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A STATISTICAL APPROACH TO OBTAIN THE BEST BLEND OF AGGREGATES

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Abstract - *Aggregate gradation is the particle size distribution of both the coarse aggregates and fine aggregates present in the concrete matrix. This is an aggregate property which has been profoundly researched for more than a century but the impacts this property on concrete properties is still to some degree misunderstood. Past research has revealed that aggregate gradation dictates the proportion of aggregate to cement paste in concrete mix, and greatly influences the overall durability of the construction material. For more than half a century, the 0.45 Power Chart (Talbot's Grading Curve with an n value of 0.45 (Richart, 1923)) has been the method taken as a standardized method by the Federal Highway Administration (FHWA) for aggregate gradations design of hot mix asphalt industry since the 1960s (Virtual Superpave Laboratory, 2005). It is now more freely being applied to concrete mix designs. However, the selection of the suitable range for the exponent n, must consider the standard deviation of actual aggregates gradations from the theoretical gradations. The combined aggregates gradations can also do by using coarseness factor (C_f) and a workability factor (W_f). The optimum concrete mix is one whose coarseness factor is around 65 and workability factor is above 35. The standard deviation is calculated by utilizing the W_f and C_f factors as guidelines. The principal objective of this investigation was to find N based on the lowest standard deviation from theoretical and actual aggregate gradations.*

Key Words: Coarse Aggregate, Sieve analysis, Standard deviation, least value, DIN curves

1. INTRODUCTION

High-Performance Concrete (HPC) is defined (Russell, 1999) as "Concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing and curing practices". Thus HPC should necessarily have improved strength and durability properties than ordinary Portland cement concrete (PCC). Mostly attempts were made to achieve durability by increasing the cementitious material content and reducing the water-cementitious material ratio. But very few have attempted to achieve HPC by using combined well-graded aggregates in concrete. The most important feature of mix design is aggregate content. The resulting mix design should have a strong aggregate skeleton for permanent deformation resistance and an optimum amount of cement, which acts as a binder for the aggregates. The void space in the aggregate skeleton can be changed by varying the gradation (particle size distribution) of a mixture. A well-graded combined aggregate gradation requires graded coarse aggregates and coarser fine aggregates. But today fine aggregates do not contain predominantly coarse particles. HPC can be achieved by combining aggregates of different sizes and blending them, thus reducing the requirement for additional water and cementitious materials. Optimized aggregate gradation should be the most basic goal of achieving HPC

2. LITERATURE REVIEW

The particle size distribution of the aggregates is called gradation. To obtain the gradation curve for aggregate, sieve analysis has to be conducted in accordance with ASTM C136. The gradations of aggregates are classified into three types, well-graded, gap-graded, and uniformly graded, which are illustrated in Figure 6-1

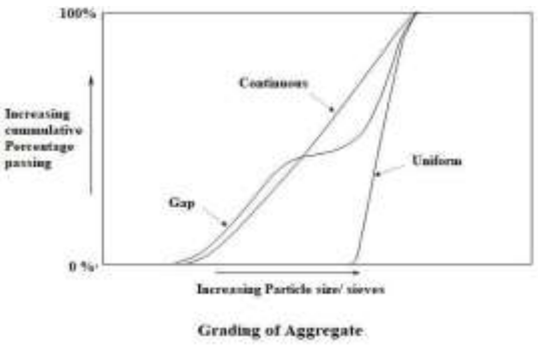


Fig 2.1 Grading Aggregate

In uniformly graded aggregates, only a few sizes govern the bulk material and the aggregates are ineffectively packed. The result is porous concrete requiring more cement paste. Gap graded aggregates constitutes in shortages of few intermediate sizes. This grading results in good concrete in the cases of comparatively low workability, where as in the cases of high workability, this leads to segregation problems. It would require a higher amount of fines, more water, and would increase vulnerability to shrinkage. Well-graded aggregates are appropriate for preparing good concrete mix, as the voids between larger sized particles is thoroughly filled by smaller sized particles to produce a well-packed structure, requiring lesser amount of cement paste. This gradation would reduce the need for excess water still maintains adequate workability. Achieving a better gradation may require the use of three or more different aggregate sizes. An optimized gradation is termed as the gradation in which operational and economic constraints are considered to obtain a mix of aggregates particle sizes that results in improved workability, durability, and strength (Popovics, 1973).

An optimum graded aggregate is the key to the mixture performance and constructability, and would provide the workability needed for placement and finishing with the lowest water- cement ratio. The 1923 ASTM C33 standard included requirements that contributed to well- graded mixtures. The 1986 ASTM C33 standard contributes to near gap grading with its inherent placement problems. The major difference in these two standards is in the sand gradation. The 1923 standard required that the sand be “predominately coarse particles” and have 85 percent passing the No.4 (4.75 mm) sieve. Today’s sands are finer with 95 to 100 percent passing the No.4 (4.75 mm) sieve (Richart, 1923)

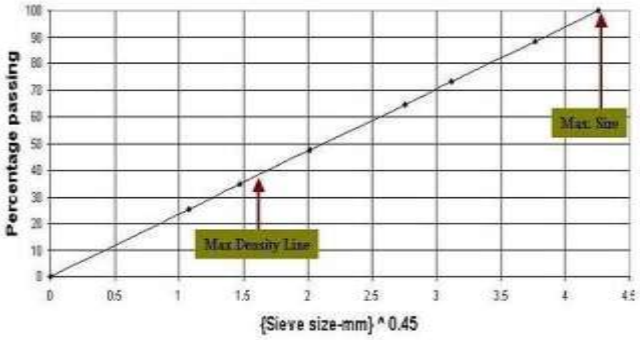
3. METHODOLOGY

3.1 Methods for Optimizing Aggregate Gradation

1. 0.45 Power Chart Method
2. Shilstone Method

3.1.1. 0.45 Power Chart Method

Aggregate gradation can be characterized by drawing a gradation plot on a 0.45 power chart, which also includes the maximum density line. 0.45 power chart was adopted by Superpave for graphical display of the aggregate gradations as per FHWA recommendations.



0.45 Power Chart for 1 inch Aggregate

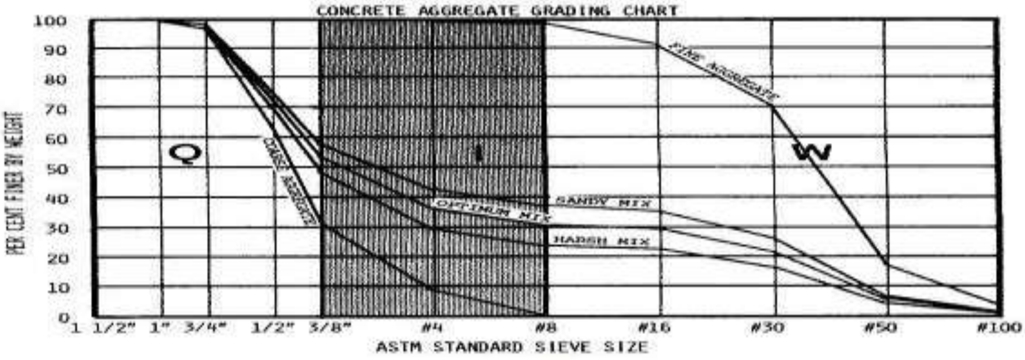
Fig 3.1 0.45 power chart for 1 inch Aggregate

3.1.2 Shilstone Method

There are three principal factors upon which mixture proportions can be optimized for agiven need with a given combination of aggregate characteristics: • The relationship between the coarseness of two larger aggregate fractions and the fine fraction.

- Total amount of mortar.
- Aggregate particle distribution.

Shilstone developed a grading chart showing the aggregate gradations and the combined gradations for the coarsest, finest, and optimum mixtures. The chart used is divided into three segments identified as Q, I, W. This was base d on comments by other mix researchers about the amount and function of the “intermediate aggregate” particles.



Combined Aggregate gradations

Fig 3.2 Combined Aggregate Gradations

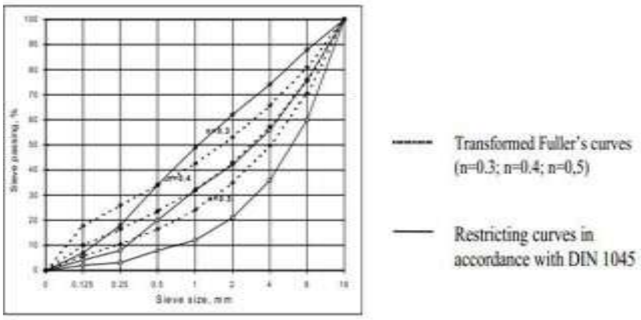
3.2 PROBLEM STATEMENT

Engineers and researchers use the 0.45 power gradation for obtaining the densest possible (maximum density) packing of aggregates. There is a concern whether plotting of the sieve size raised to 0.45 power may not be universally applicable to all aggregates. Thus there is a need to evaluate the validity of the 0.45 power chart using an aggregate (other than the granite aggregate that was used to develop the 0.45 power curve), to determine whether the chart is universally applicable for all aggregates.

4. MATERIALS

In the total volume of concrete, aggregates constitute to 60-90%. So the main properties of the concrete- workability and mechanical strength, permeability, durability, depends predominantly on the selection of aggregates and its particle size distribution which has a direct effect on the total cost of hardened concrete. Hence, the aggregates mixture design becomes a main part of the concrete mix-design and optimization. Aggregate mix composition can be obtained either by means of the "ideal grading curves" method or by means of practical and theoretical determination of aggregate packing value.

Aggregate gradation is defined as the relation between standard sieve size Xi (mm) and the total amount aggregates passing through the sieve Yi(Xi). This relation can be replicated by tables, formulas or graphics. Aggregate grading optimization is pronounced by means of "ideal" grading curves which offer the best fresh and hardened concrete properties as well as good aggregate packing.



Aggregate "ideal" grading

Fig 4.1 Aggregate "ideal" grading

The "ideal" aggregate grading curve can also be defined with the help of restricting curves in graphics. Varied of transformed "ideal" curves with various degrees and the restricting curves in accordance with DIN 1045 are depicted in Fig.

5. Determination of optimum aggregate mix by analytical and numerical methods

N varieties of aggregates are provided (grading curves for the aggregates are determined). Fractions of each aggregate in the mix are to be determined to obtain the best correlation with the "ideal" grading curve.

The equation of the combined grading curve Yi is as given below:

N

$Y_i = \Sigma K_j Y_{ji}$

j=1

Here K_j – the proportion of j-st aggregate in mix;

Y_{ji} – real grading of j-st aggregate.

Coefficients K_j can be calculated by minimizing the squared sum of deviation between an "ideal" (theoretical) and a real grading curve:

$\Sigma^M (YT_i - Y_i)2$ min $\longrightarrow$

i=1

Here M – number of sieves

The most stable and reliable results are determined using the numerical method to determine the optimum aggregate mix. This method facilitates in calculating the possible proportions of each aggregate in the mixture. An optimum aggregate mix will be obtained by calculating the average squared root deviation between real and "ideal" aggregate curves calculated for all sieves

$$\sqrt{\frac{\sum_{i=1}^{M} (YT - Y_i)^2}{M-1}}$$

With the usage of a computer program which was written in the python programming language is utilized for 5 aggregate combination has been worked out. In general practice from 2 to 4 aggregates is usually used in a concrete mix. The average squared deviation S is used as a criterion of suitability of the given aggregate combination and allows to compare the possibilities to use different aggregate combinations.

Table 5.1 Standard Deviation of Samples 1 to 10.

Slno	N Value	Standard Deviation									
		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
1	0.3	6.49	9.897	7.147	4.717	8.555	6.49	7.746	9.513	7.659	9.436
2	0.35	5.691	8.466	5.438	3.719	7.086	5.691	6.973	7.817	6.109	8.132
3	0.4	5.276	7.541	4.232	3.037	6.139	5.276	6.515	6.579	5.059	7.366
4	0.45	5.083	6.945	3.308	2.568	5.626	5.083	6.248	5.685	4.43	6.968
5	0.5	4.992	6.607	2.611	2.297	5.376	4.992	6.078	5.031	4.059	6.777
6	0.55	4.921	6.411	2.185	2.165	5.326	4.921	5.962	4.711	3.939	6.722
7	0.6	4.839	6.299	1.932	2.135	5.378	4.839	5.874	4.535	3.943	6.707
8	0.65	4.733	6.199	1.813	2.155	5.502	4.733	5.838	4.505	3.991	6.708
9	0.7	4.601	6.109	1.802	2.224	5.618	4.601	5.793	4.576	4.082	6.714
10	0.75	4.445	6.033	1.868	2.321	5.764	4.445	5.787	4.707	4.244	6.721
11	0.8	4.267	5.936	1.954	2.432	5.913	4.267	5.777	4.893	4.393	6.713
12	0.85	4.08	5.831	2.071	2.573	6.067	4.08	5.819	5.098	4.541	6.694
13	0.9	3.88	5.717	2.162	2.683	6.025	3.88	5.876	5.335	4.691	6.694
14	0.95	3.676	5.592	2.292	2.831	6.355	3.676	5.973	5.577	4.867	6.683
15	1	3.474	5.459	2.411	2.987	6.912	3.474	6.061	5.833	5.049	6.68

Table 5.2 Standard Deviation of Samples 11 to 24.

Slno	N	Standard Deviation													
	Value	Sample 11	Sample 12	Sample 13	Sample 14	Sample 15	Sample 16	Sample 17	Sample 18	Sample 19	Sample 20	Sample 21	Sample 22	Sample 23	Sample 24
1	0.3	8.014	6.594	5.036	5.68	6.253	7.145	5.274	8.963	4.523	5.037	9.436	6.701	5.036	5.207
2	0.35	5.697	5.4	4.171	4.471	5.749	5.634	4.279	7.271	3.612	4.17	8.132	6.283	4.171	5.05
3	0.4	3.888	4.589	3.639	3.636	5.438	4.574	3.667	6.061	3.028	3.615	7.366	6.024	3.639	5.241
4	0.45	3.888	4.091	3.313	3.134	5.236	3.953	3.318	5.254	2.698	3.301	6.968	5.829	3.313	5.53
5	0.5	1.879	3.828	3.085	2.827	5.09	3.644	3.206	4.724	2.548	3.15	6.777	5.642	3.085	5.818
6	0.55	1.742	3.736	2.942	2.692	4.983	3.54	3.208	4.397	2.478	3.111	6.722	5.459	2.942	6.056
7	0.6	2.018	3.769	2.872	2.696	4.901	3.542	3.284	4.207	2.514	3.168	6.707	5.257	2.872	6.233
8	0.65	2.384	3.874	2.833	2.718	4.849	3.678	3.417	4.095	2.593	3.254	6.708	5.068	2.833	6.348
9	0.7	2.764	4.046	2.819	2.795	4.81	3.806	3.562	4.03	2.671	3.429	6.714	4.88	2.819	6.427
10	0.75	3.069	4.244	2.86	2.922	4.852	4.01	3.74	3.997	2.793	3.569	6.721	4.702	2.86	6.469
11	0.8	3.307	4.454	2.907	3.041	4.881	4.185	3.933	3.98	2.902	3.776	6.713	4.56	2.907	6.501
12	0.85	3.481	4.696	2.994	3.19	4.937	4.403	4.133	3.974	3.053	3.952	6.694	4.407	2.994	6.509
13	0.9	3.621	4.913	3.057	3.351	5.069	4.623	4.34	3.989	3.193	4.164	6.694	4.319	3.057	6.502
14	0.95	3.72	5.163	3.171	3.518	5.186	4.838	4.547	4.005	3.365	4.342	6.683	4.241	3.171	6.501
15	1	3.761	5.422	3.32	3.674	5.344	5.079	4.743	4.037	3.557	4.573	6.68	4.199	3.32	6.515

Table 5.3 Least Values

Slno:	Samples & N Value	Lowest standard deviation		Lowest W_f and C_f	
		N Value	Standard Deviation	N Value	Standard Deviation
1	Sample1 - 0.7	0.70	1.802	0.99	5.245
2	Sample2 - 0.6	0.60	2.135	0.92	2.745
3	Sample3 - 0.55	0.55	5.326	0.51	5.351
4	Sample4 - 0.8	0.80	5.777	0.78	5.794
5	Sample5 - 0.65	0.65	4.505	0.9	5.335
6	Sample6 - 0.55	0.55	3.939	0.96	4.926
7	Sample7 - 0.6	0.60	6.707	0.48	6.833
8	Sample8 - 0.55	0.55	1.742	0.48	6.833
9	Sample9 - 0.55	0.55	3.736	0.85	4.696
10	Sample10 - 0.7	0.70	2.81	0.84	2.96
11	Sample11 - 0.55	0.55	2.692	0.83	3.127
12	Sample12 - 0.7	0.70	4.81	0.99	**5.017**
13	Sample113 - 0.55	0.55	3.54	0.99	**5.017**
14	Sample14 - 0.5	0.50	3.206	0.78	5.741
15	Sample15 - 0.85	0.85	3.974	0.83	3.385
16	Sample16 - 0.55	0.55	2.478	0.8	2.902
17	Sample17 - 0.55	0.55	3.111	0.81	3.789
18	Sample18 - 0.6	0.60	6.707	0.86	4.405
19	Sample19 - 0.7	0.70	2.819	0.84	2.96
20	Sample20- 0.33	0.33	5.05	0.46	5.6
	Average	0.61	3.8433	0.795	4.633
	Average of two	0.7			

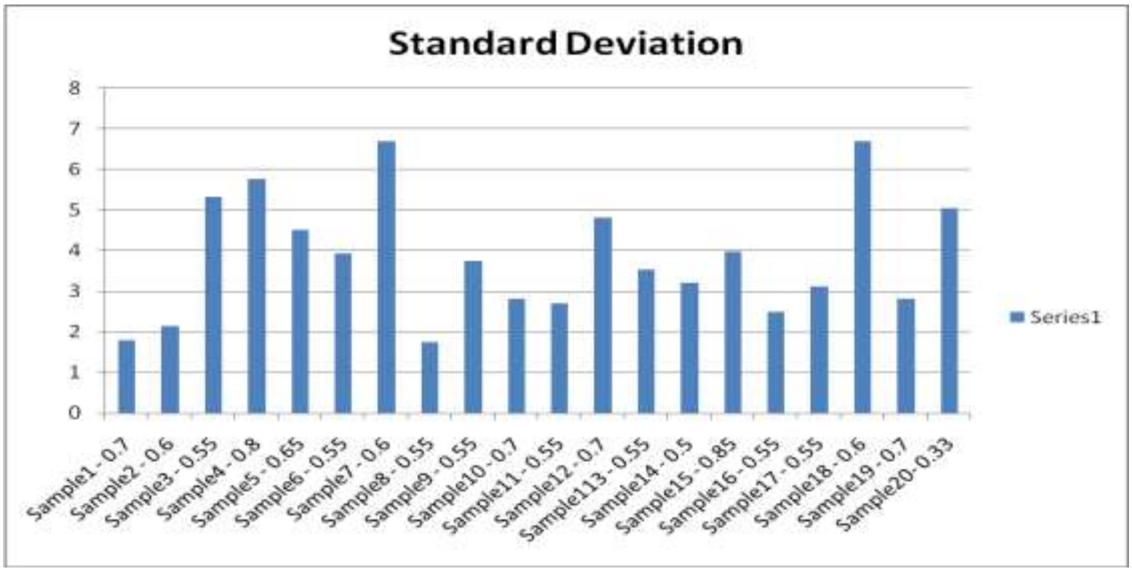


Fig 5.1 Standard Deviation

Based on standard deviation and N value we considered a DIN curve to get an maximum size of aggregate to increase workability, strength, probability and durability.

Table 5.4 DIN Curves

Sieve Size	Standard deviation	N Value		
	d/D	N=0.5	N=0.6	N=0.7
25	1	100	100	100
20	0.8	89.4427	87.469	85.5388
16	0.64	80	76.5082	73.1688
12.5	0.5	70.7107	65.9754	61.5572
10	0.4	63.2456	57.708	52.6553
4.75	0.19	43.589	36.9192	31.27
2.36	0.0944	30.7246	24.2652	19.1638
1.18	0.0472	21.7256	16.009	11.7967
0.6	0.024	15.4919	10.6691	7.34764
0.3	0.012	10.9545	7.03896	4.523
0.15	0.006	7.74597	4.64398	2.78424

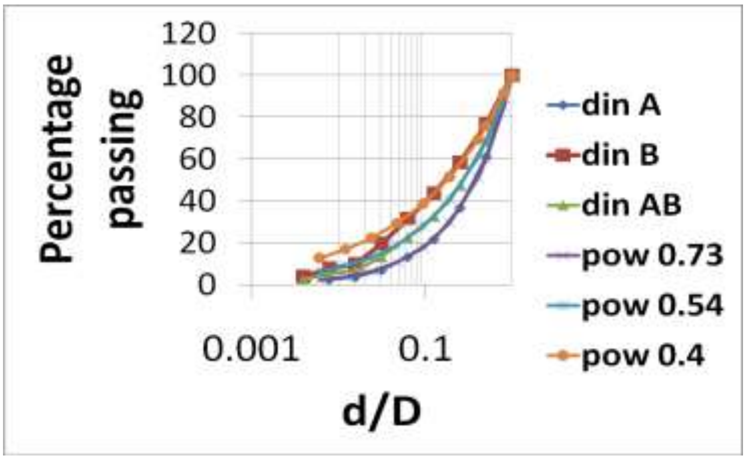


Fig 5.2 combined Grading for N values

6. CONCLUSIONS

- Use of numerical method of aggregate mix design with aid of transformed Fuller's curve allows to calculate aggregate mixes for different types of concrete as well as to use natural, non-fractional aggregates.

- Average squared deflection between the "ideal" and the real grading curve S is efficiently used as the criterion of packing quality of the aggregate.

- Use of granulation number method of concrete mix design allows protecting the physical and mechanical properties of concrete (Strength and workability) with coefficient of correlation not less than 0.95. At the same time, correlation coefficient between practical and experimental results of the standard method is 0.85 to 0.9.

- A system of concrete mix optimization gives a possibility to estimate more objectively and find a compromise variant between economy on the one hand and property on the other hand

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