. The audience's top ranked option would have been the contractor's choice, but the specifications did not allow that option. Finally, Case Study #4 was the only instance where the audience's selection and the contractor's adjustments agreed.

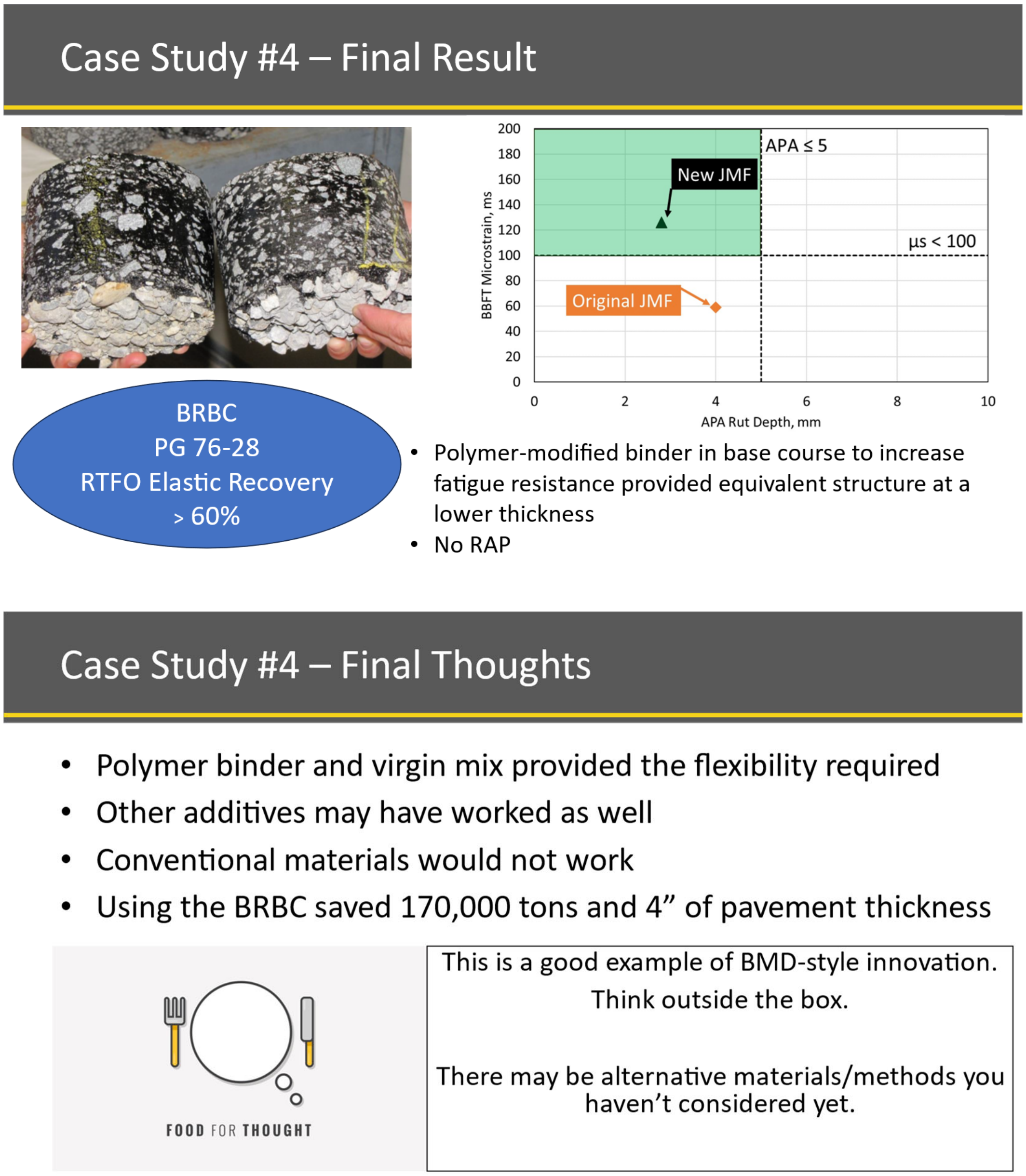


FIGURE 13 Case Study #4 final results and comments.

TABLE 1 Comparison of the Contractor's Actual Adjustment with the Audience's Ranking

	Contractor's Adjustment	Audience's Ranking
Case Study #1	Coarser gradation	5
Case Study #2	RAP stockpile	4
Case Study #3	Aggregate product	5
Case Study #4	Binder grade	1

These case studies were selected because they involved mixture adjustments that demonstrated the need for detailed knowledge of materials, understanding of specifications and criteria, and innovative problem solving. In other words, none of these problems were easily solved by simply adding or removing binder. It was expected that many of the workshop participants probably first learned about BMD mix adjustments with asphalt content as the only variable discussed. Although it is frequently acknowledged that other mix design variables can affect BMD results, experience using other mix design tools is generally lacking. Therefore, this workshop attempted to highlight instances of intelligent application of materials knowledge and out-of-the-box problem solving.

Summary and Key Takeaways

TIM ASCHENBRENER

Federal Highway Administration

The workshop sought to enhance participants' understanding of available strategies for adjusting asphalt mixtures to meet performance test requirements and identify effective techniques for achieving desired outcomes.

The first speaker was Elie Hajj of University of Nevada, Reno who set the stage with BMD definitions, philosophy, and approaches. He then provided an overview of how each presenter tied into the workshop objective. Mentimeter was used to poll the workshop participants with the BMD concept and mix adjustments to meet BMD tests criteria. A total of 75 responses were received. In general, most respondents had a level of familiarity with the BMD concept, with only a few indicating no competence in this area. On the other hand, the responses ranged across the spectrum when it came to the participants' proficiency in adjusting meet BMD test criteria, ranging from no competence to high competence levels. Thus, supporting the need and timing of this workshop to bridge the gap in knowledge by proving the participants with real word examples and effective means in adjusting asphalt mixtures.

The next speaker, Tom Bennert of Rutgers University, presented an overview of various techniques to adjust asphalt mixtures being used currently by several experienced mix designers. Information was presented from interviews of seven industry personnel of diverse regionality and organizational backgrounds to get their experiences and thoughts on BMD. Some commonalities among the responses of the interviewees included:

- Making changes following a systematic approach and only make one change at a time to properly understand the impact of that respective change.
- Conducting mix designs during plant production and making sure to produce sufficient asphalt mixture through the plant for the change to fully take into effect.
- Following the Bailey method approach to design an asphalt mixture with sufficient effective asphalt content.
- Relaxing some of the volumetric design and production parameters, especially AV.
- Utilizing the general methodology by Hveem, which was to try to get as much asphalt binder into the mix until there is a stability concern.
- Relying on information from both the mechanical performance tests and volumetric properties when making adjustments. A lot of history exists regarding volumetric impacts

on mixture performance, so proper design and adjustments should be a combined approach of information from volumetric properties and mechanical performance testing.

This was followed by a presentation by Anas Jamrah of Marathon Petroleum Company LP discussing the impacts of binder source and how mix adjustments could be made to meet performance tests. One mix design was used with three different sources of PG 64-22 binders. One rutting test and three different cracking tests were used to characterize the mixtures. It was concluded that all refinery source binders performed well against rutting, as measured by Hamburg. In terms of cracking, there were statistically insignificant differences in performance as measured by DCT and I-FIT. Fundamental engineering properties derived from fracture tests, such as fracture energy, show less variability in the results and should be considered by agencies for proper assessment of mixture performance. This also applies to IDEAL-CT, which showed the most sensitivity to binder source, through CT index. Mixture factors could be adjusted to improve the mechanical performance.

The next speaker, Randy West of Auburn University, presented the approaches to BMD and moving towards Approach D. Approach B is a slightly better starting point than Approach A since it gives mix designers the opportunity to increase optimum asphalt contents, if needed, to meet the DOT's cracking test and moisture damage test criteria without creating a problem with rutting resistance. However, the only mix design adjustment allowed with Approach B is to increase the virgin binder content. This will increase the material cost and carbon emissions of the mix. DOTs that use Approach B will have to allow either a lower mix design air void target or a lower the N_{design} to maintain a specific air void target. To advance approaches, DOTs and contractors will need to gain confidence in BMD to see better pavement performance. The best way to gain experience with BMD is with shadow projects and field validation test sections and closely monitoring their performance. Within 3 to 5 years, DOTs should be ready to move from Approach B or C to Approach D, eliminating volumetric criteria for mix design and acceptance.

The final presentation of the session was by Nathan Moore of NCAT offering four real-life case studies of mix adjustments made by contractors with options for the participants to select. In summary, the initial mixture design did not meet the BMD requirements. In all cases, the contractor was able to adjust the mixture to meet the BMD requirements. These contractors understood all the details of the specification as well as the cost and availability of their materials. When provided with limited information on each case study, the participants made their best estimate as to the adjustment the contractor selected. Often, the participants' responses did not match the contractor's adjustments. This indicates the importance of understanding the cost and availability of the materials as well as testing the mix designs.

In general, most participants at the workshop had a level of familiarity with the BMD concept prior to attending. On the other hand, participants ranged across the spectrum when it came to the proficiency in adjusting to meet BMD test criteria, ranging from no competence to high competence levels. Thus, supporting the need and timing of this workshop to bridge the gap in knowledge by providing the participants with real word examples and effective means in adjusting asphalt mixtures. It is hoped that the information shared and presented in this workshop will expand the knowledge base for implementation of BMD.