QUALITY REQUIREMENTS FOR CONCRETE AGGREGATES

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The subject of quality requirements for aggregates might have been discussed by me more authoritatively 30 to 40 years ago when I knew all about it. Now, having lived with the problem for 40 years, I am not so sure! One approach to this discussion would be to review authoritative specifications and their limits—to show how various people handle the problem. However, I believe the objective can be attained better by discussing broad general problems of aggregate evaluation—some of the things that are known and need to be known about aggregate behavior in concrete. In the time available this can be done only sketchily. I shall strive to outline the subject in such a manner as to encourage your further study rather than to attempt to inform you in detail at this time.

What kinds of aggregate do we use? Are they not those which we have learned from experience will perform passably? And are not our specification limits written in an attempt to accept “passable” materials and reject others? Further, does not our definition of “passable” depend on a number of influences, principal among which is economic availability? And, what constitutes economic availability?

It would be relatively simple to write a specification describing an aggregate which we would know, beyond any reasonable doubt, to be capable of performing irreproachably in concrete. However, in most areas it would not be possible to find a plentiful supply of such a material economically available. And, even with such a supply, we would be troubled with a substantial quantity of poor concrete, because there are many factors other than aggregates that contribute to concrete quality. It is axiomatic that much excellent concrete is made with less-than-good aggregate and that much less-than-good concrete is made with excellent aggregates.

Concrete Durability

Problems of concrete durability transcend all others. Here aggregate quality plays an important and complex role—and that role cannot be discussed usefully without consideration of the kind of concrete in which the aggregate is to be used and the environment to which the concrete is to be exposed. The three factors (aggregate quality, concrete quality, and concrete environment) cannot be separated. However, it is pertinent to discuss those characteristics of aggregates which contribute to lack of durability of concrete of reasonably good quality, used in properly designed construction and exposed to prevailing weathering conditions. And, of course, “reasonably good” concrete, in this context, means air-entrained concrete. There can be no assurance that concrete made with the best of materials, well proportioned, but without entrained air, will withstand severe weathering successfully.

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What constitutes severe weathering and what are the mechanics by which it causes concrete to disintegrate? Here is material for a series of lectures! Without committing myself to great precision or to discussing all of the many reservations and qualifications, let me endeavor to make clear to you what is admittedly an over-simplified picture.

The outstandingly important destructive weathering agency is freezing and thawing. For the record, we should mention other factors such as: wetting and drying; heating and cooling; aggressive waters and industrial wastes; de-icing solutions; the alkali-aggregate reaction phenomenon; and others. But there is not time to touch on all of these.

I will only suggest a good place to start self-study. It is the ASTM Special Publication No. 169, "Significance of Tests and Properties of Concrete and Concrete Aggregates." The many authors contributing to it are authoritative. It was arranged by a special committee of which Lowell E. Gregg, who had so much to do with your own early researches, was chairman. Not only are the discussions in this publication authoritative, but the list of references cover the important literature available at the time it was prepared.

I shall confine my discussion to the disruptive action of freezing and thawing. For the most part, concrete which will withstand freezing and thawing will do a good job in resisting most other destructive agencies—the alkali-aggregate reaction being a notable exception.

An understanding of the mechanism of frost action is of assistance in suggesting corrective and protective measures. The so-called "Powers Hypothesis" (see STP 169) affords a good basis for gaining that understanding. I present it in a greatly simplified manner and with what I hope will be considered suitable apologies to Mr. Powers and his colleagues.

Concrete is vulnerable to freezing and thawing to a substantial degree only when it is moist—and the amount and distribution of the moisture has a most profound effect on the damage done. Saturated concrete kept saturated, made with the best of aggregates, and frozen and thawed, is very vulnerable however high in quality it may be. Fairly dry concrete, kept fairly dry, is very durable even when fairly low in quality and made with inferior aggregates.

Some of the water in concrete is freezeable at ordinary below-freezing temperatures—and some of it, held in small pores, is not. The "freezeable" water freezes and expands. That causes displacement of unfrozen water, which must migrate to someplace. The distance it must go to find relief from displacement, and the resistance to such migration, determines the hydraulic pressures that are developed. Short distances and little resistance equals innocuous pressures and no disruption! Long distances and high resistances equals high pressures and heavy disruption. And this should make clear why air-entainment is such a boon and it will help to explain certain phases of aggregate behavior discussed later.

**Fine Aggregates**

Fine aggregate is less critical than coarse aggregate in the concrete durability problem. Assuming fine aggregate to be clean and reasonably well graded, the principally important characteristic is the soundness of the rains themselves. And, to what is to me an astonishing degree, air-entainment permits of the successful use of many sands that would be rejected by conventional standards.

Most river sands are relatively free of soft, friable, and non-durable grains, although they frequently have mixed with them impurities such as coal and lignite—and, sometimes, less sophisticated trash! Generally, they give a good account of themselves in conventional soundness tests. Bank sands are most likely to contain soft and friable particles resulting in high losses in soundness tests such as those made with sodium and magnesium sulphate. Impurities such as these very soft and friable particles, and such as coal and lignite, cause local and isolated damage. To contribute significantly to general concrete disintegration they must
be present in very substantial quantities—more than even approximately permissive by any standards.

As I have already pointed out, these particles are afforded good protection by air-entrainment. The reason? The migrating water does not have far to go.

In a recent investigation of aggregates conducted by organizations at the University of Maryland, sand from 36 different sources were tested for resistance to freezing and thawing in an air-entrained concrete all made with the same high quality coarse aggregate (a quartz gravel). None of these concretes had a durability factor as low as 94 percent after 300 cycles of freezing and thawing. Even though many of these sands came from sources of poor gravel, they were fairly good (5 cycles Na₂SO₄ up to 11 percent; 5 cycles MgSO₄ up to 19 percent; absorptions up to 3.7 percent).

In spite of what has just been said, I would not want to remove safeguards on soundness of fine aggregate from specifications. However, it is believed that conventional limits afford adequate protection—which is more than can be said in the case of coarse aggregate.

**Coarse Aggregates**

Now, briefly about coarse aggregates. The statement which follows may sound like an attempt at humor, but it is not. Coarse aggregates differ from fine aggregates principally in that they consist of larger particles! Sounds corny, but consider the hypothesis. These larger particles present greater distances through which the water in them must travel in order to relieve the pressures set up by freezing. And that is an important reason why coarse aggregate is generally more critical than fine aggregate to the durability of concrete.

There is much that can be said about coarse aggregate characteristics as they affect concrete durability. But, if I am to cover approximately the material outlined for myself, in the time available, I must omit that discussion. I refer you again to ASTM Special Publication 169 and, in particular, to the chapter on aggregate soundness by Delmar L. Bloem, my successor as Director of Engineering of the two Associations.

In the aggregate evaluation study referred to earlier in the discussion of fine aggregates, 56 gravels were tested. These were collected from donors requested to send materials with borderline characteristics. They were frozen and thawed in air-entrained concrete with the same high-quality sand being used throughout. Some of the coarse aggregates with very high sulfate losses gave good resistance to freezing and thawing in concrete and some with low losses gave poor resistance. Statistically, there was a trend in the expected direction, but the correlation was poor.

Absorption of coarse aggregate, again, showed a trend; while the correlation was better than for soundness tests, it offered no promise as a reliable specification tool. Los Angeles Abrasion. It gave an inverse relationship and certainly offered no promise of judging the durability of coarse aggregate in concrete—however useful that test may, or may not, be in judging other performance.

I am not saying that these tests are of no use in guiding judgment in evaluating aggregates, but I am saying that they are not good quantitative specification tools.

**Aggregate Evaluation**

What is the answer? It is my firm conviction that service records, coupled with freezing and thawing tests of the aggregates in question, in concrete, offer the most promise—and the only one on the horizon at the present time. But even accepting this, the solution is not cut and dried.

Much could be said about selecting the conditions for the concrete freezing
and thawing tests. There are several of us in this room who will guarantee to devise conditions to disintegrate the best of concrete in a few cycles of freezing and thawing, within conventional limits of temperature, or to permit the worst of concrete to last indefinitely. The question is how heavy a hammer may be used and still be realistic.

The preceding suggests exhaustive studies of each aggregate source and the preparation of tailored specifications for each. I am sorry that this sketchy treatment is necessary—but one lecture, no matter how long, is not enough to cover the subject.

The Chert Gravel Problem

I would be remiss if I did not make special mention of a particular gravel aggregate available in large quantities in Kentucky, Tennessee, Arkansas, Missouri, Illinois, Indiana, Mississippi, Louisiana, Texas, Oklahoma, and to a lesser degree elsewhere. All of you will recognize this material—a gravel consisting essentially of micro-granular silica and almost universally, and I believe somewhat misleadingly, referred to as chert. The variety of these gravels, of other aggregates, and of impurities in aggregates, which consist of essentially microgranular silica, is too great to be covered so loosely by such omnibus terminology.

Chert gravels, so-called, are predominantly hard and strong. They produce concrete of high strengths—both compressive and flexural. The amount of concrete made with them which has behaved well over the years far exceeds that which has behaved poorly. These gravels represent an economic asset too great to permit of failing to take full advantage of them.

This is a problem to which many organizations have devoted a great deal of attention and laboratory research. Principal among these are the Highway Departments of Kentucky, Missouri, Tennessee, and Indiana—and I must also include the Joint Research Laboratory of the two Associations as being among these principal investigators.

Cherts and chert gravels vary greatly in physical characteristics. They range from hard dense flint-like particles to lightweight porous particles. They are of a variety of colors. Chert gravels, resulting from weathering and erosion of chert-bearing limestones, practically always have been distributed by water, and are generally of the hard and relatively durable variety. Some gravels, particularly those of glacial origin, contain white, chalky and non-durable cherts, generally as a minor constituent. Such cherts have undergone little weathering and are the same as those appearing as impurities in many limestones.

The least pressing problem of chert is that of determining permissive limits on obviously unsound chert and of developing means of eliminating excessive quantities of such particles from the finished product. The major problem has to do with chert occurring, not as an impurity, but as the important mineral constituent of the gravel. The problem is to define the conditions under which the wide range of gravels which are predominantly chert may be used.

Concrete disintegration, which has been attributed to chert gravel has occurred for the most part in road slabs. It is clear that the severity of climatic conditions is of considerable importance. Such disintegration as has occurred is predominantly in the northern portion of the chert gravel area. No questions of importance with respect to durability have arisen in the southern portion of that area.

The environment of its use as well as the quality of chert gravel are important factors. Chert gravels from certain sources have given satisfactory service records under any of the environments in which they were used. The most suspect of chert gravels have given some good service records in any of the localities in which they have been used.

Concrete pavements showing the most disintegration attributed to chert gravel also show numerous sections in entirely satisfactory condition. Generally, disintegrated sections are on terrain where opportunities for natural drainage are not good. On the other hand, the good sections of doubtful gravel are generally on terrain where drainage is reasonably good.
The results of a recent investigation of chert gravel conducted by NSCA-NRMCA at the University of Maryland are outlined in a paper by Delmar L. Bloem presented before the recent annual meeting of the Highway Research Board. I recommend this paper for your study. The following is quoted directly from the summary of this yet-to-be-published paper:

"These investigations provided quantitative information verifying a number of concepts concerning the freezing and thawing resistance of concretes made with chert gravel:

(a) The relative performance of the chert gravels in relation to other aggregates is likely to be distorted by laboratory tests made on highly saturated concretes containing highly saturated aggregate. The pore structure of the cherts is such that they are highly vulnerable under these conditions. Since concrete in actual practice will almost never be so highly saturated when exposed to freezing, laboratory treatment should logically include a realistic respite from continuous saturation.

(b) A moderate amount of drying of the concrete before exposure to freezing and thawing greatly enhances the performance of the chert gravels.

(c) Once the concrete has had a reasonable opportunity to dry, its immunity to freezing damage is retained in large measure even after extended resoaking. In these tests, the concrete could tolerate much higher total moisture contents induced by resoaking than were sufficient to cause rapid failure before the concrete had had an opportunity ever to lose the original water.

(d) Reducing the maximum size of the chert gravel improves resistance of the concrete to freezing and thawing.

"Considered in the light of the established service records of many chert gravels, these studies provide encouraging evidence that, for most exposures and with judicious application of normal precautions in removing and excluding water from the concrete, these gravels can be expected to perform well in concrete exposed to freezing and thawing."

Closure

There are numerous other phases of aggregate quality and the influences of different aggregate characteristics on concrete which could be discussed profitably—but time has run out. Some of these are: (a) the advantages of reduced sizes of coarse aggregate; (b) the greater-than-generally-recognized effects of fine aggregate on concrete strengths, both compressive and flexural, and on other properties; (c) aggregate beneficiation; and there are a great many others.

Both producers and users are fully aware of the rapid depletion of mineral aggregate resources. These result not only from production and use but, more importantly, from unavailability due to zoning and land use. Added to this is the fact that still available materials frequently represent lower quality than those already mined and used; and there is the further circumstance that some materials heretofore considered acceptable have been down-graded by more stringent standards. However we look at it, we face a decreasing supply of mineral aggregates and a greatly increased demand for them. We are faced with the necessity of learning how to make successful use of materials sometimes considered substandard.

We hear a great deal about beneficiation. Undoubtedly some part of the answer to our problem lies there. However, we must bring about a better understanding of what the procedures will do. We must disabuse ourselves of the naive idea that almost anything can be accomplished by the magic of beneficiation. Make use of beneficiation, yes. But do not fail to understand its limitations and the great benefits to be derived from construction practices designed to maintain concrete in a less than saturated condition.