METHODS OF SAMPLING AND TESTING
MT 122-17
OPTIMIZED AGGREGATE GRADATION FOR HYDRAULIC CEMENT CONCRETE MIX DESIGNS

1 Scope

1.1 This method outlines the procedure for analyzing combined aggregate gradations for optimized concrete mix designs.

2 Referenced Documents

MT Materials Manual

MT 201 Sampling Roadway Materials
MT 202 Sieve Analysis for Fine and Coarse Aggregate

3 Apparatus

3.1 The apparatus required for sampling aggregates and performing sieve analysis will be as stated in MT 201 and MT 202.

4 Procedure

4.1 Submit sieve analysis reports showing the cumulative combined percent passing, the cumulative combined percent retained, and the combined percent retained as shown in the sieve analysis Table 1. Include in the report, each individual aggregate gradation starting with the largest appropriate sieve for that material and including all the consecutive smaller sieve sizes through the #200 (75-µm) sieve. They are to include: 1 1/2-in. (37.5-mm), 1-in. (25-mm.), 3/4-in. (19-mm), 1/2-in. (12.5-mm), 3/8-in. (9.5-mm), #4 (4.75-mm), #8 (2.3-mm), #16 (1.18-mm), #30 (60-µm), #50 (300-µm), #100 (150-µm), and #200 (75-µm) sieves. For coarse and intermediate aggregates, the #16 (1.18-mm) through #100 (150-µm) sieves may be determined mathematically.

4.2 Submit the following charts used to perform aggregate gradation analysis:

- Coarseness Factor Chart (Figure 1)
- 0.45 Power Chart (Figure 2)
- Percent Retained Chart (Figure 3)

4.3 Perform a sieve analysis according to MT 202 for each aggregate that will be used in the optimized mix design. Complete a sieve analysis with the percent passing and the relative percent volume of each aggregate used in the proposed mix design as shown in Table 1.

Table 1: Sieve Analysis

% Passing Agg (P)	Coarse Aggregate			Mid	Fine Aggregate		Combined Aggregate		Each Sieve
	1	2	3	1	1	2			
Sieve	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing (C_P)	% Retained (C_R)	% Retained (C)
2 in.	100.0%	0.0%	0.0%	100.0%	100.0%	0.0%	100.0%	0.0%	0.0%
1 1/2 in.	100.0%	0.0%	0.0%	100.0%	100.0%	0.0%	100.0%	0.0%	0.0%
1 in.	100.0%	0.0%	0.0%	100.0%	100.0%	0.0%	100.0%	0.0%	0.0%
3/4 in.	96.0%	0.0%	0.0%	100.0%	100.0%	0.0%	97.8%	2.2%	2.2%
1/2 in.	63.0%	0.0%	0.0%	100.0%	100.0%	0.0%	79.7%	20.4%	**18.2%**
3/8 in.	28.0%	0.0%	0.0%	95.0%	100.0%	0.0%	60.0%	**40.1%**	19.7%
No. 4	9.0%	0.0%	0.0%	65.0%	100.0%	0.0%	46.8%	53.2%	13.2%
No. 8	2.0%	0.0%	0.0%	3.0%	96.0%	0.0%	**35.9%**	**64.1%**	10.9%
No. 16	1.0%	0.0%	0.0%	1.0%	76.0%	0.0%	28.0%	72.0%	7.9%
No. 30	0.0%	0.0%	0.0%	0.0%	45.0%	0.0%	16.2%	83.8%	11.8%
No. 50	0.0%	0.0%	0.0%	0.0%	17.0%	0.0%	6.1%	93.9%	10.1%
No. 100	0.0%	0.0%	0.0%	0.0%	6.0%	0.0%	2.2%	97.8%	4.0%
No. 200	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%	0.4%	99.6%	1.8%
Pan	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.4%
Blend % (R)	**55.0%**	**0.0%**	**0.0%**	**9.0%**	**36.0%**	**0.0%**	100.0%		

5 Calculations

5.1 Calculate the cumulative combined percent passing each sieve using the following equation:

$$C_P = \sum\{(P_A)(R_A)\}$$

where:

C_P = Cumulative Combined % Passing
P_A = % Passing of Aggregate
R_A = Relative % of Aggregate

5.2 Calculate the cumulative combined percent retained on each sieve using the following equation:

$$C_R = 100\% - C_P$$

where:

C_R = Cumulative Combined % Retained
C_P = Cumulative Combined % Passing

5.3 Calculate the combined percent retained on each sieve using the following equation:

$$C = C_R - C_{RX}$$

where:

C = Combined % Retained
C_R = Cumulative Combined % Retained
C_{Rx} = Cumulative Combined % Retained of next larger sieve size

6 Charts

6.1 *Coarseness Factor Chart*—Use the cumulative combined sieve analysis to determine the coarseness and workability factors. Plot the coarseness and workability factors on the Coarseness Factor Chart (Figure 1).

Determine the coarseness factor using the following equation:

$$\mathrm{CF} = \left(\frac{\mathrm{S}}{\mathrm{T}}\right) \mathrm{x}\ 100$$

where:

CF = Coarseness Factor
S = Cumulative % Retained on the 3/8 in. Sieve
T = Cumulative % Retained on the No. 8 Sieve

The workability factor is the cumulative combined percent passing the No. 8 sieve. Increase the workability factor by 2.5 percentage points for every 94 lb. per cubic yard of cementitious material used in excess of 564 lb. per cubic yard in the mix design. Decrease the workability factor by 2.5 percentage points for every 94 lb. per cubic yard of cementitious material used below 564 lb. per cubic yard in the mix design. Do not adjust the workability factor if the amount of cementitious material is 564 lb. per cubic yard.

For Class Pave concrete, the coarseness factor and workability factor must plot within the workability box defined as follows:

- coarseness factor must not be greater than 68 or less than 52
- workability factor must not be greater than 38 or less than 34 when the coarse factor is 52
- workability factor must not be greater than 36 or less than 32 when the coarseness factor is 68.

For other classes of concrete the Workability Factor must plot within Zone II.

Aggregate blends that plot in Zone III may be considered for approval of a mix design if a ¾-inch nominal maximum or smaller size aggregate is utilized.

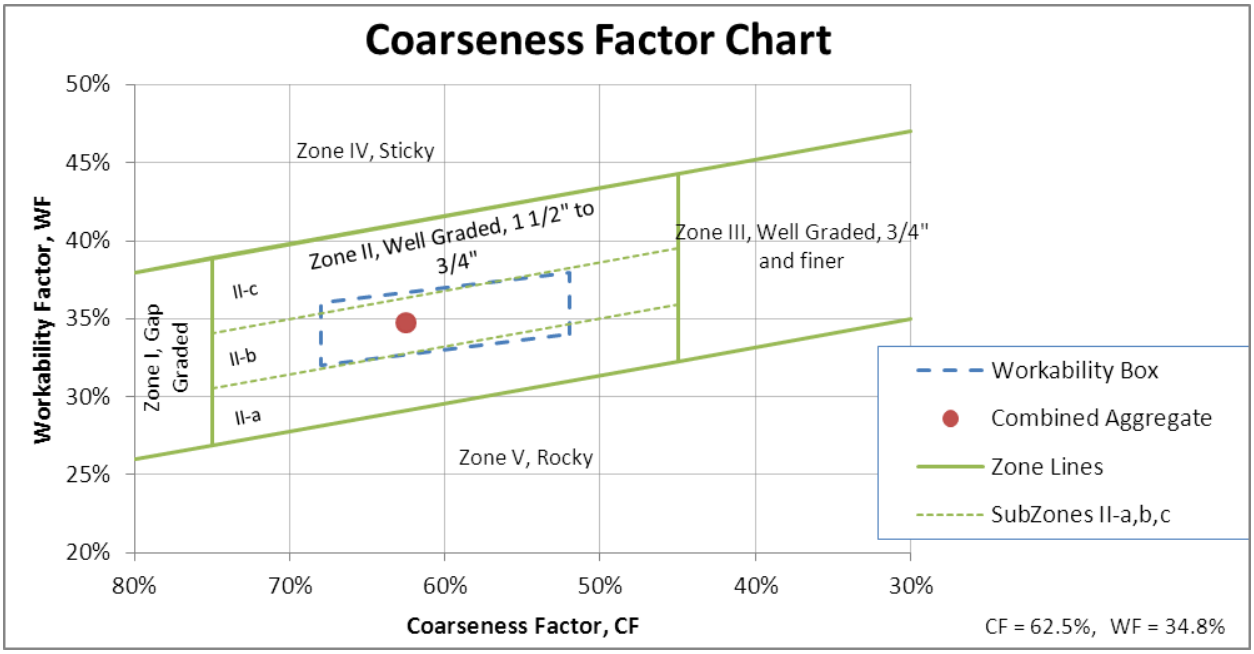


Figure 1: Coarseness Factor Chart

6.2 *0.45 Power Chart*—The 0.45 Power Chart (Figure 2) is created by plotting the cumulative percent passing (y-axis) vs. the sieve sizes raised to the power of 0.45 (x-axis). The cumulative percent passing should generally follow the maximum density line and should not deviate beyond the maximum and minimum tolerance lines. There may be a "hump," beyond the tolerance line and above the maximum density line around the No. 16 sieve. There will always be a dip below the maximum density line around the No. 30 sieve. These deviations are typical and should not be cause for rejection of a gradation unless results from trial batches indicate workability problems.

The maximum density line is a straight line calculated with the following equation:

$$P = \left(\frac{d}{D}\right)^{0.45}$$

where:

P = % Passing
d = sieve size being considered
D = nominal maximum sieve size

The nominal maximum sieve size is one sieve larger than the first sieve to retain ≥10%.

The tolerance lines are straight lines drawn on either side of the maximum density line. Draw the tolerance lines from the origin of the chart to 100% of the next sieve size smaller and larger than the maximum density sieve size.

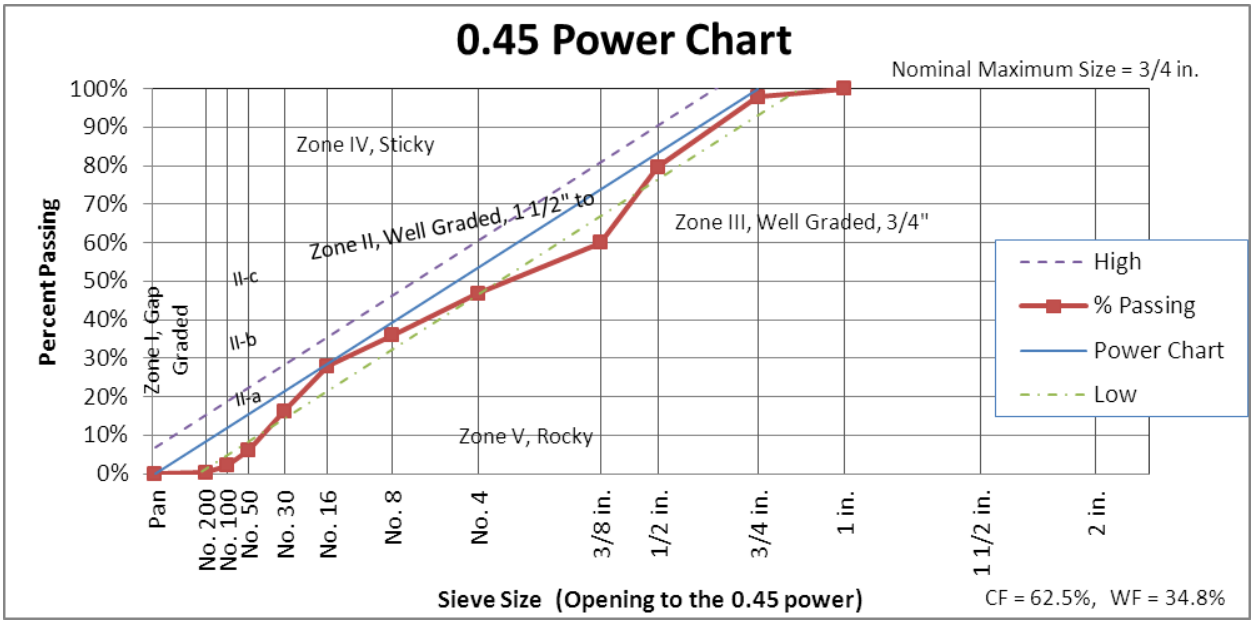


Figure 2: 0.45 Power Chart

6.3 *Percent Retained Chart*—Create the Percent Retained Chart (Figure 3) by plotting the combined percent-retained (y-axis) vs. the sieve sizes (x-axis). The sum of the percent retained on any two adjacent sieves, excluding the first and last sieve that retains material, must not be less than 13%.

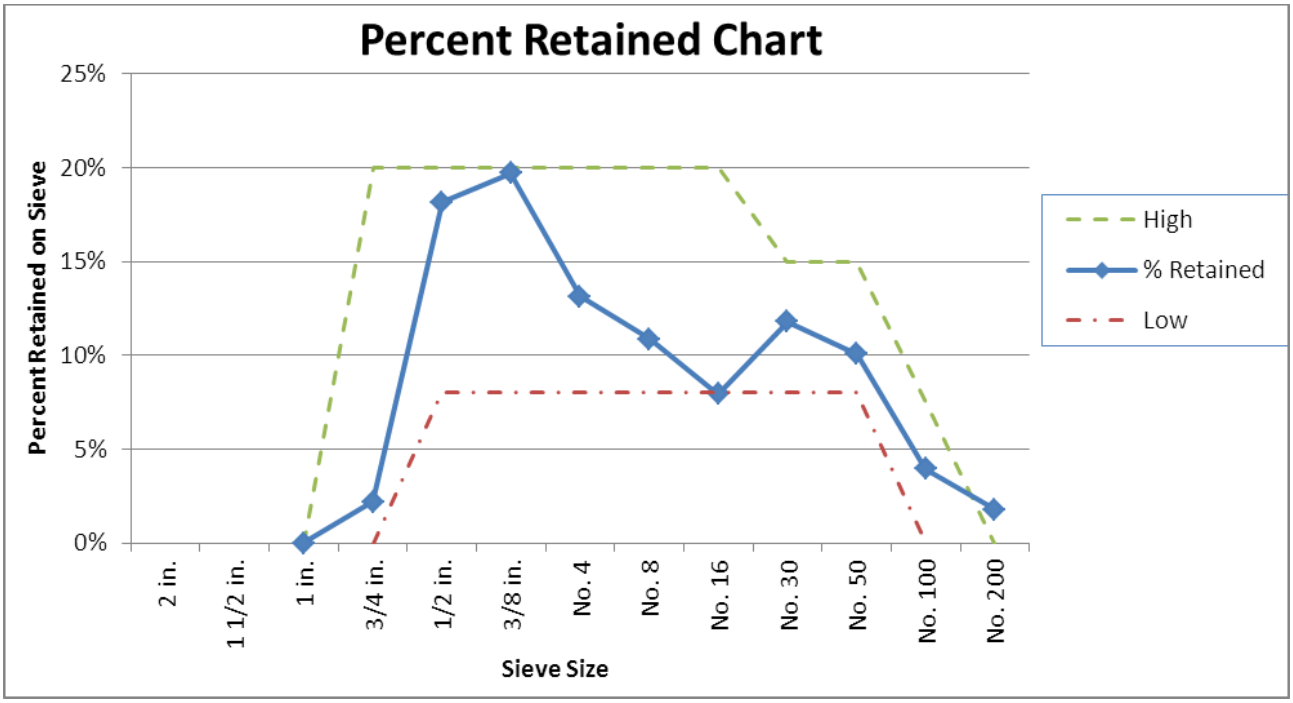


Figure 3: Percent Retained Chart

6.4 *MDT Optimized Gradation Worksheet* — May be used to perform the aggregate gradation analysis. It allows the user to input sieve analysis results and aggregate percentages, generating all of the previous charts.



MDT Optimized
Gradation Charts.XLS

6.5 *Selection of Optimized Aggregate Gradation* — Use the aggregate gradations and proportions that plot within the limits of the three charts described above as the basis for trial batches. Perform trial batches with varying aggregate proportions meeting the limits of the three previous charts to determine which concrete mix proportions meet contract requirements.

The Materials Bureau may allow the use of aggregate gradations and proportions that exceed the limits of the 0.45 Power Chart and the percent-retained chart. This may be permitted if the coarseness and workability factors plot within the workability box on the Coarseness Factor Chart and the trial batch results meet all contact requirements.

6.6 *Aggregate Gradation Monitoring and Aggregate Proportion Adjustment* — Monitor the aggregate gradation by plotting the results of each sieve analysis on the three previous charts. Perform sieve analysis on a lot by lot basis determined by MT 601.

Any adjustments to the aggregate proportions during concrete production to keep the coarseness factor and workability factor plotted within the workability box on the Coarseness Factor Chart are subject to the Project Manager's approval.