Test Procedure for

OPTIMIZED AGGREGATE GRADATION FOR
HYDRAULIC CEMENT CONCRETE MIX DESIGNS

TxDOT Designation: Tex-470-A


1. SCOPE

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

2. UNITS OF MEASUREMENT

2.1 The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

3. APPARATUS

3.1 The apparatus required for sampling aggregates and performing sieve analysis will be as stated in:

- Tex-400-A
- Tex-401-A.

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 below. Include in the sieve analysis report all standard sieves starting with the nominal maximum aggregate size of the proposed aggregate to the No. 200 sieve.

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

- Coarseness Factor,
- 0.45 Power, and
- Percent Retained.

4.3 Perform sieve analysis according to Tex-401-A for each aggregate that will be used in the optimized mix design. Complete the Sieve Analysis table, like the one shown below.
containing example data, with the percent passing and the percent of each aggregate used in the proposed mix design.

4.4 Determine the percent of each aggregate used by the gradation analysis.

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

\[
\text{Cumulative Combined } \% \text{ Passing } = \sum (A)(B)
\]

Where:
A = % Passing of Aggregate and
B = % of Aggregate.

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

\[
\text{Cumulative Combined } \% \text{ Retained } = 100\% - C
\]

Where:
C = Cumulative Combined % Passing

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

\[
\text{Combined } \% \text{ Retained } = D - E
\]

Where:
D = Cumulative Combined % Retained and
E = Cumulative Combined % Retained of next larger size.
Table 1—Sieve Analysis Table

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Coarse Aggregate</th>
<th>Fine Aggregate</th>
<th>Cumulative Combined</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1% Passing</td>
<td>2% Passing</td>
<td>3% Passing</td>
<td>1% Passing</td>
</tr>
<tr>
<td>2 in.</td>
<td>100</td>
<td>100</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>1-1/2 in.</td>
<td>100</td>
<td>100</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>1 in.</td>
<td>95</td>
<td>100</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>3/4 in.</td>
<td>62</td>
<td>100</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>1/2 in.</td>
<td>35</td>
<td>100</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>3/8 in.</td>
<td>20</td>
<td>95</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>No. 4</td>
<td>1</td>
<td>65</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>No. 8</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>96</td>
</tr>
<tr>
<td>No. 16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>79</td>
</tr>
<tr>
<td>No. 30</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>45</td>
</tr>
<tr>
<td>No. 50</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>17</td>
</tr>
<tr>
<td>No. 100</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>No. 200</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Pan</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>% of Aggregate</td>
<td>50%</td>
<td>13%</td>
<td>0%</td>
<td>37%</td>
</tr>
</tbody>
</table>

5. CHARTS

5.1 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:

\[
\text{Coarseness Factor} = \left( \frac{S}{T} \right) \times 100
\]

Where:

S = % Cumulative Retained on 3/8 in. Sieve and
T = % Cumulative Retained on 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.

The coarseness factor and workability factor must plot within the workability box defined as follows:

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

5.2 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. However, there typically will be a “hump,” possibly beyond the tolerance line, 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:

\[
\% \text{ Passing} = \left( \frac{d}{D} \right)^{0.45}
\]

Where:
\( d \) = sieve size being considered and
\( D \) = nominal maximum sieve size.

The nominal maximum sieve size is one sieve larger than the first sieve to have \( \leq 90\% \) passing.

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.

5.3 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%.

5.4 Optimized Aggregate Gradation Workbook—Form 2227, “Optimized Aggregate Gradation Workbook,” may be used to perform the aggregate gradation analysis. This Excel workbook allows the user to input sieve analysis results and aggregate percentages, and it creates all of the charts needed for aggregate proportions selection.

5.5 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 that meet the limits of the three charts to determine which concrete mix proportions meet the strength requirements.

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

5.6 Aggregate Gradation Monitoring and Aggregate Proportion Adjustment—Monitor the aggregate gradation by plotting the results of each sieve analysis on the Coarseness Factor Chart, 0.45 Power Chart, and Percent Retained Chart. Perform sieve analysis before each production day.

Adjust the aggregate proportions during concrete production, if necessary, to keep the coarseness factor and workability factor plotted within the workability box on the Coarseness Factor Chart. Adjustments to the aggregate proportions that also require adjustments to water or cementitious material contents will require development of new concrete mix proportions and new trial batches.

![Coarseness Factor Chart](figure1.png)

Figure 1—Coarseness Factor Chart

1. Shilstone and Shilstone, “Performance-Based Concrete Mixtures and Specifications for Today,” Concrete International, February 2002
Figure 2—0.45 Power Chart

Figure 3—Combined Percent Retained