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D. L. Moe
*South Dakota State University*

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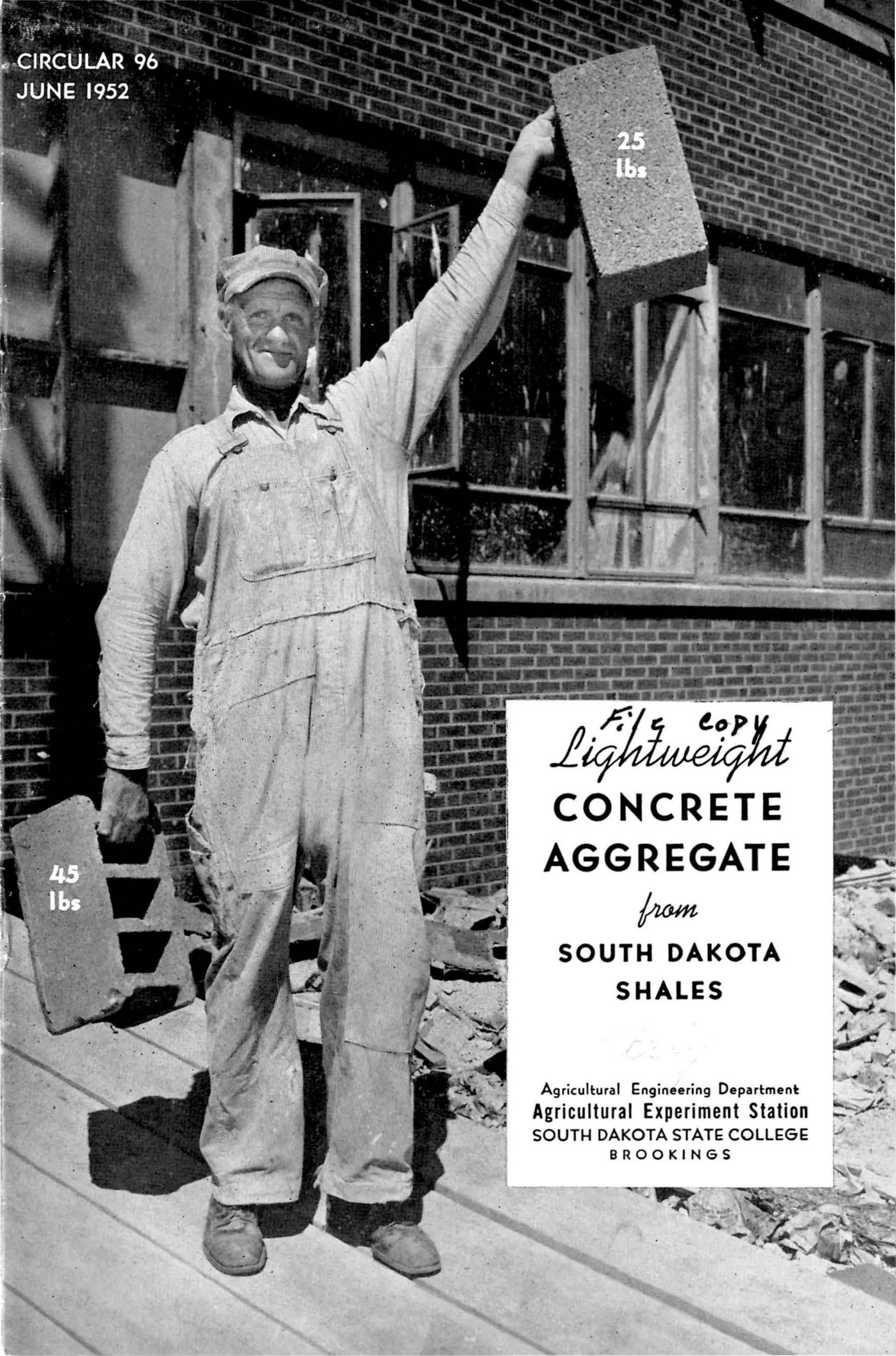


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# Lightweight CONCRETE AGGREGATE *from* SOUTH DAKOTA SHALES

Agricultural Engineering Department
Agricultural Experiment Station
SOUTH DAKOTA STATE COLLEGE
BROOKINGS

# Lightweight Concrete Aggregate From South Dakota Shales

Dennis L. Moe[1]

The development of South Dakota shales for a lightweight concrete aggregate by the Agricultural Engineering Department of the Agricultural Experiment Station was prompted by several factors. First of all, an abundant supply of various shales is in existence west of the Missouri River in the state. The shortage of the finished product is nationwide, and the need for a good aggregate in farm building is pressing. Also, the existing plants in production are somewhat scattered, which increases the transportation charges and the cost to consumer.

At the present time, there is no high quality lightweight aggregate produced in the state. There are a few plants in operation producing a small amount of perlite, froth-like particles of acidic volcanic glass, white to gray in color. A considerable volume of cinders from power plants and furnaces is being used.

The tremendous growth of the building block industry in the last 15 years has been one of the outstanding construction developments in America, as product sales multiplied 80 times in the 10 years prior to 1946. During World War II, increased construction brought about a scarcity and restricted use of highly competitive building materials. However, the tremendous growth of the building block industry has not been due to scarcity of other materials alone, since concrete blocks have been utilized more and more in building construction since the depression days of the early "thirties."

An acute shortage of good lightweight aggregates has existed for approximately eight years. This may be partially attributed to the change-over to various furnace fuels from coal and the increased use of powdered coal, eliminating to a marked degree, "clinkers" and cinders that have been used in large quantities in the past for concrete aggregates. There also has been an increasing market for precast building units. Using lightweight aggregate concrete in large commercial

[1]Assistant Agricultural Engineer, South Dakota Agricultural Experiment Station.

Acknowledgment is made to Dr. Alvin Moxon, former Head, Experiment Station Chemistry Department, for the original survey and for initiating this shale research.

buildings has augmented the enormous demand for suitable aggregates and also contributed to the market shortage.

Private industry and various governmental agencies have undertaken considerable investigation in developing lightweight aggregates from shales, clays, slates, and slag. The Bureau of Mines has published information on the different aspects of the industry from time to time. Also, a cooperative project has been carried out by the Bureau of Mines, Norris, Tennessee, in conjunction with the Tennessee Valley Authority. Geologists and engineers of the Tennessee Valley Authority have investigated raw materials, procured samples, and estimated manufacturing costs of shales in Tennessee.[2]

Since the wide range of geological formations over the state makes it impossible to give reliable recommendations as to the possibilities of the raw shale for a concrete aggregate without a careful and detailed laboratory study of the specific shale in question, this research was undertaken. The purpose of this research was to determine the feasibility of obtaining a finished product from raw shales suitable for concrete and concrete block construction which would have as many desirable characteristics as possible. The results are given in this preliminary report.

## Desirable Properties

Lightweight aggregate products are usually divided into two groups with distinct uses and properties for each group. Group "A" is a high-quality material for which the compressive strength should be over 1000 pounds per square inch. Group "B" is usually a low-cost, low-strength aggregate suitable for use in concrete blocks for which a compressive strength of 1000 pounds per square inch is more than adequate. At the present time there is an unfilled need for both groups of aggregates.

In general, the following qualities should be sought in a good aggregate:

1. Light weight
2. Strength
3. A rounded edge particle
4. Low water absorption
5. Uniform particle-size gradation
6. Chemical inertness
7. Low production cost

Light weight in aggregates is desirable in order to make a concrete that effects a worthwhile saving in weight. It should not be more than one-half the weight of the standard sand and gravel aggregate it replaces.[3] The bulk density of gravel aggregate is approximately 100 pounds per cubic foot; therefore, lightweight aggregates should weigh 50 pounds per cubic foot or less.

Strength is a necessary item, with the individual particles of the aggre-

[2]Conley, J. E., Wilson, H., Klinefelter, T. A. and others. *Production of Lightweight Concrete Aggregates from Clays, Shales, Slates and Other Materials.* Report of Investigations. U.S.D.I. Bureau of Mines. Nov. 1948.

[3]Standard specifications for concrete aggregates. American Society for Testing Materials. Designation: C33-46.

gate being as strong as possible. For a concrete of a given strength, less cement is usually needed for a stronger aggregate than for a weaker one. This results in a cost saving plus a lighter weight concrete. At times in certain specific applications, however, a weak aggregate product could never be brought up to a certain strength regardless of the amount of cement used.

An aggregate should have a spherical surface and no sharp edges. If sharp corners or an oblique configuration is present on the particles, the concrete is usually hard to work into the forms, tends to honeycomb, and makes a harsh concrete.

A low water absorption is a definite advantage in concrete aggregates, as absorbed moisture has a tendency to dehydrate the cement.

An aggregate must have a good range of sizes with a sufficient amount of fines.[4] A good size gradation is a very important factor for good workability of the concrete and for appearance of blocks.

Chemical inertness of an aggregate is also very important, as certain compounds have a tendency to react with the cement thereby affecting its setting.

The initial cost per cubic yard is probably the most important factor in determining the acceptability of a good lightweight aggregate. The extra cost over heavier aggregates must be offset by one of three things, or a combination of all three: (1) less weight to permit elimination of reinforcing steel and lighter form construction, (2) better thermal and acoustical qualities, (3) ease in handling.

[4]Standard method of test for sieve analysis of fine and coarse aggregates. American Society for Testing Materials. Designation: C136-46.

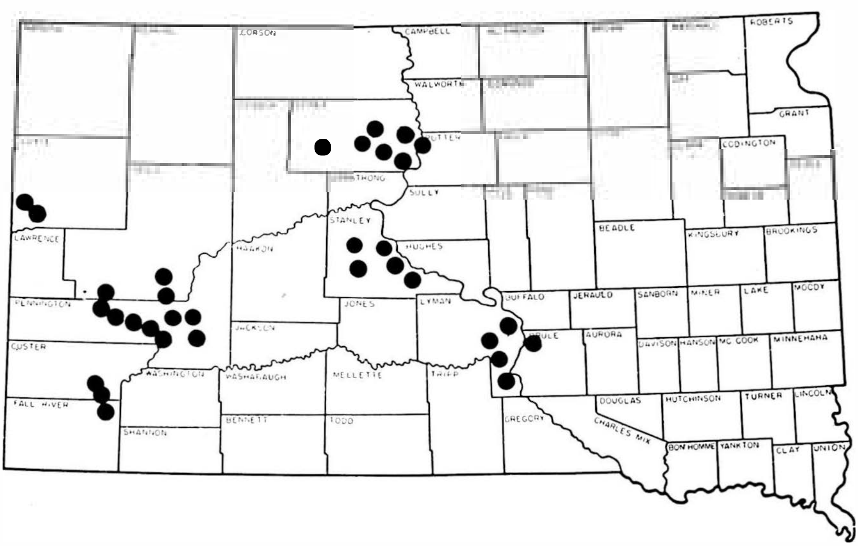
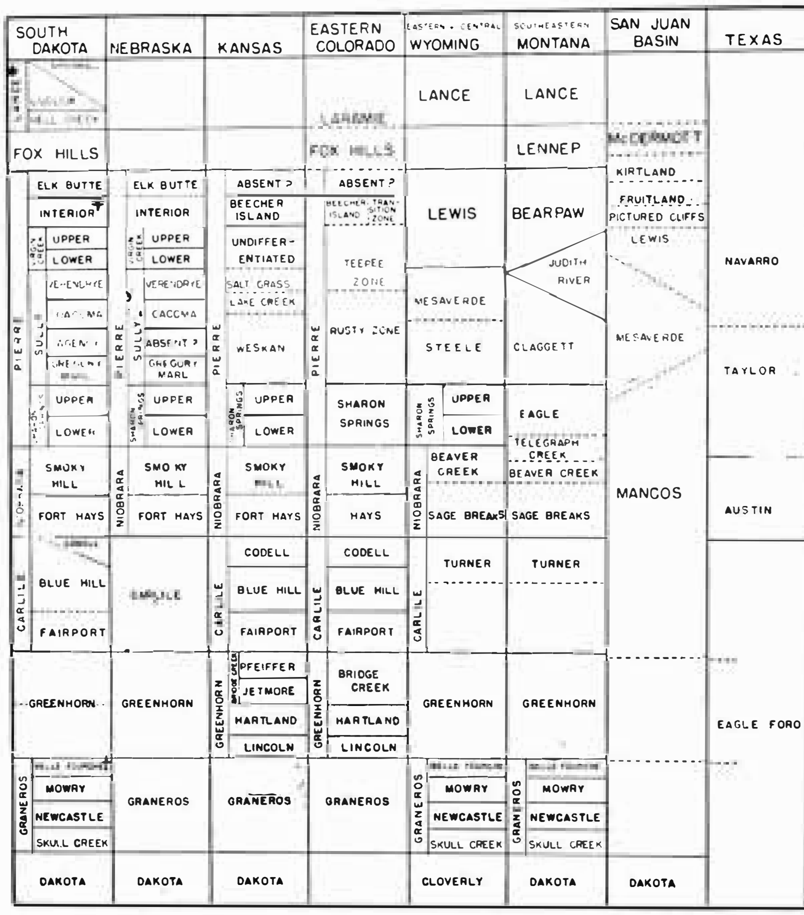



**Fig. 1. Location of shale sampling points in South Dakota**

# Raw Materials

A survey of the possible raw materials suitable for lightweight aggregate production was made west of the Missouri River during the summer of 1950. Nineteen different geological strata were sampled the first year and tested for expanding characteristics. In 1951, 14 additional samples were collected and tested from various locations throughout the western portion of the state. From this total of 33 samples two seemed to have good possibilities and one looked particularly




*Micropaleontological evidence suggests that the upper Lance, including the Cannonball formation and its equivalent, the Ludlow member of the Lance, are early Eocene or Neocene.
†Recent investigations indicate that all of the Belle Fourche shale is Greenhorn rather than Graneros.
‡Mobridge.

**Fig. 2. Correlation Chart showing probable equivalent formations in other states. Note: Virgin Creek is shown in the fifth division down, left hand column under South Dakota**

good. Figure 1 shows the locations of sampling. The shale from the Virgin Creek member of the Pierre formation offered the best possibilities, and it has been with this member that most of the research deals. Figure 2 shows the stratigraphic position of the Virgin Creek shale.

One excellent outcrop of the Virgin Creek shale in South Dakota is located near Creston, and several others equally good near Promise.

"The Pierre formation has been defined as the series of gray shales lying above the Niobrara Chalk and below the Fox Hills Sandstone. It lies at the surface over about 20,000 square miles of the state of South Dakota, and is present under younger deposits in much of the remaining area. Because it is the formation out of which much of the present topography is carved, the thickness is highly variable. It ranges from at least 1700 feet where the sequence is complete, to nothing where it has been entirely removed by erosion."[5]

In many locations of the Virgin Creek member in South Dakota, the shale can be scooped up from the surface of the outcrops without blasting. Mechanical handling breaks the shale into particles of about the size suitable for heating.

## Expansion Process

All of the raw shale samples were tested for expansion in crucibles in an electric furnace at the Station Chemistry laboratory. The crucibles used held approximately one-half cup each, and four could be used at one time. The process prior to heating involved sizing the aggregate by screening. After considerable testing, most of the work involved four sizes: (a) particles passing through a .371 inch mesh screen, (b) particles passing through a .187 inch mesh, (c) particles passing through a .0937 inch mesh, and (d) particles passing through a .0394 inch mesh. After expansion the weights per cubic foot of the finished product corresponding to the above screen sizes were: 39.1, 43.8, 52.0, and 57.9 pounds per cubic foot.

Considerable testing was required for each shale to obtain an expansion or a bloating of the material. In the original work, difficulties were encountered as to the proper temperatures to use and the time element involved at each temperature range. The best heating process found for the Virgin Creek shale was to introduce the material at a temperature not exceeding 400° C. After a preheating period of 20 minutes at 400° C., the temperature can rise fairly rapidly up to 1050° to 1070° C.

In the batch process used in the laboratory, the material reached this temperature range in approximately 40 minutes. The Virgin Creek shale expands in a unique manner. As the temperature approaches 1050° C. the surface becomes pyroplastic (ability to be molded by heat), and after a few minutes the shale particles begin to bloat with

[5]Gries, John Paul, *Economic Possibilities of the Pierre Shale*, University of South Dakota, May 1942.

Fig. 3. Raw and expanded Virgin Creek shale

the interior of the particle becoming cellular or honeycombed. Upon cooling, the surface becomes hard and more or less glazed. The resulting particles are very strong and the surface is about as hard as glass.

This particular shale expanded well without excessive heat requirements, which is a determining factor in commercial production. If the temperature is too high at the beginning, or if heating is too rapid, considerable shattering occurs before the surface is sufficiently plastic to hold the particles in single pieces as they bloat.

Some bloating was obtained at 1020° C., but it was not consistently satisfactory below 1050° C. Bringing the heat up rapidly without a preheating period resulted in about 40 percent of the material expanding to a degree where it was lighter than water, which gave a bulk density of approximately 50 pounds per cubic foot. A stronger product was obtained by preheating; however, expansion was slower and required a slightly higher temperature. Too rapid heating caused an explosive shattering of the particles. Extremely slow heating was also found to be undesirable. When the heating period was well over an hour, the temperature necessary for bloating was over 1100° C., and the material was glossy and fused into hard clusters.

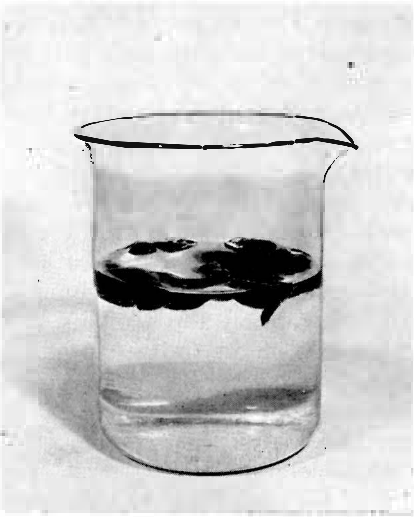


Fig. 4. Expanded shale floating on water

Slight sticking tendencies were noticed, but in a rotary kiln in large production this would be minimized. However, slow heating in a rotary kiln might cause some sticking, especially if the material were held above 1000° C. for more than 15 minutes. Further experimental work in a rotary kiln is necessary to show the proper cycle for a strong product with a minimum of sticking.

At temperatures used in the laboratory the interior of each piece was the original light gray color, and the outer shell was light brown with the surface completely sealed. The majority of the unbroken particles float on water and do not absorb more water than 3 percent by weight. Figure 3 shows the raw Virgin Creek shale and the same material after expansion. The expanded shale floating on water is pictured in Fig. 4.

## Testing

A large number of test cylinders and test cubes have been made from expanded Virgin Creek shale. These have been tested in the laboratory. Figure 5 shows a few of these test cubes. Physical tests on the processed aggregate weighing less than 50 pounds per cubic foot indicate that the aggregates are as good or better than the best lightweight aggregates which have been made from other shales and other expanding materials.

A number of concrete blocks of the 8″x8″x16″ standard size have been made, such as those shown in Fig. 6. Various volume proportioning of cement (such as a 1:2:4 mix)

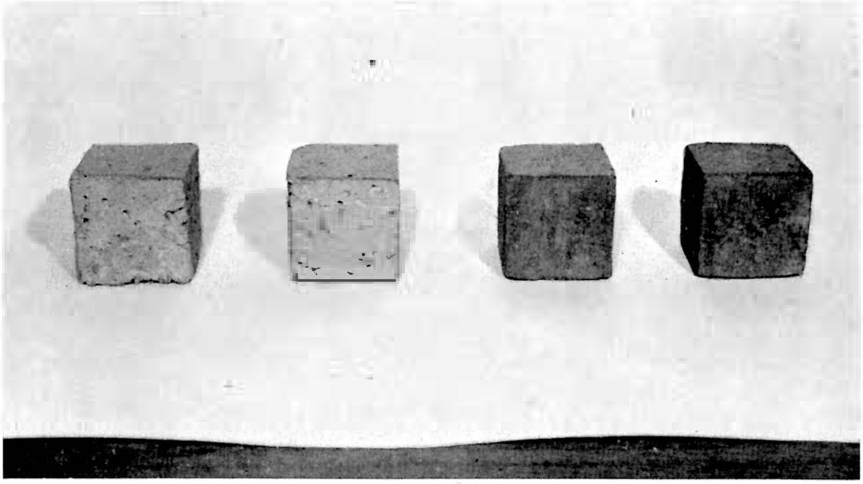


Fig. 5. Laboratory test cubes

to given parts of dry aggregate, including fine and coarse material was used, and compressive strength tests were performed on these blocks. Due to the variation in the rates of water absorption and total absorption of the various-sized grains of the aggregates, the water-cement ratio method was impracticable for designing mixes. The water requirement of the mix was therefore based on a given consistency as measured by the slump cone.[6] A consistency corresponding to a slump of 4 to 5 inches was found to be satisfactory for casting specimens. Some difficulty was experienced in controlling this consistency as the aggregates were used in a dry condition. Admittedly, this method is not entirely satisfactory for lightweight aggregate concrete.

Throughout the tests, "Darex," an air entraining agent, and a high early strength cement were used. Consequently, the majority of the compressive strength tests were taken after seven days with a few at 28 days.

In general, lightweight aggregate mixtures require a higher percentage of fines to coarse aggregate than do sand-gravel aggregates to produce a reasonably workable concrete. There is a limit, however, to the proportioning of fines to coarse for any given cement content, beyond which the strength of the concrete will be adversely affected. Aggregates, which are lighter in weight, usually require more ce-

[6]Standard method of slump test for consistency of Portland Cement-Concrete. American Society for Testing Materials. Designation: C143-39.

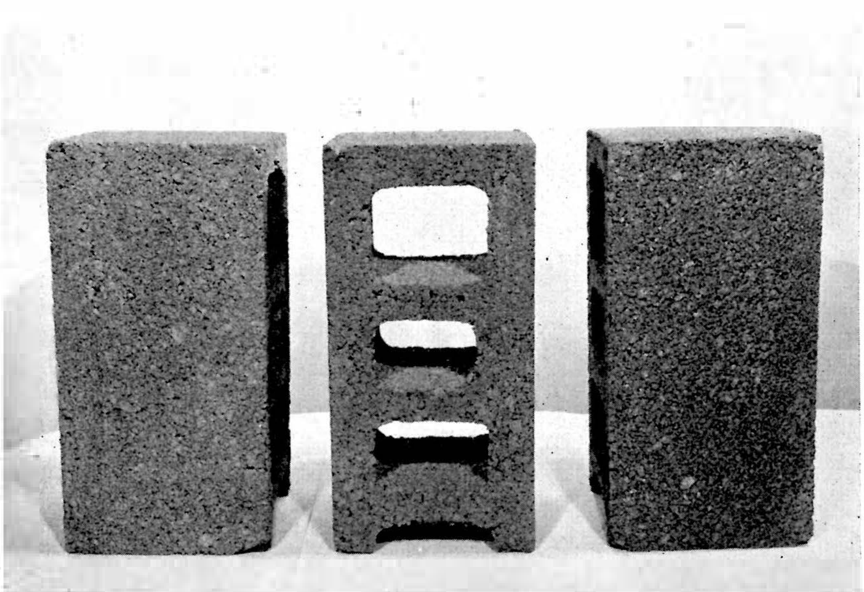


**Fig. 6. Standard size concrete blocks of expanded Virgin Creek shale**

ment to develop comparable strengths to heavier aggregates.

In seven - day compressive strength tests, concrete blocks weighing from 22 to 26 pounds tested 1265 pounds to 1805 pounds per square inch when mixed with a proportion of one part cement to six parts aggregate, including both fines and coarse.

Figures for the shrinkage tests on specimens at the end of 100 days were considerably larger than those for sand and gravel aggregates but were less than published figures for the majority of lightweight aggregates.

Indications are that thermal conductivity values which represent heat loss in British Thermal Units per hour per square foot of area per degree Fahrenheit temperature difference per inch of thickness will be comparable to other expanded aggregates made from shales.

To date, no tests have been made on resistance to freezing and thawing.

## Commercial Development

At the present time, a number of manufacturers and individuals have shown considerable interest in the commercial development of South Dakota shales for a lightweight concrete aggregate. Numerous advantages have already been listed for such undertakings, such as the existing shortage of good materials, the availability in practically unlimited quantities of the raw product within the state at convenient locations, and the increasing demand for lightweight concrete blocks. However, it may be pointed out that many important factors have to be kept in mind if the construction and successful operation of an aggregate plant is considered. The following are a number of suggested essentials not necessarily stated in the order of importance:

1. Capital of approximately $350,000 to build and equip a plant for profitable production.

2. A shale deposit of 4 million to 5 million cubic yards in one location.

3. Railroad facilities at the plant site.

4. An annual market for at least 80,000 cubic yards of the aggregate. An annual market for approximately 200,000 cubic yards within a radius of 300 miles from the plant is preferable.

5. A natural gas supply within not more than 19 miles from the plant, assuring a supply of approximately 40 million cubic feet per month.

6. Ample electrical power at reasonable rates.

7. An overburden (soil and rock) overlying the shale not to exceed 15 feet.

8. Adequate highway facilities to and from the plant site.

9. Adequate labor supply.

10. Year around water supply at the plant site.

Several plant sites in South Dakota should meet most of these essentials with some qualifications. For example: lignite coal could possibly be substituted for natural gas.

# Summary

The results of the study, to date, may be summarized as follows:

1. An abundant supply of the raw material is present at favorable locations in western South Dakota.

2. The test results show that a lightweight concrete aggregate of adequate structural strength, quality, and uniformity may be produced from South Dakota shales.

3. Concrete blocks of adequate strength weighing approximately one-half the weight of sand-gravel concrete blocks were made.

4. These blocks had volume proportions of cement to dry aggregate mixtures comparable to other expanded aggregates made from shale.

5. The sizing of shale before expansion, resulting in a sealed particle, gives definite advantages in lessening the total moisture absorption.

6. The Virgin Creek shale does not require excessive temperatures for expansion.

7. The process of expansion may be performed successfully in a rotary kiln without excessive fusing or clinkering, thus eliminating crushing of the finished product.

8. Shrinkage tests compare favorably with other expanded aggregates processed from shales.