

**DEPARTMENT OF TRANSPORTATION**  
**DIVISION OF ENGINEERING SERVICES**  
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## **Method of Test to Determine Combined Gradations for Hot Mix Asphalt (HMA) using up to 25% Reclaimed Asphalt Pavement (RAP)**

### **A. SCOPE**

1. Reclaimed asphalt pavement (RAP) may be combined with virgin aggregate and virgin asphalt binder at a central mixing plant to produce hot mix asphalt (HMA).
2. This lab procedure is applicable to all HMA mixtures containing up to 25% RAP aggregate in the aggregate blend.
3. Physical properties of the asphalt extracted from RAP and RAP aggregate will not be tested.

### **B. SUMMARY OF METHOD**

1. Obtain representative samples of the RAP (See Section C).
2. Evaluate the RAP (See Section D). Determine:
  - a. Amount of asphalt binder
  - b. Aggregate gradation
  - c. Theoretical maximum specific gravity using AASHTO T209 Method A (Rice).
3. Prepare the mix design (See Section E):
  - a. Determine the combined gradation of the HMA mixture based on proposed proportions of RAP and virgin aggregate to be used.
  - b. Calculate the amount of virgin asphalt binder in the HMA mixture.
  - c. Calculate batch weights for each ingredient in the mixture.
  - d. Determine the optimum bitumen content (OBC) per AASHTO R35.
4. Conduct testing during production (See Section F)

### **C. RAP SAMPLING**

1. For the mix design, a minimum of 3 separate representative samples of RAP (minimum 40 lbs. each) shall be obtained in accordance with the applicable sections of CT 125, Appendix A, except processed RAP may be sampled from stockpiles.
2. During production, representative samples of RAP shall be obtained in accordance with the applicable sections of CT 125, Appendix A, and the following:
  - a. Batch Plant – Samples shall be taken from the RAP system as it is discharged into the weigh hopper (CT 125, Appendix A, Section A).
  - b. Continuous Mixing Plant- Samples shall be taken from the RAP system as it enters the pugmill or drier-drum mixer (CT 125, Appendix A, Section B).

### **D. RAP EVALUATION**

1. Prepare each RAP sample separately for evaluation.
2. Particles of RAP shall be separated by hand so that the particles of the fine aggregate portion pass the No. 4 sieve. Care must be taken to avoid fracturing the aggregate.
3. Samples shall be prepared in accordance with AASHTO T47. Split or quarter each sample into representative portions for ASTM D 2172/ AASHTO T164, AASHTO T308, and AASHTO T209 testing. After the required test samples have been prepared, combine the remaining RAP material for subsequent splitting into representative mix design test samples.
4. Determine the asphalt binder content of each RAP sample using ASTM D 2172 /AASHTO T164, Method B (3 minimum). Calculate and report the individual and average asphalt binder content. Perform a sieve analysis on each sample of recovered aggregate in accordance with AASHTO T30 (3 minimum). Calculate and report the individual and average gradation.
5. Burn asphalt from each RAP sample in accordance with AASHTO T308 for aggregate gradation (3 minimum). Calculate and report the individual and average asphalt binder content (for information only). Perform a sieve analysis on each sample of recovered aggregate in accordance with AASHTO T30 (3 minimum). Calculate and report the individual and average gradations.
6. Determine a correlation factor to be used for RAP gradation testing during production. The correlation factor for each sieve shall be determined by taking the average gradation of the ASTM D 2172/ AASHTO T164 samples minus the average gradation of the AASHTO T308 samples.
7. Determine the theoretical maximum specific gravity (Rice) of each RAP sample in accordance with AASHTO T209 (3 minimum). Calculate and report the individual and average values.

The above procedures are summarized in Table 1:

**Table 1 – RAP Evaluation**

Tests	Sample			Description
	1	2	3	
ASTM D 2172/AASHTO T164, Method B	X	X	X	Report individual and average asphalt contents to 0.1%
AASHTO T30 from extraction	X	X	X	Report individual and average gradation results for each sieve.
AASHTO T308	X	X	X	Report individual and average asphalt contents to 0.1% for information only).
AASHTO T30 from ignition oven	X	X	X	Report individual and average gradation results for each sieve.
AASHTO T209	X	X	X	Report individual and average results.
Determine Aggregate Gradation Correlation Factor	X			Average gradation of ASTM D 2172/ AASHTO T164 minus average gradation of AASHTO T308

**E. MIX DESIGN**

1. Determine the RAP percentage that will be used in the mix design (maximum 25% RAP aggregate in the aggregate blend).
2. Determine the combined gradation of the HMA mixture based on proposed proportions of RAP and virgin aggregate to be used in accordance with section F.1.b.
3. Calculate batch weights for each ingredient in the mixture using the provided batching sheet.

Note<sup>1</sup>: When using RAP in HMA mix designs, the aggregate gradations and total asphalt content are altered slightly from original batch percentages due to the asphalt contained in the RAP.

4. The RAP shall be oven dried to a constant mass in accordance with AASHTO T209 SEC. 9.2., except the temperature must not exceed 100°F.
5. Prepare and test specimens (virgin aggregate, RAP, and new asphalt binder) in accordance with AASHTO T312 except as follows:
  - a. If treating aggregate with lime (anti-strip) is specified, only the virgin aggregate shall be treated. Treating the RAP with lime is not allowed.
  - b. Virgin aggregate shall be heated to 20°F above mixing temperature<sup>2</sup> and RAP shall be heated to 230°F for a maximum of 2 hours. RAP shall not be reheated.
  - c. Add the proper amount of virgin aggregate to the mixing bowl and then add the proper amount of RAP. Dry mix for a minimum of 10 seconds. Add the proper amount of asphalt binder and proceed with wet mixing. The first batch shall be considered a butter batch and discarded.
  - d. Use AASHTO T209 to measure theoretical maximum specific gravity (Rice).

Note<sup>2</sup>: Mixing temperature is the range of temperature where the unaged asphalt binder has a rotational viscosity of  $170 \pm 20$  centistokes measured in accordance with AASHTO T316.

**F. TESTING DURING PRODUCTION TO VERIFY JOB MIX FORMULA (JMF)**

1. During production, sample and test as follows:
  - a. Asphalt Content – When developing a correction factor for asphalt content, (AASHTO T308), include the proposed portion of RAP. A new correction factor will not be required unless the RAP proportion changes by more than 5% from the JMF, the RAP processed stockpiles change in binder content by 2% or more, or the Rice specific gravity changes by 0.06 or more. Samples for determining asphalt content must be taken in accordance with CT 125, Part 7.
  - b. Aggregate Gradation – When determining the combined gradation, burn off the RAP sample in accordance with AASHTO T308. Report the asphalt content of the RAP sample to 0.1% (for information purposes only). Perform a sieve analysis on recovered aggregate in accordance with AASHTO T30. Add the correlation factor established in Section D.6. Report the actual gradation, the correlation factor, and the corrected gradation for each sieve size. Mathematically combine the virgin and corrected RAP aggregate gradations at the correct proportions to obtain the combined gradation.

**G. EXAMPLE**

See spreadsheets below:

**7.1 RAP  
EVALUATION**

Determine the asphalt content and gradation of the RAP aggregate for the samples provided:

Given:

Test	CT 125 Appendix A	ASTM D2172 / AASHTO T164 Method B	AASHTO T308	AASHTO T209
RAP Sample	Weight (lbs.)	Asphalt Content <sup>1</sup> (%)	Asphalt Content <sup>2</sup> (%)	Theo. Max Specific Gravity of RAP (G <sub>mm</sub> )
1	42	5.80%	5.90%	2.535
2	44	5.60%	5.60%	2.521
3	43	5.90%	5.90%	2.542
Avg.	43	5.77%	5.80%	2.533

<sup>1</sup> by total weight of mix; <sup>2</sup> for information only

**AASHTO T30 RAP Gradation** (aggregate recovered from ASTM D2172 / AASHTO T164 and AASHTO T308)

Sieve Size	Sample 1		Sample 2		Sample 3	
	ASTM D2172 / AASHTO T164	AASHTO T308	ASTM D2172 / AASHTO T164	AASHTO T308	ASTM D2172 / AASHTO T164	AASHTO T308
1 1/2"	100	100	100	100	100	100
1"	100	100	100	100	100	100
3/4"	100	100	100	100	100	100
1/2"	82.3	81.5	81.1	81.9	84.3	83.9
3/8"	78.2	78.7	77.5	76.8	75.1	74.3
No. 4	62.4	63.3	65.2	63.8	59.4	61.4
No. 8	51.2	50.5	50.3	49.7	44.6	45.1
No. 16	38.5	39	35.6	34.7	28.7	28.2
No. 30	27.6	27.2	21.8	22.2	19.9	20.6
No. 50	17.7	17.4	13.2	13.5	12.8	10.5
No. 100	11.1	11.3	9.4	8.9	13.2	12.7
No. 200	4.8	4.2	5.1	4.7	5.3	3.9

Calculate:                    **RAP Aggregate Gradation Correlation Factor**

For each Sieve:

$$\text{Rap Aggregate Gradation Correlation Factor} = (\text{Avg. ASTM D2172 / AASHTO T164 gradation}) - (\text{Avg. AASHTO T308 gradation})$$

Sieve Size	Average Rap Gradation		Correlation Factor
	ASTM D2172 / AASHTO T164	AASHTO T308	
1 1/2"	100	100.0	0.0
1"	100	100.0	0.0
3/4"	100	100.0	0.0
1/2"	82.6	82.4	0.1
3/8"	76.9	76.6	0.3
No. 4	62.3	62.8	-0.5
No. 8	48.7	48.4	0.3
No. 16	34.3	34.0	0.3
No. 30	23.1	23.3	-0.2
No. 50	14.6	13.8	0.8
No. 100	11.2	11.0	0.3
No. 200	5.1	4.3	0.8

### Worksheet for Computing Laboratory Batch Weights for HMA Mixtures Containing RAP

Date: \_\_\_\_\_  
 Mix Type: \_\_\_\_\_

Prepared By: \_\_\_\_\_

- yellow cell denotes a required input.

% RAP Aggregate in Aggregate Blend (25% Maximum)	Asphalt Content of RAP (TWM) <sup>1</sup>
25%	5.77%

<sup>1</sup> TWM= Total Weight of Mix

**Table 1: Batch Weights for Virgin Aggregate, RAP and New Asphalt Binder**

Parameter	Sample #1	Sample #2	Sample #3	Sample #4	Sample #5
Desired Total Asphalt Content of Mix, % (TWM)	5.0%	5.1%	5.2%	5.3%	5.4%
Desired Hot Mix Sample Weight, g	2000	2000	2000	2000	2000
Desired Weight of Aggregate, g	1900.0	1898.0	1896.0	1894.0	1892.0
Weight of RAP Asphalt	27.4	27.4	27.3	27.3	27.3
New Asphalt, % (TWM)	3.63%	3.73%	3.83%	3.93%	4.04%
Weight of New Asphalt to be Added, g	72.6	74.6	76.7	78.7	80.7
RAP, % (TWM)	25.1%	25.1%	25.1%	25.0%	25.0%
Weight of RAP to be Added, g	502.4	501.9	501.3	500.8	500.3
New Aggregate, %	71%	71%	71%	71%	71%
Weight of Virgin Aggregate, g	1425.0	1423.5	1422.0	1420.5	1419.0
Check	2000.0	2000.0	2000.0	2000.0	2000.0

**Table 2: Combined Gradation Summary**

AGGREGATE:	RAP		3/4"		1/2"		3/8"		Chip		Dust		Washed Dust		Blend <sup>2</sup>	Spec Limits
% of Blend w/ RAP:	25%		14%		12%		12%		13%		6%		18%		100%	
% of Blend w/o RAP:	0.0		19%		16%		16%		17%		8%		24%		100%	
Sieve Size	Desired % Passing	% of Blend (w/ RAP)	Desired % Passing	% of Blend (w/ RAP)	Desired % Passing	% of Blend (w/ RAP)	Desired % Passing	% of Blend (w/ RAP)	Desired % Passing	% of Blend (w/ RAP)	Desired % Passing	% of Blend (w/ RAP)	Desired % Passing	% of Blend (w/ RAP)	Total Blend (w/ RAP)	
1 1/2"	100.0	25%	100.0	14%	100.0	12%	100.0	12%	100.0	13%	100.0	6%	100.0	18%	100%	100.0
1"	100.0	25%	100.0	14%	100.0	12%	100.0	12%	100.0	13%	100.0	6%	100.0	18%	100%	100.0
3/4"	100.0	25%	97.0	14%	100.0	12%	100.0	12%	100.0	13%	100.0	6%	100.0	18%	100%	93-100
1/2"	99.0	25%	29.0	4%	86.0	10%	100.0	12%	100.0	13%	100.0	6%	100.0	18%	88%	82-94
3/8"	91.0	23%	7.0	1%	30.0	4%	90.0	11%	100.0	13%	100.0	6%	100.0	18%	75%	
No. 4	50.0	13%	2.0	0%	2.0	0%	13.0	2%	80.0	10%	93.0	6%	90.0	16%	47%	44-54
No. 8	33.0	8%	2.0	0%	1.0	0%	2.0	0%	17.0	2%	68.0	4%	59.0	11%	26%	24-34
No. 16	27.0	7%	2.0	0%	1.0	0%	1.0	0%	2.0	0%	52.0	3%	37.0	7%	17%	
No. 30	21.0	5%	2.0	0%	1.0	0%	1.0	0%	1.0	0%	40.0	2%	25.0	5%	13%	13-18
No. 50	15.0	4%	2.0	0%	1.0	0%	1.0	0%	1.0	0%	30.0	2%	15.0	3%	9%	
No. 100	10.0	3%	2.0	0%	1.0	0%	1.0	0%	1.0	0%	22.0	1%	8.0	1%	6%	
No. 200	6.3	2%	1.9	0%	1.1	0%	0.8	0%	0.8	0%	16.4	1%	3.5	1%	4%	2.0-6.0

<sup>2</sup> Must = 100%

Table 3: Input for Bin Batch Weights (from Table 1)<sup>3</sup>

Total Asphalt Content, %	5.2
Desired Sample Wt., g	2000
Weight of RAP, g	501.6
Weight of New Asphalt, g	76.7
Wt. of Virgin Aggregate, g	1422.0

<sup>3</sup>When using RAP in HMA mix designs, the aggregate gradations and total asphalt content are altered slightly from original batch percentages due to the asphalt contained in the RAP. Therefore, the input data above must be entered separately for each total desired asphalt content to properly determine batch weights at each asphalt content.

**Bin Batch Weights**

Fraction	RAP		3/4"		1/2"		3/8"		Chip		Dust		Washed Dust	
		501.6		265.4		227.5		227.5		246.5		113.8		341.3
1" - 3/4"	0.0	0.0	3.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3/4" - 1/2"	1.0	5.0	68.0	180.5	14.0	31.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1/2" - 3/8"	8.0	40.1	22.0	58.4	56.0	127.4	10.0	22.8	0.0	0.0	0.0	0.0	0.0	0.0
3/8" - No. 4	41.0	205.7	5.0	13.3	28.0	63.7	77.0	175.2	20.0	49.3	7.0	8.0	10.0	34.1
No. 4 - PAN	50.0	250.8	2.0	5.3	2.0	4.6	13.0	29.6	80.0	197.2	93.0	105.8	90.0	307.2
	100.0	501.6	100.0	265.4	100.0	227.5	100.0	227.5	100.0	246.5	100.0	113.8	100.0	341.3

**Cumulative Bin Batch Weights**

Fraction	RAP		3/4"		1/2"		3/8"		Chip		Dust		Washed Dust	
1" - 3/4"	0.0	0.0	8.0	509.6	0.0	767.0	0.0	994.6	0.0	1222.1	0.0	1468.6	0.0	1582.3
3/4" - 1/2"	5.0	5.0	180.5	690.1	31.9	798.9	0.0	994.6	0.0	1222.1	0.0	1468.6	0.0	1582.3
1/2" - 3/8"	40.1	45.1	58.4	748.5	127.4	926.3	22.8	1017.3	0.0	1222.1	0.0	1468.6	0.0	1582.3
3/8" - No. 4	205.7	250.8	13.3	761.7	63.7	990.0	175.2	1192.5	49.3	1271.4	8.0	1476.5	34.1	1616.4
No. 4 - PAN	250.8	501.6	5.3	767.0	4.6	994.6	29.6	1222.1	197.2	1468.6	105.8	1582.3	307.2	1923.6
	501.6		265.4		227.5		227.5		246.5		113.8		341.3	

 - yellow cell denotes a required input.

## **H. HEALTH AND SAFETY**

It is the responsibility of the user of this test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Prior to handling, testing or disposing of any materials, testers must be knowledgeable about safe laboratory practices, hazards and exposure, chemical procurement and storage, and personal protective apparel and equipment.

Caltrans Laboratory Safety Manual is available at:

[http://www.dot.ca.gov/hq/esc/ctms/pdf/lab\\_safety\\_manual.pdf](http://www.dot.ca.gov/hq/esc/ctms/pdf/lab_safety_manual.pdf)

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