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**PART II – CONSTRUCTION MATERIALS AND METHODS
SECTION 11**

HOT MIX ASPHALT PAVEMENT

11.1 GENERAL

These Specifications include general requirements applicable to all types of plant mixed hot mix asphalt pavements (HMA) and reference sections and subsections of the 2005 edition of the Colorado Department of Transportation (CDOT) Standard Specifications for Road and Bridge Construction. This work consists of one or more courses of asphalt mixture constructed on a prepared foundation in accordance with these Specifications. These Specifications shall apply to all new and resurface construction within the City of Arvada.

11.2 MATERIALS

The HMA pavement shall be composed of a mixture of aggregate, filler or additives, asphalt cement, and recycled asphalt pavement (RAP) where specified. Up to 20 percent RAP is allowed in mix designs. All mixes shall be designed and produced with one percent hydrated lime.

11.2.1 Aggregate

Aggregates for HMA shall be of uniform quality, composed of clean, hard, durable particles of crushed stone, crushed gravel, or crushed slag. Excess of fine material shall be wasted before crushing. The material shall not contain clay balls, vegetable matter, or other deleterious substances and shall meet the following requirements.

AGGREGATE PROPERTIES

Aggregate Test Property	Coarse: Retained on #4	Fine: Passing the #4
Fine Aggregate Angularity, CP-L 5113 Method A Traffic Level: < 8,000 ADT Traffic Level: ≥ 8,000 ADT		40% Min. 45% Min
Two Fractured Faces, CP-45 Top and Middle Lifts Bottom Lifts	80% Min. 70% Min.	
LA Abrasion, AASHTO T 96	45% Max.	
Flat and Elongated (Ratio5:1) %, AASHTO M 283	10% Max.	
Adherent Coating (Dry Sieving) ASTM D 5711	0.5% Max.	
Sand Equivalent. AASHTO-L 176		45% Min.

The HMA aggregate gradation for the proposed design job mix gradation shall be wholly within the control point gradation range set forth in the following table. The allowable job mix gradation for production shall be the design job mix gradation with the tolerances of Section 11.13.3 applied. The proposed design job mix and the final allowable job mix gradation for production shall report all sieve sizes listed in the table.

GRADATION RANGE
Percent by Weight Passing Square Mesh Sieves, AASHTO T 11 & T 27

Sieve Size	SX (1/2" nominal)		S (3/4" nominal)		SG (1" nominal)	
	Control Points	Restricted Zone*	Control Points	Restricted Zone*	Control Points	Restricted Zone*
1-1/2"					100	
1"			100		90-100	
3/4"	100		90-100			
1/2"	90-100					
3/8"						
#4						39.5
#8	28-58	39.1	23-49	34.6	19-45	26.8-30.8
#16		25.6-31.6		22.3-28.3		18.1-24.1
#30		19.1-23.1		16.7-20.7		13.6-17.6
#50		15.5		13.7		11.4
#200**	2.0-8.0		2.0-7.0		1.0-7.0	

*The restricted zone is a guideline only. It is recommended that mix design gradations go above the restricted zone boundaries, on the "fine" side.

**These limits shall include the weight of lime at 1.0%.

11.2.2 Recycled Asphalt Pavement

Recycled Asphalt Pavement (RAP) material shall be of uniform quality and gradation with a maximum size no greater than the nominal aggregate size of the mix.

The contractor shall identify the source of each RAP stockpile proposed to be incorporated in the asphalt mixes. Contractor shall identify the project from which the material was removed, mix data from the original project including mixture type, aggregate classification, location and depth of the pavement structure. Extracted gradation information shall also be provided along with a description of the stockpile location and quantity. Additional material shall not be added to an approved RAP stockpile during the course of the work.

The Engineer may reject a RAP stockpile for non-uniformity based on visual inspection. RAP stockpiles containing concrete chunks, grass, dirt, wood, metal, coal tar or other foreign or environmentally restricted materials shall not be used. Stockpiles are to be worked in such a manner that the materials removed are representative of a cross section of the pile.

Mixes shall not contain more than 20 percent RAP.

11.2.3 Asphalt Cement

The Contractor shall provide an acceptable 'Certification of Compliance' from the supplier for each applicable asphalt cement grade. Asphalt Cement binder shall meet the requirements of the Superpave Performance-Graded Binders (PG) as presented below.

PROPERTIES OF SUPERPAVE PERFORMANCE GRADED BINDERS

PROPERTY	PG 58-28	PG 64-22	PG 76-28
Average Daily Traffic (ADT) Volume <u>or</u> Equivalent Single Axle Load (ESAL) Volume *	< 8,000 ADT < 300,000 ESAL	< 40,000 ADT < 1million ESAL	≥ 40,000 ADT ≥ 1 million ESAL
Flash Point Temperature, °C, AASHTO T 48	230 Min.	230 Min.	230 Min.
Viscosity at 135 °C, Pas, ASTM D 4402	3 Max.	3 Max.	3 Max.
Dynamic Shear, Temperature °C, where C**/Sin δ @ 10 rad/sec. ≥ 1.00 Kpa, AASHTO TP 5	58	64	76
Rolling Thin Film Oven Residue Properties, AASHTO T 240			
Mass Loss, %, AASHTO T 240	1.00 Max.	1.00 Max.	1.00 Max.
Dynamic Shear, Temperature °C, where G**/Sin δ @ 10 rad/sec. ≥ 2.20 Kpa, AASHTO TP 5	58	64	76
Elastic Recovery ¹ , 25°C, % Min.*	N/A	N/A	50 Min.
Pressure Aging Vessel Residue Properties, Aging Temperature 100 °C AASHTO PP1			
Dynamic Shear, Temperature °C, where G**/Sin δ @ 10 rad/sec. ≤ 5,000 Kpa, AASHTO TP 5	19	25	28
Creep Stiffness, @ 60 sec. Test Temperature in °C, AASHTO TP 1	-18	-12	-18
S, Mpa, AASHTO TP 1	300 Min.	300 Min.	300 Min.
m-value, AASHTO TP 1	0.300 Max.	0.300 Max.	0.300 Max.
Direct Tension Temperature in °C, @ 1.0 mm/min., Where Failure Strain >1.0%, AASHTO TP 3	-18	-12	-18

* 18,000 lb single axle load over 20 year design life

** Elastic Recovery by Task Force 31, Appendix B Method

Note: PG 76-28 is recommended for intersections of high volume arterial streets.

11.2.4 Lime

Lime shall be added at the rate of 1% by dry weight of the aggregate and shall be included in the amount of material passing the No.200 sieve. Hydrated lime for aggregate pretreatment shall conform to the requirements of ASTM C 207, Type N. In addition, the residue retained on a 200-mesh sieve shall not exceed 10% when determined in accordance with ASTM C 110. (Drying of the residue in an atmosphere free from carbon dioxide will not be required.)

11.2.5 Tack Coat

The emulsified asphalt for Tack Coats shall be CSS-1h or SS-1h and conform to AASHTO M208 and ASTM D2397 or AASHTO M140 and ASTM D977, respectively.

11.3 **MIX DESIGN AND PLANT PRODUCED MIXTURE REQUIREMENTS**

11.3.1 General Requirements

The mix design materials shall be in accordance with the requirements of Section 11.2. The design job mix formula (JMF) for each mixture shall establish a single percentage of bituminous material to be added to the aggregate, and a single temperature for the mixture at the plant discharge point. The City may test the Contractor's proposed JMF for each hot bituminous pavement grading utilizing materials actually produced and stockpiled for use. The Contractor shall provide a sufficient quantity of each aggregate, mineral filler, recycled asphalt and additive for the required laboratory tests if requested by the City.

After the JMF is approved, a new JMF shall be submitted to the Engineer if there is a change in the sources of materials.

11.3.2 Allowable Mix Production Range

The proposed job-mix gradation for each mixture required by the project shall be within the Master Range of Table 703-4, CDOT Section 703, before the tolerances shown in Table 401-1, CDOT Section 401 are applied. The weight of lime shall be included in the total weight of the material passing the No. 200 sieve.

After the JMF is approved, all mixtures shall conform to the production tolerance ranges of Table 401-1 and the tolerances shall be applied to the JMF to establish the allowable mix production ranges for mix production.

If one or more samples of hot mix asphalt pavement (HMA) fail to meet the mix production requirements, the Contractor shall core the area represented by the failing sample as directed by the Engineer. The Engineer will take possession of the cores and will perform necessary tests for each of the sample locations. Duplicate cores may be taken and retained by the Contractor at the Contractor's expense. The time during which the core samples are taken and their location shall be established by the Engineer. Taking cores and patching the core holes will be done at the expense of the Contractor.

The plant produced mix may be tested by the City for conformance with the allowable mix production range, moisture susceptibility, stability and/or flow, and volumetric criteria shown in the Tables below at a testing frequency to be designated by the City. If two consecutive production samples fail to meet any of these criteria and show no correlation to the mix design, the Contractor shall take corrective action and verify compliance with the criteria before continuing production. Measures taken to bring the mix into compliance shall be submitted to the Engineer prior to continuing production.

11.3.3 Marshall Mixture Design Method

The Marshall mixture design method shall not be used unless approved by the Engineer.

The mix design for hot mix asphalt pavement (HMA) shall conform to the criteria of design and production tables below. The optimum percent asphalt cement content shall be chosen in accordance with Asphalt Institute Manual MS-2.

HMA bid items will specify the mixture gradation and the Marshall blows to be used for the mix design.

Lab compactive effort shall be by Marshall Compactor for mix designs and testing of plant produced mix. For Grade SG mix, when any particle is retained on the 1-inch screen the sample shall be compacted in 6" diameter molds with either Cox Kneader Compactor using CDOT procedures. Stability requirements for Grade SG mix will not apply.

**REQUIRED HOT MIX PROPERTIES - DESIGN AND PRODUCTION
Asphalt Institute MS-2 and AASHTO T-245 Test Methods**

Average Daily Traffic (ADT) Volume <u>or</u> Equivalent Single Axle Load (ESAL) Volume *	< 8,000 ADT < 300,000 ESAL	≥ 8,000 ADT ≥ 300,000 ESAL
Marshall Blows	50	75
Marshall Stability, lbs	1800	2000
Marshall Flow, 0.01 inch	8-18	8-16

* 18,000 lb single axle load over 20 year design life

VOLUMETRIC AND STRIPPING CRITERIA - DESIGN AND PRODUCTION

Air Voids, MS-2 Test Method	3.0% to 5.0%		
Voids Filled with Asphalt (VFA), MS-2 Test Method	65-78% for 50 blow Marshall Method 65-75% for 75 blow Marshall Method		
Voids in Mineral Aggregate, (VMA) Minimum VMA% based on air voids in actual mix			
Nominal Maximum Particle Size *	Mix Air Voids, Percent **		
	3.0	4.0	5.0
1"	11.0	12.0	13.0
3/4"	12.0	13.0	14.0
1/2"	13.0	14.0	15.0
Stripping Criteria (Moisture Susceptibility)			
Tensile Strength Ratio, (Lottman) percent retained, CP-L 5109 Test Method	80% minimum		
Dry Split Tensile Strength CP-L 5109 Test Method	30 psi minimum		

* The nominal maximum size is defined as one sieve larger than the first sieve to retain more than 10 percent.

** The specified minimum VMA value shall be interpolated for air voids between those listed.

11.3.4 Superpave Mixture Design Method

A proposed design job mix shall be submitted for each mixture required by the Contract. The design shall be determined using Colorado Procedure CP-L 5115 for the Superpave Method of Mixture Design. Guidance is provided in "Superpave Level 1 Mix Design" SP-2 published by the Asphalt Institute. Mix designs shall meet the following requirements:

SUPERPAVE MIXTURE PROPERTIES

Average Daily Traffic (ADT) Volume or Equivalent Single Axle Load (ESAL) Volume *	Paths/Trails	< 8,000 ADT < 300,000 ESAL	≥ 8,000 ADT ≥ 300,000 ESAL
Initial gyrations, N _{initial} (Air Void >11.0%), For Information Only	6	7	8
N _{initial} Air Voids, For Information Only	>8.5	>9.5	>11.0
Design gyrations, N _{design} (Air Void:3.5% to 4.5%) (See Note 1)	50	75	100
Hveem Stability (Minimum) CP-L 5106 (Grading S & SX only)	n/a	28	30
Voids Filled with Asphalt (VFA), %, MS-2	70-80	65-78	65-75
Lottman, Tensile Strength Ratio, % Retained, CP-L 5109, Method Bill D -	80 Min.	80 Min.	80 Min.
Lottman, CP-L 5109 Dry Tensile Strength, psi	30 Min.	30 Min.	30 Min.
VMA %. CP-48	refer to table in Section 11.2.1		

* 18,000 lb single axle load over 20 year design life

Note 1: Maximum Theoretical Specific Gravity of mix by CP-51.

Note 2: Refer to Section 11.13 for production tolerances.

The Voids in Mineral Aggregate (VMA) shall be based on tests of the Bulk Specific Gravity of the Compacted Mix (CP-L 5103) and Aggregate (T 84 & T 85), and calculated according to CP-48. All mixes shall meet the minimum VMA specified below.

MINIMUM VMA, %

Nominal Maximum* Particle Size	Air Voids**		
	3.5%	4.0%	4.5%
1" (SG)	12.5	13.0	13.5
3/4" (S)	13.5	14.0	14.5
1/2" (SX)	14.5	15.0	15.5

* Nominal Maximum Particle Size is defined as one sieve size larger than the first sieve to retain more than 10%, but shall not exceed the 100% passing size. The Nominal Maximum Particle Size can vary during mix production even when the 100% passing size is constant.

** Minimum VMA criteria applies to both design and plant produced mix. The minimum VMA criteria shall be linearly interpolated based on actual air voids.

11.4 MIXTURE DESIGN SUBMITTALS

11.4.1 General Requirements

Mixture designs, Certificates of Compliance, and laboratory data shall be submitted for approval at least seven (7) calendar days before construction is to begin. The mix design must be approved by the Engineer prior to the start of construction.

11.4.2 Mix Design Submittals

The Contractor shall submit all mix designs to the Engineer for approval. Mix designs shall be performed in a materials laboratory under the direct supervision of a professional engineer licensed in the state of Colorado and practicing in this field. In addition, the Contractor shall submit as part of the mix design, documents to verify the following:

- A. Source of materials,
- B. Gradation, specific gravity, source and description of individual aggregates and the final blend,
- C. Aggregate physical properties (CDOT Subsection 703.04),
- D. Design Job Mix Formula (JMF),
- E. Asphalt cement properties (CDOT Section 702),
- F. Mixing and compaction temperatures used,
- G. Mix properties determined at a minimum of four asphalt cement contents and graphs showing mix properties versus asphalt cement content,
- H. Properties at the optimum asphalt cement content and
- I. Lottman test data at the optimum asphalt cement content.

The City reserves the right to verify the proposed mix design for each hot asphalt pavement grading utilizing materials actually produced and stockpiled. If requested by the City, a sufficient quantity of each aggregate, mineral filler, RAP, and additive for the required laboratory tests shall be provided. The City may request a Certificate of Conformance or Certificate of Compliance at any time on any material used.

11.4.3 Change in Source or Grade

Should a change in the source Lime occur, or more than one temperature grade change on either the high or low end of Asphalt Cement (AC) occur, a one point verification test (at optimum asphalt content) of the mix must be performed to verify that the applicable criteria is still met. If this testing shows noncompliance, a new Design Job Mix shall be established before the new AC or lime source is used. Any change in aggregate type or source will require a new mix design. The one point verification test may be performed on lab mixed samples or on plant mixed samples

11.4.4 Mix Verification

Production verification shall occur prior to the start of the project. The production verification shall be performed by LABCAT Level C accredited technicians to verify the volumetric properties of the mix. If the mix has been produced for another project within the last 90 days, data from that project can be submitted for this verification.

11.5 EQUIPMENT

11.5.1 Mixing Plant

The mixing plant shall be capable of producing a uniform material, have adequate capacity, and be maintained in good mechanical condition. Defective parts shall be replaced or repaired immediately if they adversely affect the proper functioning of the plant or plant units, or adversely affect the quality of the hot bituminous plant mix.

Dust, smoke, or other contaminants shall be controlled at the plant site to meet all air quality requirements in the "Colorado Air Quality Control Act," Title 25, Article 7, CRS and regulations promulgated thereunder.

11.5.2 Hauling Equipment

Trucks used for hauling HMA shall have clean beds thinly coated with a minimum amount of paraffin oil, lime solution, or other approved release agent. Petroleum distillates such as kerosene or fuel oil will not be permitted. Each truck shall have a cover of canvas or other suitable material to protect the mixture from the weather and excessive temperature loss or cooled layers of mix in truck.

11.5.3 Bituminous Pavers

Self-propelled pavers shall be provided for full lane width paving, and shall be equipped with a screed assembly, heated if necessary, capable of spreading and finishing the bituminous plant mix material in full lane widths applicable to the typical section and thickness shown in the Contract. Pavers used for shoulders, patching and similar construction not requiring fine grade control shall be capable of spreading and finishing courses of asphalt plant mix material in widths shown in the Contract.

The paver shall have an automatic distribution system that will place and spread the mixture uniformly in front of the screed.

The paver shall be capable of operating at forward speeds consistent with uniform and continuous laying of the mixture. Stop and go operations of the paver shall be avoided. The screed or strike-off assembly shall produce the specified finished surface without tearing, shoving, or gouging the mixture. Self-propelled pavers shall be equipped with automatic screed controls with sensors capable of sensing grade from an outside reference line, and maintaining the screed at the specified longitudinal grade and transverse slope. The sensor shall be constructed to operate from either or both sides of the paver and shall be capable of working with the following devices when they are required for the situation:

- A. Ski-type device at least 30 feet in length.
- B. Short ski or short shoe.
- C. At least 5,000 feet of control line and stakes.

The controls shall be capable of maintaining the screed at the specified transverse slope within plus or minus 0.1 percent. Automatic mode should be used where possible. If the automatic controls fail or malfunction the equipment may be operated manually for the remainder of the normal working day, provided specified results are obtained.

Paving operations shall be suspended until satisfactory corrections, repairs, or equipment replacements are made if the specified surface tolerances are not maintained.

Placement of HMA on a waterproofed bridge deck shall be accomplished with equipment that will not damage the membrane or protective covering.

11.6 MANUFACTURE

11.6.1 Preparation of Aggregates

Heating and drying of the aggregates shall be accomplished without damaging the aggregate. Lime shall be added to achieve complete and uniform coating of the aggregate. When hydrated lime is used it shall be added to the aggregate in accordance with one of the following methods:

- A. Lime Slurry Added to Aggregate: The hydrated lime shall be added to the aggregate in the form of a slurry and then thoroughly mixed in an approved pugmill. The slurry shall contain a minimum of 70 percent water by weight.
- B. Dry Lime Added to Wet Aggregate: The dry hydrated lime shall be added to wet aggregate and then thoroughly mixed in an approved pug mill.

The lime-aggregate mixture may be fed directly into the hot plant after mixing or it may be stockpiled for not more than 90 days before introduction into the plant for mixing with the asphalt cement. The hydrated lime may be added to different sized aggregates and stockpiled, by adding 75 percent of the lime to the aggregate passing the No.4 sieve and 25 percent to the aggregate retained on the No.4 sieve.

11.6.2 Mixing

The dried aggregates and asphalt cement shall be combined in the mixer in the quantities required to meet the design job mix. The materials shall be mixed until the aggregate is completely and uniformly coated, and the asphalt cement is uniformly distributed throughout the aggregate. Baghouse fines shall be fed back to the mixing plant in a uniform and continuous manner so as to maintain uniformity in the mixture. The baghouse, fines feeder, auger, and related equipment, shall be in good working condition and operated in accordance with manufacturer's recommendation.

The mixture temperature shall conform to the requirements of the following table:

MIXTURE TEMPERATURES

Asphalt Grade	Minimum Discharge Temperature	Maximum Discharge Temperature	Minimum Delivered Temperature *
PG 58-28	275 °F	305 °F	235 °F
PG 64-22	290 °F	320 °F	235 °F
PG 76-28	320 °F	350 °F	280 °F

* Delivered mix temperature shall be measured behind the paver screed.

HMA mix shall be produced at the lowest temperature within the specified temperature range that produces a workable mix and provides for uniform coating of aggregates (95 percent minimum in accordance with AASHTO T 195), and that allows the required compaction to be achieved.

HMA mix may be stored provided that any and all characteristics of the mixture are not altered by such storage. If storing or holding of the mixture causes segregation, excessive heat loss, or adversely affects the quality of the finished product, storage will not be allowed and unsuitable mixture shall be rejected.

When placing hot bituminous mixture over bridge decks covered by waterproofing membrane, the minimum temperature of the mixture when rolling operations begin shall be 250° F. The job mix temperature may be increased up to 30° F to obtain this temperature.

11.6.3 Hauling and Delivery

Each truck shall use covers to protect the mix during transport in cold weather, dust storms or precipitation. A load of mix that is delivered with improper gradation, thermal segregation or temperature below the specified minimum delivered temperature shall be rejected. Delivered mix temperature shall be measured behind the paver screed.

11.7 **TACK COAT**

Prior to placement of HMA, a tack coat shall be applied to all existing concrete and asphalt surfaces. A tack coat shall be used when the surface to be overlaid is old, glazed, dried out or subjected to dust or traffic film. If the surface of the first course is contaminated by sand, dust or foreign material deposited by traffic or wind, brooming alone is not acceptable. A very light tack coat should be applied after brooming has been completed.

The material shall be in accordance with Section 11.2.5. The emulsified asphalt shall be diluted 1:1 with water and applied at 0.10 ± 0.01 gallons per square yard of diluted material. The City may direct other application rates to match the age of condition of the surface.

The surface to receive the tack coat shall be dry and cleaned by sweeping or other approved method until dust, debris, and foreign matter are removed. The surface shall be cleaned such that the tack coat bonds adequately to the entire surface and to the upper asphalt lift. The tack coat shall then be applied uniformly by squeegee, brooms, or distributor. Prior to paving, the tack must be allowed to break, meaning that all water must have evaporated. Contaminated areas shall be cleaned and tack coat shall be reapplied.

11.8 **PLACEMENT**

Hot mix asphalt shall be placed only on approved, properly constructed surfaces that are free from loose material, water, frost, snow or ice. The hot mix asphalt shall be placed in accordance with the air and surface temperature limitations shown in the table below and only when weather conditions permit the pavement to be properly placed and finished as determined by the City.

Contact surfaces of curbs, gutters, manholes and other structures shall be tack coated prior to placing asphaltic concrete adjacent thereto.

Asphaltic concrete, to provide in place compacted thickness of four (4) inches or less, shall be placed and struck off by means of bituminous pavers. Use of spreader boxes to place the bituminous mixture shall be limited to asphaltic sidewalks or trails, trench patching and the bulbs of cul-de-sacs. Black base bituminous mixtures, whose in place compacted thickness is to be greater than four (4) inches and less than seven and one half (7 1/2) inches, may be uniformly spread using a patrol.

Along the lip lines of gutters and crossspans sufficient bituminous material shall be deposited so that, after compacting, the wearing surface will remain not less than 1/8" nor more than 1/4" above the concrete. For median curb wearing surface will be from 1/4" to 1/2" below concrete.

Placement temperature as stated shall be increased by 5 degrees F for each 10 miles per hour wind velocity to a maximum increased minimum placement temperature of 70 degrees F.

MINIMUM AIR and SURFACE TEMPERATURES LIMITATIONS for MIX PLACEMENT

Compacted Layer Thickness	Top Layer of Pavement*		Lower Layers*	
	PG 58-28 PG 64-22	PG 76-28	PG 58-28 PG 64-22	PG 76-28
< 2 inches**	60 °F	75 °F	N/A	N/A
2 inches to < 3 inches	50 °F	65 °F	40 °F	50 °F
3 inches or more	50 °F	50 °F	40 °F	40 °F

- * Air temperature is taken in the shade. Surface temperature is taken on the subgrade or base.
- ** Layer thickness less than 2 inches is not allowed for superpave mixes.

Placement temperature shall not be less than the specified minimum delivered temperature shown in the table of Section 11.6.2. The mixture shall not be placed at a temperature lower than 245 degrees F for mixes containing PG 58-28 or PG 64-22 asphalt, and 290 degrees F for mixes containing polymer modified asphalt. Mix which is too cold or damaged by weather will be rejected.

The mixture shall be laid upon an approved surface, spread and struck off to obtain the required grade and elevation after compaction. The minimum lift thickness shall be at least three times (preferably four times) the nominal particle size. The mixture should be placed approximately 25 percent thicker than the existing surrounding mat thickness to account for compaction. Raking is discouraged and will not be allowed except to correct major problems of grade and elevation. Casting or raking that causes any segregation will not be permitted.

On areas where the use of mechanical spreading and finishing equipment is impracticable, the mixture shall be carefully dumped, spread, raked, screeded, and luted by hand tools to the required compacted thickness plus 25 percent. Carefully move or minimally work the HMA mix with the use of rakes, lutes, or shovels to avoid segregation. Mixtures made with modified asphalt cement require more rapid completion of handwork areas than for unmodified mixtures. Hauling and placement sequences shall be coordinated so that the paver is in constant motion. Excessive starting and stopping shall not be allowed. A construction joint shall be placed at any time the paver stops, and the screed drops enough to cause a surface dip in violation of Section 11.13.1, Surface Tolerances; or the mat temperature falls below the breakdown temperature allowed in Section 11.12, Compaction. Bituminous pavers shall be used to distribute the mixture either over the entire width or over such partial width as may be practicable. Echelon paving will be permitted.

Variation between any two (2) contacts with the surface shall not exceed 3/16" in ten (10) feet. All lumps or depressions exceeding the specified tolerance shall be corrected by removing defective work and replacing it with new material as directed.

During placement and compaction of plant mix bituminous pavement, observation and testing shall be on a full-time basis. For each 1000 tons of material placed or at least one for each day of production, a field sample shall be taken and subjected to Marshall or Rice extraction and gradation analysis. Also, determination of the VMA for the mix is required and bulk specific gravity testing shall be performed on aggregate obtained from stockpiles at the plant.

Mix temperatures will be checked on each truck and where the temperature does not

meet Specifications, the load shall not be placed. Regardless of job-mix temperatures, the mixture shall not be delivered for use on the roadway at a temperature less than 235 degrees F, or 260 degrees F for rubberized asphalt (per CDOT). In no case shall asphalt be placed with air or surface temperatures less than 45 degrees F, otherwise reference Table 401-3 CDOT.

During compaction the density of the pavement shall be checked randomly, for information only, at the rate of one test for each 500 lineal feet of travel for each lift. Either during or after completion of the paving the final pavement thickness and density shall be determined for the plant mix bituminous pavement using coring, rings or other acceptable methods. Thickness determinations shall be made at random locations at intervals of approximately 500 feet in each travel lane as determined and marked by the City Inspector. Coring must be completed in the presence of a City Inspector.

11.9 LONGITUDINAL JOINTS

11.9.1 Joint Placement

The longitudinal joints in both a new pavement and an overlay pavement layer shall offset the joint in the layer immediately below by a minimum of 6 inches. The joints in any pavement layer shall not fall in a wheel track or path. The joints in the top layer of new pavement not built on top of an existing pavement shall be located on lane lines, or as shown on the plans. Longitudinal joints shall be minimized where feasible with wide paving pulls or echelon paving. Joints shall not cross any centerline, lane line, or edge line unless approved by the Engineer.

Longitudinal joints in the wearing surface layer shall be hand luted and provide a uniform transition, after compacting, between passes with the paving machine. Longitudinal joints in the wearing surface shall generally be located as follows:

- A. For two lane roadways - at the center line of the pavement and at the outside edge of the traveled lanes.
- B. For roadways of more than two lanes - at the lane lines and at the outside edge of the travel lanes.

The Contractor shall submit, prior to paving, a joint plan and pavement marking plan showing locations and the methods to field establish a control line. The City must approve such plan prior to paving. The Contractor shall use a continuous string line to delineate longitudinal joints during paving as shown on the joint plan. All string line shall be removed at the end of each day's paving.

11.9.2 Joint Construction

When shown by a detail in the Specifications or on the plans, longitudinal joints shall be constructed using a 1-inch vertical face and a 3:1 taper. The free edge of the paved pass shall be laid as straight as possible, to the satisfaction of the City. This joint, if cold, shall be tack coated prior to placement of adjacent paving.

The new compacted mat shall overlap the previously placed mat no more than 1.5 inches. Excess overlap or thickness shall not be raked or cast onto the new mat, but shall be wasted by pulling back and removing. The hot edge shall be blocked or bumped in a smooth line consistent with the previous longitudinal edge. Minor raking will only be allowed to correct major grade problems or provide mix around manholes and meter covers. The longitudinal joint shall be rolled from the hot side, and overlap the joint by approximately 6 inches on the cold side.

11.10 TRANSVERSE JOINTS

The Contractor shall submit, prior to paving, a joint plan showing locations and the methods to be used to construct transverse joints. The City must approve such plan prior to paving. Placing of the HMA shall be continuous with a minimum of transverse joints, and rollers shall not pass over the unprotected end of a freshly laid mixture. Transverse joints shall be formed by cutting back on the previous run to expose the full depth of the course. Tack Coat material shall be applied to contact surfaces of all joints just before additional mixture is placed against the previously compacted material.

The end of transverse joints shall be located such that they will be constructed with a full head of mix in front of the screed. When butt joints are constructed, runoff boards shall be used to support the roller on the downstream side of the joint. All tapered sections, rounded edges and segregated areas shall be removed to achieve a vertical face at the butt joint before paving is restarted.

When a tapered joint is required for traffic access, the ramp shall be removed back to a full depth from segregated section before paving is restarted.

When restarting paving operations, the paver screed shall be placed on starter block on the completed side of the transverse joint. Starter block should be approximately 25% of the thickness of the existing completed mat, so that adequate grade and compaction can be achieved on starting the paving operation. The screed should be nulled (angle removed) when on starting blocks and an up angle of attack set. Proper head of mix should be introduced into the paver prior to starting. The new compacted (downstream) side of the joint may be up to 3/16 inches higher than the old (upstream) side. Raking of this joint shall not be allowed except to correct major grade problems. The surface tolerance at the transverse joint must be verified with a 10-foot straight edge before the paver is more than 100 feet from the joint.

11.11 SEGREGATION

The asphalt mixture shall be transported and placed on the roadway without segregation. All segregated areas shall be removed immediately and replaced with specification material before the initial rolling. If more than 50 square feet of segregated pavement is removed and replaced in any continuous 500 linear feet of paver width laydown, operations shall be discontinued until the source of the segregation has been determined and corrected.

The City will visually determine areas that are segregated, and may also use density and gradation measures to help in this determination. The City will visually determine the extent of the segregation. The Contractor will not be allowed additional compensation for correction of segregated areas.

11.12 COMPACTION

The temperature of the mixture immediately behind the screed is shown in Section 11.6.2. The breakdown compaction shall be completed before the mixture temperature drops 20 °F.

The HMA shall be compacted by rolling. The number, weight, and type of rollers furnished shall be that which is sufficient to obtain the required density and surface texture while the mixture is in a workable condition. Compaction shall begin immediately after the mixture is placed and be continued until the required density is obtained. Final compaction shall be obtained using steel wheel rollers.

On all lifts of asphaltic concrete, breakdown rolling shall immediately follow the spreading sequence using a steel wheeled drum roller followed by rubber tired rollers, free of recapped tires, then followed by steel wheel finish rolling. Rolling shall start at the sides and proceed longitudinally parallel with the street center line, each trip overlapping one-half (1/2) of the roller width, gradually progressing to the crown of the street. Rolling shall be continued until all roller marks are eliminated and a minimum density of ninety-five (95) percent of Marshall density (ASTM D1559) or between (92) percent and (96) percent of maximum theoretical density of a laboratory specimen made in the proportions of the job mix formula determined according to Colorado Procedure #51 has been obtained. Field density determinations will be made in accordance with Colorado Procedure #44 and #81. Use of vibratory rollers with the vibrator on shall not be allowed during surface course final rolling.

If the required density is not achieved and the surface temperature falls below 185 °F, or there is obvious surface distress or breakage, no further compaction effort will be permitted unless approved by the City. The criteria for mixtures containing PG 76-28 asphalt cements shall be 235 °F. These minimum compaction temperatures may be adjusted according to the asphalt cement supplier recommendations. Adjusted minimum compaction temperatures must be shown on the approved mix design. Pavement operations shall be suspended when density requirements are not met, and the problem shall be resolved prior to continuing paving operations.

All roller marks shall be removed with the finish rolling. Use of vibratory rollers with the vibrator on will not be permitted on any bridge decks.

A rolling pattern or procedure shall be established during the beginning of paving operations, which will achieve the required compaction and surface tolerances. This procedure may be re-evaluated throughout the paving operations.

All HMA paving shall be compacted to a density of 92 percent to 96 percent of Maximum Theoretical (Rice) Density, (CP-51: Maximum Specific Gravity of Bituminous Paving Mixtures) with the average (mean) of five random and consecutive density tests equaling at least 93 percent of CP-51. If more than three random density tests fall below 93 percent of CP-51, corrective measures shall be taken by the Contractor. Compaction of less than 90 percent of CP-51 will be cause for removal and replacement. The average (mean) of the 3 most recent production CP-51 Rice values shall be used in calculating Relative Compaction according to CP-44.

The City will core the pavement on City projects (unless otherwise noted) and the Contactor/Developer will be required to core the pavement on private developer projects in order to obtain field density tests in accordance with Colorado Procedure 44, Method B (AASHTO T 230), or for field calibration of nuclear density equipment in accordance with the Appendix of Colorado Procedure 81 (ASTM D-2950). The Contractor shall tack, fill and compact all core holes. Coring shall be completed for every 500 lane feet. Untested areas during placement will also require cores to be taken to verify compaction.

Along forms, curbs, headers, walls, and all other places not accessible to the rollers, the mixture shall be thoroughly compacted with mechanical tampers.

11.13 PRODUCTION TOLERANCES

11.13.1 Surface Tolerances

The variation between any two contacts with the surface shall not exceed 3/16 inch in 10 feet. Irregularities exceeding the specified tolerance shall be corrected at the Contractor's expense. Transverse measurements for variations shall exclude breaks in the crown sections.

11.13.2 Plant Production Criteria

The plant produced mix may be tested by the City for conformance with the allowable mix production range, moisture susceptibility, stability and/or flow, and volumetric criteria at a testing frequency to be designated by the City. If two consecutive production samples fail to meet any of these criteria and show no correlation to the mix design, the Contractor shall take corrective action and verify compliance with the criteria before continuing production. Measures taken to bring the mix into compliance shall be submitted to the Engineer prior to continuing production.

11.13.3 Job Mix Formula Tolerances

Production test results that deviate from the design job mix by more than the following tolerances are subject to Section 11.14:

JOB MIX FORMULA TOLERANCES

Passing No. 3/8" and Larger ¹	+/- 6%
Passing No.4 and No.8	+/- 5%
Passing No.30	+/- 4%
Passing No.50	+/- 3%
Passing No.200 ²	+/- 2%
Air Voids	+/- 1.2%
VMA	+/- 1.2%
Hveem Stability ³	See footnote #3
Asphalt Content	+/- 0.3%
Asphalt Content, Mixes with >10% RAP	+/- 0.4%

¹ There is 1.0 percent tolerance for the maximum sieve size.
² Mixes with No. 200 sieve material produced over 7.0 percent are allowed only when Air Voids are kept within 1.2 percent of the Air Voids at mix design optimum and VMA still meets requirements.
³ Hveem Stability must meet the minimum value specified in Section 11.3.4.

When disagreements concerning determination of specification compliance occur only valid tests from both the City and Contractor will be considered. The City shall determine validity. Generally, valid tests are those in which sampling and test have been performed according to referenced procedures and the results are within stated precision statements. When disagreements occur with Asphalt Content and gradation tests results, solvent extracted aggregate testing shall take precedence over burnoff oven extracted aggregate, which shall take precedent over cold feed belt testing.

11.14

PAYMENT REDUCTION

All work performed and all materials furnished shall conform to the lines, grades, cross sections, dimensions, and material requirements, including tolerances, shown in the contract. For those items of work where working tolerances are not specified, the Contractor shall perform the work in a manner consistent with reasonable and customary manufacturing and construction practices.

When the City determines that the material furnished, work performed, or the finished product is not in conformity with the contract and has resulted in inferior or unsatisfactory product, the finished product or materials shall be removed and replaced or otherwise corrected by, and at the expense of, the Contractor unless the Engineer determines that the work can be accepted at a reduced price. Payment reduction, when allowed, shall be accomplished by adjusting pay quantities as indicated herein and applying contract unit prices to the reduced quantities. If allowed, the City shall:

- A. Document the basis for acceptance by "Cure Notice" which shall provide for an appropriate adjustment in the payment quantity for such work or materials not otherwise provided for in this section.
- B. Notify the Contractor in writing that the payment shall be adjusted in accordance with this section when "P" is 25 or less.
- C. In lieu of payment (quantity) adjustment, permit correction or replacement of the finished product provided the correction or replacement does not adversely affect the work or the City.

Materials shall be sampled and tested by a qualified Testing Laboratory in accordance with the sampling, testing schedules, and procedures contained in the Section 11.15 Testing and Inspection. The approximate maximum quantity represented by each sample shall be as set forth in the testing schedule. An additional number of samples, in relation to the quantity of materials represented, may be selected and tested at the City's discretion. The quantity represented by five consecutive random samples shall constitute a lot, whenever production schedules and material continuity permits. When, it is necessary to represent short production runs, significant material changes, or other unusual characteristics of the work, the City may establish a lot consisting of the quantity represented by any number of consecutive random samples from one to seven inclusive. Testing results that are determined to have sampling or testing errors, as determined by the City, shall not be used.

Materials or work shall only be evaluated for price adjustment when deviations from Specifications occur on any of the individual tests for the lot. The several individual test values shall be averaged and the percentage of payment (quantity) reduction for the lot shall be determined by applicable formula. This shall apply only when a payment reduction factor for the element is listed in the Payment Reduction Factor table of this section. The formula in (a) and (b) below shall be used only when the lot is represented by three to seven tests inclusive.

- A. $P = (X_n + aR - T_u) * F$ Shall be used if a maximum limit only is specified or; when the average of the several test values is above the mid point of the specification band or above the job-mix formula value.
- B. $P = (T_L + aR - X_n) * F$ Shall be used if the minimum limit only is specified or; when the average of the several test values is below the mid point of the specification band or below the job-mix formula value.

- C. When the lot is represented by fewer than three tests, the materials shall be evaluated for cost (quantity) reduction by the following procedure: Lots represented by two tests shall be divided into two separate lots represented by one test each, as determined by the City. Each lot that deviates from the Specifications shall be cost adjusted by one of the following formula.

$P = 0.76 * (T_o - T_u) * F$ When a maximum limit only is specified or the test value is above the maximum specified limit.

$P = 0.76 * (TL - T_o) * F$ When a minimum limit only is specified or the test value is below the minimum specified limit.

Where:

P is the percentage of reduction in payment quantity.

X_n is the average of the several test values from samples taken from the lot, with “n” indicating the number of values.

a is a variable factor to be used in “n” changes according to the following:

when “n” is	“a” equals
3	0.45
4	0.38
5	0.33
6	0.30
7 or greater	0.28

R is the difference between the highest and lowest values in the group of several test results from the lot.

T_u is the upper or maximum tolerance limit permitted by the Specifications.

T_L is the lower or minimum tolerance limit permitted by the Specifications.

T_o is the test value of the test that deviates from the Specifications.

F is the cost reduction factor to be applied for each element as shown in the following table:

PAYMENT REDUCTION FACTORS

ELEMENT	FACTOR "F"
100 percent size sieve	1
1/2 inch sieve and larger	1
No. 100 sieve to 3/8 inch sieve inclusive (except 100 percent size sieve)	3
No. 200 sieve	6
No. 200 sieve (cover coat material)	25
Density of Bituminous mixture	8
Asphaltic Cement content (all asphalt-aggregate mixtures)	20
Total air voids	30
Voids in mineral aggregate	20
Stability	5

If "P" is less than ten, or a negative quantity, the material shall be accepted as being in conformity. In cases where one or more elements show a positive "P" value, such positive values shall be added and the resulting sum shall be used to determine whether the material is in conformity. If the total "P" value is between 10 and 25, the City may require correction or may accept the material at a reduced cost. If "P" is greater than 25, the City may: 1) require complete removal and replacement with specification material at no additional cost to the City; 2) require corrective action to bring the material into conformity at no additional cost to the City; 3) where finished product is found to be capable of performing the intended purpose and the value of the finished product is not affected, permit the Contractor to leave the material in place with an appropriate cost adjustment to be based on the City's evaluation but not to be less than that which would have occurred had an adjustment been made where "P" = 25.

When aggregate sieve analysis for aggregate base course deviates from the specification requirements and the total "P" is three or greater, the reduction shall apply to the contract cost (quantity) multiplied by 0.60.

If asphaltic cement content, aggregate sieve analysis, or compaction deviates from the specification requirements and the total "P" is three or greater, the reduction shall apply to the contract cost (quantity) multiplied by 0.60 for aggregate base course and Hot Bituminous Pavement mixtures.

Payment adjustment for those elements that are not included in the Table of Payment Reduction Factors shall be determined by the City.

The Contractor shall not have the option of accepting a payment reduction in lieu of producing specification material. Continued production of non-specification material shall not be permitted. Material that is obviously defective shall be isolated and rejected without regard to sampling sequence or location within a lot.

For thickness deficiencies, payment reductions shall be per Lot, based upon a Lot encompassing 250 lineal lane feet or the quantity between tests, and shall be at the cost of the entire pavement system. The entire pavement system shall include only those items placed as part of this contract and those items impacted: mobilization, traffic control, subgrade preparation, pavement materials and installation, striping, and traffic signal loops need be considered.

PAYMENT REDUCTION –THICKNESS

Price Reduction	0%	25%	45%	Remove & Replace
Thickness Deficiency	0 – 0.5 inch	0.5 – 1.0 inches	1.01 – 1.5 inches	➤ 1.5 inches

11.15 TESTING AND INSPECTION

City Engineering Inspectors shall be responsible for checking temperatures of mix in truck and on pavement, segregation, rolling patterns and other construction means and methods which affect the performance of the pavement system. The Contractor shall provide assistance in sampling and testing at all facilities and at the job site.

Testing of HMA shall be performed in accordance with the following table and Table 15.1 of these Specifications. Testing shall be performed by a qualified geotechnical engineer working under the direction of a Colorado Registered Professional Engineer and shall be paid for by the developer on private projects. Testing will be performed and/or paid for by the City on City projects unless otherwise noted in the Special Conditions for the City project.

SCHEDULE FOR MINIMUM MATERIALS SAMPLING AND TESTING

Test	Standard	Minimum Frequency
In Place Density	ASTM D1188, D2950	One test for each 500 Lineal Feet per layer of HBP per Lane alternating lanes
Thickness & Density (Core)	AASHTO T166 ASTM D3549	One test for each 500 Lineal Feet per Lane alternating lanes
Air Voids & VMA	AASHTO T269 ASTM D3203	One test for each mix design
Gradation	AASHTO T27 ASTM C136	One test for each day or 1,000 tons placed
Hveem/Marshall Stability	AASHTO T245, T247, T166 ASTM D1559, D1561	One test for each mix design
Asphalt (AC) Content	AASHTO T164, T269, TP53 ASTM D2172, D3202, PS90	One test for each day or 1,000 tons placed
Maximum Theoretical Specific Gravity (Rice)	AASHTO T209 ASTM D2041	One test for each day or 1,000 tons placed

11.16 MEASUREMENT

HMA shall be measured based by the delivered tons of accepted material, complete-in-place on City projects.

11.17 PAYMENT

Haul, aggregate, asphalt cement, asphalt recycling agent, additives, lime, tack coating and all work necessary to complete each hot bituminous pavement item shall be included in the unit bid price and will not be paid separately on City projects.

Pay items for patching on City projects shall be complete-in-place to include sawcutting, removal of existing asphalt, excavation to subgrade of the specified patch section, tack coating, placement of new hot bituminous pavement material, and compaction.

The pay items for overlaying on City projects shall be complete-in-place to include sweeping and tack coating of existing bituminous pavement.