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THE APPLICATION OF GEOLOGY IN THE BENEFICATION OF AGGREGATES

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The demand for suitable aggregates for use in construction is ever increasing. In highway construction alone, it has been estimated that 750 million tons are being required annually. Along with the increased need, suitable sources are rapidly being depleted and, in the case of the "urban sprawl," zoned out of existence. To meet these demands, highway engineers are seeking new sources and the better use of existing sources.

Efforts to provide adequate quantities of aggregates have taken many directions. These include materials surveys for locating and identifying new sources, and the upgrading of existing sources. New sources, such as synthetic aggregates, are being considered and, in some instances, used. Improved exploration techniques and recent developments in aerial photography are aiding in material surveys. At the same time, stabilizing additives and better identification of aggregate particles are aiding in upgrading existing sources.

Although beneficiation is a term more frequently applied to the removal of unwanted fractions by such methods as heavy media separation, jigging, rising current classification, and elastic fractionation, it also may be applied to the improvement of aggregates through a better understanding of their characteristics. The latter viewpoint is expressed in this paper.

The selection of an aggregate source and the suitability of the aggregates depend on the task the aggregates must perform. After the tasks have been clearly identified, suitability may be determined by service records, in the case of existing sources, and laboratory tests where new sources are being considered.

The basis for evaluating aggregate suitability where adequate service records do not exist is related to the aggregate properties and in-service tasks. The properties are encompassed in physical and chemical characteristics, and grading. An understanding of these properties and techniques for their evaluation are essential to the selection and the assignment of an aggregate for a particular use. It must be recognized that a "perfect" aggregate to meet demands under all situations does not exist, so it becomes a matter of establishing a desirable performance level and finding an aggregate suitable for that level. To require aggregate properties beyond those needed for a particular performance level is uneconomical.

Although materials engineers frequently refer to aggregate as an inert material in concrete and bituminous mixes, it is becoming recognized that they do have "active" properties and are, in fact, an important constituent of the mixture. In judging the "worth" of an aggregate, empirical means, such as the Los Angeles abrasion and the sodium sulfate soundness tests, are frequently used. Yet these tests fail to represent any in-service condition, and in fact provide little information about aggregate characteristics. For aggregate selection and beneficiation, it istics. For aggregate selection and beneficiation, it is essential to understand their physical and chemical properties.

The role the geologist can play in aggregate selection and beneficiation is readily apparent from a listing of physical and chemical properties such as given in Table I. This becomes obvious when one also recognizes that "all of the mineralogic, physical, and chemical properties of rocks, including those important to the suitability of aggregate, stem from (1) their geologic conditions of orgin and (2) from the later processes of weathering and alteration to which they have been subjected during their geologic history" (*1*). The adoption by the American Society for Testing and Materials of such standards as ASTM C294 on "Descriptive Nomenclature of Constituents of Natural Mineral Aggregates" and C295 on "Petrographic Examination of Aggregates

*The opinions and conclusions expressed or implied are those of the Author. They are not necessarily those of the Highway Research Board, the National Academy of Sciences, the Bureau of Public Roads, the American Association of State Highway Officials, nor of the states participating in the Program.

for Concrete" further serves to point to the geologist's role. In recent years petrographic and geologic know-how has been brought to bear on highway problems and significant contributions have been made to provide a better understanding of aggregate constituents and their influence on degradation, soundness, alkali activity and skid resistance (*2, 3, 4*).

The importance of geology in aggregate beneficiation was recognized at the outset of the National Cooperative Highway Research Program. One of the initial six areas of research was on aggregate beneficiation. This area was allocated $250,000 to contract research on the "benefication of poor aggregate and the manufacturing of suitable aggregate from local materials including the development of new and improved stabilizing agents.

The Program's Advisory Panel divided these funds to support projects deemed most pressing. They include:

Project 4-1, Development of Appropriate Methods for Evaluating the Effectiveness of Stabilizing Agents

Project 4-2, A Study of Degrading Aggregates in Bases and Subbases with Production of Excessive Amounts of and/or Harmful Types of Fines

Project 4-3(1), Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete

Project 4-4, Synthetic Aggregates for Highway Uses

Project 4-5, A Study of the Mechanism Whereby the Strength of Bases and Subbases is Affected by Moisture and Frost

In analyzing these problems from the viewpoint of subject matter, it may be observed that volume change, degradation, frost and moisture, and stabilizing agencies, were considered major areas of need. The importance of geopogy is recognized in at least four of the six studies.

As further support of the thesis that geology does have a role in aggregate beneficiation, a brief description of four of the above NCHRP projects and their status follows:

The investigation of synthetic aggregates, conducted at Battelle Memorial Institute, has been completed (*5*). Its objectives were directed towards exploring the feasibility of utilizing artificial aggregates. The study was, in effect, a state-of-the-art report on the existence or potential existence of synthetic aggregates and their potential uses. Sources of pertinent information found in geologic literature aided materially in the conduct of the study.

Among other things, the selective use of materials on the basis of their contribution to the layered structure of the roadway is suggested as a possible means of obtaining maximum economic utilization of construction aggregates. For example, high-quality aggregates are needed in surface mixtures, whereas materials of lower quality may be used in base and subbase work. At present, economic considerations restrict the use of many potential sources of synthetic materials other than those existing for lightweight aggregates.

The research on degrading aggregates (*6*) continues at Purdue University. It is expected that this study will show not only the mechanism of degradation, but also what aggregate properties to measure to predict degradation. The researchers, after reviewing the history of aggregate degradation and reassessing the problem, concluded that the degradation problem was widespread geographically and that numerous rock types were affected.

In the research, the Los Angeles abrasion test is being used to characterize aggregate degrading. Laboratory tests include differential thermal (DTA) analysis, X-ray diffraction, insoluble residue, and petrographic analysis. The petrographic work has been by examination of hand-picked specimens, polished sections, and thin sections. In the case of thin sections, the following characteristics were observed:

1. Grain size
2. Grain size distribution
3. Grain interlock
4. Void characteristics
5. Weathering

The research is continuing and the final report is due in July 1965.

Two studies just completed relied heavily on petrographic examination for aggregate identification and classification. This sections as well as polished sections were studied. These were the projects at Virginia Polytechnic Institute headed by Dr. Richard Walker (*7*) and the one at Pennsylvania State University under the direction of Dr. Thomas Larson (*8*). Both projects were assigned the same objective of developing a quick method of test to distinguish deleterious particles and predict their behavior under various degrees of exposure in concrete subjected to freezing and thawing.

The research approach by Dr. Walker at VPI utilized a variety of coarse aggregates ranging from traprock and limestone to a variety of gravels. Concretes were made from the whole coarse aggregates as well as from their constituents. The specimens were exposed to alternate cycles of freezing and thawing and at the end of selected cycles were measured for length, weight, and dynamic modulus. A rather detailed petrographic description of each type aggregate and, in some instances, individual particles was reported. Dr. Walker noted that an experienced petrographer was used in the study.

In the Penn State study, Dr. Larson reported that the research included evaluation of pore characteristics, aggregate particle expansion, petrographic examination, and the Powers freeze-thaw test. In summarizing the petrographic studies, it was noted that the analysis explained and predicted the behavior of the test aggregates in freeze-thaw testing, but that petrography alone can not isolate all possible effects of the several potentially deleterious features in most aggregates.

Although only four of the six NCHRP studies assigned by the panel on aggregate beneficiation are herein discussed, the studies at the University of Illinois and Michigan Technological University pertain to aggregate beneficiation, but geology plays only a minor role in the research.

Another area of importance to the highway and materials engineer in which geologists can assist is that of skid resistance. It is apparent that types of aggregates and their mineralogical constituents play a major role in pavement slipperiness. Research has pointed to the influence of geologically different limestones on skid resistance (*9*). Petrographic studies coupled with laboratory and field testing of concrete and bituminous mixtures may eventually lead to selected use of limestone in surface mixtures.

Probably the greatest influence of geologic techniques has been in the studies of alkali-aggregate reaction. The petrographer has isolated such minerals as opal, chalcedony, and different types of rocks and gravels that react with cement alkalies to cause concrete deterioration. Rhoades and Mielenz (*1*) noted that: "The physical and chemical properties of particles critical to the suitability of aggregate arise from their petrographic and mineralogic composition, texture, and internal structure. Therefore, the serviceability of aggregate under anticipated conditions can be predicted accurately only if the petrographic and mineralogic characteristics are known and evaluated."

In summary, the geologist has an important part in the beneficiation of aggregates in highway construction. His greatest contribution can be through providing a better understanding of the physical and chemical properties as they relate to the aggregates desired performance.

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TABLE I
Aggregate Properties

Physical	*Chemical*
Strength	Solubility
Elasticity	Stability
Hardness	Alkali resistance
Toughness	Organic impurities
Volume stability	Combustible and Volatile material
Porosity	Coal and lignite
Permeability	
Absorption	
Density	
Wear resistance	
Soundness	
Thermal	
Soft fragments	
Silt and clay	
Gradation	

FREEZE-THAW CHARACTERISTICS OF AGGREGATES

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INTRODUCTION

Premature deterioration of concrete under freezing and thawing conditions is often attributable to the aggregate fraction. Past research has shown that the freeze-thaw characteristics of aggregate are related, in a general way, to such properties as: (*1*) porosity, (*2*) absorption, and (*3*) bulk specific gravity. Actually it is the pore system—that is, the size, shape, arrangement and continuity of the pores—that governs the freeze-thaw characteristics. Distress in aggregate particles arises from hydrostatic pressure induced when a portion of its absorbed pore-water is frozen. The degree of distress or damage manifested is dependent upon the amount of permeable porosity, the degree of saturation, the severity of freezing, and the rupture strength of the rock particle and the restraint imposed upon it.

Porosity, an index to the pore system, is expressed as the ratio of the void or pore volume to the total volume. Absorption, an index to the pore system, is expressed as a ratio of the weight of absorbed water to the weight of the solid component. Since this ratio is dependent upon the specific gravity of the solid component, it may be quite variable. Bulk specific gravity, another index to the pore system, is also quite variable since it is dependent upon the specific gravity of the solid component. It is evident, of course, that porosity is an independent parameter. If absorption, which is easily determined, were expressed as the ratio of volume of water to the total bulk volume of the rock particle, then this index would also be independent of other parameters.

The exact limits that should be placed on these physical properties to control aggregate quality remains controversial. This is due not only to the variables just mentioned but also to the methods used for determining aggregate durability. Present methods employ composite samples for tests; and, therefore, the results of such tests are composite or average values. For example, the average value of absorption obtained from a composite sample may exhibit a low value—indicating a sound aggregate; however, if each particle were analyzed, it might be found that a portion of the aggregate is so highly absorptive as to be detrimental to concrete. It is the percentage of these deleterious particles in aggregate that is so important.

A second factor in freeze-thaw testing is the antecedent moisture condition of the aggregate—which heretofore has not been duly considered. For instance, a sample of aggregate which is in a highly saturated condition in its natural environment or a stockpile may be oven-dried in preparation for laboratory freeze-thaw testing; many of the standard procedures require that this be done routinely. Even subsequent re-soaking often fails to restore the original moisture condition; and, since aggregate must be critically saturated to be vulnerable to damage, the duration of such freeze-thaw testing may merely reflect the time required for the aggregate to become critically saturated. Ideally, in such testing, consideration should be given to: (1) from a given antecedent moisture condition, the time required for the aggregate to acquire critical saturation in the environment to be imposed and, (2) once critically saturated, whether the aggregate can withstand the stresses accompanying freezing.

Heretofore, the discrete conditions previously mentioned have not been compensated for by methods of test in determining aggregate soundness. Logically, in determining the soundness of an aggregate sample, the freeze-thaw testing should be conducted on a per particle basis. Each particle should be saturated at the onset of test and kept saturated during testing. For study purposes the degree of saturation may be varied. However, maximum saturation definitely establishes the ultimate susceptibility of aggregate to damage from freezing and thawing.

In order to obtain objective data pertaining to the freeze-thaw characteristics of aggregate—that is, to establish more definitive relationships between the effects of freezing and thawing of an aggregate and its physical properties of porosity, absorption and bulk specific gravity—a method of test was devised