REPORT OF PROJECT COMMITTEE ON CORRELATION OF RESEARCH IN MINERAL AGGREGATES

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EFFECT OF FLAT AND ELONGATED PARTICLES IN MINERAL AGGREGATES

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Specifications are almost unanimous in requiring mineral aggregates to be "free from flat and elongated particles," or, at least, to be free from "injurious amounts of" such pieces A study of the literature of investigations of aggregates for various uses does not reveal the basis for this limitation It probably results from the cumulative effect of opinions formed from a consideration of several different factors Like many other general requirements in specifications it represents an expression of desire for the ideal rather than a consideration of economic limits

The purpose of this report is to cite whatever of definite information is available on the effect of flat and elongated particles and to suggest procedure for investigations to supply sufficient supplementary data to permit the correct evaluation of their effects The limitation of flat and elongated particles is directed particularly to coarse aggregates used for concrete and, therefore, this report is restricted to a discussion of that phase of the problem

Flat and elongated particles are claimed to have deleterious effects on the workability and strength of concrete and, particularly, on the surface and surface finish of concrete subjected to wear Opinions formed from a consideration of these factors, together with a tendency to confuse "flat and elongated" particles with "soft, friable and laminated" pieces, are undoubtedly responsible for the somewhat indefinite limitation commonly included in specifications Only in a few cases have definite maximum percentages been stated and these, so far as can be learned are based on judgment rather than definite information Just as rarely is a definition of what constitutes a flat and elongated particle included In a few cases it is arbitrarily defined as one having its greatest dimension five times, or more, its least dimension

INVESTIGATIONS OF FLAT AND ELONGATED PARTICLES

It is only recently that investigations have been carried out which have for their principle purpose a study of the effect of flat and elongated particles These are the following

1 *Effect of Flat Particles on Concrete Making Properties of Gravel*, by Stanton Walker and C E Proudley, 1929 Proceedings American Society for Testing Materials, Part I and July 1929 issue National Sand and Gravel Bulletin

2 *An Investigation of the Effect of Flat and Elongated Pieces in Crushed Stone Used as an Aggregate in Concrete Pavements*, by A T Goldbeck, May 1930 issue The Crushed Stone Journal

In addition to these reports, a reference to data which may be of value is contained in "Coarse Aggregate in Concrete as a Field for Needed Research" by Herbert J Gilkey, 1927 Proceedings American Concrete Institute

The following discusses available information of a specific nature, with particular reference to its adequacy and to supplementary data which are required

EFFECT ON WORKABILITY

Coarse aggregates consisting wholly, or in a large measure, of flat and elongated particles produce a somewhat less workable concrete for given arbitrary mixtures than if the particles are more nearly spherical or cubical in shape From this effect it was easy to form the opinion that an ideal aggregate should not contain such particles and to incorporate the expression of such a desire in specifications

Definite information on differences in workability between concrete made with coarse aggregate consisting entirely of flat particles and that made with similar aggregate of a conventional shape would be of interest However, so far as the practical problem is concerned, sufficient information probably will be obtained from studies of aggregates containing quantities of flat particles such as are likely to occur in practice

The reports by the National Crushed Stone Association and the National Sand and Gravel Association contain information which has a bearing on this phase of the problem In these investigations the slump test and observations of experienced operators were depended upon as measures of workability The conclusion is stated in the National Crushed Stone Association's report that

"The presence of flat pieces only slightly increases the percentage of voids in the stone and requires no change in water-ratio to produce concrete of the same consistency as obtained with stone having zero per cent of flat particles"

It also states that,

"The presence of up to 10 per cent of flat pieces in the stone has no noticeable effect on the difficulty of finishing 1–2–4 concrete, provided that the same stone with the flat pieces removed produces concrete which may be finished without difficulty."

The same statements may be made with equal accuracy concerning the tests of gravel described in the report of the National Sand and Gravel Association, after making, of course, the necessary editorial modifications to accord with the details of the tests

While it is recognized that entirely adequate methods of measuring workability were not used in these tests and that the range of proportion is not wide, it is believed that they furnish sufficiently conclusive information on the effect on workability for all practical purposes for coarse agregates containing flat particles up to about 10 or 15 per cent This problem should be a part of a general investigation of the effect of shape of particle on the workability of concrete No conclusive results will be obtained from such an investigation until an acceptible solution to the problem of measuring workability of concrete is found

With reference to workability, it is concluded, therefore, that,

1 The problem of the effect of flat and elongated particles on the workability of concrete should be considered as a part of the general problem of the effect of shape of particle on this factor

2 Investigators are not ready to make a thorough study of this problem until an acceptable method for the measurement of workability is developed

3 The investigations reported by the National Crushed Stone Association and the National Sand and Gravel Association indicate that flat and elongated particles, in the quantities likely to be encountered do not have an appreciable effect on the workability, it is believed that these investigations furnish sufficiently conclusive information for practical purposes, pending the results of the investigation of the general problem

These recommendations should not be interpreted as indicating that further information is not required In any investigations of the effect of flat and elongated particles careful attention should be paid to the workability of the concrete

EFFECT ON STRENGTH

The determination of the effect of flat and elongated particles on the strength of concrete was one of the principle objectives of the two investigations discussed above The following are conclusions from them bearing on this question

From report of the National Sand and Gravel Association

"For gravel graded from $\frac{1}{4}$ to $2\frac{3}{4}$ inches 10 per cent of flat particles caused no decreases in compressive or flexural strength in a 1 2 $3\frac{1}{2}$ mix

"For gravel graded $\frac{1}{4}$ to $\frac{3}{4}$ inches 14 per cent of flat particles caused no decrease in compressive or flexural strength in a 1 2 $2\frac{1}{2}$ mix"

From report by the National Crushed Stone Association

"Flat pieces up to 10 per cent in the 1 2 4 mixtures and 15 per cent in the 1 2 $3\frac{1}{2}$ mixtures do not decrease the strength of the concrete"

It should be pointed out that these investigations do not cover percentages of flat particles greater than those mentioned in the conclusions, in other words, they do not provide information as to what would be the effect of percentages of flat particles higher than 10 per cent in one case and 15 per cent in another

Professor Gilkey, in his paper on "Coarse Aggregate in Concrete as a Field for Needed Research," gives an interesting sidelight on this problem, where the coarse aggregate consisted entirely of flat particles He says, "There is no question but that thin or elongated particles of materials, otherwise suitable, are a source of weakness in concrete The particles are well embedded doubtless but bear alternately against the soft mortar bedment and the harder aggregate particles They are thus loaded like beams within the mass and an earlier break down will occur because of flexural failure of aggregates within the concrete mass The genuineness of this condition was illustrated a few years ago Two coarse aggregates were made by breaking up $\frac{1}{4}$-inch and $\frac{1}{8}$-inch scraps of plate glass until they would pass a $1\frac{1}{4}$-inch sieve The concretes from these aggregates failed at lower load than concretes of more compactly shaped aggregates The thinner plate glass carried much less load than the $\frac{1}{4}$-inch

A consideration of the problem and of the investigations quoted brings up the interesting speculation as to whether or not flat and elongated particles affect the strength of concrete, (if they affect it) because of the effect of their shape on the grading or because of the effect of their shape on the strength of particle Probably one, or both, factors enter, depending on the quality of the materials It is readily apparent, of course, that a flat and elongated particle will be more easily fractured by bending or shearing stresses than more compact ones The modified Deval Abrasion tests of the gravel reported by the National Sand and Gravel Association bear this out It is not so apparent what bearing this fact has on the strength of the concrete

The tests referred to by Professor Gilkey represent an unusual condition not likely to be encountered in practice In these tests the relationship between strength of mortar and its bond with the coarse aggregate

and the various characteristics of the coarse aggregate such as strength, modulus of elasticity, surface texture, etc , are considerably different than for conventional materials The tests carried out by the two aggregate associations are in the direction of being contradictory to those reported by Professor Gilkey, although of course, they cover only relatively small percentages of flat and elongated pieces

With reference to the effect of flat and elongated particles on the strength of concrete it may be concluded

1 That, for the quantities of flat particles likely to be encountered in the commercial types of aggregates, the compressive and transverse strength of concrete is not reduced by their presence

2 That, in order to obtain more comprehensive information, a general investigation should include percentages up to 100 per cent of flat and elongated particles Some suggestions for procedure for securing aggregate to make such tests are given further on in this report

EFFECT ON SURFACE FINISHING

Concern is expressed by many over the difficulty caused by flat or elongated pieces of aggregate in concrete when attempting to obtain a smooth finished surface It is claimed that flat pieces have been observed to catch on the finishing belt and to pull out and drag, thereby causing a torn surface hard to finish to a satisfactory smoothness

In the investigation by the National Crushed Stone Association this feature was one of the principal points of study and an effort was made to simulate the conditions of depositing, working and finishing that would obtain in the normal road finishing operation The conclusion which was drawn from this study has already been given above and is to the effect that up to 10 per cent of flat particles in a 1–2–4 mix or 15 per cent in a 1–2–3½ mix (the maximum percentages tried) no additional difficulty in finishing was experienced due to their presence This phase of the problem was not given particular attention in the National Sand and Gravel Association's study However, no greater difficulty in finishing was observed with the flat particles than without them and undoubtedly, the tendency to catch onto the finishing tools would be no greater with gravel than for stone

While the investigations cited above throw considerable light on the question, further studies probably are required to permit of entirely definite conclusions It is recommended that these studies be along the following lines

1. Make additional laboratory tests such as those carried out by the National Crushed Stone Association but covering a wider range of mixtures and percentages of flat particles

2 Make observations of the finishing of a concrete road made with aggregate containing flat and elongated particles to determine, first if

the particles which drag under the strike-board, float or belt are characterized by peculiarities of shape and size and, second, the relation, if any, between the amount of such dragging and the percentage of those particles in the aggregate

It is not believed that this factor is a particularly important phase of the problem. Undoubtedly other characteristics of aggregates have a more important bearing on the ease of surface finishing than do the presence of flat particles in the amounts ordinarily encountered

EFFECT ON QUALITY OF SURFACE

Aside from any effect which the presence of the flat particles may have on the strength of the concrete it is sometimes argued that there is a tendency for the flat and elongated pieces of work to the top and lie parallel to the surface, subsequently to be kicked out by traffic or popped out by weathering Pitting and scaling have been attributed to the presence of thin or flat particles near the surface Whether the usual run of flat particles encountered in coarse aggregates would act in this manner was one of the objects of the investigations undertaken by the two aggregate associations

One of the general conclusions drawn by the National Crushed Stone Association from their study is that,

"The indications are that the flat pieces do not lie in a position such as to cause trouble at the surface of a concrete slab"

This conclusion was the result of observations of the distribution of the coarse aggregate particles through the mass of concrete at the broken sections of the beams

The National Sand and Gravel Association's study of this item was made by finishing slabs containing flat particles and removing the surface mortar to a depth of about $\frac{3}{8}$ inch by means of Con-tex The conclusion from this work was that

"Observations of the surface texture of vigorously finished slabs made with $\frac{1}{4}$ to $2\frac{3}{4}$ inches gravel, containing 0 to 15 per cent of flat particles, indicate that, in a road slab, the flat particles would not have a tendency to float to the surface or arrange themselves in such a way as to be readily broken out by traffic These slabs and field observations indicate that there would not be an undue amount of pitting due to flat particles of a sound and durable nature"

Evidently there are two factors to be considered for this phase of the problem, as follows.

(1) How are the flat particles distributed in the finished concrete?

(2) What effect does the presence of a flat particle, lying in a horizontal position at or near the surface of a road slab, have upon the quality of the wearing surface?

The effect of flat and elongated particles on the quality of the surface is one of the most important factors of the problem The investigations cited above give some information on the position of the particles. Indirectly, they give information on the effect on quality, since they show that an undue proportion of flat particles are not present on the surface However, supplementary information will probably be required before any conclusions will be generally accepted

The distribution of the particles might be studied in several ways Observations of the position of the aggregate in broken sections gives a general indication but leaves much to the imagination Removal of the surface by means of Con-tex satisfactorily uncovers those particles immediately adjacent to the surface but the shape of the underside of some apparently flat particles of considerable size is not readily determined Concrete mixed with a strong retardant, such as sugar, so that the slab may be readily disintegrated by hand after the mass has stiffened, offers a method studying the position of the particles

The effect on surface quality probably can best be determined by abrasion tests and by freezing and thawing tests. An accelerated abrasion test simulating the action of traffic should provide information of value Studies with the Talbot-Jones rattler should furnish information as to the tendency of the flat particles to be broken out by impact. Controlled and accelerated freezing and thawing tests made on specimens, the surfaces of which have flat particles predominating, should furnish conclusive information

It is suggested therefore that laboratory tests be carried out along the following lines

1 Make slabs from concrete for a wide range in proportions and percentages of flat particles in the coarse aggregate The specimens should include slabs for which the surface is made with concrete containing coarse aggregate consisting entirely of flat particles which have been carefully arranged so that their largest surface is parallel to the surface of the slab

2 Finish slabs by several different methods

3 Observe position of flat and elongated particles by one or all of several methods such as the following

(a) Observations of broken sections

(b) Observations of surfaces disintegrated by Con-tex

(c) Observations of position of particles in concrete to which a retardent has been added to prevent setting

4 Make abrasion and impact tests on slab surfaces

5 Make freezing and thawing tests on slab surfaces

AGGREGATES FOR STUDIES OF EFFECTS OF FLAT AND ELONGATED PARTICLES

Probably one of the most difficult features of conducting an investigation of the effect of flat and elongated particles, or the more general study of the effect of shape of particles, is presented by the problem of securing the proper aggregates Natural aggregates do not arrange themselves into convenient classification of shape, and even to obtain an approximately satisfactory separation requires laborious hand picking and the exercise of considerable judgment

It appears, therefore, that laboratory investigations will yield most value and can be carried out most conveniently by the utilization of artificial aggregates It is suggested that they can be made from mortar, terra-cotta, glass or metal It is believed that the use of mortar offers a practical solution to the problem although metal aggregate might be used to advantage in a study of shape without reference to strength of particle

It is suggested also that the use of artificial aggregates will offer a valuable means of carrying out studies of the effect of strength and surface texture of particles

SUMMARY

The discussion in the preceding report is summarized in the following

1 The factors which should be considered in a study of the effect of flat and elongated particles in coarse aggregate on the quality of concrete are

a Workability of concrete
b Strength of concrete
c Finish of concrete
d Quality of surface of concrete

2 The first and the last factors in the above list are of most importance The second and third are of minor importance

3 The data available indicate that flat and elongated particles, in the quantities likely to be encountered in practice (10 to 15 per cent), do not have a deleterious effect on the concrete

4 Further investigations are required before conclusions which will be generally accepted can be drawn

5 Artificially molded aggregates seem to offer a convenient method for the study of the effect of flat and elongated particles