Lessons LEARNED

BALANCED MIXTURE DESIGN

Improving Cracking Resistance in Virginia

This case study illustrates how a volumetric mix design (VMD) with inadequate cracking resistance was modified to meet the Virginia Department of Transportation's (VDOT) balanced mix design (BMD) specifications, using two design modification approaches: 1) increasing asphalt binder content; and 2) increasing RAP content, adding a rejuvenator, and increasing asphalt binder content. See a summary of VDOT's BMD specifications.

Original Volumetric Mix Design

A VDOT-approved 9.5mm nominal maximum aggregate size (NMAS) surface mix with 30% reclaimed asphalt pavement (RAP) was obtained from an asphalt contractor in Virginia. The mix was designed following the Superpave volumetric approach, using a PG 64-22 virgin binder and trap rock aggregates. The mix had a volumetric optimum binder content (OBC) of 5.2%, which corresponded to 4.0% air voids and 16.3% voids in mineral aggregate (VMA) at 50 gyrations. Table 1 summarizes the performance test results at the volumetric OBC. As shown, the mix passed VDOT's APA and Cantabro test requirements but failed the IDEAL-CT requirement with an average CT_{index} of 45; therefore, it was expected to have good rutting resistance and durability but inadequate cracking resistance.

Table 1. BMD Test Results of 30% RAP Mix at Volumetric OBC (5.2%)

BMD Test Parameter	Test Result (Average)	VDOT BMD Spec.	Pass/Fail
APA Rut Depth (mm)	2.7	≤8.0	Pass
IDEAL-CT CT_{index}	45	≥70	Fail
Cantabro Mass Loss (%)	5.2	≤7.5	Pass

BMD Modification Approach 1

The first BMD modification used to improve the cracking resistance of the original mix design was to increase the asphalt binder content. Because VDOT's BMD specifications allow the *Performance Design* approach with full relaxation of the volumetric requirements (for both mix design and production) when the performance requirements are met, the mix was modified by adding more virgin binder while keeping all the other mix components and proportions unchanged. The mix was first tested with IDEAL-CT at the volumetric OBC (5.2%) and three additional binder contents starting at 5.5%. As shown in

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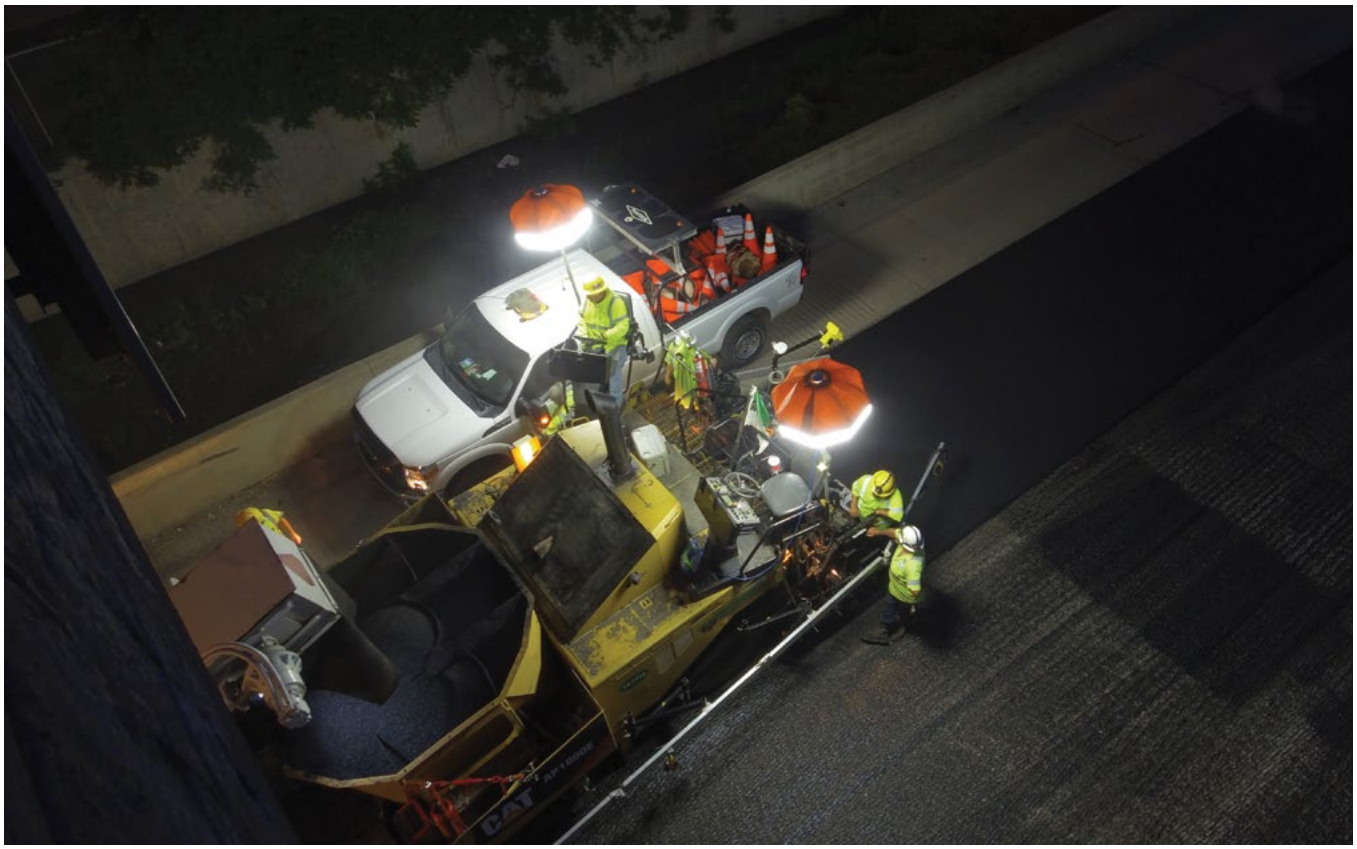


Table 2, the CT_{index} of the mix increased as the binder content increased, which indicated improved cracking resistance. The mix passed VDOT's minimum average CT_{index} criterion of 70 at the 5.5%, 5.7%, and 6.2% binder contents. Based on these results, 5.5% was selected as the preliminary performance OBC of the mix for further verification of rutting resistance and durability. At this preliminary performance OBC, the mix met VDOT's APA and Cantabro test criteria, as shown in Table 3. Therefore, 5.5% was accepted as the final performance OBC that met all VDOT's BMD requirements. At this binder content, the mix had 2.9% air voids and 16.2% VMA.

Table 2. IDEAL-CT Results of 30% RAP Mix at Various Binder Contents

Binder Content (%)	Average CT_{index}	VDOT BMD Spec.	Pass/Fail
5.2 (Volumetric OBC)	45	≥70	Fail
5.5	75		Pass
5.7	105		Pass
6.2	142		Pass

Table 3. BMD Test Results of 30% RAP Mix at Performance OBC (5.5%)

BMD Test Parameter	Test Result (Average)	VDOT BMD Spec.	Pass/Fail
APA Rut Depth (mm)	3.3	≤8.0	Pass
IDEAL-CT CT_{index}	75	≥70	Pass
Cantabro Mass Loss (%)	4.7	≤7.5	Pass

BMD Modification Approach 2

The second BMD modification used to improve the cracking resistance of the original mix design was to increase the RAP content (using the same RAP source) and add a rejuvenator. The RAP content of the mix was first increased to 45% and the virgin aggregate proportions were then adjusted to keep the combined gradation similar to the original mix design. The modified 45% RAP mix had a volumetric OBC of 5.2% and 16.7% VMA at 50 gyrations. To mitigate the stiffening impact of RAP, the mix was rejuvenated with a bio-based rejuvenator that

Table 4. IDEAL-CT Results of 45% RAP Mix at Volumetric OBC (5.2%) and Various Rejuvenator Dosage Levels

Rejuvenator Dosage Level	Average CT_{index}	VDOT BMD Spec.	Pass/Fail
No Rejuvenator	20	≥70	Fail
Low	38		Fail
Medium	44		Fail
High	42		Fail

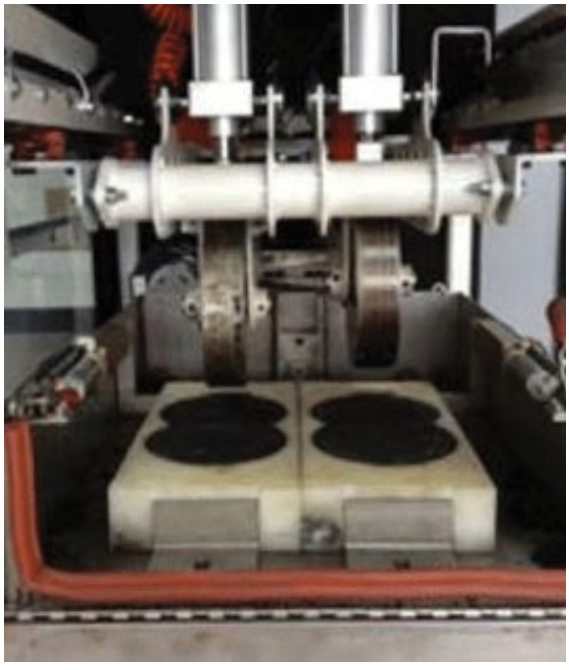
Table 5. IDEAL-CT Results of Rejuvenated 45% RAP Mix at Various Binder Contents

Binder Content (%)	Average CT_{index}	VDOT BMD Spec.	Pass/Fail
5.2 (Volumetric OBC)	44	≥70	Fail
5.5	56		Fail
5.7	62		Fail
5.8	81		Pass
6.2	105		Pass

Table 6. BMD Test Results of Rejuvenated 45% RAP Mix at Performance OBC (5.8%)

BMD Test Parameter	Test Result (Average)	VDOT BMD Spec.	Pass/Fail
APA Rut Depth (mm)	3.4	≤8.0	Pass
IDEAL-CT CT_{index}	81	≥70	Pass
Cantabro Mass Loss (%)	3.0	≤7.5	Pass

has been evaluated on the National Center for Asphalt Technology (NCAT) Test Track; more information about the product can be requested through NCAT. Because of the addition of the rejuvenator, the same PG 64-22 virgin binder was used instead of a softer binder, which would typically be used to accommodate the increased RAP content. Table 4 summarizes the IDEAL-CT results of the 45% RAP mix at the volumetric OBC, with and without the rejuvenator. As shown, adding the rejuvenator improved the cracking resistance of the mix as indicated by higher CT_{index} results, but adjusting rejuvenator dosage did not appear to have a significant impact in this case.



Despite the significantly improved IDEAL-CT result from adding the rejuvenator, none of the rejuvenated 45% RAP mixes met VDOT's minimum average CT_{index} criterion of 70. Therefore, the mix was further modified by adding more virgin binder while keeping the rejuvenator at the 'medium' dosage level. For this second-step modification effort, the rejuvenated 45% RAP mix was first tested with IDEAL-CT at the volumetric OBC (5.2%) and several additional binder contents starting at 5.5%, which consider the addition of the rejuvenator. As shown in Table 5, increasing the binder content improved the cracking resistance of the mix as indicated by an increase in the average CT_{index}. The mix passed VDOT's IDEAL-CT criterion at the two highest binder contents. Based on these results, 5.8% was selected as the preliminary performance OBC of the rejuvenated 45% RAP mix for further verification of rutting resistance and durability. At this preliminary performance OBC, the mix passed VDOT's APA and Cantabro test criteria, as shown in Table 6. Therefore, 5.8% was accepted as the performance OBC of the rejuvenated 45% RAP mix, which corresponded to 2.3% air voids and 16.5% VMA at 50 gyrations.

Table 7. Volumetric Results of Mix Designs before and after BMD Modifications

Mix Property	Original VMD	Modified BMD 1	Modified BMD 2
Total Binder Content (%)	5.2	5.5	5.8*
RAP Content (%)	30	30	45
Additive	-	-	Rejuvenator
RAP Binder Replacement (%)	24	24	38
Virgin Binder Content (%)	3.9	4.2	3.6
Virgin Binder Grade	PG 64-22	PG 64-22	PG 64-22
Air Voids (%)	4.0	2.9	2.3
VMA (%)	16.3	16.2	16.5
VFA (%)	75.5	82.1	86.1

Summary

Table 7 summarizes the volumetric results of the mix designs before and after BMD modifications. Although the rejuvenated 45% RAP mix (modified BMD 2) had a higher total binder content than the modified 30% RAP mix (modified BMD 1), it had a significantly lower virgin binder content, which highlights the potential of using high RAP mixtures with rejuvenators as a cost-effective approach to achieve BMD.

Finally, Figure 1 compares the APA and IDEAL-CT results of the original VMD and modified BMDs on a performance diagram. The dashed lines in the performance diagram represent VDOT's test criteria. As shown, the original VMD is located outside the 'balanced performance' zone on the performance diagram due to the failing IDEAL-CT result. The two modified BMDs, on the other hand, fall within the 'balanced performance' zone with passing APA and IDEAL-CT results and, therefore, are expected to have balanced rutting and cracking resistance.

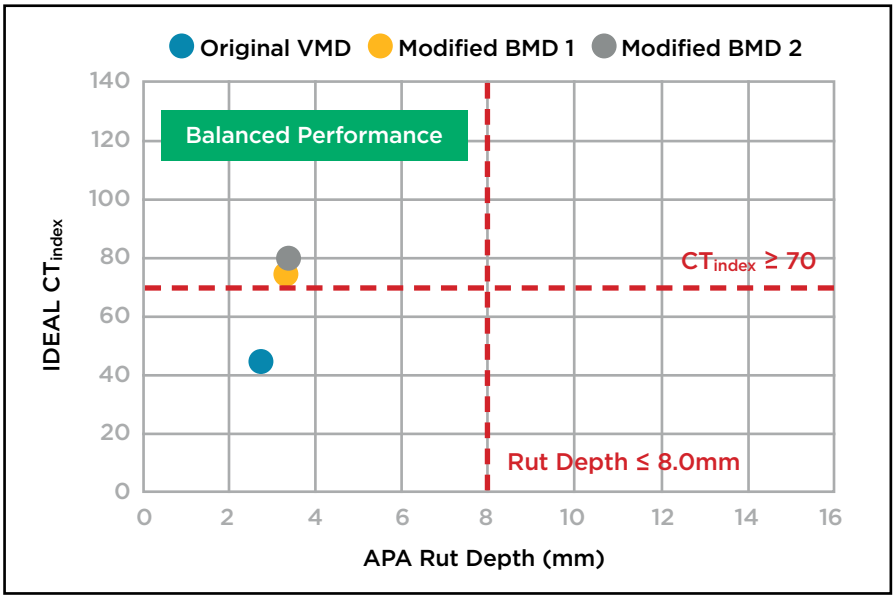


Figure 1. Performance Diagram of Mix Designs before and after BMD Modifications