REPORT CDOT-2019-06

December 2019

Improving Durability of Asphalt Mixtures

APPLIED RESEARCH & INNOVATION BRANCH

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COLORADO
Department of Transportation

Technical Report Documentation Page

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16. Abstract

Some of the hot mix asphalt pavements constructed for CDOT prior to 2016 have demonstrated premature cracking and raveling distress. The appearance of these pavements is reported to be that of pavements which contain lower than desirable asphalt binder content. However, quality control and quality assurance data obtained from these projects indicates that asphalt content, VMA and dust to asphalt ratio are all within acceptable mixture design and specification limits. This could mean that current mixture design and specification limits are not appropriate for these pavements or that adjustments to asphalt content may be necessary during construction due to changes in asphalt mixture proportions.

The two objectives for this research were to review the 2016 asphalt mixture specifications to determine whether changes were warranted that could lead to more durable asphalt mixtures and, if so, adjust the specification accordingly and construct test sections to evaluate the revised specification.

The results of this work lead to the conclusion that the dust to asphalt ratio determined during mixture design, while calculated in accordance with the recommendations of the Strategic Highway Research Program (SHRP) for the Superpave Mixture Design procedure were correct, the 1 percent hydrated lime required for each mixture design was not being counted as dust. This meant that dust to asphalt ratio was actually higher than calculated. In addition, VMA was lower than recommended based on nominal maximum aggregate size. This occurred because of changes to the mixture nominal maximum aggregate size during construction.

A test pavement was constructed in 2017 to determine if changes in the dust to asphalt content to account for 1 percent hydrated lime and an increase in VMA would produce improved durability. At this writing, two years after construction, no apparent differences in performance are evident between test and control sections.

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Contents

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Craig Weiden, former CDOT Region 2 Materials Engineer, was instrumental in providing the project where the test sections on US50 were established. Special Provisions including the revised specifications were required so the contractor understood what was expected regarding the various test sections.

The scientific curiosity and engineering interest provided by all individuals involved with this project are gratefully acknowledged for without the cooperation of the principals involved studies like this are considerably more difficult or impossible to achieve.

EXECUTIVE SUMMARY

Some of the hot mix asphalt pavements constructed for CDOT prior to 2016 have demonstrated premature cracking and raveling distress. The appearance of these pavements is reported to be that of pavements containing lower than desirable asphalt binder content. However, quality control and quality assurance data obtained from these projects indicates that asphalt content, VMA and dust to asphalt ratio are all within acceptable mixture design and specification limits. This could mean that current mixture design and specification limits are not appropriate for these pavements or that adjustments to asphalt content may be necessary during construction due to changes in asphalt mixture proportions.

The two objectives for this research were to review the 2016 asphalt mixture specifications to determine whether changes were warranted that could lead to more durable asphalt mixtures and, if so, adjust the specification accordingly and construct test sections to evaluate the revised specification.

The results of this work lead to the conclusion that the dust to asphalt ratio determined during mixture design, while calculated in accordance with the recommendations of the Strategic Highway Research Program (SHRP) for the Superpave Mixture Design procedure were correct, the 1 percent hydrated lime required for each mixture design was not being counted as dust. This meant that dust to asphalt ratio was actually higher than calculated. In addition, VMA was lower than recommended based on nominal maximum aggregate size. This occurred because the mixtures became finer during construction, which should have triggered an increase in the minimum VMA.

To determine if changes in the method of calculation of dust to asphalt ratio and higher minimum VMA have an effect on asphalt mixture performance, a test pavement was constructed in 2017 on US50 west of Canon City, Colorado. Three 500 foot long evaluation sections for the higher VMA and lower dust to asphalt ratio asphalt mixture were established with three adjacent 500 foot long control evaluation sections. The control sections utilized the prevailing 2016 specifications. In addition, to these evaluation sections, two additional evaluation sections were installed as part of the FHWA “higher density study” being conducted around the country. This provides a unique comparison of the status quo control, status quo at two higher compaction efforts, and the higher VMA/lower dust to asphalt mixtures. The result of this experiment will provide CDOT with information relative to the benefits of the 2016 specification at higher relative compaction versus the revised 2016 specification at higher VMA and lower dust to asphalt.

At this writing, nearly two years after construction, no apparent differences in performance are evident between any of the test or control sections. However, since differences in performance are seldom seen at only two years’ service, this observation is not conclusive. Therefore, further observation of the test sections is warranted to determine if changes in CDOT policy regarding VMA and dust to asphalt ratio are justified.

INTRODUCTION

Background

Asphalt pavement durability is measured by the ability of the pavement to resist weathering. The asphalt coating on the aggregates is the waterproofing element in the pavement. An asphalt pavement becomes more susceptible to weathering when the asphalt coating on the aggregates is inadequate, the asphalt coating becomes oxidized and therefore embrittled, the voids are too high, there is incompatibility between the aggregate surface and the asphalt binder or a combination of these factors.

Inadequate film thickness (Roberts, et al 1991) can create a lack of cohesion between aggregate particles and create a pavement that appears lacking in binder or 'dry'. Oxidation of the asphalt occurs more rapidly under this situation causing the pavement to become brittle and susceptible to cracking earlier in the life of the pavement. Many Colorado aggregates tend to be hydrophilic. This resulted in the mandatory use of 1 percent hydrated lime in all CDOT specified asphalt mixtures beginning in the 1990's. Thin asphalt films are more easily penetrated by water than thick films. Consequently, the combination of thin, oxidized films in the presence of possibly hydrophilic aggregates is the perfect formula for a rapid reduction of durability. However, measuring film thickness by comparing aggregate surface area to effective asphalt content has been found to be questionable based on aggregate gradation (Kandhal and Chakraborty 1996). This is because it is unlikely all the aggregates will have the same average asphalt film thickness. And, obtaining a value for film thickness is dubious, at best, since there is no agreed upon method for measuring surface area of irregularly shaped crushed aggregates. The values shown by the Asphalt Institute (MS-2) are based on the work of Francis Hveem (Hveem 1942) using kerosene and MC250 cutback asphalt.

The alternative to measuring film thickness is the calculation of the volume of void space within an asphalt mixture. These voids in the mineral aggregate, or more correctly, voids *between* the mineral aggregate (VMA) are the volume of voids between the aggregate particles of a compacted paving mixture. In other words, the VMA is the volume occupied by everything but the *bulk* aggregate, or the effective asphalt and the air void volumes (McLeod 1956). By specifying a minimum VMA requirement, therefore, a minimum film thickness is obtained since air void volume is usually a constant of 4 percent.

Minimum VMA recommendations are based on nominal maximum aggregate size (NMAS). NMAS is defined as one sieve size larger than the first sieve to retain greater than 10 percent of the particles. Unfortunately, the coarsest aggregate has significantly lower surface area than the finest aggregate. So, if during mixture design VMA is established based on the coarse aggregate gradation but during construction the fine fraction of the mixture becomes finer, the surface area of the mixture increases (Aschenbrener and MacKean 1994). If VMA does not increase to accommodate this change, the film thickness will decrease and durability could suffer (Hudson and Davis 1965). However, VMA is based on the NMAS, not the fine aggregate gradation. So, if the coarse aggregate does not change during construction, the design VMA will meet the specifications, even though the film thickness may be lower than desired.

Objective

The objective of this research was to determine if VMA and the ratio of dust to asphalt in asphalt paving mixtures affect asphalt pavement durability.

APPROACH

This research began with the hypothesis that asphalt pavements in Colorado were suffering from a lack of asphalt binder. This thesis was based on observations of early performance of some asphalt pavements. This early performance appeared as cracking and loss of the fine aggregate fraction of the asphalt pavements, both of these results potentially being symptoms of inadequate durability caused by low asphalt content. To determine if the practices in place by CDOT were contributing to this lack of durability a review of CDOT mixture design and construction practices was completed. The results of this review revealed several items that could potentially lead to lower than desired asphalt pavement durability and should be considered. These potential causes and effects on durability include:

1) Calculating dust to asphalt ratio based on total P200 in mixture. This would include the 1 percent hydrated lime used in all asphalt mixtures.
2) Reduced film thickness of binder for some mixtures. This happens when the asphalt mixture aggregate gradation becomes finer during construction, but the VMA is not adjusted upward to accommodate the change.
3) Pay for asphalt binder as a separate item. This eliminates the incentive for contractors to lower asphalt content of mixtures during construction. An alternative to this would be to pay for any increase in asphalt during construction in the event asphalt content must increase to account for changes between design and 'as-built' volumetric properties.
4) Determine how much of the binder from any RAP used in the mixture is acting as an effective binder and not simply as a particulate filler.
5) Utilize 4% air voids during design, but use 3.5% during production realizing the drop that usually occurs between design and production.
6) Changes in aggregate specific gravity between design and production. This can have a marked effect on the 'as-built' VMA.

The first two items shown above were determined to be the most expedient to test in the field to measure effects on durability. Therefore, pavement test sections were incorporated within Project STA 0503-089, "US50/SH9 Royal Gorge Resurfacing Project" west of Canon City, Colorado. The geographic boundaries of the project are approximately 10 miles west of Canon City and 7 miles east of Texas Creek, Colorado as shown on Figure 1. The project scope required the contractor to remove 2 inches of the existing pavement by cold milling and replacing with 2.5 inches of new hot mixed asphalt (HMA) resulting in a 10 year 18 kip ESAL design life. The new HMA consisted of a CDOT SX gradation using 100 gyrations of compaction and a PG58-28 asphalt binder. Approximately 31,000 tons of HMA were utilized.

Figure 1. Project Location

Condition of the pavement prior to milling consisted of low to moderate severity longitudinal and transverse cracks at 20 to 100 foot intervals, low to moderate severity alligator cracking generally in the wheelpaths and no significant permanent deformation.

Traffic in 2016 was measured at 20,000 AADT with 3 percent trucks.

Construction

APC Southern produced the HMA and paved the project. The asphalt plant was located in the Tezak gravel pit at approximately milepost 249.5, three miles west of Texas Creek, Colorado at an elevation of 6200 MSL. An overview of the plant is shown in Figure 2.

Figure 2. Overview of Asphalt Plant Site

The asphalt plant was a portable CMI counterflow drum mix plant assembled specifically for this project and is shown in Figure 3.

Figure 3. Mixing Drum

The plant is rated at 400 tons of HMA per hour at mean sea level (MSL).

The plant burner was fueled with propane and the mixture was produced using four gradations of aggregate from four cold bins shown in Figure 4 and one RAP source supplied via the RAP collar.

Figure 4. Cold Bins

Aggregate consisted of coarse rock, 'clean' crusher fines, crusher fines, and 'naturals' shown in Figures 5, 6, 7 and 8. The RAP is shown in Figure 9.

Figure 5. Rock

Figure 6. 'Clean' Crusher Fines

Figure 7. Crusher Fines

Figure 8. 'Naturals'

Figure 9. RAP

Mixture temperatures at the plant were set at 315F. Haul times varied from 10 to 15 minutes resulting in temperatures at the screed varying from 290 – 300F.

Paving

All paving occurred in July and August, 2017.

Paving consisted of tacking the milled surface, placing the HMA using an echelon paving train 32 feet wide in the west bound driving and passing lanes, but paving in the eastbound direction as shown in Figure 10.

Figure 10. Echelon Pavers

Tack coat was CSS-1h emulsion diluted 1:1 and applied at 0.05 gallons per square yard. Pavers were Cedar Rapids CR-552 machines placing approximately 3.25 inches of loose mixture to achieve the desired 2.5 inches compacted thickness. The HMA was delivered to the pavers using bottom dump tractor trailers hauling approximately 22 tons per truck. All trucks were tarped. The mixture was deposited on the milled surface and picked up using Cedar Rapids pickup machines as shown in Figure 11.

Figure 11. Pickup Machine

Compaction consisted of a Caterpillar CB64 breakdown roller, followed by a Hypac C784A, followed by a Caterpillar CW34 pneumatic, followed by a Caterpillar CB54XW as shown in Figures 12, 13, 14 and 15.

Figure 12. Cat CB64

Figure 13. Hypac C784A

Figure 14. Cat CW34

Figure 15. Cat CB54XW

The mixture temperature at the screed varied from 290F to 300F recorded with an infrared Fluke digital thermometer. The temperature at breakdown varied from 230 to 270F using the same instrument.

Environment

Weather during construction was clear in the morning and afternoon with thunderstorms either occurring or threatening in the afternoon. The milled pavement temperature during construction was 90F with ambient temperatures ranging from 75F at 6am to 85F at 3 pm.

Test and Control Sections

Test sections and control sections were established to test the hypothesis that an increase in VMA and decrease in dust to asphalt ratio affects asphalt pavement performance. The test sections consist of pavement constructed with VMA and dust to asphalt ratio approximately in accordance with the special provision shown in Appendix A. The special provision increases the VMA in the asphalt mixture by 0.5 percent and includes the hydrated lime in the mixture as part of the dust in the dust to asphalt ratio calculation. The control sections consist of pavement with VMA substantially lower and dust to asphalt higher than that prescribed in the special provision. Both test and control sections were located based on these criteria and in locations where relative compaction was practically equal. This is the reason the length of the evaluation portion of the control section is 780 feet and the length of the evaluation portion of the test section is 900 feet.

Control Sections

Three control sections were established which have lower VMA than desired and a dust to asphalt ratio higher than specified. The three control sections are located between stations 3826+14 and 3833+94 in the westbound driving lane as shown on Figure 16.

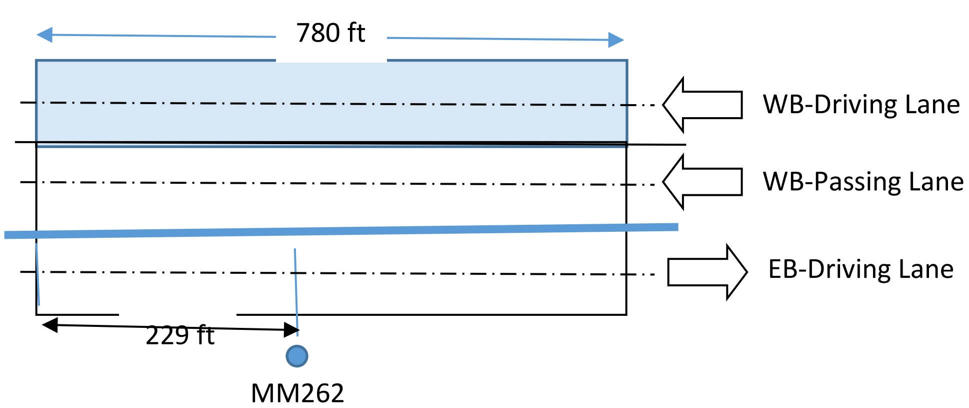

Figure 16. Control Section Locations

VMA of the control mixture was measured at 14.3 percent. This mixture meets the requirements of a 9.5 mm nominal maximum size asphalt mixture. Therefore, the required VMA for this mixture in accordance with the special provision should have been 17.1 percent. The dust to asphalt ratio for this mixture is 1.3 compared with the special provision requirement of 1.2, maximum. Relative compaction of the control mixture averaged 94 percent with a standard deviation of 0.53 percent.

Test Sections

Three test sections were established which have VMA approximately equal to that desired and with dust to asphalt ratios within the boundary established by the special provision. The three test sections are located between stations 4050+49 and 4059+49 in the westbound driving lane as shown on Figure 17.

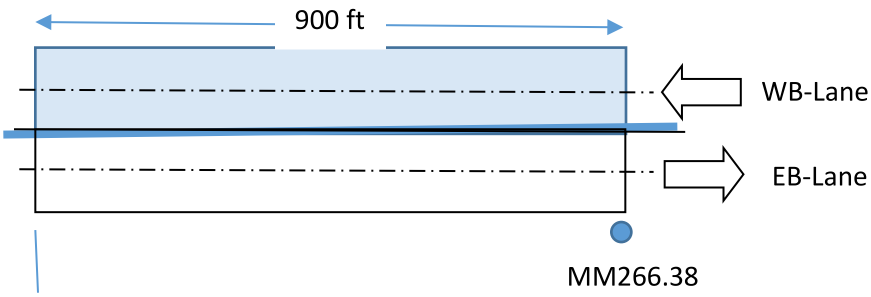

Figure 17. Test Section Locations

VMA of the test section mixture was an average of 15.3 percent. This mixture meets the requirements of a 12.5 mm nominal maximum size asphalt mixture. Therefore, the required VMA for this mixture in accordance with the special provision should have been 16.1 percent. The dust to asphalt ratio for this mixture is 1.2 compared with the special provision of 1.2, maximum. Relative compaction of the control mixture averaged 93.5 percent with a standard deviation of 0.64 percent.

EXPERIMENT DESIGN

The three test and three control sections are considered replicate samples in this experiment. Therefore, differences in performance between the "compliant" VMA/ dust:asphalt mixture and the "non-compliant" control mixture can be analyzed using conventional analysis of variance techniques. The model for analysis is as follows:

$$Y_{ijk} = \mu + C_i + T_j + \varepsilon_{ijk}$$

Where,

Y_{ij} = Dependent variable
μ = Effect due to overall mean
C_i = Effect due to control section ("non-compliant")
T_j = Effect due to test section ("compliant")
ε_{ij} = Random error

The properties of the 'compliant' test and 'non-compliant' control mixtures are summarized in Table 1.

Table 1. Test and Control Section Properties

Property	Test Section ('Compliant')		Control Section ('Non-Compliant')	
	As-built	Target	As-built	Target
VMA, %	15.3	16.1	14.3	17.1
Dust/Asphalt	1.2	1.2	1.3	1.2

ANALYSIS

The test and control sections have been in service for approximately two years at this writing. No differences in performance were observed after condition surveys conducted at 6, 12, 18, and 21 months and the pavement is in very good condition for both the experimental and control sections as seen in Figure 18. However, slight bumps transverse to the centerline have begun to appear in the experimental sections near the shoulder and right wheelpath. These slight bumps appear directly over cracks in the underlying pavement as shown in Figure 19 and can only be seen when lighting allows.

Figure 18. Experimental Section at Approximately MM266.30

Figure 19. Transverse Crack in Shoulder at Approximately MM266.30

The 24 month condition survey conducted in 2019 revealed the beginning of raveling in the control sections. Figures 20 and 21 depict this as a loss of fine aggregate in the asphalt pavement on the shoulder at 215 feet and 455 feet east of MM262.

Figure 20. Slight Raveling in Control Section at Approximately MM262.05

Figure 21. Slight Raveling in the Control Section at Approximately MM262.08

This slight loss of aggregate on the surface should be observed during the next several years to determine if the material in this area is progressively deteriorating. If progressing, further evaluations should be done to determine if the cause can be linked to the material properties since this control section has significantly lower VMA (14.3%) compared with the desired VMA (17.1%) for this asphalt mixture.

The dependent variable, raveling, can then be analyzed using conventional analysis of variance (ANOVA) techniques to ascertain whether the observed performance between the pavements is statistically significant. The hypothesis that the lower than desired VMA and higher than desired dust to asphalt ratio ('non-compliant') mixtures will produce poorer performance can be tested using this form of analysis. If this is the outcome of the experiment then decisions can be made regarding the benefits of changing the way hot mix asphalt pavement is specified by CDOT.

CONCLUSIONS

1. Two asphalt pavement experimental features were installed on US50 west of Canon City in 2017 in order to evaluate the effects of VMA and dust to asphalt ratio.
2. The two experimental features differ significantly with respect to VMA and dust to asphalt ratio. One feature is close to compliance with the special provision utilized on the project. The other feature contains significantly lower VMA and higher dust to asphalt content.
3. Three evaluation sections within each of the experimental features were established so that results of pavement performance condition surveys could be analyzed statistically.
4. Slight raveling was observed in the control section during the last condition survey at 24 months service. Further observation will be needed to determine if this raveling is progressing. If so, and if less raveling is observed in the experimental section, analysis of this difference in performance should be done to determine whether differences are statistically significant.

RECOMMENDATIONS

1. Continue to monitor the performance of the six evaluation sections on US50 at 12 month intervals beginning in the early spring 2020.
2. Record all pavement distress using the standard reporting techniques described by SHRP.
3. Analyze the results of the condition surveys using conventional ANOVA techniques using the model described in the Experiment Design section of this report.
4. Based on the outcome of the analysis make decisions regarding the efficacy of specification changes with regard to VMA and dust to asphalt ratio.

5. Review Section 6.14 of the CDOT Pavement Design Manual. It states:

$$\mathbf{P_{be}\ (by\ volume) = P_{be} * (G_{mm} / G_b)}$$

Where

P_{be} = effective asphalt content, percent by total weight of mixture
G_{mm} = bulk specific gravity of the mix
G_b = specific gravity of asphalt (usually 1.010)

The designation G_{mm} usually refers to the maximum theoretical specific gravity of the mixture, not the bulk specific gravity of the mixture. See Asphalt Institute MS-2.

IMPLEMENTATION PLAN

No implementation will be justified until differences in performance between the experimental mixture and the control mixture are observed and a statistically significant effect is measured. If differences are measured and the experimental sections demonstrate superior performance, consideration should be given to changing the specifications so that when as-constructed materials vary from the materials as-designed the volumetric requirements for these materials are revised accordingly.

REFERENCES

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Appendix A – Revision of Section 403 – Hot Mix Asphalt

REVISION OF SECTION 403

HOT MIX ASPHALT

Section 403 of the Standard Specifications is hereby revised for this project as follows:

Subsection 403.02 shall include the following:

The design mix for hot mix asphalt shall conform to the following:

Table 403-1

Property	**Test Method**	Requirement
Air Voids, percent at: N (design)	CPL 5115	3.5 – 4.5
Lab Compaction (Revolutions): N (design)	CPL 5115	100
Stability, minimum	CPL 5106	30
Aggregate Retained on the 4.75 mm (No. 4) Sieve Mechanically Induced fractured faces, % minimum	CP 45	70
Accelerated Moisture Susceptibility Tensile Strength Ratio (Lottman), minimum	CPL 5109 Method B	80
Minimum Dry Split Tensile Strength, kPa (psi)	CPL 5109 Method B	205 (30)
Voids in the Mineral Aggregate (VMA) % minimum	CP 48	See Table 403-2
Voids Filled with Asphalt (VFA), %	AI MS-2	65-75
Dust to Asphalt Ratio* Fine Gradation Coarse Gradation	CP 50	 0.6 – 1.2 0.8 – 1.6

- Dust to Asphalt Ratio shall be calculated as the weight of aggregate passing the No. 200 (0.075 mm) screen plus the weight of hydrated lime divided by the weight of the effective asphalt. Effective asphalt is calculated as shown in the CDOT Pavement Design Manual 2017, Chapter 6, Section 6.14 and is reproduced here in Appendix B.

REVISION OF SECTION 403
HOT MIX ASPHALT

All mix designs shall be run with a gyratory compaction angle of 1.25 degrees and properties must satisfy Table 403-1. Form 43 will establish construction targets for Asphalt Cement and all mix properties at Air Voids up to 1.0 percent below the mix design optimum.

Table 403-2

	Minimum Voids in the Mineral Aggregate (VMA)		
Nominal Maximum Size*, mm (inches)	**Design Air Voids**		
	3.5%	**4.0%**	**4.5%**
12.5 (½)	15.1	15.2	15.3
9.5 (⅜)	16.1	16.2	16.3
	* The Nominal Maximum Size is defined as one sieve larger than the first sieve to retain more than 10%. ** Interpolate specified VMA values for design air voids between those listed. *** Extrapolate specified VMA values for production air voids beyond those listed.		

The Contractor shall prepare a quality control plan outlining the steps taken to minimize segregation of HMA. This plan shall be submitted to the Engineer and approved prior to beginning the paving operations. When the Engineer determines that segregation is unacceptable, the paving shall stop and the cause of segregation shall be corrected before paving operations will be allowed to resume.

♣The hot mix asphalt shall not contain any reclaimed asphalt pavement.

■A minimum of 1 percent hydrated lime by weight of the combined aggregate shall be added to the aggregate for all hot mix asphalt.

Acceptance samples shall be taken ●.3

REVISION OF SECTION 403
HOT MIX ASPHALT

♪The Contractor shall construct the work such that all roadway pavement placed prior to the time paving operations end for the year shall be completed to the full thickness required by the plans. The Contractor's Progress Schedule shall show the methods to be used to comply with this requirement.

Delete subsection 403.05 and replace with the following:

403.05 The accepted quantities of hot mix asphalt will be paid for in accordance with subsection 401.22, at the contract unit price per ton for the bituminous mixture.

Payment will be made under:

Pay Item	**Pay Unit**
Hot Mix Asphalt (Grading __)(__)(PG ____)	Ton

Aggregate, hydrated lime, and all other work necessary to complete each hot mix asphalt item will not be paid for separately, but shall be included in the unit price bid. When the pay item includes the PG binder grade, the asphalt cement will not be measured and paid for separately, but shall be included in the work. When the pay item does not include the PG binder grade, asphalt cement will be measured and paid for in accordance with Section 411. Asphalt cement used in Hot Mix Asphalt (Patching) will not be measured and paid for separately, but shall be included in the work.

Excavation, preparation, and tack coat of areas to be patched will not be measured and paid for separately, but shall be included in the work.

****

INSTRUCTIONS TO DESIGNERS (delete instructions and symbols from final draft):

♦ Delete from Table 403-1 those pavement gradings and properties not applicable to this project.

▲ For Gradings S, SG, SX, SF and ST insert the designation which is a part of the pay item in the parentheses. Use additional columns for Gradings S, SG, SX, SF and ST which require separate design mixes for different lab compaction requirements. Separate pay items with different designations for different lab compaction requirements are to be used.
SF and ST materials shall not be specified without prior approval of the Region Materials Engineer

♥ See Chapter 3 of Pavement Design Manual

θ Include this paragraph when allowed by the Region Materials Engineer. Contractors proposing to use WMA shall supply detailed design, production and acceptance testing requirements prior to completion of the Form 43. Approved WMA submittals shall contain all of this information prior to CDOT approval. Only CDOT Approved WMA will be allowed for use on the project.

♣ Delete this note when the standard special provision Revision of Section 401 - Reclaimed Asphalt Pavement is included in the project.

♠ Include this when excavation and patching in the roadway are required. Fill in the blank with the Grading used to designate the gradation requirements for patching.

■ Include this requirement where hydrated lime is needed to prevent stripping, as determined by the Region Materials Engineer.

● Complete this sentence with either "at the location specified in Method A of CP 41" or "at the location specified in either Method B or C of CP 41", as determined by the Region Construction and Materials personnel. Or, if preferred by the Region, delete the sentence altogether.

▼ To be used only on projects where the need for a liquid anti-stripping additive is indicated by engineering considerations.

♪ This requirement is to be added when reflective cracking is a concern, such as asphalt overlays of concrete pavement. Use when directed by the Region.

Appendix B –CDOT Pavement Design Manual Chapter 6, Section 6.14

6.14 Effective Binder Content (By Volume)

Effective binder content (P_{be}) is the amount of binder not absorbed by the aggregate, i.e. the amount of binder that effectively forms a bonding film on the aggregate surfaces. Effective binder content is what the service performance is based on and is calculated based on the aggregate bulk specific gravity (G_{sb}) and the aggregate effective specific gravity (G_{se}). The higher the aggregate absorption, the greater the difference between G_{se} and G_{sb}. The effective binder content by volume is the effective binder content (P_{be}) times the ratio of the bulk specific gravity of the mix (G_{mm}) and the specific gravity of the binder (G_b). The formula is:

$$P_{be}\text{ (by volume)} = P_{be} * (G_{mm} / G_b)$$

Where

P_{be} = effective asphalt content, percent by total weight of mixture
G_{mm} = bulk specific gravity of the mix
G_b = specific gravity of asphalt (usually 1.010)

P_{be} is determined as follows:

$$P_{be} = P_b - (P_{ba}/100) * P_s$$

Where

P_b = asphalt, percent by total weight of mixture
P_{ba} = absorbed asphalt, percent by total weight of aggregate
P_s = aggregate, percent by total weight of mixture

P_{ba} is determined as follows:

$$P_{ba} = 100 ((G_{se} - G_{sb}) / (G_{sb} * G_{se})) * G_b$$

Where

P_{ba} = absorbed asphalt, percent by total weight of aggregate
G_{se} = effective specific gravity of aggregate
G_{sb} = bulk specific gravity of aggregate

Appendix C – As-built Control Section Mixture Properties

COLORADO DEPARTMENT OF TRANSPORTATION
PROJECT PRODUCED JOB MIX FORMULA

Project: NH0503-089
Location: US50 - ROYAL GORGE WEST_SH9 JC
Region: 02 Project Code (SA#): 21255
From Project No:
From Project SA#:

Mix Design: 21255A
Date: 7/10/2017

This Job Mix Formula defines the specified gradation, asphalt cement content, and admixture dosage for the grading and project shown.

Contractor: APC Southern
Supplier: APC Southern
Plant: Mobile Plant
Pit: Tezak Pit #2 Cotopaxi
Grading & Compaction: SX 100
% RAP: 19.00 % Lime: 1.00

Components:

1. 20 1/2 Rock - Tezak Pit #2
2. 26 Crusher Fines - Tezak Pit #2
3. 27 Clean Crusher Fines - Tezak Pit #2
4. 7 Natural Fines - Tezak Pit #2
5. 19 3/8 Rap - Tezak Pit #2
6. 1 Lime - Pete Lien
7.
8.

Remarks:

Gradation (% Passing)

☐ Specification ☒ Voids Acceptance

Seive mm (in)	% Pass Min	% Pass Max
37.5 (1 1/2):	100	100
25.0 (1):	100	100
19.0 (3/4):	100	100
12.5 (1/2):	90	100
9.5 (3/8):	81	93
4.75 - #4:	50	60
2.36 - #8:	33	43
1.18 - #16:		
600 mic - #30:	16	24
300 mic - #50:		
150 mic - #100:		
75 mic - #200:	5.30	9.30

% AC: 5.20 +/- .3
Grade of AC: PG 58-28
Source of AC: SUNCOR
Max. Sp. Gr. at % AC: 2.484 +/- .01
Bulk Sp. Gr. of Combined Agg: 2.647
Bulk Sp. Gr. of Fine Agg: 2.646
Angularity (T 304): 47.7
% Agg Absorp (SSD): 1

☐ New Mix Design With Changes
☐ Mix Design Modified
☒ New Mix design with no change

Property	Voids Data at Nds Target Value	Tolerance
Stability	30	Minimum
% Voids	4.10	+/- 1.2
% VMA	min 13.5	max 15.9
% VFA	min 65	max 75

Signed ____________ Date ________
Project Engineer: Randy Johnson

Signed ____________ Date ________
Regional Materials Engineer: Craig Wieden

Signed ____________ Date ________
Contractors Representative:

Distribution:
Staff Materials
Region Materials Engineer
Resident Engineer (2)
Contractor

COLORADO DEPARTMENT OF TRANSPORTATION	Contract ID: 21255	Region: 2	Field sheet #
FIELD REPORT OF BITUMINOUS PAVEMENT AND JOINT DENSITY	Project No.: STA 0503-089	Form #43 No.: 21255A	Form #43 Date: 7/10/2017
User ID: **IBARRAJ**	Project Location: US 85, I-25 to B Street Overlay	Item #: 403	Grading: SX 100 PG 58-28

SMM/LIMS Sample ID (or Test # [Date])	Station or Location	IA	Distance from C or Control line	Mat (M) or Joint (J)	CP 81	CP 44 B	CP44 C	CP 44 L	Field Wet Density % (Corrected)	Core Specific Gravity	Daily Rice	Max Wet Density (Daily Rice x 62.4)	% Rel. Comp.	Project Spec.	In Spec? (Y/N)
7/28/2017	3826+14		2'	(M)	x				145.8		2.492	155.5	93.8	92-96	Y
7/28/2017	3828+00		7'	(M)	x				145.6		2.492	155.5	93.6	92-96	Y
7/28/2017	3833+96		21'	(M)	x				146.4		2.492	155.5	94.1	92-96	Y
7/28/2017	3835+43		19'	(M)	x				138.2		2.492	155.5	88.9	92-96	N
7/28/2017	3831+60		23'	(M)	x				147.4		2.492	155.5	94.8	92-96	Y
7/28/2017	3840+40		6'	(M)	x				145.1		2.492	155.5	93.3	92-96	Y
7/28/2017	3842+00		18'	(M)	x				143.6		2.492	155.5	92.3	92-96	Y
7/28/2017	3845+51		8'	(M)	x				145.9		2.492	155.5	93.8	92-96	Y
7/28/2017	3834+98		15'	(M)	x				139.4		2.492	155.5	89.6	92-96	N
7/28/2017	3844+15		20'	(M)	x				145.5		2.492	155.5	93.6	92-96	Y
7/28/2017	3844+18		15'	(M)	x				144.4		2.492	155.5	92.9	92-96	Y
7/28/2017	3844+25		18'	(M)	x				145.1		2.492	155.5	93.3	92-96	Y
7/28/2017	3844+22		6'	(M)	x				140.4		2.492	155.5	90.3	92-96	N
7/28/2017	3844+28		8'	(M)	x				142.0		2.492	155.5	91.3	92-96	N
7/28/2017	3844+30		4'	(M)	x				142.5		2.492	155.5	91.6	92-96	N
7/28/2017	3847+53		16'	(M)	x				147.5		2.492	155.5	94.9	92-96	Y
7/28/2017	3849+46		9'	(M)	x				140.4		2.492	155.5	90.3	92-96	N
7/28/2017	3852+24		15'	(M)	x				143.7		2.492	155.5	92.4	92-96	Y
7/28/2017	3854+53		2'	(M)	x				140.6		2.492	155.5	90.4	92-96	N
7/29/2017	3856+80		19'	(M)	x				146.9		2.492	155.5	94.5	92-96	Y
												AVG	92.5		

Remarks:	Action taken:	Tester: D. Drude	Title: Tech
Represents 1420.13 tons placed. QC did only one RPS for 1% above daily average. Tests did not show good increase above original compaction. A new compaction test section may be attemped at a later date, contractor willing.		Supervisor: (Project Engineer) Mike Schreiber	Title: EPST/PM
		Final report: Yes	No

Colorado Department of Transportation
PROJECT PRODUCED HOT MIX ASPHALT

Sample No: AT-8
Field Sheet No:
Date Received: 7/28/2017 07:00:00
Sample Desc: AT-8
Remarks:

Project No: NH0503-089
Location: US50 - ROYAL GORGE WEST_SH
SubAcct. No: 21255
Mix Design: New
Region: 02
Tested By: R2 Field

SuperPave Item 403

Form 43 Date: 7/10/2017
Form 43 No: 21255A
Grading: SX
N(des): 100

Refinery: SUNCOR
Binder: PG 58-28
Contractor: APC Southern
Pit: Tezak Pit #2 Cotopaxi

Voids Properties

Excluded Specimen No: 0

	Specimen:	Status	Specifications
% AC:	5.29	Pass	5.20 +/- 0.3
Max Sp. Gr.:	2.492	Outside Band	2.484 +/- 0.01

	Specimen 1:	Specimen 2:	Specimen 3:	Average	Status	Specifications
Bulk SG:	2.391	2.397	2.396	2.395		
Ht. N (Design):	65.4	65.7	65.4	65.5		
Voids @ N(des):	4.1	3.8	3.8	3.9	Pass	4.10 +/- 1.2
VMA @ N(des):	14.5	14.3	14.3	14.3	Pass	13.5 - 15.9
VFA @ N(des):	71.9	73.1	73.1	72.7	Pass	65 - 75

Gradation Results

esting: Voids Acceptance   Aggregate Correction: No

	Job Mix		Test Results	
Sieve mm (in)	% Pass Min	% Pass Max	Status	% Pass
37.5 (1 1/2)	100.00	100.00	Pass	
25.0 (1)	100.00	100.00	Pass	100
19.0 (3/4)	100.00	100.00	Pass	100
12.5 (1/2)	90.00	100.00	Pass	100
9.5 (3/8)	81.00	93.00	Pass	91
4.75 - #4	50.00	60.00	Fail	61
2.36 - #8	33.00	43.00	Pass	42
1.18 - #16			N/A	29
600 mic. - #30	16.00	24.00	Pass	21
300 mic. - #50			N/A	14
150 mic. - #100			N/A	9
75 mic. - #200	5.30	9.30	Pass	5.7

Aggregate Properties

N(des): 100   Gradation By: DB
AC Method: Pyrolysis Oven

	Test Result	Status	Job Mix
Angularity T 304:	.0	N/A	47.7

Bulk SG of Aggregate: 2.647
Bulk SG of Fine Aggregate: 2.646

Stability Results

Excluded Specimen No:
Stability Compacted By: DB
Stabilometer Run By:

		Status
Specimen 1:	0	
Specimen 2:	0	
Specimen 3:	0	
Average:	0	N/A

Lottman Results

Lottman Compacted By:
Lottman Loads By:

	Average	Status	Job Mix
Wet Avg. T.S.:			
Dry Avg. T.S.:		N/A	30
% Voids:	0.0		
% Saturation:			
T.S. Retained:	0	N/A	70

Appendix D – As-built Test Section Mixture Properties

Colorado Department of Transportation

PROJECT PRODUCED HOT MIX ASPHALT

Sample No:	AT-1 1st Rep	Project No:	NH0503-089
Field Sheet No:		Location:	US50 - ROYAL GORGE WEST_SH
Date Received:	8/2/2017 15:00:00	SubAcct. No:	21255
Sample Desc:	AT-1 1st Rep	Mix Design:	New
Remarks:		Region:	02
		Tested By:	R2 Field

SuperPave Item 403

Form 43 Date:	7/26/2017	Refinery:	SUNCOR
Form 43 No:	21255C	Binder:	PG 58-28
Grading:	SX	Contractor:	APC Southern
N(des):	100	Pit:	Tezak Pit #2 Cotopaxi

Voids Properties

Excluded Specimen No: 0

	Specimen:	Status	Specifications
% AC:	5.50	Pass	5.80 +/- 0.3
Max Sp. Gr.:	2.482	Inside Band	2.471 +/- 0.01

	Specimen 1:	Specimen 2:	Specimen 3:	Average	Status	Specifications
Bulk SG:	2.386	2.390	2.388	2.388		
Ht. N (Design):	65.7	66.0	66.1	65.9		
Voids @ N(des):	3.8	3.7	3.8	3.8	Pass	4.00 +/- 1.2
VMA @ N(des):	15.0	14.9	14.9	14.9	Pass	14.6 - 17
VFA @ N(des):	74.3	75.1	74.7	74.7	Pass	65 - 75

Gradation Results

esting: Voids Acceptance   Aggregate Correction: No

	Job Mix		Test Results	
Sieve mm (in)	% Pass Min	% Pass Max	Status	% Pass
37.5 (1 1/2)	100.00	100.00	Pass	
25.0 (1)	100.00	100.00	Pass	100
19.0 (3/4)	100.00	100.00	Pass	100
12.5 (1/2)	90.00	100.00	Pass	98
9.5 (3/8)	77.00	89.00	Pass	86
4.75 - #4	44.00	54.00	Pass	53
2.36 - #8	27.00	37.00	Pass	32
1.18 - #16			N/A	21
600 mic. - #30	12.00	20.00	Pass	16
300 mic. - #50			N/A	12
50 mic. - #100			N/A	8
75 mic. - #200	4.20	8.20	Pass	5.5

Aggregate Properties

N(des): 100   Gradation By: Bergles, Robert

AC Method: Pyrolysis Oven

	Test Result	Status	Job Mix
Angularity T 304:	.0	N/A	47.8
Bulk SG of Aggregate:	2.653		
Bulk SG of Fine Aggregate:	2.658		

Stability Results

Excluded Specimen No: 0

Stability Compacted By: DB

Stabilometer Run By: Bergles, Robert

		Status
Specimen 1:	30	
Specimen 2:	33	
Specimen 3:	33	
Average:	32	Pass

Lottman Results

Lottman Compacted By:

Lottman Loads By:

	Average	Status	Job Mix
Wet Avg. T.S.:			
Dry Avg. T.S.:		N/A	30
% Voids:	0.0		
% Saturation:			
T.S. Retained:	0	N/A	70

Colorado Department of Transportation

PROJECT PRODUCED HOT MIX ASPHALT

Sample No:	AT-2	Project No:	NH0503-089
Field Sheet No:	21255-0002	Location:	US50 - ROYAL GORGE WEST_SH
Date Received:	8/3/2017 11:30:00	SubAcct. No:	21255
Sample Desc:	AT-2	Mix Design:	New
Remarks:		Region:	02
		Tested By:	R2 Field

SuperPave Item 403

Form 43 Date:	7/26/2017	Refinery:	SUNCOR
Form 43 No:	21255C	Binder:	PG 58-28
Grading:	SX	Contractor:	APC Southern
N(des):	100	Pit:	Tezak Pit #2 Cotopaxi

Voids Properties

Excluded Specimen No: 0

	Specimen:	Status	Specifications
% AC:	5.44	Fail	5.80 +/- 0.3
Max Sp. Gr.:	2.487	Inside Band	2.471 +/- 0.01

	Specimen 1:	Specimen 2:	Specimen 3:	Average	Status	Specifications
Bulk SG:	2.374	2.366	2.381	2.374		
Ht. N (Design):	65.8	66.2	65.8	65.9		
Voids @ N(des):	4.5	4.9	4.3	4.6	Pass	4.00 +/- 1.2
VMA @ N(des):	15.4	15.7	15.1	15.4	Pass	14.6 - 17
VFA @ N(des):	70.5	68.9	71.8	70.4	Pass	65 - 75

Gradation Results

esting: Voids Acceptance   Aggregate Correction: No

	Job Mix		Test Results	
ieve mm (in)	% Pass Min	% Pass Max	Status	% Pass
37.5 (1 1/2)	100.00	100.00	Pass	
25.0 (1)	100.00	100.00	Pass	100
19.0 (3/4)	100.00	100.00	Pass	100
12.5 (1/2)	90.00	100.00	Pass	99
9.5 (3/8)	77.00	89.00	Pass	86
4.75 - #4	44.00	54.00	Pass	54
2.36 - #8	27.00	37.00	Pass	34
1.18 - #16			N/A	22
00 mic. - #30	12.00	20.00	Pass	16
00 mic. - #50			N/A	11
50 mic. - #100			N/A	7
5 mic. - #200	4.20	8.20	Pass	5.1

Aggregate Properties

N(des): 100   Gradation By: Bergles, Robert

AC Method: Pyrolysis Oven

	Test Result	Status	Job Mix
Angularity T 304:	.0	N/A	47.8
Bulk SG of Aggregate:	2.653		
Bulk SG of Fine Aggregate:	2.658		

Stability Results

Excluded Specimen No: 0

Stability Compacted By: Bergles, Robert

Stabilometer Run By: Bergles, Robert

		Status
Specimen 1:	32	
Specimen 2:	34	
Specimen 3:	33	
Average:	33	Pass

Lottman Results

Lottman Compacted By:

Lottman Loads By:

	Average	Status	Job Mix
Wet Avg. T.S.:			
Dry Avg. T.S.:		N/A	30
% Voids:	0.0		
% Saturation:			
T.S. Retained:	0	N/A	70

Colorado Department of Transportation

PROJECT PRODUCED HOT MIX ASPHALT

Sample No:	AT-3	Project No:	NH0503-089
Field Sheet No:	21255-0003	Location:	US50 - ROYAL GORGE WEST_SE
Date Received:	8/3/2017 18:00:00	SubAcct. No:	21255
Sample Desc:	AT-3	Mix Design:	New
Remarks:		Region:	02
		Tested By:	R2 Field

SuperPave Item 403

Form 43 Date:	7/26/2017	Refinery:	SUNCOR
Form 43 No:	21255C	Binder:	PG 58-28
Grading:	SX	Contractor:	APC Southern
N(des):	100	Pit:	Tezak Pit #2 Cotopaxi

Voids Properties

Excluded Specimen No: 0

	Specimen:	Status	Specifications
% AC:	5.84	Pass	5.80 +/- 0.3
Max Sp. Gr.:	2.478	Inside Band	2.471 +/- 0.01

	Specimen 1:	Specimen 2:	Specimen 3:	Average	Status	Specifications
Bulk SG:	2.387	2.381	2.379	2.382		
Ht. N (Design):	65.7	65.6	65.6	65.6		
Voids @ N(des):	3.7	3.9	4.0	3.9	Pass	4.00 +/- 1.2
VMA @ N(des):	15.3	15.5	15.6	15.5	Pass	14.6 - 17
VFA @ N(des):	75.9	74.8	74.3	75.0	Pass	65 - 75

Gradation Results

Testing: Voids Acceptance   Aggregate Correction: No

	Job Mix		Test Results	
Sieve mm (in)	% Pass Min	% Pass Max	Status	% Pass
37.5 (1 1/2)	100.00	100.00	Pass	
25.0 (1)	100.00	100.00	Pass	100
19.0 (3/4)	100.00	100.00	Pass	100
12.5 (1/2)	90.00	100.00	Pass	100
9.5 (3/8)	77.00	89.00	Pass	89
4.75 - #4	44.00	54.00	Fail	57
2.36 - #8	27.00	37.00	Pass	29
1.18 - #16			N/A	23
600 mic. - #30	12.00	20.00	Pass	17
300 mic. - #50			N/A	12
150 mic. - #100			N/A	8
75 mic. - #200	4.20	8.20	Pass	5.9

Aggregate Properties

N(des): 100   Gradation By: Bergles, Robert

AC Method: Pyrolysis Oven

	Test Result	Status	Job Mix
Angularity T 304:	.0	N/A	47.8
Bulk SG of Aggregate:	2.653		
Bulk SG of Fine Aggregate:	2.658		

Stability Results

Excluded Specimen No: 0

Stability Compacted By: Bergles, Robert

Stabilometer Run By: Bergles, Robert

		Status
Specimen 1:	32	
Specimen 2:	34	
Specimen 3:	33	
Average:	33	Pass

Lottman Results

Lottman Compacted By:

Lottman Loads By:

	Average	Status	Job Mix
Wet Avg. T.S.:			
Dry Avg. T.S.:		N/A	30
% Voids:	0.0		
% Saturation:			
T.S. Retained:	0	N/A	70