GRADATION OF AGGREGATE FOR CONCRETE BLOCK

Although numerous papers have been written concerning the proper gradation for concrete mixes, they have generally dealt with plastic mixes, and very little published information is available on the subject dealing specifically with the "minus zero slump" mix as used in concrete block production. Other pertinent data have been reported at various time, but usually as incidental comments in studies directed primarily to other factors of block mix composition and manufacturing details. The ideas presented in this discussion are based on commonly accepted good plant practices and review of applicable technical literature on aggregate gradation in both dry and plastic mixes.

Factors which enter into a discussion of aggregate gradation are:

1. Strength—The influence of aggregate gradation on the compressive strength of finished concrete block will determine the necessary cement content to produce block which meet specified strength requirements. Since cement is the most costly ingredient in the concrete mix, the selection of a properly graded aggregate assumes an economic aspect.

2. Texture—The surface texture of the finished block depends to a great extent upon the gradation of the aggregate. Coarse grading tends to produce rough or coarse textured block, while fine gradations generally yield block with smooth texture. The block surface desired will depend upon the use for which the block is intended and the preferences of the buying public. Regardless of which texture is made. It is always desirable to produce a uniform textured unit.

3. Porosity—In much the same way that aggregate gradation is related to texture, it is likewise related to porosity. Desired porosity will sometimes depend upon block use, but it should be noted that improvements in strength and resistance to moisture and sound transmission usually accompany an increase in density regardless of type of aggregate.

4. Workability—Workability of the concrete block mix is influenced by the gradation, as well as the surface and shape characteristics of the aggregate. Workability affects green block stability, breakage, the speed at which the block can be molded, and consequently production costs. This is another way aggregate gradation may be an economic factor.

5. Availability—Final aggregate selection is dependent upon availability and in many cases this will be the determining factor. The availability of plant facilities for separate storage of fine and coarse sizes and their recombining in proper proportions at time of batching is beneficial where a suitable and uniform combined grading cannot be consistently obtained.

AGGREGATE GRADATION AND BLOCK STRENGTH

For a given cement – aggregate ratio, block strengths theoretically should increase with an increase in the top size of the aggregate provided the aggregate is well graded and mix can be thoroughly consolidated in the machine. Almost all concrete block producers today use aggregate smaller than ½ inch although scattered reports have indicated the feasibility of using an aggregate with some material of larger size. The maximum size possible will depend on the minimum section thickness of the concrete block. Obviously the diameter of the largest particle must be less than the thickness of the web of face shells. One recommendation for combined aggregate specifies 100% passing the 3/8 inch sieve with from 20 to 30% retained on the No. 4.

The work of wilk and others indicates that for each particular aggregate there is an optimum fineness modulus (F.M)*. The curve in Fig. 1 was drawn from Wilk and Grants 2 table of values published in rock products in February, 1948. The compressive strengths shown were obtained from 3 X 6 inch cylinders made from a dry (concrete block) mix, cured in water 21 days and dried to constant weight before testing. Each point is and average of three test cylinders. The aggregate for these cylinders was blended from roofing gravel (3/8 inch to No. 8), coarse sand (no. 8 to 0) and fine sand (No.28 to 0). The amounts of roofing gravel and coarse sand were held constant while the fine sand quantity was varied to give combined aggregate F.M.'s of from 3.02 to 4.30. Results indicated in Fig. 1 show a gain in compressive strength from 1462 psi at an F.M. of 3.02 to 3462 psi at an F.M. of 3.88. As the F.M. was increased further strength showed a slight decline, indicating an optimum valve of F.M. for this particular aggregate near 3.88. Taking into account the necessity for producing a product that does not have a rough appearance led Wilk to suggest a desirable F.M. for this aggregate would be 3.70.

Fig. 2 is a copy of a set of four curves from a PCA paper by Menzel 3. Values are for 8 X 8 X 16 inch. Concrete block, of 37.5% core space, made on a power tamping block machine at a yield of 21.0 to 22.4 block per bag of cement. The aggregate was blended from fine (No. 4 to 0) and coarse (3/8 inch to No. 4) materials in proportions to yield the desired fineness modulus. It should be noted that the strengths given in Fig. 2 are on a gross area basis. The effect of grading of aggregate is shown in the bottom set of curves. From the curves it would appear that an optimum fineness modulus existed for each aggregate type and that there was a sharp decline in compressive strength when the fineness modulus was varied in either direction from this optimum valve for three of the four aggregates. The corresponding air dry block weights are shown in the top portion of Fig. 2 and show, in general, that maximum compressive strength occurred at the same fineness modulus as maximum block weight. Menzel attributed the wide differences in the shapes of these curves to the void characteristics of the aggregate which in turn are affected by the shape and surface characteristics, particularly the angularity and roughness of the aggregate particles themselves.

* Fineness Modulus—An empirical factor obtained by adding the total percentages of a sample of the aggregate retained on each of a specified series of sieves, and dividing the sum by 100. Sieve sizes applicable are: 3/8, 4, 8, 16, 30, 50, and 100.

A consideration of the minimum void theory may be used to best explain this relationship between block strength, weight, and aggregate gradation. Consider the internal structure of a piece of concrete which has been completely dried. It will consist of graded aggregate particles bound together by a cement binder, and vast number of small inter-particle void spaces, the number of which will depend upon the workability of the original mix and the amount of compaction used in manufacture. The strength developed by this concrete is proportional to the inherent strength of the aggregate, the strength of the cement binder and the bond developed between binder and aggregate. The void spaces contribute nothing to the development of strength. Voids also contribute no weight to the concrete, and the relationship between block strength and weight as shown in Fig. 2 becomes apparent.

Most of the voids present in the concrete originate in the aggregate. Few will doubt that a solid piece of stone, of certain volume, will weigh more than an equal volume of sand crushed from the same material. The volume of this interparticle void space in an aggregate may be measured by the standard method of test for voids in aggregate for concrete (ASTM Designation: C30), and this test, used in conjunction with the standard method of test for unit weight of aggregate (ASTM Designation C29) is helpful in the selection of an aggregate blend when working with a new aggregate in which the fine and coarse sizes have similar bulk specific gravities. As a starting point the weight per cubic foot of various mixtures, of the fine and coarse aggregates, can be determined. The blend yielding the highest unit weight will serve as a starting blend for a block mix. This method is usable only with aggregates in which the fine and coarse sizes have the same, or nearly the same, bulk specific gravities.

Excessive inter-particle voids will be present in a concrete block, even if produced from an optimum graded aggregate, if the mix is made too dry. Usually, excessively dry mixes will be harder to compact, give higher block porosity, poorer green block stability and lower compressive strength. For a particular block mix maximum block density (minimum voids) and strength are obtained by using the maximum water content will be limited by the tendency to produce a smeared block surface.

Compressive strength, block weight and green block stability are also affected by the amount of fine- fines (finer than No. 50) present in the graded aggregate. A recommendation of 12 to 15% of total aggregate bulk volume passing the No. 50 mesh screen will usually give satisfactory results. Percentages appreciably less than the suggested range will tend to increase porosity, permeability and absorption and may also result in poorer green block stability. Larger percentages may be detrimental as to the strength of block. The amount of fine-fines also affects surface texture. The recommended limits are given in percentage of total bulk volume rather than by weight because some lightweight aggregates have fines with higher bulk specific gravities than the coarse aggregate sizes. This is due to the difference in cellular structure of the fine and percentage of internal voids than the smaller sizes. In dealing with such materials a correction must be made in the limits if sieve analyses are run by weight.

The influence of aggregate gradation on workability of the mix is of concern because of its effect on the finished block properties and it further effect on the speed of production. An excess of fine-fines (crusher dust) in some aggregate will frequently produce a sticky mix which is slow in feeding into the mold box while a harsh mix will slow production by requiring extra care in proportioning, to avoid bleeding, and may require a longer cycle to secure compaction. The only means of correcting an excessively fine aggregate are by the addition of coarse material or by the removal of a portion of the fine sizes. Harsh mixes may be corrected by the addition of fines, removal of coarse material or use of air entrainment.

Proper control of the water content in a harsh mix is more difficult because of the tendency of such a mix to bleed. This bleeding of water to the surface will result in a smeared block face if bleeding occurs during molding. Harsh mixes tend to have poor mold ability and green block stability unless measures are taken to correct them. To avoid harshness the combined aggregates usually should contain between 12 and 15% of material passing a No. 50 mesh screen, by dry bulk volume, as given in the preceding section on strength. A mix may be harsh even though it possesses a normally adequate amount of minus 50 mesh material if there is an excess of on size or the absence of one or two sizes in the mix. Sometimes these deficiencies can be corrected by increasing the amount of fine-fines to 18 or 20%.

Another method of reducing the harshness of an aggregate mix is by the use of an air entraining admixture or the use of air entraining Portland cement. Air entrained mixes have greater workability, bleed less and show improvement in green block stability.

Sieve Size	Percentage by Bulk Volume* Coarser Than for Various Block Textures		
	Fine	Medium	Coarse
3/8	0	0	0
4	21	25	30
8	36	40	50
16	51	55	67
30	66	70	81
50	82	85	91
100	94	95	98
F.M.	3.50	3.70	4.17

Recommended gradations for fine, medium, and coarse textured surface blocks are presented in Table I. These values were obtained by plotting reasonably smooth curves on an aggregate gradation chart in such a manner as to give the desired amounts of material larger than the No. 4 sizes, smaller than the No. 50 size, and having the desired fineness modulus. The fine texture gradation and the coarse texture gradation it may be noted that the tolerance of the percentage between tine and coarse for any size is rather small.

For comparison the grading requirements for combined fine and coarse aggregate (3/8 in. to 0) from the Tentative Specifications for Lightweight aggregates for Concrete Masonry Units (ASTM Designation: C331). It would seem that the producer desiring to maintain close control of lightweight aggregate gradation would encounter difficulty in a combined aggregate were used which merely met the ASTM requirements for combined (3/8 in. to 0) aggregate. The closer NCMA limits can, however, be complied with readily by using separate fine and coarse sizes of lightweight aggregate and recombining at time of batching. The gradation limits shown by dashed lines in Fig. 4 are taken from the grading requirements of the Tentative Specifications for Lightweight Aggregates for Concrete Masonry Units (ASTM Designation: C331) for both fine and coarse aggregate sizes. Curve A of Fig. 4 is a typical gradation falling between the ASTM limits for fine aggregate, and curve B is a typical gradation for the coarse aggregate. That these two typical gradation may be blended to yield a combined aggregate meeting the NCMA suggested limits is demonstrated by curve C which has been blended by proportioning 65% of the fine size material with 35% of the coarse size.

Although there are no ASTM gradation requirements set forth for dense aggregate used in concrete masonry, the producer of dense aggregate concrete block must usually purchase aggregate material from sources normally producing to meet ASTM requirements. An examination of ASTM grading requirements indicates that no one grading falls within the NCMA suggested limits, and it is usually necessary for the dense aggregate block producer to purchase both coarse and fine aggregates and combine them when batching. Highway aggregate as given in Standard Specifications for Standard Sizes of coarse aggregate for Highway Construction (ASTM Designation: D448). Curve B is a typical grading of fine aggregate from the Tentative Specifications for Concrete Aggregate (ASTM Designation: C33). The two grading's have been blended to give Curve C which falls within the NCMA suggested grading limits. Undoubtedly similar results might have been obtained from other combinations of other ASTM dense aggregate grading's. The particular two used in this example were chosen merely to illustrate the procedure and emphasize the fact that a good gradation of aggregate can be accomplished with recombining of fine and coarse sizes.

<u>Summary:</u>

The amount of literature on the subject of proper aggregate gradation for concrete block is sparse. It is felt that research is needed on the subject particularly at the level of production. From the limited amount of information available, aggregate grading appears to be a factor in many of the physical properties of the finished block.

The fineness modulus of the aggregate grading is an excellent gage of the aggregate gradation. Some researchers have found that an optimum fineness modulus exists for any particular aggregate. A theory of inter-particle voids has been used in explanation of the optimum fineness modulus.

Suggested aggregate gradations have been presented based on a volume bases. The use of a volume basis for sieve analyses makes it possible to combine fine and coarse size aggregates of different specific gravities to meet a selected fineness modulus. An example of the necessary computation for converting from a selected gradation by volume to the weight bases as actually used in sieve analyses is presented in I. The gradation limits suggested are more stringent than combined aggregate grading requirements in the ASTM Specifications. The desired grading can be obtained from aggregates meeting ASTM gradation requirements by combining of fine and coarse sizes. This procedure is illustrated with two examples.

APPENDIX I – Method of converting Aggregate Gradation Requirements from Percentage by Bulk Volume to Percentage by Weight.

Assume that the bulk specific gravity of each individual size fraction of a particular aggregate is known from separate laboratory tests. It is desired to convert the bulk volume gradation requirements given in Table I in accordance with these known specific gravities in order that a sieve analysis can be run by weight on the entire sample. A method for making this conversion is shown in Table A.

TABLE a – Converting Gradation Requirements from Bulk Volume to Weight Basis

Sieve Size	Percent (By Vol.) Coarser than; for Medium Texture (From Table I)	"A" Individual Percent Retained (By Vol.)	"B" Bulk Specific Gravity (Assumed)	"C" "A" x "B" Weighted Specific Gravity	"D" Individual Percent Retained (By Wt.)	Percent (By Wt.) Coarser than; for Medium Texture
3/8	0	0	2.3	0	0	0
4	25	25	2.3	57.5	22.3	22.3
8	40	15	2.5	37.5	14.5	36.8
16	55	15	2.6	39.0	15.1	51.9
30	70	15	2.7	40.5	15.7	76.6
50	85	15	2.8	42.0	16.2	83.8
100	95	10	2.8	28.0	10.8	94.6
Pan	-----	5	2.8	14.0	5.4	-----
F. M.	3.70	----				3.57
Total * = 258.5						

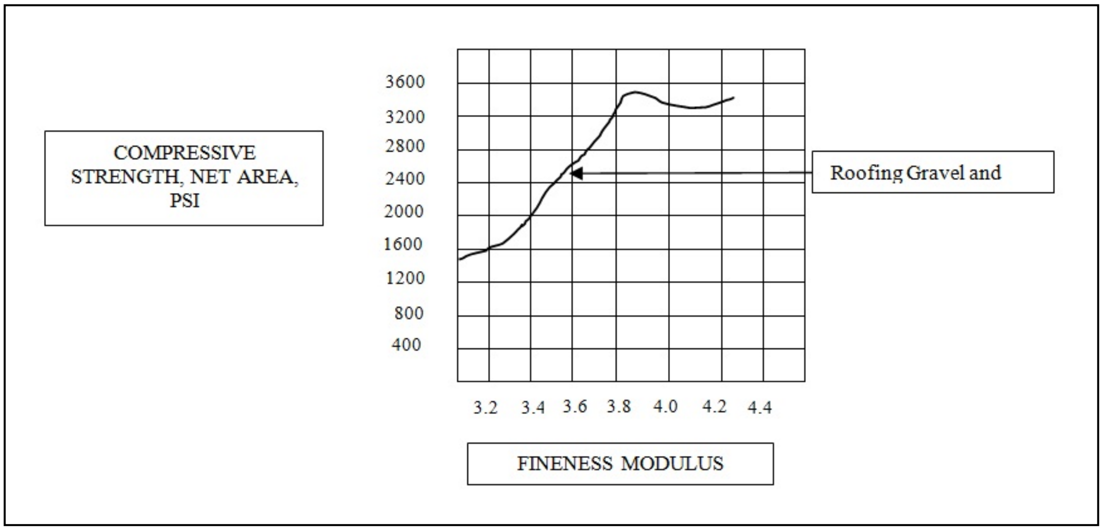
*The weighted average bulk specific gravity of the sample may be obtained by dividing total by 100, (2.59)

Referring to Table A, the individual percentages by volume (Column "A") are calculated by subtracting from the total retained on any size fraction the total retained on the next succeeding larger size. The assumed bulk specific gravities are given in Column "B" by the individual percent retained "A". The conversion to individual percent retained by weight is now made by dividing the individual values shown in Column "C" by the summation of these values (258.5). Last, the percent coarser than, by weight, is obtained as a summation of individual percentages retained. In this manner the gradation shown on a volume basis has been converted to a gradation on a weight basis which on a volume basis has been converted to a gradation on a weight basis which conforms to the differences in the specific gravities of the various size fractions.

It may be noted in Table A that the total sum of the weighted specific gravities when divided by 100 gives the weighted average specific gravity of the combined sample. This value of 2.585 (or 2.59) is the value which might be used in a calculation of mix proportions in which bulk volume proportions were desired.

It may also be noted in Table A that particle sizes having high specific gravities are increased in the conversion to a weight basis while those sizes having low specific gravities are decreased. The specific gravity of 2.8 which was assumed for the No. 50 size particles, in example, made it necessary to increase the amount of this size to 16.2 percent by weight in order to get the desired 15 percent by volume. This relationship is always true when blending aggregates by weight which have dissimilar specific gravities and the extra amount of the higher gravity aggregate which must be used to obtain a desired volumetric gradation depends on the difference between the specific gravities. Had the No.50 size particles' specific gravity been assumed as 3.8 rather than 2.8 it would have been necessary to increase the percentage by weight to 19.7 percent to obtain the desired 15 percent by volume.

Fig. I – Relation of F.M. to Compressive Strength of 3x6in. Concrete Cylinders.



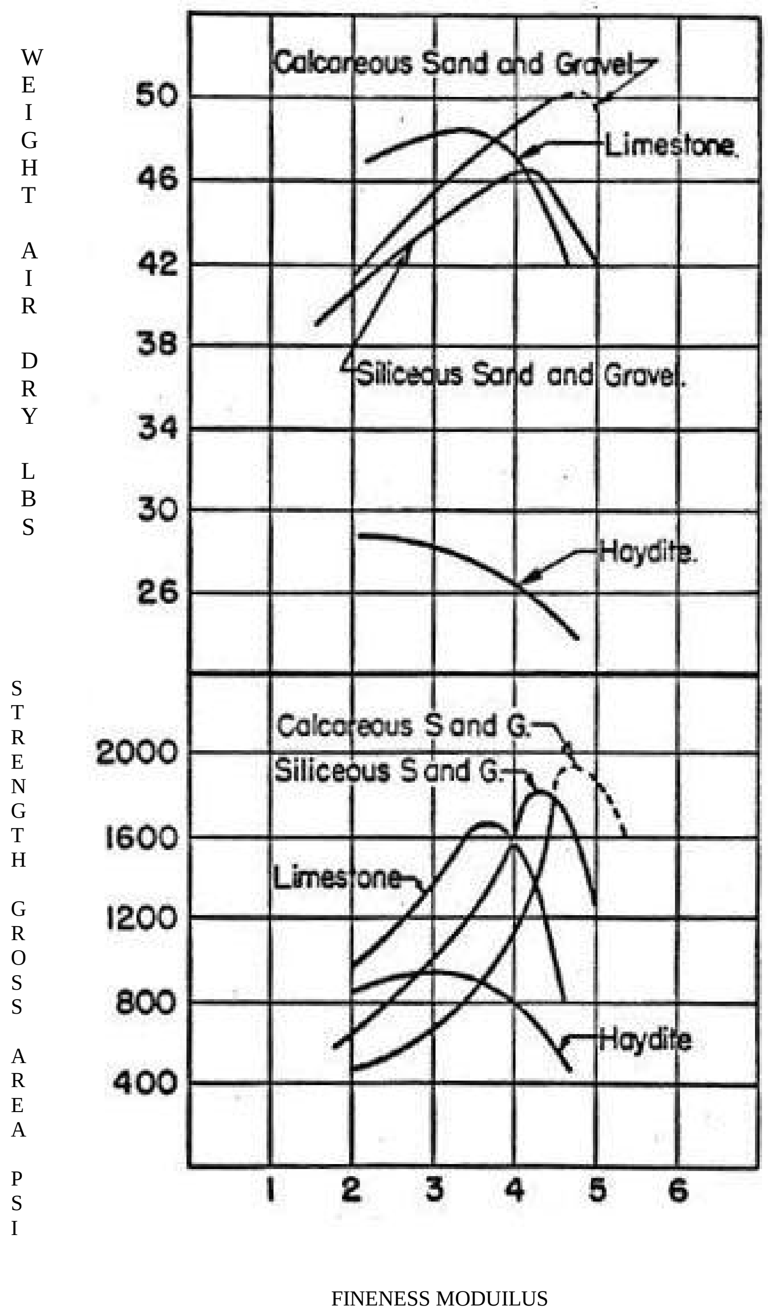


Fig. 2 – Relation of F.M. to Block Weight and Compressive Strength.
From Reference No. 3

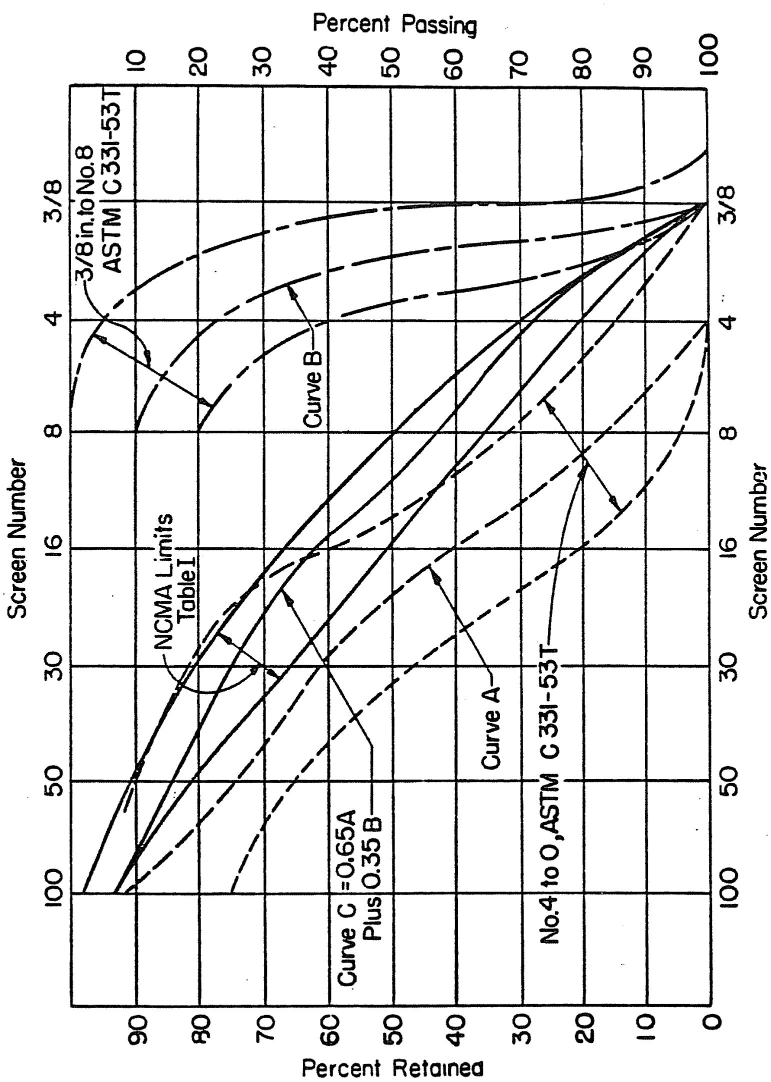


FIGURE 4 – AGGREGATE GRADING CHART