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Concrete Aggregate Combined Gradation Example

General

MDT is moving toward optimized gradations for concrete aggregate. This example presents some basic computations for optimizing a blend of multiple aggregates. Included is the production of three optimization charts that may be required to be included in the concrete mix design submittal for some projects. The 3 charts are;

- Coarseness Factor chart
- 0.45 Power chart
- Percent Retained chart

Each chart represents one aspect of an optimized aggregate gradation. The charts may be used in the mix design process to arrive at a reasonable starting point for trial batches. Trial batches are an important part of the mix design process and cannot be replaced by these computations.

For this example, two coarse aggregates and one fine aggregate will be combined into the final product. These aggregates meet the requirements of Section 701.01 AGGREGATE FOR CONCRETE of the Standard Specification with the exception of Coarse Aggregate #2.

Coarse Aggregate #2 doesn't meet the gradation requirement of Section 701.01. This material is a mid-sized material intended to be used to help optimize the combined gradation. Use of this type of material isn't required but may be approved on a case by case basis. Approval will be based on an analysis of the combined gradation using the three charts and other factors.

The amount of cementitious material in the mix is also needed in the computations. For this example, it is assumed that the mix will use 520 lb/yd^3 of cementitious material. This is the combined weight of cement, fly ash, silica fume, and other pozzolans used in the mix.

The procedure shown is the same for other combinations of aggregates.

Individual Aggregate Gradations & Combined Gradations

For each aggregate used in the mix design, include a gradation analysis that is representative of the aggregate. The gradations should be current and are typically the average of more than one individual test for each aggregate.

The following chart shows example individual aggregate gradations and combined aggregate gradation information. This chart contains all the data needed to produce the three aggregate optimization charts.

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	Coarse Aggregate % Passing			Fine Aggregate % Passing		Combined Aggregate Gradation		
Sieve Size	Coarse #1	Coarse #2	Coarse #3	Fine #1	Fine #2	% Passing	Cumulative % Retained	% Retained on Each Sieve
2 in.	100%	100%	0%	100%	0%	100.0%	0.0%	0.0%
1 1/2 in.	100%	100%	0%	100%	0%	100.0%	0.0%	0.0%
1 in.	100	100	0	100	0	100.0	0.0	0.0
3/4 in.	96	100	0	100	0	97.8	2.2	2.2
1/2 in.	63	100	0	100	0	79.7	20.4	18.2
3/8 in.	28	95	0	100	0	60.0	40.1	19.7
No. 4	9	65	0	100	0	46.8	53.2	13.2
No. 8	2	3	0	96	0	35.9	64.1	10.9
No. 16	1	1	0	76	0	28.0	72.0	7.9
No. 30	0	0	0	45	0	16.2	83.8	11.8
No. 50	0	0	0	17	0	6.1	93.9	10.1
No. 100	0	0	0	6	0	2.2	97.8	4.0
No. 200	0	0	0	1	0	0.4	99.6	1.8
Pan	0	0	0	0	0	0.0	100.0	0.4
% used in Combined	**55%**	**9%**	**0%**	**36%**	**0%**	100.0%		

Information from this chart is used to produce three charts that are commonly used to help optimization a combined gradation.

- Coarseness Factor chart
- Power chart
- Percent Retained on Each Sieve chart

Each of these charts is described below.

Coarseness Factor chart

The computation for the Coarseness Factor (CF) and the Workability Factor (WF) are given below.

$$CF = \frac{Q}{R}100 \qquad percent$$

$$WF = W + \frac{2.5(C - 564)}{94} \qquad percent$$

Where;

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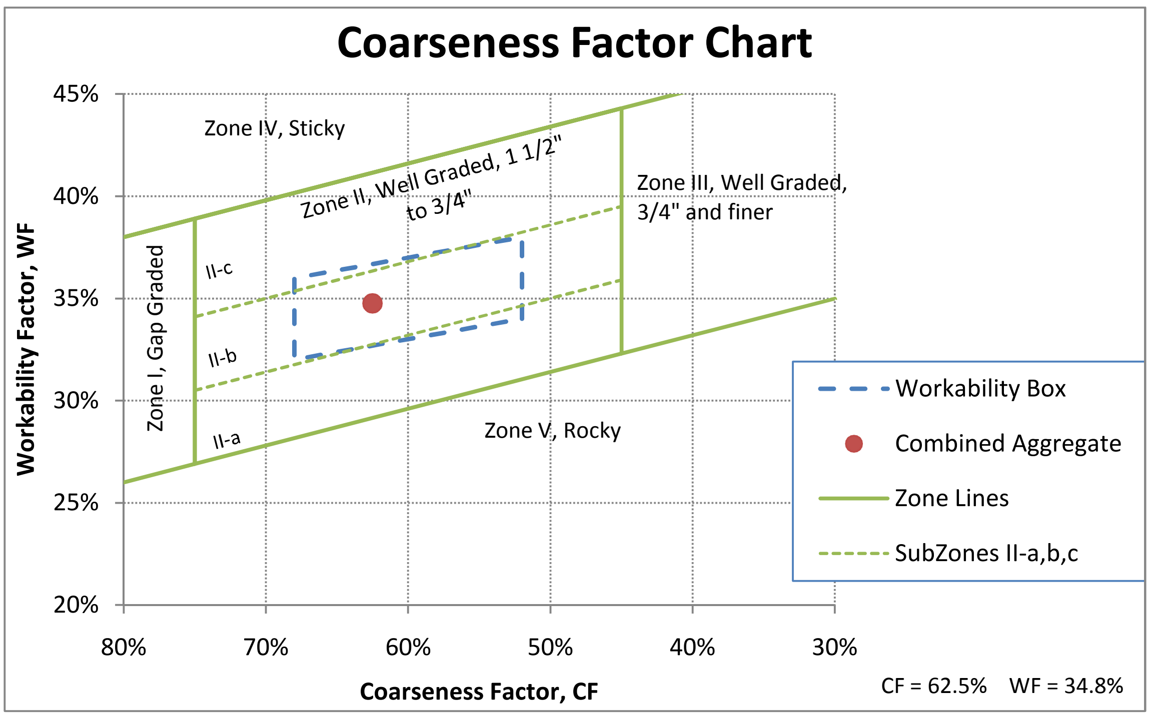
$$Q = Cumulative\ \%\ Retained\ on\ the\ \frac{3}{8}\ sieve$$
$$R = Cumulative\ \%\ Retained\ on\ the\ No.8\ sieve$$
$$W = \%\ Passing\ the\ No.8\ sieve$$
$$C = Cementitious\ Material\ Content\ in\ lb/yd^3$$

In this example, C = 520 lb/yd^3 so the factors are;

$$CF = \frac{40.1}{64.1}100 = 62.5\%$$

$$WF = 35.9 + \frac{2.5(520 - 564)}{94} = 34.7\%$$

The Coarseness Factor chart for this data is shown below.



Combined aggregates that plot within Zone II are generally considered to be reasonable mixes. Combinations that plot near the boundaries of Zone II are more prone to problems either during placement or in overall durability. The Workability Box shown is a reasonable target for the combined aggregate for many mixes. The Workability Box is defined by the corners coordinates shown. Combinations that fall into the Workability Box have a higher probability of satisfying the project needs both during placement and for the long term.

Workability Box	
CF	**WF**
68	32
68	36
52	38
52	34

Some researchers have divided Zone II into 3 subzones, II-a, II-b, and II-c. Some of the research indicates that mixes using high range water reducers that are in Zone II-a have a tendency to segregate. This subzone is generally below the Workability Box.

Power chart

The Power Chart is a plot of the percent passing each sieve size and the sieve size in microns to the 0.45 power. A well graded, tight packing aggregate that produces a maximum density will approximately plot along a straight line. This straight line is the Power Chart line and may be plotted using the following equation.

$$\%\ Passing = \left(\frac{d}{D}\right)^{0.45} \qquad\qquad Power\ Chart\ line$$

Where;

$$d = Square\ Opening\ of\ the\ Sieve\ Size\ being\ considered$$
$$D = Square\ Opening\ of\ the\ Nominal\ Maximum\ Sieve\ Size$$
$$Nominal\ Maximum\ Sieve\ Size = one\ sieve\ larger\ than\ the\ first\ sieve\ to\ have\ \leq 90\%\ passing$$

The actual plot is compared to this line. The combined grading should generally be within ± 7 percentage points of the Power Chart line. Data for the example aggregate is given below.

Sieve Size	Square Opening, in.	Square Opening, Microns	$Microns^{0.45}$	Combined Aggregate % Passing	Power Chart Equation	Deviation
2 in.	2	50800	131.1	100.0%	100.0%	0.0%
1 1/2 in.	1.5	38100	115.2	100.0%	100.0%	0.0%
1 in.	1	25400	96.0	100.0%	100.0%	0.0%
3/4 in.	0.75	19000	84.2	97.8%	100.0%	2.2%
1/2 in.	0.5	12700	70.3	79.7%	83.4%	3.8%
3/8 in.	0.375	9510	61.7	60.0%	73.2%	13.3%
No. 4	0.187	4760	45.2	46.8%	53.6%	6.8%
No. 8	0.0937	2380	33.1	35.9%	39.3%	3.3%
No. 16	0.0469	1190	24.2	28.0%	28.7%	0.7%
No. 30	0.0234	595	17.7	16.2%	21.0%	4.8%
No. 50	0.0117	297	13.0	6.1%	15.4%	9.3%
No. 100	0.0059	149	9.5	2.2%	11.3%	9.1%
No. 200	0.0029	74	6.9	0.4%	8.2%	7.9%
Pan	0	0	0.0	0.0%	0.0%	0.0%

The grading curve for the portion of the combined aggregate passing the No. 30 sieve will typically fall below the power chart line to allow space for the cementitious materials in the final mix.

The 0.45 Power chart of this data is shown below.

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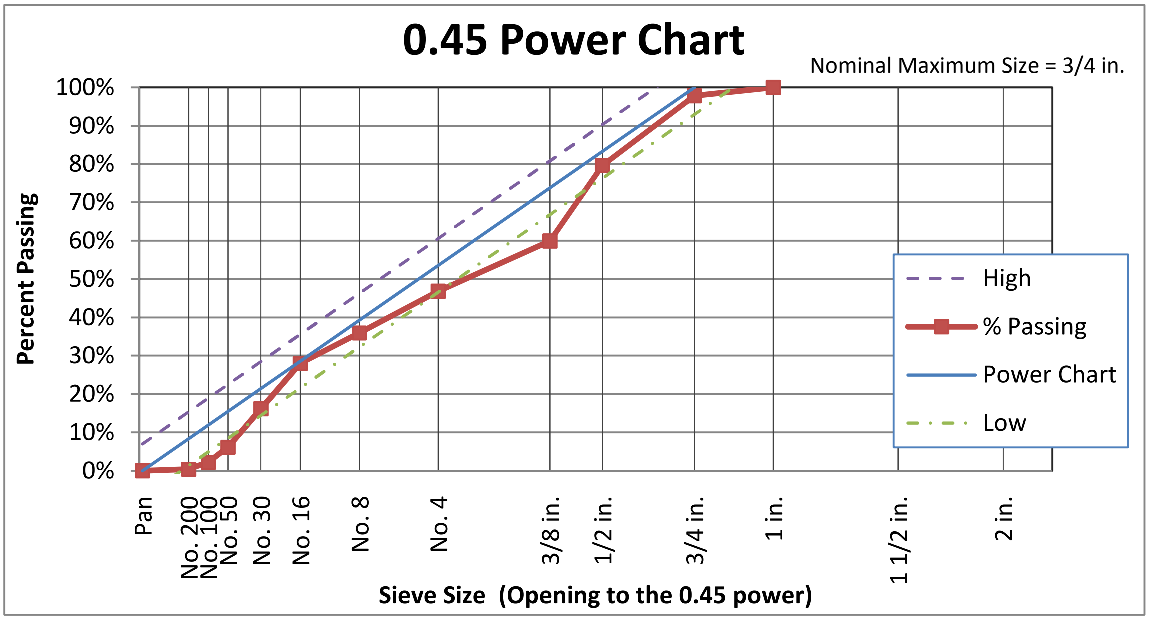

Combined aggregates that tend to plot above the Power Chart line will tend to be stiff and may require high doses of high range water reducer. Blends that plot far below the Power Chart line are too coarse and tend to segregate.

Percent Retained chart

The Percent Retained chart is a plot of the percentage of aggregate retained on each individual sieve. The chart can be used to indicate mixes that should be workable and have a reasonably low water demand.

Limits for the material retained on each sieve for satisfactory reduction in water demand while providing good workability have been recommended and are shown in the table. In addition, the difference between percent retained on consecutive sieve sizes should be less than 10 percentage points.

Sieve Size	Recommended Percent Retained on Each Sieve		
	1½" Max Size Aggregate	**1" Max Size Aggregate**	**¾" Max Size Aggregate**
1 in.	8 – 18		
3/4 in.	8 – 18	8 – 20	
1/2 in., 3/8 in., No. 4, No. 8, No. 16	8 – 18	8 – 20	8 – 20
No. 30, No. 50	8 – 15	8 – 15	8 – 15

The percent retained on each screen for the example aggregate is given in an earlier table above. This data is plotted on a Percent Retained chart below.

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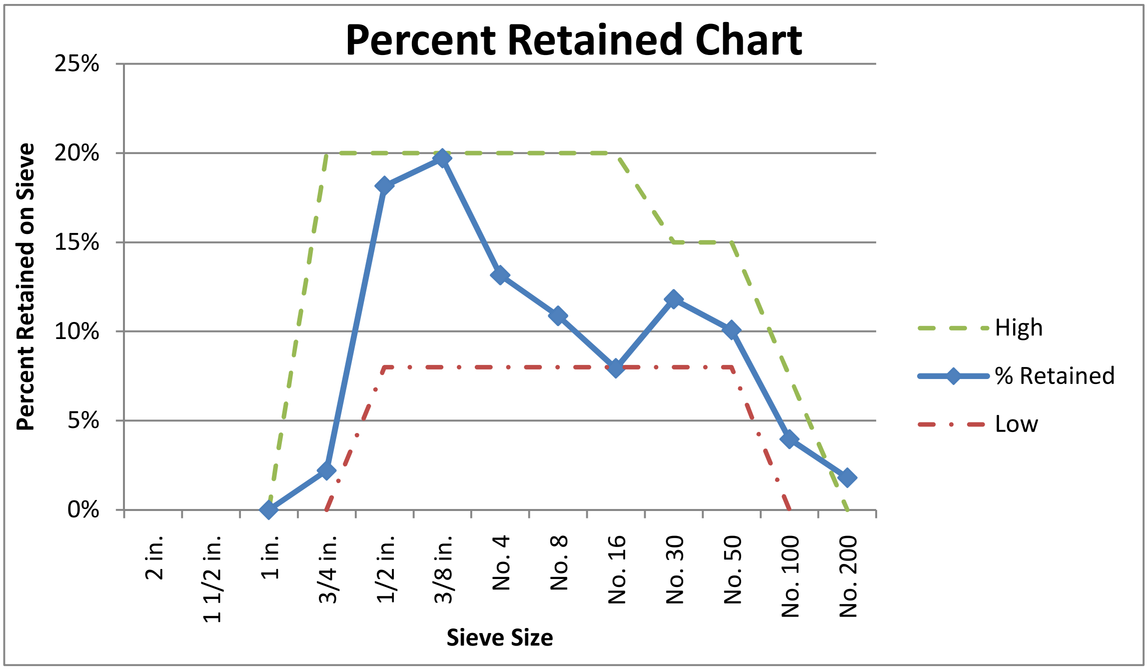

It is generally desirable to have at least at total of 13% of the combined aggregate retained on any two adjacent sieves. Mixes with less than this percentage on adjacent sieves tend to segregate.

Summary

The example presents the information needed to produce three charts that are useful in evaluating a combined aggregate gradation for a concrete mix. The charts may be used together to choose an aggregate blend that will likely meet the needs of the project for cost, workability, and durability. That blend should be the starting point for trial mixes that confirm the mix properties.

The aggregate blend used in the example should not be considered to be an ideal blend. It is a blend of a set of aggregates and is subject to the limitations of those individual aggregates. It plots within the Workability Box on the Coarseness Factor chart. Both the 0.45 Power Factor chart and the Percent Retained chart indicate the blend may be coarse. Overall, it may be a reasonable blend to move forward to trial batches.

Optimizing concrete aggregate in the mix design can have several benefits including increased workability, reduced segregation, reduced cracking, and reduced cement content. In many cases the end product can be improved with little additional cost and potential cost savings from reduced cement usage. There are commercial mix design tools available to optimize a concrete mix design. Many include this type of optimized aggregate approach. One is available from Kansas University at http://www.iri.ku.edu/projects.html under the Bridge Deck Cracking projects. MDT also has a spreadsheet that produces the charts and tables in this document.