

Heavy Liquid Media for Separating Aggregates With Different Durability Characteristics

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This paper describes the use of heavy liquid separation techniques for separating aggregates on the basis of specific gravity. Correlations of specific gravity with the durability of concrete in which the aggregates are used are pointed out, and the results of some laboratory studies of gravels separated by means of this technique are discussed. A commercial process of heavy media separation, which might be used to improve the quality of gravel aggregates for field construction, is also described.

PREVIOUS INVESTIGATIONS

The occurrence of occasional failures of concrete structures caused by lack of durability of the concrete has led to a large amount of investigation and research to determine the causes of the failures and to establish preventive measures. Many causes and factors contribute to the durability characteristics of concrete; and among these, the aggregate has become recognized as a very important factor in some cases. Although the great majority of aggregates are durable and cause no deterioration of concrete, there are some materials that invariably produce concrete of inferior durability. The durability of the aggregate is of considerable importance in this area, where freezing and thawing of the concrete is a major cause of failure (1, 2, 3, 4).

The intensive research of the past two decades on concrete and aggregate durability has resulted in the recognition and evaluation of the important physical and chemical properties of aggregates which affect the strength and durability of concrete. An excellent discussion of these properties of the aggregates is included in a paper by Rhoades and Mielenz (5) in the 1948 A.S.T.M. Symposium on Mineral Aggregates. The same symposium also con-

tains many other important papers on distribution, production, significance of tests and uses of aggregates.

With respect to physical soundness and quality of an aggregate, the most important of all properties are the porosity characteristics of the material (2, 4, 5). The size, abundance and continuity of the internal pores within the aggregate particles affect the strength and bond characteristics, the rate of chemical attack, the specific gravity, and determine the durability in freezing and thawing. Aggregates that contain a large quantity of small, continuous pores absorb water readily, reaching and attaining a high degree of saturation. When subjected to freezing and thawing in concrete, these materials cause failure of the mortar in tension by means of the pressure resulting from freezing of the water they contain.

RELATIONSHIP OF POROSITY AND SPECIFIC GRAVITY

All aggregate particles are composed of mineral material and pore or void space, which is filled by either air or water. Since the solid material has a much higher weight per unit volume than does the void space, the bulk specific gravity of the aggregate will vary with the percentage of the total volume that is occupied by air or water filled pores. Figure 1 shows the relationship of the bulk

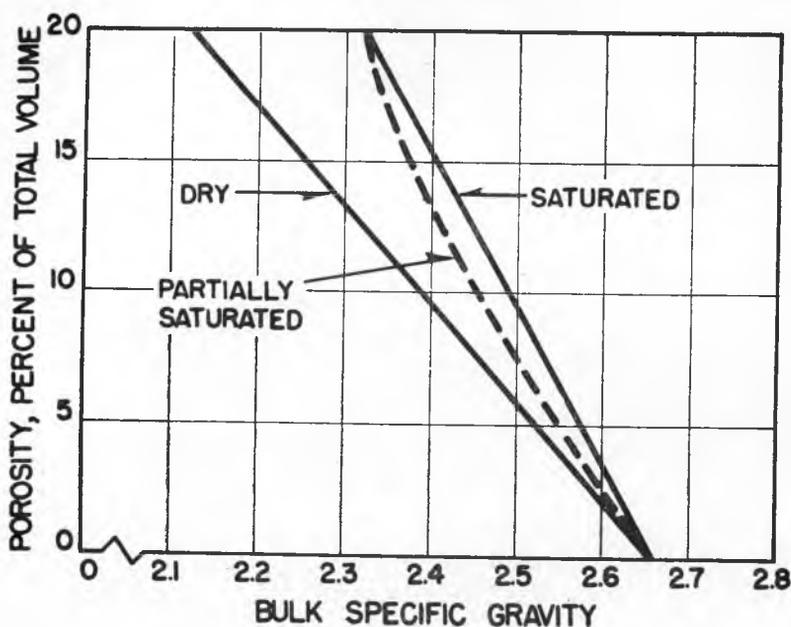


Fig. 1.

specific gravity of chert with the porosity, expressed as a percentage of the total volume of the particles.

Three curves are shown in the figure: one for bulk dry specific gravity, one for the bulk saturated-surface-dry specific gravity and the third for a partially saturated specific gravity. The dry specific gravity curve assumes that none of the pores are filled by water, with the saturated curve based on the assumption that all of the void space is water filled. Even with vacuum saturation, some of the pores will probably still contain air, especially in the materials with the lower percentages of porosity. Tests conducted on a variety of aggregates (2, 3) indicate that the materials with low porosity are frequently only about 50 per cent saturated, with the saturation increasing with higher porosity so that very porous aggregates tend to have a high percentage of the voids filled with water. The curve for partially saturated material in Fig. 3 is based upon the assumption that 50 per cent of the voids are filled with water at five per cent porosity and that the saturation increases to 100 per cent of the pore space filled at a porosity of 20 per cent. This curve more nearly approximates the conditions actually encountered than do the other two.

The variation of bulk specific gravity with porosity is sufficiently great to indicate the possibility of estimating the relative porosity of aggregates from their specific gravity, provided the comparison is limited to materials that are mineralogically similar. The reason for this restriction is apparent if we consider the differences in specific gravity of the solids (mineral material alone) in aggregates. For example, the chert illustrated in Fig. 1 has a specific gravity of 2.66 for a zero porosity condition; the specific gravity of a dolomite under the same conditions would be about 2.87. Thus, a dry bulk specific gravity value of 2.50 would indicate a porosity of six per cent for the chert, but a dolomite having the same bulk specific gravity would contain 13 per cent void space. When used in conjunction with other tests, however, specific gravity is sometimes used as an indication of the suitability of an aggregate (6).

PRESENT USES OF HEAVY LIQUID SEPARATION

The first use of specific gravity as a measure of porosity and, therefore, an indication of probable durability, is reported by Wuerpel (7) and Wuerpel and Rexford (8) in investigations of the durability of chert. Research on Indiana cherts reported by

Sweet and Woods (9) established a correlation of durability in freezing and thawing with the bulk specific gravity. A specific gravity of 2.45 was found to provide an excellent separation between non-durable and durable particles of chert. The present State Highway Commission of Indiana specification requiring that an aggregate contain not more than three per cent chert having a specific gravity less than 2.45 is based upon these investigations.

The heavy liquid separation method used in the studies of cherts was as follows:

1. Carbon tetrachloride (specific gravity 1.58) and acetylene tetrabromide (specific gravity 2.97) were mixed together to give liquids of the desired specific gravities. The specific gravities of the heavy liquids were checked by a hydrometer.

2. The chert was prepared for test by soaking in water for 24 hours to fill the voids and prevent entrance of the heavy liquid into the pores.

3. The specimens were then surface dried and placed in the heavy liquid.

If they sank, their specific gravity was greater than that of the liquid; if they floated, they were lighter. By using a series of heavy liquids of different specific gravities, the specimens can be divided into specific gravity groups or ranges by determining between which two heavy liquids their specific gravity lies.

Another application of heavy liquid separation that has been used for many years, is the separation of known deleterious materials such as shale, coal and lignite from aggregates in laboratory tests. This use is based, not upon variations in specific gravity caused by the porosity of the materials, but upon the fact that some materials known to be deleterious are naturally lighter in unit weight than are the desirable materials in the aggregate. The standard A.A.S.H.O. methods of test for determining the amounts of shale and other light weight materials in aggregates (10) are based upon heavy liquid separation techniques, and use differences in specific gravity to differentiate the materials.

HEAVY LIQUID SEPARATION OF GRAVELS

A preliminary study of the applicability of heavy liquid separation to the study of durability of aggregates in general was carried out in the Joint Highway Research Project laboratories several years ago (11). This study, although not conclusive, indicated that

the technique would be of value in separating the non-durable from the durable materials in gravel aggregates, and showed that the heavy liquids used did not have any significant effect upon either the absorption or specific gravity of the materials.

The tests, such as the pore size and degree of saturation, applied to crushed stones in previous laboratory studies (2, 3, 4) could not be applied to the gravel aggregates because of their complete lack of homogeneity. However, the heavy liquid separation technique offered a chance of separating gravels into durability groups, at least to the extent of removing light cherts, sandstones and shales which were likely to be deleterious in nature. Accordingly, an extensive program of investigation of gravels was started. The results discussed in this paper are from the study carried out by Mr. E. Venters as his thesis subject for the degree of Master of Science in Civil Engineering (12).

TEST PROCEDURES

Four gravel aggregates were tested: two with good field performance records, one with a poor record and one with a very bad record of field performance. A large quantity of aggregate was obtained from each source and separated by sieving into the size fractions No. 4- $\frac{3}{8}$ in., $\frac{3}{8}$ - $\frac{1}{2}$ in., $\frac{1}{2}$ - $\frac{3}{4}$ in., $\frac{3}{4}$ -1 in., and over 1 in. Each size fraction was then tested separately.

The aggregate samples were immersed in water for 24 hours and then surface dried and separated into specific gravity ranges by heavy liquid techniques, using mixtures of carbon tetrachloride and acetylene tetrabromide. The specific gravity ranges used were: less than 2.44, 2.44-2.55, 2.55-2.66, and over 2.66. The gravel fractions, after heavy liquid separation, were washed, dried and the percentage of the total aggregate contained in each specific gravity range determined.

Subsequent testing of each gravel fraction included determination of the absorption and degree of saturation (using vacuum saturation) and separation by rock types.

Freezing and thawing tests of concrete in which the individual specific gravity fractions were used as aggregate were also run. For this purpose, only the gravel aggregate from $\frac{1}{2}$ -1 in. in size was used, because of the difficulty of obtaining sufficient quantities of the small sizes by heavy liquid separation. The sand and smaller sizes of coarse aggregate used in the concrete mixes were materials known to have good durability. The concrete mix design and test

methods were the same as those used in previous laboratory studies (2, 13, 14).

AGGREGATE TEST RESULTS

The results of the tests on the gravel aggregate with the poor field performance record are shown in Figure 2. The data shown are averages for all particle sizes from No. 4 to 1 in.

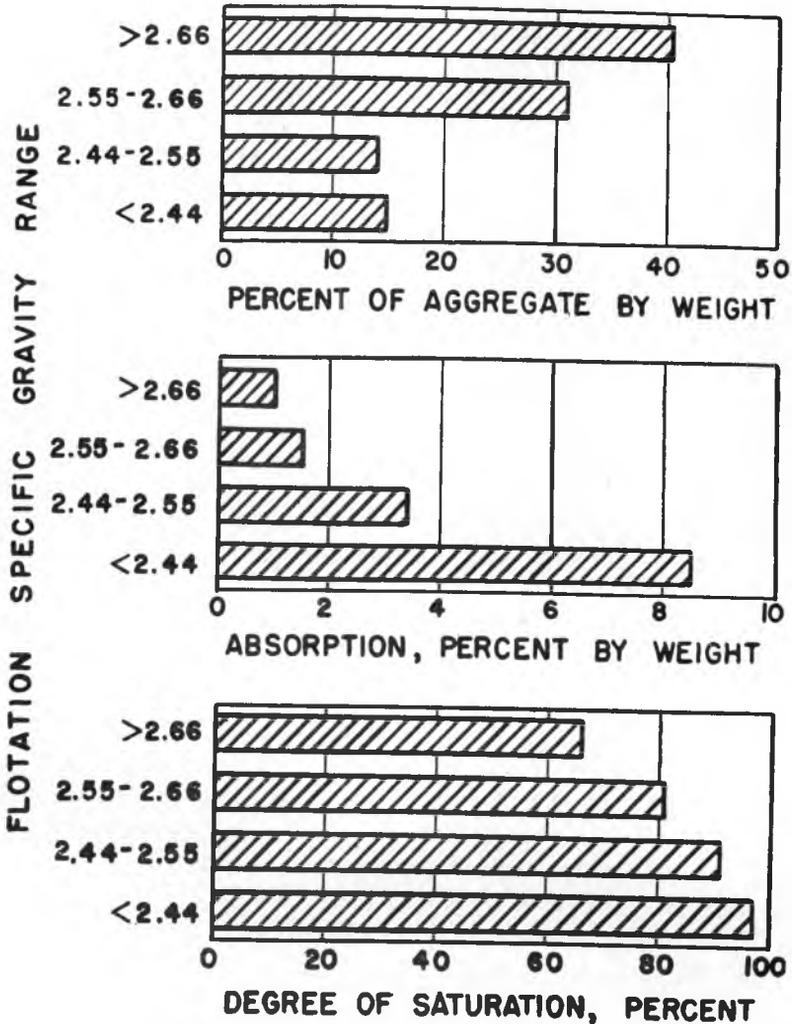


Fig. 2. Specific gravity, absorption and degree of saturation data for a gravel aggregate with a poor field performance record.

The upper graph in the figure shows the percentages of the material that fell in each of the specific gravity ranges. Despite the poor performance record of the aggregate, the majority of the gravel particles were in the two highest specific gravity ranges, with approximately 14 per cent in each of the two lower groups. In contrast, the gravels with good performance records had about 10 per cent in each of these lower ranges, and the corresponding figure for the aggregate with very poor field performance was 23 per cent.

The second graph shows the relationship of absorption under vacuum to the specific gravity of the material. The fraction over 2.66 in specific gravity had an absorption of only 1.0 per cent; and the material between 2.55 and 2.66, 1.5 per cent. The absorptions increased greatly with decreasing specific gravity—to 3.4 per cent for the 2.44-2.55 range and 8.5 per cent for the lowest specific gravity group. This relationship between absorption and specific gravity held true for all gravels tested.

The lower graph on the figure shows the degree of saturation—that is, the percentage of the voids filled with water by vacuum saturation—for each specific gravity range. The results shown for the poor performing gravel are very similar to those for the other aggregates tested. The degree of saturation increases as specific gravity decreases, with the two lowest specific gravity fractions having, respectively, 91 and 97 per cent of the voids filled with water. Previous work (2, 3) has shown that aggregate with a degree of saturation of 90 per cent or more produces poor durability in concrete subjected to freezing and thawing. The results of the freezing and thawing tests in this study substantiate that conclusion.

FREEZING AND THAWING TEST RESULTS

The curves of change in dynamic modulus of elasticity with cycles of freezing and thawing of air-entrained concrete containing the various specific gravity fractions of the poor performing gravel as the coarse aggregate are shown in Figure 3. The specific gravity range used and the air content of the concrete is shown for each curve. The data plotted are average results for three specimens in each case.

It can readily be seen that the durability varied directly with the specific gravity of the aggregate. The material over 2.66 in specific gravity had the best durability as shown by the top curve.

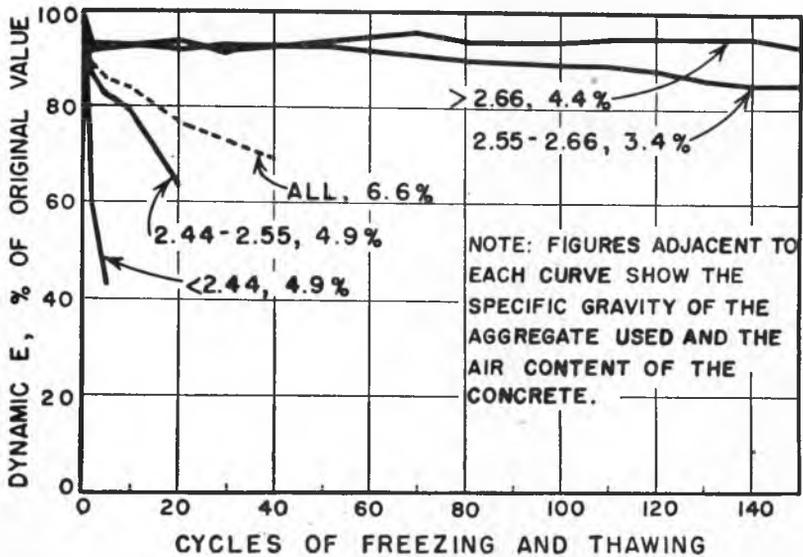


Fig. 3. Durability of concrete made with gravel aggregate divided into different specific gravity fractions.

Next, and only a little below it, is the curve for the specific gravity range 2.55-2.66. Both of these gravel fractions are considered to have good durability. The lowest curve shows very poor durability for the lightest aggregate fraction—failure in less than five cycles of freezing and thawing. Next above it is the 2.44-2.55 fraction, still poor in durability, but higher than the material in the specific gravity range less than 2.44.

The dashed line in the middle is the durability curve for the mixture of all specific gravity ranges, as found in the original sample. It occupies an intermediate position, reflecting the influence of the non-durable low specific gravity particles mixed with the durable heavier material.

The relationship of specific gravity of the aggregate to the durability of the resulting concrete, shown in this figure, was found to exist for all the gravels tested, regardless of source and service record. The relative durabilities of the different gravels, using all specific gravities (material as received), varied with the percentage of low specific gravity material contained in the aggregate.

CONCLUSIONS FROM GRAVEL INVESTIGATION

Based upon the results of the study of gravel durability using heavy liquid separation, the following conclusions were drawn:

- a. The deleterious or non-durable particles in gravels consist principally of cherts, sandstone and shales, with small amounts of badly weathered calcareous and igneous rocks.
- b. The non-durable constituents have low specific gravity, high absorption and high degree of saturation as compared to the durable portions of the aggregate.
- c. The non-durable portions of gravels can be effectively separated from the durable portions by the use of heavy liquid separation techniques.

The successful removal, in the laboratory, of non-durable particles from aggregates by means of heavy liquid separation techniques, leads to consideration of the possibility of using the method as a part of the production process to improve aggregates for field use. The laboratory method, as such, would not be satisfactory for field use because of the high cost of the liquids and the great losses from evaporation and removal in the washwater that would be encountered in the field. Similar methods, however, that have been used for many years in the mining industry for concentration of ores may be adapted to use in aggregate production (15, 16).

DESCRIPTION OF COMMERCIAL PROCESSES

The commercial processes, known as "Heavy-Media Separation Processes,"* utilize a suspension of finely ground solids in water (16). These suspensions act as a heavy liquid in making separations on a bulk specific gravity basis. Practically all plants now in operation use ferrous media of high specific gravity, such as magnetite or ferrosilicon (an alloy of 85 per cent iron with 15 per cent silicon).

The heavy-media separation techniques used with ferrous media ground to suitable fineness are said (16) to have the ability to make sharp separations at any specific gravity from 1.25 to 3.40 with the specific gravity maintained within plus or minus 0.01. The cost of the heavy media is relatively low and losses are kept to a minimum by the use of magnetic recovery methods. Treatment of material ranging in size from over 3-in. down to 10 mesh is feasible in one operation. The separation method is currently in use with a wide variety of materials such as lead, zinc, iron, magnesite, fluorspar, tin, coal, etc.

* The American Cyanamid Company, New York, N. Y., is sole technical and sales representative for these processes on behalf of American Zinc, Lead and Smelting Company, that controls the patents.

it is returned to the cone by means of the pump (E). On the washing screen, practically all of the remaining medium is removed by water sprays and the finished sink and float products are discharged to bins, storage piles or screening processes if subsequent size separation is required.

The medium removed by washing is too dilute and often too contaminated by fines for immediate reuse. It passes through a magnetizing coil (F) into the medium thickener (G). The change in the charge on the particles from the action of the magnetizing coil causes them to flocculate and settle rapidly in the thickener. Overflow water from the thickener may be returned by means of a pump (H) to serve as spray water.

The medium, with any non-magnetic fines it contains, is pumped (J) from the thickener to a magnetic separator (K). The material enters the separator just under a belt which has a magnet assembly mounted just above its lower section. The magnetic medium is picked up by the belt and discharged through the hopper at the other end of the separator. The reject material consists principally of non-magnetic fines and may be discarded or go to a secondary magnetic separator for removal of more of the medium.

The recovered medium goes from the magnetic separator to a densifier (L). Essentially a screw-type classifier, the densifier partially dewateres the medium and acts as a storage reservoir for clean medium. It assists in regulating the specific gravity of the medium in the separatory cone. Overflow from the densifier returns to the thickener. The medium passes through a demagnetizing coil (M) to give the particles a dispersing effect, and is then returned to the medium sump.

USE FOR GRAVEL BENEFICIATION

That the process illustrated above is applicable, at least in some cases, to beneficiation of gravel aggregates is shown by the fact that it was successfully used for this purpose in Canada in 1948 and 1949 (17, 18, 19, 20). The Royal Canadian Air Force engineers used heavy-media separation to remove excessive amounts of shale from concrete aggregate for runway construction at Rivers, Manitoba.

The aggregate available locally for this project contained about two per cent shale in the plus 1-in. size and five per cent in the smaller coarse aggregate sizes. An apparently complete elimination of the shale was readily obtained by use of the heavy-media separa-

tion process with magnetite as the heavy medium and a specific gravity of 2.43. A small plant was used, operating at a rate of about 30 cubic yards per hour. Operation was reported to be simple and relatively trouble-free and the cost was approximately 20 cents per cubic yard—about the equivalent, in Manitoba, of the cost of a two-mile truck haul (17).

Heavy-media separation equipment in use in the mining industry ranges in size from a small unit having a capacity of four to 20 tons per hour (20) to a unit with an hourly capacity of 2,000 tons (19). Operating costs vary with locality, size of plant, etc. Costs reported for ore concentration range from eight cents per ton of crude ore handled in 275-ton per hour units to 60 cents per ton handled in plants processing four tons per hour (20).

SUMMARY

The information and test data presented and discussed above may be very briefly summarized by the following statements:

1. The bulk specific gravity of an aggregate varies with the porosity. Since porosity controls durability in freezing and thawing, the specific gravity can, in some cases, be used as an indication of aggregate quality.
2. Heavy liquid separation is being currently used, in laboratory testing, for this purpose and also to remove known deleterious materials that have low specific gravities from concrete aggregates.
3. The deleterious constituents in the glacial gravels of this area can be removed by heavy liquid separation, thus improving the durability of concrete in which the aggregate is used.
4. Commercial heavy-media separation methods exist that have, in one case, been successfully applied to gravel beneficiation. These methods are worthy of consideration for more extensive use to improve the quality of concrete aggregates for field use.

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