BALANCED MIXTURE DESIGN

Improving Cracking Resistance in Alabama

This case study illustrates how a volumetric mix design (VMD) with inadequate cracking resistance was modified to meet the Alabama Department of Transportation's (ALDOT) balanced mix design (BMD) specifications, using two design modification approaches: 1) increasing asphalt binder content; and 2) using a warm-mix asphalt (WMA) additive to lower mixture production temperature and increasing asphalt binder content. See a summary of ALDOT's BMD specifications.

Original Volumetric Mix Design

An ALDOT-approved 12.5mm nominal maximum aggregate size (NMAS) surface mix with 20% reclaimed asphalt pavement (RAP) was obtained from an asphalt contractor in Alabama. The mix was an ALDOT ESAL Range "A/B" mix with design traffic of 1 to 10 million equivalent single axle loads (ESAL). It was designed following the Superpave volumetric approach, using a PG 67-22 virgin binder and a blend of granite, gravel, and sand. The mix had a volumetric optimum binder content (OBC) of 5.2%, which corresponded to 3.9% air voids and 14.7% voids in mineral aggregate (VMA) at 60 gyrations (based on NCAT's mix design verification results). Table 1 summarizes the performance test results at the volumetric OBC. As shown, the mix passed ALDOT's HT-IDT requirement with an average strength of 39 psi but failed the IDEAL-CT requirement with an average CT_{index} of 28; therefore, it was expected to have good rutting resistance but inadequate cracking resistance.

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 ALDOT's BMD specifications allow the *Performance Design* approach with full

Table 1. **BMD Test Results of Original Mix Design at Volumetric OBC (5.2%)**

BMD Test Parameter	Test Result			ALDOT BMD Spec. (Average)	Pass/Fail
	# Replicate	Average	Standard Deviation		
HT-IDT Strength (psi)	3	38.7	3.8	≥20	Pass
IDEAL-CT CT_{index}	6	27.6	4.5	≥55	Fail

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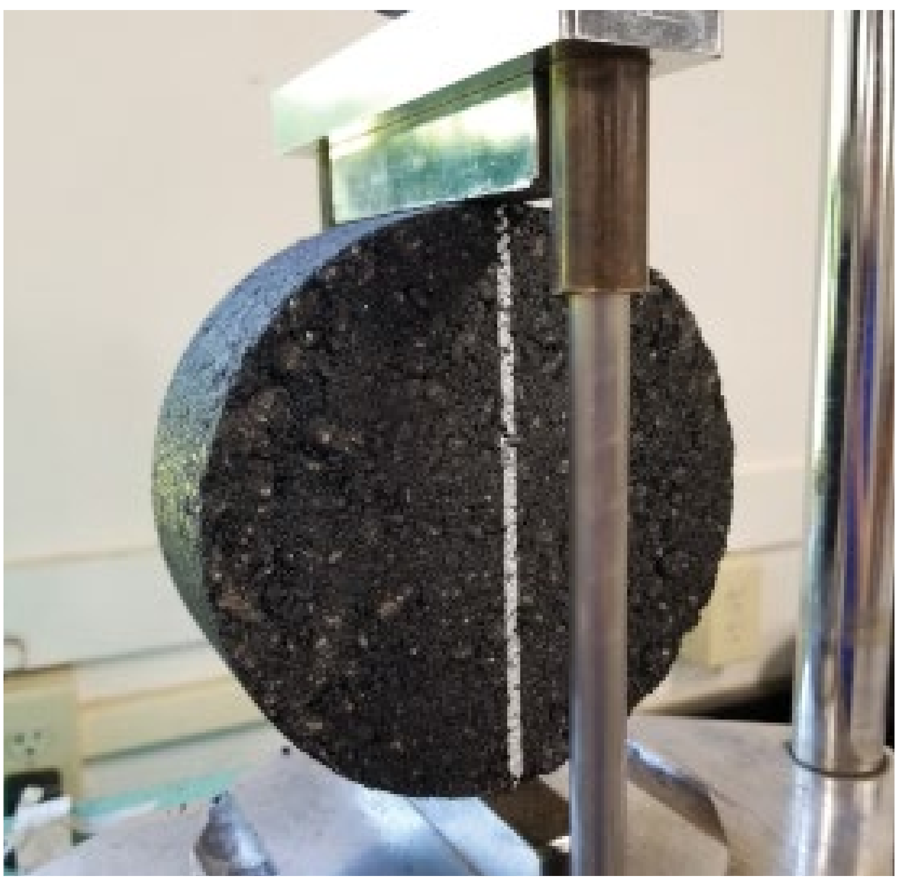
Table 2. IDEAL-CT Results of Original Mix Design at Various Binder Contents

Binder Content (%)	CT_{index}			ALDOT BMD Spec. (Average)	Pass/Fail
	# Replicate	Average	Standard Deviation		
5.2 (Volumetric OBC)	6	27.6	4.5	≥55	Fail
5.5	8	37.2	11.6		Fail
5.8	7	52.0	6.0		Fail
5.9	7	55.7	9.9		Pass
6.1	6	69.8	6.5		Pass

Table 3. BMD Test Results of Original Mix Design at Performance OBC (5.9%)

BMD Test Parameter	Test Result			ALDOT BMD Spec. (Average)	Pass/Fail
	# Replicate	Average	Standard Deviation		
HT-IDT Strength (psi)	5	27.4	2.7	≥20	Pass
IDEAL-CT CT_{index}	7	55.7	9.9	≥55	Pass

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 several additional binder contents starting at 5.5%. To consider the impact of variability on the IDEAL-CT results, each binder content was tested with a minimum of six replicates. As shown in Table 2, the average CT_{index} of the mix increased gradually with the binder content, indicating improved cracking resistance. However, the sensitivity of CT_{index} to increasing binder content for this mix was not as pronounced as expected based on previous experience, which highlights the need to consider the sensitivity of mixture performance tests to different mixture components and proportions in the BMD modification process. Nevertheless, the mix passed ALDOT's minimum average CT_{index} criterion of 55 at the 5.9% and 6.1% binder contents. Based on these results, 5.9% was selected as the preliminary performance OBC of the mix for further verification of rutting resistance, although 6.0% or 6.1% could be selected with a higher safety factor on the IDEAL-CT results. At this preliminary performance OBC, the mix met ALDOT's HT-IDT test criterion with an average strength of 27 psi (Table 3).



Therefore, 5.9% was accepted as the final performance OBC that met ALDOT's BMD requirements. At this binder content, the mix had 1.8% air voids and 14.5% VMA.

BMD Modification Approach 2

The second BMD modification used to improve the cracking resistance of the original mix design was to add a WMA additive to lower the mixture production temperature. Two WMA additives with different chemical compositions were evaluated, which are referred to as WMA-1 and WMA-2. In both cases, the additive was added at a dosage of 0.5% by weight of the total binder, which is a typical rate for lower-temperature WMA applications. For BMD performance testing, the two WMA mixes were mixed at 255°F, conditioned for 4 hours at 240°F, and compacted at 240°F, while the original hot-mix asphalt (HMA) mix was mixed at 305°F, conditioned for 4 hours at 275°F, and compacted at 275°F. The conditioning temperature for the WMA was intentionally reduced to 240°F to accompany its lower mixing temperature compared to the HMA, which is consistent with recommendations of NCHRP projects 09-49 and 09-52 (Epps Martin et al., 2013; Newcomb et al., 2015). Table 4 presents the IDEAL-CT results of the HMA and WMA mixes at the volumetric OBC. As shown, the two WMA mixes had higher average CT_{index} than the original HMA mix, which indicated that using WMA to lower mixture production temperature improved the mixture cracking resistance. It is hypothesized that this improvement was mainly due to the reduced asphalt aging associated with the lower production temperature.

Despite the improved IDEAL-CT results over the original HMA mix, the two WMA mixes did not meet ALDOT's minimum average CT_{index} criterion of 55 at the volumetric OBC. Therefore, they were further modified by adding more virgin binder while keeping all the other mix components and proportions unchanged. For this second-step modification effort, the two WMA mixes were first tested with IDEAL-CT at the volumetric OBC (5.2%) and several additional binder contents starting at 5.5%. Again, each binder content was tested with a minimum of six replicates to consider the impact of variability on the IDEAL-CT results. As shown in

Table 4. IDEAL-CT Results of Original HMA versus Modified WMA Mixes at Volumetric OBC (5.2%)

Mix Type	CT_{index}			ALDOT BMD Spec. (Average)	Pass/Fail
	# Replicate	Average	Standard Deviation		
HMA	6	27.6	4.5	≥55	Fail
WMA-1	7	37.3	5.2		Fail
WMA-2	7	49.1	10.5		Fail

Table 5. IDEAL-CT Results of Modified WMA Mixes at Various Binder Contents

Mix Type	Binder Content (%)	CT_{index}			ALDOT BMD Spec. (Average)	Pass/Fail
		# Replicate	Average	Standard Deviation		
WMA-1	5.2 (Volumetric OBC)	7	37.3	5.2	≥55	Fail
	5.5	7	53.0	13.7		Fail
	5.6	8	60.6	10.4		Pass
	5.8	8	67.6	13.4		Pass
WMA-2	5.2 (Volumetric OBC)	7	49.1	10.5	≥55	Fail
	5.5	8	56.0	6.6		Pass
	5.6	8	64.0	11.8		Pass
	5.8	6	67.4	9.2		Pass

Table 6. **BMD Test Results of Modified WMA Mixes at Performance OBC (5.6%)**

Mix Type	BMD Test Parameter	Test Result			ALDOT BMD Spec. (Average)	Pass/Fail
		# Replicate	Average	Standard Deviation		
WMA-1	HT-IDT Strength (psi)	3	21.0	0.7	≥20	Pass
	IDEAL-CT CT_{index}	8	60.6	10.4	≥55	Pass
WMA-2	HT-IDT Strength (psi)	3	20.4	1.1	≥20	Pass
	IDEAL-CT CT_{index}	8	64.0	11.8	≥55	Pass

Table 5, increasing the binder content improved the cracking resistance of the two WMA mixes as indicated by a gradual increase in the average CT_{index}. The WMA-1 mix passed ALDOT's IDEAL-CT criterion at 5.6% and 5.8% binder contents, while the WMA-2 mix had passing IDEAL-CT results at the 5.5%, 5.6%, and 5.8% binder contents. Based on these results, 5.6% was selected as the preliminary performance OBC of the two WMA mixes for further verification of rutting resistance.

Note that for the WMA-2 mix, 5.6% was selected as the preliminary performance OBC over 5.5% to provide a higher safety factor in passing the IDEAL-CT criterion. At this preliminary performance OBC, both mixes marginally passed ALDOT's HT-IDT test criterion with an average strength of slightly over 20 psi (Table 6). Therefore, 5.6% was accepted as the performance OBC of the two WMA mixes, which corresponded to 2.7% air voids and 14.5% VMA at 60 gyrations.

Summary

Table 7 summarizes the volumetric results of the mix designs before and after BMD modifications. All the BMD modifications evaluated in the case study resulted in a significant increase in the total binder content of the mix for improved cracking resistance. Nevertheless, the two WMA mixes had a considerably lower total binder content than the modified HMA mix, highlighting the potential of

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

Mix Property	Original HMA	Modified HMA	Modified WMA-1	Modified WMA-2
Total Binder Content (%)	5.2	5.9	5.6	5.6
RAP Content (%)	20	20	20	20
Additive	-	-	WMA-1	WMA-2
RAP Binder Replacement (%)	21%	19%	20%	20%
Virgin Binder Content (%)	4.1	4.8	4.5	4.5
Virgin Binder Grade	PG 67-22	PG 67-22	PG 67-22	PG 67-22
Air Voids (%)	3.9	1.8	2.7	2.7
VMA (%)	14.7	14.5	14.5	14.5
VFA (%)	74	87	81	81

using WMA to lower mixture production temperature as a cost-effective approach to achieve BMD. Note that the cost comparison between the two BMD modifications is beyond the scope of this case study; however, in practice, asphalt contractors are recommended to pursue the most cost-effective BMD modification approach to meet the performance test requirements while remaining competitive in a low-bid environment. It is also worth noting that although the increased binder content due to BMD modifications will increase the material cost of the mix, it has the potential to improve the performance and life span of the pavement, which will likely justify the higher material cost from a life-cycle cost perspective.

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

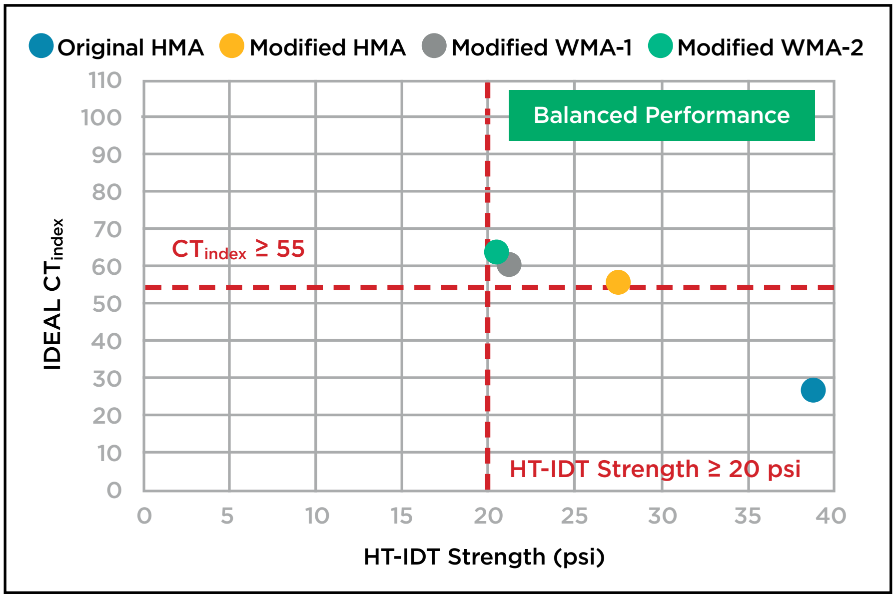


Figure 1. **Performance Diagram of Mix Designs before and after BMD Modification**

References

Epps Martin, A., Arambula, E., Yin, F., Cucalon, L.G., Chowdhury, A., Lytton, R., Epps, J., Estakhri, C., and Park, E.S. (2014.) NCHRP Report 763: Evaluation of the Moisture Susceptibility of WMA Technologies. Transportation Research Board of the National Academies, Washington, DC.

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