Mines Branch Information Circular IC 137

DEVELOPMENT OF THE CANADIAN LIGHTWEIGHT AGGREGATE INDUSTRY*

by

H. S. Wilson**

SYNOPSIS

The lightweight aggregates used in Canada are: expanded clay, shale, slag, and perlite; exfoliated vermiculite; and pumice. The history of their production is traced, and the raw materials and the methods of processing are described. Production data and the uses of the various materials are briefly reviewed. Other uses to which these materials might be put are discussed.

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Direction des mines

Circulaire d'information IC 137

L'EXPANSION PRISE PAR L'INDUSTRIE CANADIENNE DES AGRÉGATS LÉGERS*

par

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RÉSUMÉ

Comme agrégats légers, le Canada utilise l'argile, le schiste argileux, le laîtier et la perlite expansés; la vermiculite exfoliée; et la pierre ponce. L'auteur donne un historique de leur production. Il décrit les matières premières et les méthodes de traitement employées. Il passe en revue des données sur la production et les usages des différents produits. Il traite aussi d'autres usages auxquels on pourrait appliquer ces derniers.

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INTRODUCTION

The lightweight aggregates produced in Canada are expanded clay, shale, slag, perlite, exfoliated vermiculite and pumice. Each of these materials is used as aggregate in lightweight concrete. Depending on the choice of aggregate and design of mix, concrete can be of a structural or insulating type, or can be formed into blocks or bricks.

The term "lightweight aggregate" is somewhat misleading because these materials have other uses which are determined by certain physical properties. They can be used in refractory concrete, plaster, stucco, acoustic tile, and underground pipe insulation. In addition, they may be used as loose insulation, roofing gravel, soil and fertilizer conditioners, and as filtration beds. Lightweight aggregates are used chiefly in the construction industry. They are relatively new compared to many other construction materials, but their use is now well established and markets are increasing. In 1961, production was valued at $6,000,000 compared with $3,200,000 in 1954, which is an increase of 87 per cent over the 8-year period. This expansion should continue as uses for lightweight aggregate become more diversified, and lightweight products become more widely accepted by industry.

Increasing costs of building materials and labour used in construction have resulted in a continuing rise in construction costs. The adoption of lightweight construction materials is a partial answer to this problem. Their use can result in lower cost for other structural components such as steel framework and foundations. One outstanding example of this is the 21-storey Grady Memorial Hospital built in Atlanta, Georgia. About 20,000 cubic yards of lightweight concrete was used in its construction. Compared with the use of conventional concrete, the reported reduction of dead load amounted to 17,500 tons. In large structures savings such as this more than offset the higher cost of the lightweight aggregate.

Lightweight aggregate products are often preferred because the ease of handling has proved an important factor, and their thermal insulation and acoustical properties are superior to those of products made with conventional aggregate.

EXPANDED CLAY AND SHALE

Historical Development

Lightweight building materials have been used in Europe for many centuries. Pumice, in the form of blocks, was used in structures erected during the time of the Roman Empire. It is only 80 years since lightweight materials were first used on this continent, and in Canada the period is even shorter.

Cinders have been utilized in Canada for about 50 years as concrete aggregate, but the increasing use of oil and natural gas in industrial installations has resulted in an inadequate supply of cinders.

In 1927, the first manufactured lightweight aggregate in Canada was produced. It was an expanded shale aggregate produced at Cooksville, Ont., in a rotary kiln. The process was developed in the United States, and patented in 1917 by Mr. Stephen Hayde. A second plant was erected in 1952 in Edmonton, Alta. Since then, expansion of this branch of the industry has been fairly rapid, particularly in the western provinces. At the end of 1961 there were 11 plants in production in Canada. They are located at Saturna Island, B.C.; Edmonton (2), Calgary, Alta., (2); Regina, Sask. (2); Winnipeg, Man. (2); Cooksville, Ont.; and St. Francois du Lac, Que. Production in 1961 amounted to about 395,700 cubic yards.

Raw Material

To produce a suitable lightweight aggregate from clay or shale by expansion in a rotary kiln, the raw material must possess certain qualities. It must contain a combination of fluxes that will develop a viscous glass when heated to the point of incipient fusion. Also, it must contain a mineral or minerals that will dissociate when the material is in the viscous state and release a gas or gases. If these conditions exist, the gases will be entrapped within the glass formed, and the particles of clay or shale will expand or bloat. The raw material should also have a fairly wide vitrification range in order that temperature fluctuations within the kiln will not have too marked an effect on the product. It is difficult to maintain the temperature within limits of less than about 50 degrees. One of the troublesome components of clays and shales, particularly those found in Ontario and Quebec, is lime in the form of calcite. A small quantity is desirable, for it acts as both a flux and a gas-producing agent. In larger quantities, however, the fluxing action is excessive, and a small increase in temperature above that at which vitrification has begun will result in extensive fusion. This is caused by the formation of glass of low viscosity.

Many theories have been offered as to why one material will bloat whereas another will not. Chemical analysis is of little value in resolving this problem, as it does not show in what combination the components are present. Riley[1] based his theory of the causes of bloating on laboratory determinations. He showed how certain minerals act both as fluxes and as gas-forming compounds by adding them to a synthetic non-bloating material. He found that when hematite, calcite, pyrite and magnesite were added individually, poor bloating resulted. All of these minerals dissociate and release a gas. When a mixture of hematite, calcite and pyrite was added, good bloating resulted. It was thus evident that a combination of fluxes was sometimes more beneficial than a single flux.

Everhart, Ehlers, Johnson and Richardson[2] bloated a large number of clays from Ohio. They collected the bloating gases by crushing the bloated pellets in a vacuum. Chemical analyses of these gases indicated that over 80 per cent of the clays produced only carbon dioxide. The balance of the clays produced both carbon dioxide and sulphur dioxide, but never sulphur dioxide alone. By mineralogical analysis, it was found that calcite was the predominant source of carbon dioxide. Dolomite and ankerite were less common sources. In a few cases carbon dioxide came from coal. Pyrite and occasionally marcasite were the sources of the sulphur dioxide. The investigation indicated that the carbonates and, to a lesser degree, the sulphides in these clays were the gas-forming minerals.

Processing

The Rotary Kiln Process

All Canadian plants producing lightweight aggregate from clay or shale use the rotary kiln process. The kilns vary in length from 50 to 160 feet, and in diameter from 6 to 10 feet. Production varies from 5 to 15 cubic yards per hour, depending on the kiln. Some of the more efficient plants use a rotary cooler to cool the aggregate and, at the same time, to preheat air for combustion. One plant makes use of a rotary dryer to preheat the raw material. The more efficent plants consume about 2 million Btu of heat per cubic yard of aggregate produced. Selling price of the aggregate varies between $5.00 and $7.40 per cubic yard.

The Sintering Process

Sintering is another process for producing lightweight aggregate from clay or shale; it is not used in Canada, but is used extensively in the United States. This process has been adapted from the metallic-ore-processing industry, in which it is used to agglomerate finely-sized ore, or to drive off undesirable volatile components of the ore. In the lightweight aggregate industry, a much wider range of raw materials can be processed by sintering than by the rotary kiln process, because the raw material does not have to bloat. In fact, it is probably more desirable if it does not bloat appreciably. The raw material, usually crushed to about minus 3/8 inch, is mixed with 5 to 10 per cent minus 3/16 inch low-volatile fuel, such as coke or anthracite coal, and pelletized. This agglomerates the finely-sized material. The pelletized mixture is placed as a porous bed on a sintering machine, the most common of which is the travelling-grate type. The bed of material passes first under an ignition hood, where the fuel at the surface is ignited. Following this, it progresses over a series of wind boxes which draw a large quantity of air down through the bed. This gradually moves the zone of ignition down until the material has sintered to a porous clinker. The clinker, when cooled, is crushed to aggregate size. This aggregate is harsh and is more suited for use in concrete blocks than in structural concrete. The rotary kiln product is generally less harsh than the sintered product, and finds use in both concrete block and structural concrete.

EXFOLIATED VERMICULITE

Historical Development

The production of exfoliated vermiculite began in Canada in 1938. Except for a period during 1957, all the raw material used by this branch of the industry has been imported. About 85 per cent comes from Montana, U.S.A., and the balance comes from the Transvaal, Union of South Africa. The Canadian deposit worked in 1957 was located near Perth, Ontario. There is now considerable interest in developing Canadian deposits. At present, four companies in Canada are operating ten exfoliating plants located in Vancouver and New Westminster, B.C., Calgary, Alta., Regina, Sask., Winnipeg, Man., Toronto (2) and St. Thomas, Ont., and Montreal, Que. (2). In 1961, the production of exfoliated vermiculite was about 316,000 cubic yards. It sold at 25 to 30 cents per cubic foot.

Raw Material

The vermiculites are a group of micaceous minerals. They differ from the true micas in that magnesium or calcium replaces potassium within the lattice, and water molecules are present between the lattice layers[3]. On heating, the steam formed from the water causes mechanical separation and buckling of the plates. This exfoliation, which is perpendicular to the basal cleavage, results in a product having a volume as much as 22 times the original.

There are two theories on the origin of vermiculite. The most widely accepted theory is that it is the result of hydrothermal alteration of micas, such as biotite and phlogopite. Myers[4] believes that the deposit of vermiculite near Libby,Montana is a product of direct alteration of pyroxenite, and that the associated biotite was formed from the same rock.

Exfoliating plants receive the raw vermiculite in a sized, concentrated form. Various methods are employed to produce this material. These include crushing, screening, winnowing, wet classifying, and wet tabling. Concentrates obtained from wet processing must be dried.

Exfoliating Process

All the Canadian plants use vertical furnaces for exfoliating vermiculite. Most furnaces are from 2 to 4 1/2 feet square and between 8 and 35 feet high. One plant uses a furnace of circular cross-section. The raw vermiculite is fed into the top of the furnace, falls past baffles, which spread the material, and into the hot zone located near the bottom of the furnace. Exfoliation takes place in a few seconds. The exfoliated vermiculite is recovered at the bottom or the top of the furnace, depending on whether the burners are horizontal or vertical. The maximum temperature is 1800 to 2000° F. The unit weight of exfoliated vermiculite varies from 4 to 12 pounds per cubic foot, depending on the size.

EXPANDED PERLITE

Historical Development

Expanded perlite was first produced in Canada shortly after World War II. All the raw material used is imported from the western United States. Deposits of perlite are found in central British Columbia near Francois Lake, and in southern British Columbia near Clinton, but at present are not considered economic.

At present eight plants are producing this lightweight aggregate in Canada. They are located at New Westminster, B.C., Calgary, Alta., Winnipeg, Man., Caledonia and Hagersville, Ont., and Montreal, Beauport, and Charlesbourg, Que. In 1961, 92,000 cubic yards of expanded perlite was produced. It sold at 25 to 35 cents per cubic foot.

Raw Material

There are two theories of the origin of perlite, which is a hydrous glassy rock. One theory is that perlite was formed by slow-cooling under pressure of a near-surface intrusion of magma. The second, and more probable, theory is that perlite is of secondary origin, the result of hydrothermal alteration of pumice and rhyolite. Very little if any beneficiation of the raw perlite is required, but the crushing and screening must be controlled to produce a product of the proper size. Perlite in its natural state ranges in colour from greyish-green to nearly black, but when heated rapidly to 1700 to 2000 $^{\circ}$F a white cellular product results.

Expanding Process

Four Canadian producers use rotary kilns to expand perlite, and four producers utilize vertical kilns. The most common rotary kiln is the Murdock-Stein type. It is of stainless steel construction, either double- or triple-pass, 3 to 4 feet in diameter, and 12 to 20 feet in length. This multi-pass kiln preheats the material before it falls into the flame. The product is blown from the end of the kiln in the expanded form. The vertical kilns are from 1 1/2 to 2 1/2 feet in diameter, three are 15 feet in height, and one is 30 feet in height. The raw material is fed into the kilns above the burner, which is located at the bottom of the kiln. The expanded perlite is blown from the top. In one of these installations, a rotary kiln is used to preheat the raw perlite. Because perlites vary in composition, different heat treatments must be used to obtain products of highest quality. The unit weight of the expanded material varies from 3 to 15 pounds per cubic foot.

PUMICE

In Canada pumice is used as a lightweight aggregate on a very limited scale. It is imported into British Columbia from the western United States. Deposits of this natural lightweight material have been found in British Columbia and the Yukon, but for economic reasons they have not been developed. Pumice is similar to perlite in chemical composition, but differs in physical structure. This lightweight, vesicular rock was formed by rapid cooling of siliceous lava after its expansion by the contained gases. Pumice is used in Canada entirely as a lightweight aggregate for concrete block manufacturing.

EXPANDED SLAG

Historical Development

In 1948, expanded blast furnace slag entered the field of lightweight aggregates in Canada. The first plant was erected at Port Colborne, Ont. In 1950, a second plant to produce this aggregate was constructed at Sydney, N.S. A third plant was built at Hamilton, Ont., in 1954. For economic reasons, plants producing expanded slag must be located close to iron and steel plants where slag is available.

Expanding Process

Several processes are used to expand blast-furnace slag. The installation at Port Colborne uses the Gallai-Hatchard batch process, which employs two concrete tanks or pits designed to hold enough water to initiate expansion, and water sprays imbedded in the floor of the pit provide water to complete the expansion. The slag is poured into the pit from slag ladles. The plant at Sydney, N.S., uses the Gallai-Hatchard process, and also a second method. In the second method the slag is struck by a stream of water as it leaves the blast furnace. The expanded product falls into hopper cars stationed below the furnace. The plant at Hamilton uses a variation of this process, called the Kinney-Osborne process. In this installation, the stream of slag from the end of the slag runner leading from the blast furnace falls into a stream of water, steam and air.

The product is thrown against a target plate and falls onto a stockpile. In all processes, different products are produced by varying the amounts of expanding media; for example, an excess of water is used to produce granulated slag, which is finer in size than expanded slag.

Expanded slag is harsh and angular and, like the sintered clay aggregate, is more suited to use in concrete blocks than in structural concrete. In 1961, production of expanded slag was 266,900 cubic yards. This product sold at $2.25 to $3.60 per cubic yard.

PRODUCTION AND CONSUMPTION

Figure 1 shows the volume of the four principal lightweight aggregates produced in Canada in the period 1954 to 1961.

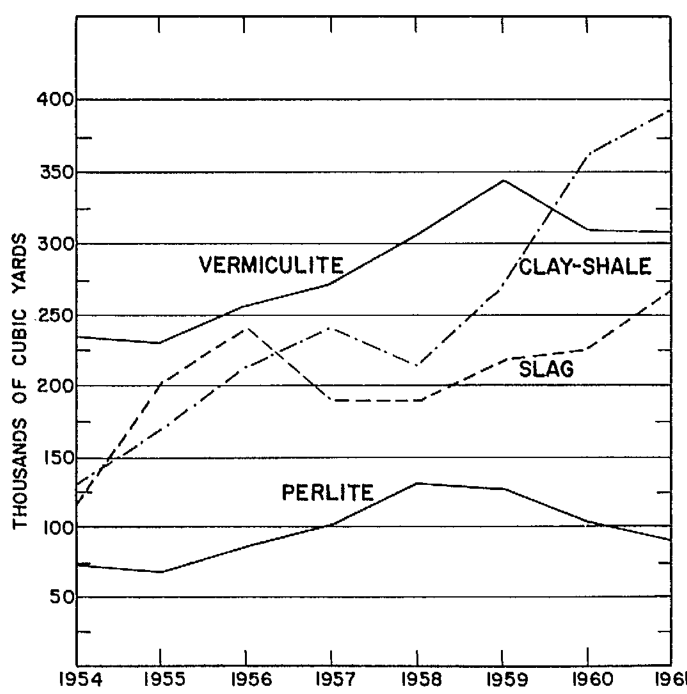

Figure 1 - Production Volume of Lightweight Aggregates, 1954-1961.

The general trend has been upward, as this industry benefitted from the construction boom of recent years. Until 1959, the aggregate that was produced in greatest volume was vermiculite. In 1960 the production of expanded clay and shale aggregates surpassed that of vermiculite, as shown in Figure 1.

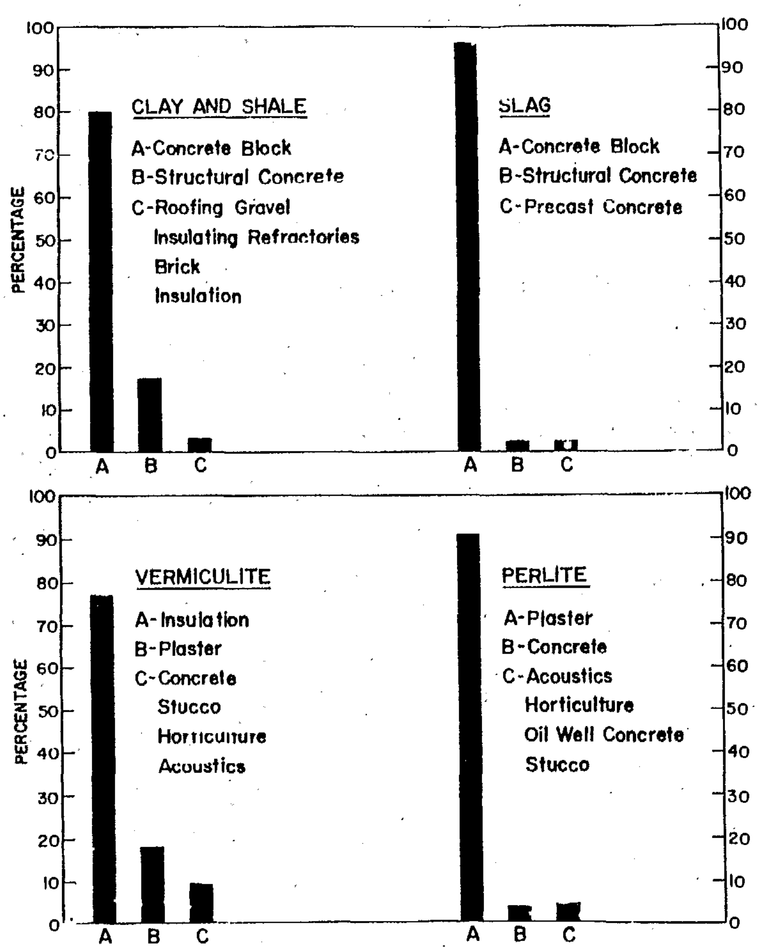

Figure 2 - Consumption of Lightweight Aggregates: 1961

Figure 2 illustrates that each lightweight aggregate has one major use. This picture has not changed appreciably for several years. During the five-year period 1956 to 1961, the concrete block manufacturing industry consumed from 70 to 84 per cent of the total production of expanded clay and shale aggregate, and from 90 to 96 per cent of the total production of expanded slag aggregate. The percentage of vermiculite production used as insulation varied from 61 to 77 per cent, and the percentage of perlite used as plaster aggregate, from 70 to 91 per cent of total production. Although percentage consumption in major applications has not increased continuously, there has been a definite trend upward. In all cases, the 1960 figure exceeds that for 1956. The percentage consumption of aggregates for the minor uses in most cases has decreased over the five-year period.

FUTURE DEVELOPMENTS

The future of the lightweight aggregate industry in Canada cannot be predicted with certainty, but there is reason to be optimistic. Most Canadian producers are members of active associations that are engaged in informing architects, engineers, and the public on the properties and uses of the individual types of lightweight aggregate. It is the application of the materials to secondary and new uses that should receive the most attention.

New applications of lightweight aggregate should be developed. For some time there has been considerable interest in an all-clay lightweight block which is in limited production in the United States and probably could be manufactured from the clay and shale aggregate produced in Canada. The aggregate could be bonded by a clay having a lower vitrification temperature than that of the aggregate raw material. If the same raw material is to be used for aggregate and bond, a flux might be needed to reduce the maturing temperature of the clay bond below that of the aggregate. The aggregate originally fired to a eutectic temperature would probably vitrify at a lower temperature when fired the second time.

Several organizations have undertaken investigational work on this project. Blocks containing 70 to 80 per cent aggregate that are comparable to lightweight concrete blocks have been produced. These 8" x 8" 16" blocks have weights of 23 to 27 pounds and compressive strengths of more than 1000 pounds per square inch (gross area). One report has estimated that the cost of the all-clay block would be about 10 per cent higher than the comparable concrete product.

In the parts of Canada where conventional aggregate is readily available, an expanded clay or shale aggregate costs about 150 per cent more than conventional aggregate. The cost of the fuel used in the rotary kiln is one of the main reasons for the higher cost of the lightweight aggregate. A rotary kiln is an inefficient heat-exchanger. Parsons[5] has reported that a good rotary lime kiln installation approaches 40 per cent efficiency. He also indicated that many lightweight aggregate plants operate at efficiencies of less than 10 per cent. Proper kiln design and operation, and the use of recuperative coolers undoubtedly would result in increased efficiency, lower production cost, and a more competitive price for the aggregate.

The finer the size of a clay, shale or slag aggregate, the higher the bulk specific gravity. Therefore, to reduce the weight of an all-clay block, the coarser grade of aggregate, minus 3/8 inch, should be used. Material of such particle size would, however, preclude the use of conventional brick and tile extrusion equipment as difficulties in extrusion and cutting would be encountered. The most practical methods of forming would be by pressure or vibration.

The Structural Clay Products Research Foundation, Geneva, Ill., has developed a fine-grained lightweight aggregate. The process utilizes a specially designed vertical kiln, 30 feet in height, with the hot zone near the bottom. The clay or shale is fed into the top of the kiln, and falls freely to the bottom. The product, when bonded with clay, would be more suited to formation of block by the extrusion process than would the coarser product now being produced in Canada.

Robinson[6] investigated the properties of vermiculite-clay mixtures. He found that structural shapes could be manufactured by extrusion or pressing. The use of 20 per cent vermiculite by weight resulted in a unit weight of 70 pounds per cubic foot and a crushing strength of 950 pounds per square inch. With 60 per cent vermiculite, the unit weight was 37 pounds per cubic foot and the crushing strength, 400 pounds per square inch. Correct selection and careful control of the manufacturing procedure were extremely important. Rapid drying and firing were possible. A typical schedule was: 2 hours drying at 300 °F, 4 hours firing to maturing temperature, 4 hours soak, and 3 hours cooling time.

A structural material similar to that already described, but which does not make use of lightweight aggregate, is a cellular clay product. Nicolson and Bole[7] produced such cellular clay products by several methods. The first was the water-foam process, in which water and a wetting agent were whipped into a stable foam to which ground clay, grog, and calcined gypsum were added. After further whipping, slabs were cast, dried and fired. In the second method, the clay-foam process, the dry materials were mixed with water and the foaming agent and gypsum were added last. Fired slabs made by both processes had unit weights of 50 to 60 pounds per cubic foot and compressive strengths of 800 to 1500 pounds per square inch. Cold water absorption after 24-hour soaking varied from 35 to 50 per cent. A typical firing cycle was 28 hours to maturing temperature and a 4-hour soak. In the third method, the fire-bloating process, synthetic mixtures composed of fire clay and selected fluxes were fired to give various physical properties. By adjusting the composition, the unit weight was varied from 47 to 74 pounds per cubic foot, the compressive strength from 800 to 4650 pounds per square inch and the absorption from 0.4 to 57 per cent. Thus, units were produced having the combined properties of low density, low absorption and high strength.

These products are not manufactured in Canada, but they could be a stimulant to Canadian industry. More work is needed to determine their value in construction.

MINES BRANCH PARTICIPATION

Since 1949, the Mines Branch of the Department of Mines and Technical Surveys, at Ottawa, has carried out a survey of clay and shale deposits throughout Canada, and has assessed their potential as sources of material for lightweight aggregates. This work is now complete. Six reports have been published on the results, and one more will probably be published during 1962. Many materials have been submitted by individuals and organizations for evaluation. This phase of the work will continue. Several of the companies manufacturing lightweight aggregates have been assisted in locating and evaluating potential raw materials. Test work has also been undertaken on materials from deposits of vermiculite and perlite.

In test work at the Mines Branch, a preliminary evaluation of clays and shales is made in a gas-fired stationary kiln having a hearth area 4 by 8 inches. Small amounts of the material are subjected to "flash heat" treatment at various temperatures and for varying lengths of time. These tests indicate the extent of bloating and the temperature range through which bloating takes place. Subsequent tests are made on promising materials in a 5 foot by 5 inch propane-fired rotary kiln. Results give an indication of the quality of aggregate that might be produced. A 12 foot by 12 inch gas-fired rotary kiln is used for tests on a pilot plant scale. Aggregates produced in this kiln can be used in making concrete test mixes. Complete evaluation gives information on extent of bloating and the bloating temperature range of the raw material, and on the unit weight, crushing strength, and concrete-making properties of the aggregate.

Facilities are also available for sintering clays or other materials, and for evaluating vermiculite and perlite raw materials. These facilities can be used only on limited quantities of material.

CONCLUSIONS

John M. Neff[8] stated - "One reason that terra cotta has very little sale today is because it is too heavy. Labour costs are high and terra cotta doesn't lend itself to automation. I am not condemning anyone in the terra cotta field, but if they had taken some of the weight out of their product, more would be used today."

"The same with brick. There is absolutely no reason why a brick should weight the amount it does. It took 5000 years to get holes in them and take out part of that weight."

We might say that the holes in brick marked an important trend in construction materials industry, decreasing the weight of structural components and reducing the cost of structures.

The products now being manufactured in Canada with lightweight aggregates, and others that could be produced in the future, possess properties that are beneficial to the construction industry. Materials can be designed to be low in weight, high in strength, low in absorption, fire resistant, and high in thermal and acoustic insulation. More research and development work is necessary to make full use of such properties.

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