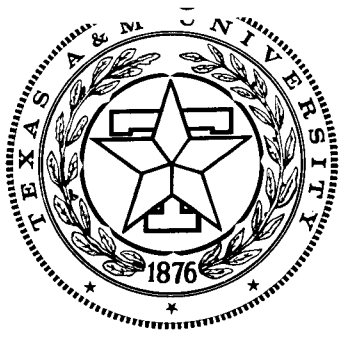

TEXAS TRANSPORTATION INSTITUTE

TEXAS HIGHWAY DEPARTMENT

COOPERATIVE RESEARCH

Characteristics of Lightweight Concrete Supplement

2-8-54-1

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration
Bureau of Public Roads

BIBLIOGRAPHY No. 189
SURVEY OF LIBRARY FACILITIES PROJECT

CHARACTERISTICS OF LIGHTWEIGHT CONCRETE SUPPLEMENT

1. Investigation of Aggregate Durability in Concrete. R. D. Gaynor and R. C. Meininger, National Sand and Gravel Association. Paper to be presented at 46th Annual Meeting, January 1967.

The effects of aggregate on the freezing and thawing durability of concrete and methods of specifying aggregate quality have and continue to be of concern to both aggregate producers and highway engineers. The reported data highlight certain difficulties in the interpretation of conventional empirical soundness, freezing and thawing, and other tests.

Concretes made with 56 different coarse aggregates failed quite rapidly in ASTM C 291 rapid freezing in air and thawing in water when the coarse aggregates were saturated under vacuum and incorporated in concretes which were continuously moist cured prior to exposure. Based on service records and limited outdoor exposure tests, the C291 test is very severe and may be unduly sensitive to the effects of very small percentages of potential popout producing materials in the course aggregate. The small specimens and high rates of freezing employed in the laboratory test contribute to this popout sensitivity.

Resistance to this laboratory test was not correlated with results of usual specification test such as Los Angeles abrasion or soundness. Although deficient in precise quantitative significance, durability decreased with increased absorption of the coarse aggregate, percentage of lightweight particles, percentage of chert, percentage of lightweight chert and percentage of deleterious particles.

Additional tests demonstrate the beneficial effects of drying the aggregate before incorporation into concrete of a short drying period during curing before exposure to laboratory freezing and thawing.

When similarly highly saturated, the concretes made with 36 sands all withstood at least 450 cycles of laboratory freezing and thawing.

2. A Study of Lightweight Aggregate For Structural Use, M. Barrett Clisby and J. G. Wallace. Mississippi State University, Engineering and Industrial Research Station (State College, Miss.). Sept. 1964. 127 pp.

The primary objective of this study was to develop design and economic criteria for the utilization of lightweight concrete in prestressed concrete bridge girders. The secondary objective was to devise a method of determining the modulus of concrete in bending and to compare the results with the modulus obtained from standard axial tests of plain concrete cylinders. This investigation was undertaken to determine the physical characteristics of a particular lightweight aggregate concrete. The lightweight aggregate considered is an expanded clay which is produced by a rotary kiln process in Jackson, Miss. Comparative tests were conducted on hard-rock concrete.

Six 40-ft prestressed beams and over 100 cylinders and prisms were tested to destruction. The lightweight concrete aggregate compared favorably with the hard-rock concrete. It was, however, more easily damaged in handling.

3. The Properties of Chert Aggregates in Relation to Their Deleterious Effect in Concrete, E. L. Michaels, M. E. Volin, and A. P. Ruotsala. Final Report, Project R-121, Michigan Technological University, Inst. of Mineral Research (Houghton, Mich.), July 1965. 122 pp. App.

The ultimate objective of this study was to classify the characteristics of cherts found in Michigan gravel deposits and to determine the individual characteristics of primary importance in causing the deleterious effects of the cherts when used as an aggregate component in concrete.

Measurements and tests consisting of specific gravity, 24-hour and 20-day absorptions, degree of saturation, effective porosity, pore size distribution, permeability, longitudinal pulse velocity, tensile strength, chemical, DTA and X-ray analysis, microscopic examination, and both confined and unconfined freezing and thawing tests of durability were conducted. Tests for indications of alkali-reacivity were made, and the relationship between chert particle size and freeze-thaw durability was tested by freezing and thawing saturated cherts of four separate size classes in mortar cylinders. This latter tests indicated no apparent relationship.

No one property was found to discriminate between deleterious and durable cherts. However, experimental procedures and statistical analyses have established that several properties show promise for such discrimination if used in conjunction with one another.

4. Optimum Steam Curing Procedures for Structural Lightweight Concrete, J. A. Hanson, Journal of the American Concrete Institute (P. O. Box 4754, Redford Station, Detroit, Mich. 49219), Vol. 62, pp 661-672, June 1965. Portland Cement Assoc., Research and Development Laboratories, Bull. D92 (Reprint).

This paper describes the effects of various steam curing procedures on the compressive strength, tensile splitting strength, and modulus of elasticity of structural lightweight concrete. Particular emphasis is given to steaming procedures compatible with the time requirements of modern prestressing plants, and the investigation was patterned after a similar investigation of normal weight concrete. In addition, a halfday curing cycle was studied. The investigation was restricted to a single lightweight aggregate without the inclusion of natural sand.

The optimum conditions for steam curing lightweight concrete were found to be little different from those for normal weight concrete. The allowable variation in presteaming period was somewhat less. The reduction of potential strength development by steam curing was found to be less for lightweight concrete than for the normal weight material.

5. Critical Mechanical Properties of Structural Lightweight Concrete and the Effects of These Properties on the Design of the Pavement Structure. William B. Ledbetter, Ervin S. Perry, James T. Houston and J. Neils Thompson. Res. Rept. No. 55-3F, Center for Highway Research, Univ. of Texas, Austin, Texas, Jan. 1965. 82pp.

Critical mechanical properties of structural lightweight concrete were determined and utilized in the evaluation of a design of concrete pavements. Also presented are the critical mechanical properties resulting from unrestrained volume changes. Particular attention is given to compressive, direct tensile, and indirect tensile (split cylinder) strength at various ages of the concrete.

The critical properties determined indicate that concrete pavements can be designed with lightweight concrete and that expected performance in regard to the effects of warping stresses and pavement deflection will be better when lightweight concretes are used. However, the effects of restrained volume change of lightweight concrete on pavement performance can be detrimental if improper curing, or curing for too short a time, occurs. The need for further research into the effects of curing on lightweight concrete pavement performance is emphasized.

6. Use for Neutron Radiation for Determination of Water Content of Ordinary Concrete and Lightweight Concrete Structures, Simo Rannikko. Nordisk Betong (Drottning Kristinas vag 26, Stockholm 70, Sweden), Vol. 8, No. 3, pp. 379-384. 1964 (In Swedish).

Preliminary tests were performed to determine the water content of lightweight concrete with the aid of neutron damping by the hydrogen nuclei of the water. This method of moisture determination, based on the use of neutron radiation, may be an improvement over conventional procedure, which consists in sampling, weighing, and drying, because it is nondestructive, rapid, and may be done on the site. The radiation method is less accurate but eliminates the uncertainity as how well a sample represents the structure to be examined.

Preliminary experiments indicate that this test, when made by transmissio measurements, give the mean water content of the structure. Incident measurements also gave results expectedly dependent on the distribution of moisture. Consequently, it would seem worthwhile to carry out more extensive basic research on the radiation method. After completion of this research, only a given set of basic calibration data would be necessary for measurements of the water content in actual practice.

7. Investigation of Properties of Lightweight Concrete, Dean C. McKee and H. T. Turner. Louisiana State University (Baton Rouge, La.), Div. of Eng. Res. Bull. No. 74, 1964, 70 pp.

Results are reported of a study of the shrinkage characteristics of structural quality lightweight concrete. Aggregate absorption and volume change characteristics are the principal reasons for the differences in behavior between these lightweight concrete mixes and comparable sand and gravel mixes. The aggregates absorb moisture from the mix to such an extent that slump and water/cement ratio have little meaning unless qualifying conditions are stated. The aggregates change volume with changes in absorbed moisture so that measureable specimens shrinkage is increased up to twice that of comparable sand and gravel specimens. Curing conditions are most important insofar as shrinkage is concerned.

The techniques used for the determination of shrinkage during the first 24 hours after a specimen has been cast and of aggregate volume changes with absorbed moisture appear promising; however, additional studies in these areas are justified.

When initial aggregate moisture is the only variable, the unit weights of the various specimens tend to approach the same value if the same storage conditions are maintained.

Lightweight aggregate concrete specimens may be prepared with compressive strengths comparable to companion sand and gravel specimens with high air contents. The tensile strengths (at 28 days) will not usually compare favorably to those obtained from sand and gravel concrete, probably due to almost 100 percent aggregate fracture on the failure plane for lightweight aggregate and less than 20 percent for gravel.

8. Gas-Producing Agents in the Production of Lightweight Aggregates, S. K. Chopra, Kishan Lal and V. S. Ramachandran. Journal of Applied Chemistry (14 Belgrave Square, London S. W. 1, England), Vol. 14, No. 5, pp. 181-185. May 1964.

The bloating phenomenon in an illitic clay was studied by techniques such as differential thermal analysis, X-ray diffraction, chemical analysis and gas chromatographic analysis. The results indicate that both organic matter and calcium carbonate behave as gas-producing agents. Hydroxyl water, air trapped in the press, and ferric oxide do not significantly contribute to the bloating.

9. Mix Design for High-Quality Concrete Using Crushed Rock Aggregates, Barry P. Hughes. Journal of the British Granite and Whinstone Federation (16 Berkeley St., London W1, England), Vol. 4, No. 1, pp. 33-53, Spring 1964.

The methods of mix design most commonly used at the present time are usually intended for a specific application, such as "high-strength", "normal," "shielding" or "lightweight" concrete, and for a particular aggregate grading, such as continuous or gapped. The present method aims to provide a more unified approach for all fully compacted structural concretes and to make the best use of the available materials without imposing unnecess restrictions on the aggregate grading. It is fundamental to this approach that the aggregate type (shape, specific gravity, inherent strength, etc.) must necessarily affect the design.

10. Replacement of Lightweight Aggregate Fines with Natural Sand in Structural Concrete. J. A. Hanson, Journal of the American Concrete Institute, (P. O. Box 4754, Redford Station., Detroit, Mich. 48219), Vol. 61, No. 7, pp. 779-793. July 1964.

Results are reported of an investigation of the effect of replacing the fines of four particular structural lightweight aggregates with equal volumes of natural sand. Cement contents were varied to obtain compressive strengths between 3,000 and 6,000 psi. A comparison of the reported physical properties for lightweight concrete was provided by tests of normal weight concrete of corresponding compressive strength.

The test results are presented for each of the lightweight aggregates showing the mix and physical properties, as functions of the partial or complete fine aggregate replacement, for concretes at compressive strength levels of 3,000, 4,000, 5,000 and 6,000 psi. In general, the structural properties were improved as the amount of natural sand was increased, but this improvement was achieved only with considerable increase in the unit weight. Decrease of total water and cement contents required for a given slump and compressive strength were greater for the harsher crushed aggregates. All properties measured in this study for a particular strength level, with the exception of unit weight, were found to be linearly related to the amount of fines replaced with sand.

11. Deleterious Properties of Chert, Final Report, New York Dept of Public Works (Albany, N. Y.), Physical Res. Rept. RR64-6, Oxt. 1964. 23 pp. Apps.

This report on the cherts occurring in the Onodaga limestone formation in central and western New York supplements Interim Report RR62-7, "Deleterious Properties of Chert." Included are the results of additional mortar-bar tests for potential alkali reactivity, a limited study of admixtures to control the alkali-aggregate reaction, soundness tests on the cherts and a field survey of air-entrained concrete containing chert in the coarse aggregate.

The results presented in both reports indicate that eight of the nine chert types identified in the Onodaga formation are potentially alkali reactive and can cause excessive expansion in concrete when used with cements having alkali contents above 0.70 percent. However, the field survey produced no evidence of an alkali-aggregate reaction, either because small quantities of chert occurred in the aggregate or alkali contents were probably less than 0.70 percent. Ther other chert, a non-reactive porous type, is physically unsound and capable of causing popouts in concrete. This chert generally occurs in small proportions in the quarried aggregate, so that the likelihood of serious damage to concrete is remote. This is supported by the field survey. Specific recommendations are presented concerning the future use of these aggregates in concrete.

12. Production of Lightweight Aggregate from Washery Refuse, J. W. Myers, J. J. Pfeiffer, and A. A. Orning. U. S. Bureau of Mines (Dept of the Interior,

Washington, D. C.), Rept. of Investigations No. 6449, 1964, 19 pp. Journal of the American Ceramic Society, Ceramic Abstracts, Vol. 47, No.11, p. 308, Nov. 1964.

13. The Effect of the Type of Aggregate on the Diagonal Cracking of Reinforced Concrete Beams, R. Taylor and R. S. Brewer. Magazine of Concrete Research (52 Grosvenor Gardens, London, S. W. 1), Vol. 15, No. 44, pp. 87-92, July 1963.

Comparative tests are reported on reinforced concrete beams without shear reinforcement made with different types of aggregate: two types of light weight aggregate and one gravel aggregate were used. Other variables were the concrete strength and the type of reinforcement.

The principal results of the tests were as follows:

For concretes of similar cube strength, the average diagonal cracking loads of the beams made with lightweight aggregate were lower than those of the beams with gravel aggregate.

The average diagonal cracking loads of beams reinforced with ordinary mild-steel were higher than those of the corresponding beams reinforced with an equivalent area of cold-worked deformed bars.

The diagonal cracking load increased with increasing concrete strength, the rate of increase being similar for all three types of concrete.

14. Antrim, John deCourcy. M.S.C.E., Purdue University, August, 1958. A Study of the Fatigue Properties of Air-Entrained Concrete. Joint Highway Research Project No. 19, July 1958, pp. 1-144.

This investigation was concerned with establishing whether or not there is a definite distinction between the resistance to fatigue of air-entrained plain concrete and non-air-entrained plain concrete. Two mix designs were used, one for the non-air-entrained concrete and one for the air-entrained concrete, each being designed to produce a compressive strength of 4000 psi. Cylindrical specimens, 3 inches in diameter by 6 inches in height, were used. Numerous cylinders were tested in static compression to arrive at an estimate of the ultimate static compressive strength of each type of concrete. Other cylinders were tested in compression at specific stress levels at a speed of 1000 cycles per minute in the Krouse-Purdue Axial-Load Fatigue Testing Machine. A statistically sound analysis was insured by using over 50 specimens for the fatigue testing and over 200 specimens for the static testing.

It was found that within the limits of the investigation, the fatigue behavior of air-entrained plain concrete is similar to that of non-air-entrained plain concrete. The results also show, however, that the air-entrained concrete is more uniform than the non-air-entrained concrete with regard to both fatigue and static strength properties.

15. Schuster, Robert Lee, Ph.D., Purdue University, January, 1961, A Study of Chert and Shale Gravel in Concrete. Joint Highway Research Project No. 15, Sept. 1960, p. 1-193.

Certain chert and shale gravels have long been recognized as harmful when included in portland-cement concrete exposed to freezing and thawing. Many organizations have specifications limiting percentages of these material in concrete aggregates, but few of these specifications distinguish between types of chert and shale from different geographical areas nor do they always take into account the basic physical properties of these materials.

In this study, pore characteristics, mineralogy, texture, and structure were determined for cherts and shales from nine Indiana glacial gravel deposits by means of microscopic petrography, x-ray diffraction, and the common specific gravity and absorption techniques. Blends of tow, four, six and ten percent of chert or shale from each source were made with a standard durable crushed limestone coarse aggregate, and these blends were used in 3- by 4- by 16-inch air-entrained concrete beams subjected to up to 300 cycles of freezing-and-thawing. A measure of the amount of deep-seated deterioration of the beams was provided by durability factors calculated from the results of non-destractive sonic testing of the beams at intervals during freeze-thaw testing. Severity of surface deterioration was also evaluated. The influence of the basic properties of the chert and shale gravels on the results of the freeze-thaw tests was then determined. On the basis of the results of these tests, study was made of the existing specifications on cherts and shales to determine whether the specifications realistically categorize these materials.

Despite significant differences in their mineralogies, no difference was noted in the freeze-thaw durabilities of the various chert samples. For all the cherts, significant deep-seated and surface deterioration occurre only in beams containing six to ten percent of material with a bulk specific gravity (saturated surface-dry basis) of less than 2.45.

Although the basic properties of the shales varied even more widely than those of the cherts, none of the shales caused deep-seated failure of the concrete. However, the most porous shales caused "popout" damage which was especially severe at the six to ten percent level.

16. A Study of Chert and Shale Gravel in Concrete, R. L. Schuster, J. F. McLaughlin, Joint Highway Research Project, pp. 1-59, January 1961.

In spite of considerable past study of cherts and shales, there is still much to be learned about the physical properties of these materials and their effects on the durability of concrete.

In the past little has been done to differentiate between cherts and shales of the same general type, but that are obtained from different geographic areas. A purpose of this study was to determine if the basic

properties of cherts and shales from other parts of the state, and if significant differences in the properties of these materials were found, to attempt to determine if these differences also result in differences in durability.

Another objective was to quantify the effects of different chert and shale gravels on the freeze-thaw durability of concrete tests specimen containing small percentages of these materials.

The cherts and shales used in this investigation were obtained by hand-picking from glacial gravel deposits widely scattered thoughout the state of Indiana. In this way six chert and five shale samples, constituting as widely divergent a group of cherts and shales as could be found in Indiana, were obtained. The geographic locations of the sources for these samples are shown in Figure 1.

17. S. Popovics, A Method of Evaluating Gradings on Concrete Aggregates, Joint Highway Research Project Purdue University, No. 7, pp. 1-110, Feb. 1961.

This study is concerned with the numerical characterization of the grading of concrete aggregates.

The fineness modulus and specific surface area concepts are discussed. It is shown analytically that the fineness modulus is an average - specifically, it is proportional to the average of the logarithimic particle size distribution. It is also shown analytically that the specific surface area is a variance - specifically, it is porportional to the second moment of a particle size distribution function.

Since a distribution is characterized fairly well by its average and its variance, the hypothesis is made that an aggregate grading is adequately defined if its maximum size, fineness modulus, and specific surface area are given. A corollary of this hypothesis is that concrete with the same properties in both the plastic and hardened state will be produced by aggregate gradings that have the same numerical values of maximum size, fineness modulus, and specific surface areas, regardless of the details of the gradings, and if other proportions of the mix are the same.

This proposition was tested. It is shown that certain results from the literature substantiate the hypothesis, particularly for the properties of hardened concrete.

In order to test the hypothesis more adequately a series of concrete mixes was designed to incorporate three gradings - a continuous, a one-gap and a two-gap that have the same values of the three parameters in question. These gradings were incorporated in mixes that were both rich and lean, and wet and dry. The concretes were made and the properties of slump, flow, bleeding capacity, segregation, unit weight, and compressive strength

were determined, using standard procedures whenever possible. The experimental results were analyzed statistically, and the results of this analysis confirm the hypothesis to a reasonable degree of confidence.

A method is then presented for the use of this concept in combining various gradings to obtain desired values of fineness modulus and specific surface.

18. W. E. Gray, J. F. McLaughlin, J. D. Antrim, A Study of the Fatigue Properties of Lightweight Aggregate Concrete, Nov. 1960, No. 20, Joint Highway Research Project Purdue University, pp. 1-23.

Fatigue tests were conducted on two different lightweight aggregate concretes, one proportioned for a high strength and the other for a low strength. Specimens of approximately the same age were tested at stress levels of 40,50,60,70 and 80 percent of the ultimate static compressive strength of the respective mixes. Within the limits of the investigation the fatigue behavior of high-strength lightweight concrete was similar to that of low-strength lightweight concrete. In addition, the fatigue behavior of the lightweight aggregate concrete appears to be similar to that found for a normal weight concrete in a previous study.

19. W. H. Gray, A Study of the Fatigue Properties of Lightweight Aggregate Concrete, Joint Highway Research Project Purdue University, Sept. 1960, No. 14, pp. 1-117.

It was the purpose of this study to determine the fatigue properties of lightweight aggregate concrete and to investigate the effects of varying the mix proportions and strength of the mix on this property. Fatigue tests were performed on concrete having two mix designs; one being designed for a static compressive strength of 3,500 psi and the other designed for a static compressive strength of 6,000 psi. Five batches of concrete were made using each mix design, and from each batch 30 cylindrical specimens 3 inches in diameter and 6 inches in length were cast. About one-half of these specimens were used in this study. Nearly 70 specimens were tested in static compression to arrive at estimates of the static ultimate compressive strengths of the batches of concrete and nearly 50 other were tested in fatigue. Fatigue tests were conducted at various stress levels at speeds of 1,000 and 500 cycles per minute in two different fatigue testing machines. The Krouse-Purdue machine was used to test at a speed of 1,000 cycles per minute and an Amsler machine was used to test at a speed of 500 cycles per min

It was found that within the limits of this investigation the fatigue properties of the lightweight aggregate concrete were not changed by varying the strength of the concrete or aggregate proportions of the concrete. It was als found that the rate of testing used in this testing program had no effect on the fatigue properties of lightweight aggregate concrete. Comparison of data collected in this study with data collected in a previous study indicated that the fatigue properties of lightweight aggregate concrete are not significantly different than the fatigue properties of normal weight concrete.