INVESTIGATIONS

IN

CERAMICS AND ROAD MATERIALS

(Testing and Research Laboratories)

1925

Annual reports on Mines Branch investigations are now issued in four parts, as follows:—

Investigations of Mineral Resources and the Mining Industry.

Investigations in Ore Dressing and Metallurgy (Testing and Research Laboratories).

Investigations of Fuels and Fuel Testing (Testing and Research Laboratories).

Investigations in Ceramics and Road Materials (Testing and Research Laboratories).

Other reports on Special Investigations are issued as completed.

CERAMICS AND ROAD MATERIALS, 1925

INTRODUCTORY

Howells Frechette

Chief of Ceramics and Road Materials Division

In addition to the usual investigations, and testing of samples of clays, shales, and other materials for ceramic purposes, and stones and gravels for road construction, two special researches were begun in 1925.

In co-operation with the Research Council of Canada, an exhaustive laboratory investigation of the suitability of magnesite from Grenville township, Quebec, for the manufacture of high-grade refractory brick, was undertaken. R. T. Watkins, Ceramic Engineer, was appointed by the Research Council to conduct this research and assumed his duties in the Mines Branch laboratories on November 4. He devoted the remainder of the year to preliminary experiments and the preparation of apparatus to be used in the moulding and burning of the magnesite test-bricks.

J. F. McMahon, Ceramic Engineer, was appointed for one year, beginning October 3, 1925, to study the refractory properties of moulding sands and to evolve, if possible, a satisfactory laboratory method for determining their resistance to high temperatures.

During the summer field season, L. P. Collin spent two weeks at brick plants in the vicinity of Hamilton and Toronto and completed the collection of data relative to the cost of burning brick in that district. Later he visited a number of brick and tile plants in Quebec, and practically all of the operating plants in the Maritime Provinces. Technical advice, which should be of service, was given at many of the plants and in every case was gratefully accepted. Data on the cost of burning could be obtained only at one brick plant in Nova Scotia since the other plants were operating on reduced schedule or were temporarily closed.

The growing demand for highly refractory ceramic materials makes the discovery, if possible, of suitable deposits of minerals of the andalusite group desirable. With this in view, L. P. Collin visited a number of localities in Nova Scotia where these minerals are reported to occur.

L. P. Collin continued his research on the compounding of porcelain bodies for electrical heating devices, but the time available did not permit of its completion.

Permission was granted to the Department of Colonization and Development of the Canadian Pacific Railway to place one of their engineers in the Ceramic Laboratory during the winter months for the purpose of testing a number of clays from Saskatchewan. The work was con-

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ducted by G. H. Hutt under the direction of L. P. Collin. Many of the samples proved to be high-grade clays suitable for finer ceramic products. It is expected that a report covering the work will be published at an early date.

The principal equipment installed during the year was a down-draft gas kiln of the double chamber type. This kiln, the larger chamber of which measures 30 by 24 by 22 inches and which has attained a temperature of over 1500° C. (2732° F.), was designed for burning refractory wares and porcelain. This kiln is particularly useful for burning draw trials when a large number of clay samples are under test, since it has a second chamber in which the temperature may be maintained considerably below the temperature of the large chamber.

During the year 114 samples of clay and shale were tested to determine their suitability for ceramic purposes. These samples were submitted for testing by officers of this department, the British Columbia Bureau of Mines, the Canadian National Railways, the Canadian Pacific Railway, and by individuals.

One sample submitted by S. C. Ells of the Mineral Resources Division was a fragment of black, slaty shale from Graham island, such as is used by the Indians for carving. Even when finely ground, it is non-plastic. It burns to a light buff colour and produces a fairly hard brick when fired to cone 03 (1994° F.). Fusion tests show that it falls in the class of No. 1 fireclays. It deforms at about cone 31 (3182° F.).

The transverse and compression strengths and absorption were determined on 15 samples of clay brick, and one sample of sand-lime brick.

A number of other tests were also conducted on ceramic materials.

Owing to the illness of R. H. Picher, Road Materials Engineer, only a limited amount of work was carried out on road materials surveys.

I

CLAY WORKING PLANTS IN QUEBEC, NOVA SCOTIA, AND NEW BRUNSWICK

L. P. Collin

It had been intended to extend the field investigations connected with the burning of brick and tile to cover the plants in the Maritime Provinces, but it was found impossible to carry out this programme as many of the plants were inactive and most of the remainder were operating only part of the time because of the general business depression resulting from the strike of the coal miners in Nova Scotia. However, it was decided to visit the plants operating with a view of studying some of the technical difficulties being encountered and if possible to assist the manufacturers in overcoming them.

The following plants were visited in New Brunswick and Nova Scotia:

New Brunswick

M. Ryan and Son, Fredericton.
The Foley Pottery, Ltd., St. John.
Steven Brick Co., Ltd., St. John.

Nova Scotia

George Brooks, New Glasgow.
Stephen Brooks, New Glasgow.
Standard Clay Products, Ltd., New Glasgow.
Nova Scotia Clay Works, Ltd., Pugwash.
Nova Scotia Clay Works, Ltd., Elmsdale.
James B. Miller, Elmsdale.
L. E. Shaw, Ltd., Avonport.

Three plants were visited in Quebec, namely:
The Citadel Brick Company, Boischatel.
The Sherbrooke Brick Company, Lennoxville.
The Granby Clay Products, Ltd., Granby.

A number of suggestions were made at the various plants for the purpose of improving the quality of the ware and lowering the cost of production. At one plant considerable trouble was being experienced due to very wet clay. Soft-mud brick were being made and at times the clay was so wet that the bricks would slump and lose their shape when being removed from the moulds. This caused a great loss at the machine besides causing trouble in the setting of the kilns, and an unsatisfactory finished product because of the variation in the size of the brick. Conditions were studied and it was suggested that the addition of a small amount of hydrated lime might stiffen the clay mixture and help the moulded bricks to retain their shape. This was tried out and a decided improvement was noted. The mixture was much stiffer, and the bricks were firm and retained their shape when taken from the moulds.

A plant was visited where many of the bricks were badly scummed when taken from the kilns. Upon investigation it was found that the scummed bricks were always in the upper part of the kilns which were of the up-draft type. The scumming did not appear in every batch and it occurred only in scattered portions near the top. It was found that the bricks were sometimes a little wet when set in the kiln and this was evidently the cause of the trouble. The clay contained compounds of sulphur which were broken up into sulphur dioxide and trioxide in the lower part of the kiln before the wet brick in the top were dried. The oxides of sulphur in the presence of the moisture formed sulphuric acid which attacked calcium compounds in the clay and left a white coating of calcium sulphate on the bricks. If the brick were all thoroughly dried before being set in the kiln it is very unlikely that any scum would be formed.

At another plant where trouble was encountered with scumming, it was found that the scum appeared on the bricks when they were taken from the drier. The water used for tempering contained no soluble salts and it was, therefore, evident that the clay must hold a small percentage of soluble material, probably calcium sulphate. The manufacturer was advised to use a small percentage of barium carbonate so as to render these salts insoluble, and thus prevent the formation of scum.

At another plant where wire-cut brick were manufactured the clay column cracked badly as it came from the die. The cracks ran across the column and would occur quite regularly for a few minutes and would then cease for a time. Upon investigation it was found that waste brick from the machine were allowed to drop in a pile on the floor and were fed direct to the pug mill from time to time. Usually, considerable drying took place in these before they were fed into the machine and consequently they were not properly broken up and tempered before reaching the auger. After the feeding of the waste brick was stopped the most of the cracking ceased. The cracks remaining were rather small and irregular. Upon further investigation it was found that two things were responsible for these. First, the material was not ground sufficiently fine because of badly worn rolls, and second, the feeding of the pug mill was very irregular, at times it was brimming over and at other times it was nearly empty. After these conditions were corrected the column was smooth and free from cracks.

An examination was made of an old clay property in St. John county, New Brunswick, which the owners were desirous of re-opening. It was found that most of the good clay had been used, and that the clay below the present pit level contained many limestone pebbles. A sample of this clay taken near the surface was tested in the Mines Branch laboratories and gave the following results:

The clay, which was light red and contained many pebbles, some of which were limestone, was quite plastic and worked well when tempered with 25 per cent of water. Briquettes were moulded, dried, and burned. The average drying shrinkage was 7·3 per cent, and the results of the burning tests were as follows:

Temperature °F.	Fire shrinkage Per cent	Absorption Per cent
1742	0·4	17·2
1886	1·0	14·8
1994	7·0	2·3

The clay fused at cone 2 (2138°F.)

The briquettes burned to 1742 and 1886 degrees were fairly hard and salmon coloured. The one burned to 1994 was steel hard and a fairly good red. One of the briquettes was cracked due to limestone pebbles. This clay could be used for the manufacture of soft-mud brick but the lime pebbles would be very likely to cause considerable trouble especially as this sample was taken near the surface and the pebbles seem to become more numerous lower down.

A sample of shale was taken from the property of the Nova Scotia Clay Works, Ltd., at Pugwash. It was a dark red, well weathered shale and was fairly plastic and worked well when tempered with 18 per cent of water.

Briquettes were moulded and burned with the following results:

Temperature ° F.	Fire shrinkage Per cent	Absorption Per cent
1742	0·4	15·0
1886	1·4	12·5
1994	6·0	5·5

The shale fused at cone 4 (2210° F.)

The drying shrinkage averaged 4·0 per cent.

The briquette burned at 1742 degrees was rather soft but was fairly good red in colour. The one burned at 1886 degrees was quite hard and the colour was the same as the one burned to 1742 degrees. The briquette burned at 1994 degrees was a very dark red and was steel hard.

The shale in the weathered state should be a very good material for the manufacture of face brick, but it could be improved by the addition of a small percentage of clay to increase the plasticity. It would be necessary to expose the hard unweathered shale to the weather for a year before it would be sufficiently plastic for the manufacture of stiff-mud brick.

II

ANDALUSITE IN NOVA SCOTIA

L. P. Collin

During the past few years andalusite has been recognized as a valuable ceramic material. Its outstanding properties are, extremely high refractoriness, the toughness which it imparts to porcelain bodies, as well as high dielectric resistance. Its principal uses are as an ingredient for spark plug porcelains and vitrified, pyrometer-tube bodies. Unfortunately, workable deposits of industrial importance are rare. Owing to the rapidly increasing demand for this mineral and as field work was being done in Nova Scotia, it was deemed advisable to investigate the occurrences mentioned in the Geological Survey report, Memoir No. 74, "A List of Canadian Mineral Occurrences," by Robert A. A. Johnston, which are as follows:—

Halifax county—Geizer hill, to the west of Halifax city; Beaver Dam, near Sheet Harbour.
Queens county—Broad river, about 1½ miles from the mouth.
Shelburne county—Red head, Port Latour, and Shelburne Harbour.
Yarmouth county—Above Yarmouth and Pubnico.

Before investigating these occurrences a visit was made to the Provincial Museum at Halifax, where the matter was discussed with the Curator, Mr. H. Piers. He stated that the deposits in Halifax county were of no value, as the crystals of andalusite were very small and were not abundant. However, a specimen was found in the Museum which had been collected from the western shore of the northwest arm of Whitehaven harbour, Guysborough county. As the andalusite crystals in this specimen were fairly large and very abundant, it was decided to investigate the deposit.

At all of the localities visited the andalusite occurred as crystals embedded in schists. At Red head, Port Latour, and Shelburne Harbour, the crystals were much altered and contained so many very small garnets that it was at once evident that these occurrences were not of economic importance. The crystals at Broad river were very small and not very abundant. Near Yarmouth and Pubnico, the deposits were very similar to those seen in Shelburne county.

The deposit in Guysborough county appeared to be of some importance. The crystals were of fair size and were quite numerous. A 50-pound sample was obtained from the shore, near Doughboy rock where the occurrence appeared at its best.

The andalusite crystals when examined under the microscope, however, were found to have a great number of small garnet crystals embedded in them. A sample sent to the Ore Dressing Division for a preliminary concentration test, showed only between 5 and 6 per cent total recovery of an andalusite product and while this product was found to be very refractory, it was not pure andalusite. The garnet product totalled between 9 and 10 per cent, but the garnets were too small to have any industrial value.

Because of the small percentage of andalusite obtained and the fact that no valuable by-products can be produced, it seems doubtful if this deposit is of any industrial importance.

CAUSES AND PREVENTION OF SCUMMING AND EFFLORESCENCE

L. P. Collin

Scumming is one of the most common troubles encountered in ceramic manufacture, and it is sometimes one of the most difficult to overcome. It may appear on the clay as it is taken from the pit, on the ware as it comes from the drier, or it may develop in the kiln. Most scum is a decided detriment, although some people believe that the presence of a white coating on brick is evidence that it is hard-burned.

The terms scumming and efflorescence are used with different meanings by authorities on the subject. The men who have written the most and who are most often quoted are: Seger, Binns, and Lovejoy. Although Seger has written profusely on this subject he does not give any specific definitions of the terms. Binns states that scumming is due to a chemical action between the sulphur contained in the kiln gases, which may have its origin in the fuel used or in the clay itself, and some of the constituents of the clay, chiefly calcium, thereby forming a white compound. Efflorescence is a chemical term which refers to the deposit of a floury residue, caused by the evaporation of a solution containing a chemical salt. In the case of clay ware, this residue may be seen on the surface of a piece, and is the result of the evaporation of the water which has been brought to the surface by capillary attraction and which contains the soluble salts which were in the mass.

Lovejoy states that scum is an insoluble coating which appears on the ware in the process of manufacture, and that efflorescence is the soluble coating which appears on the finished product in the stock pile, or in the wall.

Binns' definition of scumming limits the use of the word to the coating formed in the kiln by a chemical reaction between sulphur and compounds of the product. He includes under efflorescence the deposition of soluble salts by capillary attraction whether it occur during the process of manufacture or on the finished product. Lovejoy makes a sharp dividing line between scumming and efflorescence by saying that scumming appears during the process of manufacture, and that efflorescence appears on the finished product. However, he says that scum is insoluble. There is no doubt that there is a decided tendency for this coating to become insoluble due to its reaction with the kiln gases and the various minerals in the ware during the latter part of the burn, but it would seem that quite often a part of this coating might be soluble, and that, under certain conditions, it might all be soluble. Binns' definitions are technically correct without a doubt, but Lovejoy's are closer to expressing the popular understanding of these terms.

The most commonly accepted definitions are those given by Jackson in his "Descriptive Bibliography of Scumming and Efflorescence." They are as follows:

Scumming.—The formation on the surface of a ceramic body of a deposit of foreign matter during the process of manufacture.

Efflorescence.—The formation on the surface of a finished ceramic ware of a deposit of foreign matter due to exposure to weather.

It is believed that the use of the terms, as expressed by him, will tend to avoid misunderstanding and confusion by allowing a sharp dividing line to be drawn between the two without imposing limitations as to solubility. That is, scumming occurs during the process of manufacture, and efflorescence occurs on the finished product.

CAUSES OF SCUMMING

There are many causes of scum, of which the five following may be considered the most important:

1. Soluble salts in the raw material;
2. Soluble salts in tempering water;
3. Scum developed from the lubricating oils;
4. Scum developed in drying and water-smoking;
5. Scum developed during the burn.

It is quite evident that soluble salts are the basic cause of most scumming. When the ware is being dried, the soluble salts, if any are present in the clay, are carried by the water to the surface of the ware and deposited there as the water evaporates.

Practically all clays and shales contain salts which are soluble in water. The percentage of these varies considerably according to the nature of the materials. Not only does the percentage vary in different clays, but it is quite likely to vary in the same clay from time to time. The reasons for this are as follows: ground waters are constantly percolating through clay beds. These waters may bring in soluble salts to the clays, and they may also take out a considerable amount from the clays. Other soluble salts may be formed in the clays by the process of weathering. For example, a clay containing pyrites and calcium compounds, if exposed to the weather, may form calcium sulphate which is a soluble salt. The pyrites or iron sulphide is oxidized and, in the presence of water, forms iron oxide and sulphuric acid. This sulphuric acid attacks the calcium compounds present and forms calcium sulphate. This may account for the fact that scumming is most prevalent, in many cases, in the spring. The clay bank has been exposed to the weather during the winter and has been subjected to frosts and thaws. These tend to break up the clay, particularly that which forms the open face of the bank. This results in a considerable quantity of clay being oxidized, and, if pyrites be present, soluble salts may be formed which are not present in the unweathered portion of the deposit. Again, the water produced by the melting snow and the heavy spring rains may drain through the clay mass and escape at the face of the bank. This water is quite likely to contain soluble salts, and as it reaches the face of the bank, evaporation takes place with a consequent deposition of soluble salts. This may take place to such an extent that the clay at the face of the bank will contain a much larger percentage of soluble salts than the remaining part of the clay.

Weathering may, however, have the reverse effect and leach out the soluble salts. This would depend largely on the nature of the ground waters and the drainage conditions of the clay deposit.

The most common of the soluble salts found in clays are those of sodium, potassium, calcium, and magnesium, and they may occur as chlorides, sulphates, carbonates or nitrates. These salts do not need to be present in large quantities in order to cause trouble. It has been found that as little as $0\cdot1$ per cent of calcium sulphate may give rise to the deposition of a white coating on the wares.

Calcium salts are the most prevalent, and cause the greater part of the trouble with scum. Magnesium salts, however, seem to be more active this way, and a smaller percentage of them may cause more trouble than a like quantity of calcium salts. As a rule, clays used for the manufacture of brick and tile do not contain appreciable quantities of the soluble salts of the alkalis. The water used for tempering very often contains sufficient calcium or magnesium salts, or both, to produce scum, and in some localities it contains relatively large amounts of the alkalis, sodium and potassium. As this water is distributed throughout the clay mass, these salts are carried with it and, of course, act exactly the same way as if they had been present in the clay when it was taken from the pit. The quantity of water used for tempering has a very decided influence on the degree of scumming. The greater the amount of water used, the greater the amount of soluble salts that can pass into solution, and subsequently be brought to the surface. The importance of this will be realized when it is remembered that calcium sulphate, which is the most troublesome of the soluble salts, requires 400 times its own weight of water to dissolve it. This is one of the reasons why dry-pressed brick may show less scum than those made by the soft-or stiff-mud process.

Many of the crude oils, which are used for lubrication, contain sulphur, and this is quite likely at some stage of the manufacture, to form sulphates. In addition to this, these oils may contain salts and dirt, simply as impurities in suspension, and with the drying and burning of the ware, a residue will be left on its surface.

Drier Scum

Scum may be developed in the drier, even if the ware contains no soluble salts when it is put in to dry. There is only one cause for this, and that is the presence of sulphur compounds in the atmosphere. Sulphur gases may be introduced into radiated heat driers by leakage. They may be introduced into waste heat driers in two ways. All bituminous coals and many oils and gases contain sulphur in some form. As the fuel is burned, part of the sulphur is given off as the dioxide (SO_2) and a small percentage as the trioxide (SO_3). Consequently if any of the products of combustion are taken into the drier, sulphur gases are sure to be present. If waste heat is being drawn from a cooling kiln while the ashes are hot, sulphur gases are very likely to be carried over into the drier. The chemistry of the sulphur reactions is as follows: Under favourable conditions the sulphur dioxide may be partly or completely converted into sulphur trioxide which, in the presence of moisture will at once produce sulphuric acid. Thus, in a drier tunnel containing products of combustion, it is possible to have an appreciable quantity of sulphuric acid present. The sulphuric acid attacks certain minerals present in clays, especially the compounds of calcium, forming soluble sulphates. These sulphates may be formed not only at the surface but within the ware, and with the drying of the ware they are brought to the surface and deposited.

Kiln Scum

There seem to be two distinct causes of the scum which is developed in the kiln, one of which is closely related to the drier scum just mentioned:

(1) When brick are taken from the drier and placed in the kiln, they still contain water. This is divided into two classes, hygroscopic water and chemically combined water. The hygroscopic water is not all given up until a temperature of several hundred degrees Fahrenheit has been reached, and the chemically combined water does not begin to come off much below 700° F. During the burning of the ware the kiln atmosphere nearly always contains sulphur dioxide and trioxide introduced from the fuel or by the decomposition of the pyrites in the clay from which the ware is made. There is considerable moisture or water vapour present, particularly during the early part of the burn, with which the sulphur trioxide combines to form sulphuric acid. Thus, to a limited extent because of the relatively small amount of water present in the atmosphere, scum may be formed in the kiln much the same as in the drier.

(2) The other cause of scum developing in the kiln is rather puzzling and has been somewhat harder to explain. Fortunately it is comparatively rare. This particular type of scum is usually found to occur when a wet, dirty fuel, high in sulphur, has been used, and is believed to come entirely from that source. Some of the sulphates are more or less volatile, and if present in the fuel, or if formed in the burning of the fuel, may be carried over the bag walls to be deposited onto the relatively cool ware. The more volatile salts will be revolatilized as the heat advances in the kiln and will be driven off completely before the burn is finished. It is possible that some of the more stable sulphates will remain as a scum on the ware. It is more likely that the greater part of the scum of this character is produced by a reaction of sulphuric acid and ash from the fuel. It has already been shown how sulphuric acid may be formed in the kiln, and it does not volatilize until a temperature of nearly 700° F. has been reached. The temperature in the bottom of the kiln is considerably lower than in the top (if a down-draft kiln) so that sulphuric acid may be present in the cooler part of the kiln even when the fire-boxes have reached a high temperature. Considerable ash may be carried over from the fire-boxes, especially when the fires are being stirred, and deposited on the ware. If sulphuric acid be present it will attack the ash and form stable sulphates which will be burned into the ware and will remain as a permanent coating.

PREVENTION OF SCUMMING

In order to understand better the methods of scum prevention, it may be well to remember that soluble salts are the cause of nearly all scum. If they are present in the raw materials they must not be allowed to form a deposit on the surface of the ware. One way of preventing this is by removing the soluble salts, and another is to render them insoluble. If they are not present in the raw materials, their formation must be prevented, or if this cannot be done, the soluble salts formed must be rendered insoluble as far as is possible.

The first thing to consider then is the prevention of scum which is caused by soluble salts present in the raw material. It was mentioned that one way of overcoming their action was by removing them. If clays or shales are exposed to the action of the weather, it would seem that any

soluble salts which are present would gradually be leached out by the action of rain water and ground waters. This does occur and bad cases of scumming have been cured by weathering the clay. However, if a clay or shale contains any appreciable amount of pyrites, the weathering would result in the formation of more soluble salts, because of the oxidation of the pyrites, followed by the formation of sulphuric acid, which would react with the minerals present in the clays or shales, and form soluble sulphates. Thus it would be quite possible to form soluble salts as rapidly or even more rapidly than the waters would carry them away. It may be said that if a clay contain soluble salts, but does not contain pyrites or similar sulphur compounds, scum may be decreased or possibly entirely eliminated by allowing the clay to weather.

Another method mentioned was to change the soluble salts into insoluble salts or rather salts whose solubility is so low that they would not cause the formation of scum. Various compounds of barium have been used in this connexion for many years. Practically all of the soluble salts which cause scum are sulphates, and calcium sulphate is by far the most troublesome of these. If a sufficient quantity of barium carbonate be added to a clay containing calcium sulphate, the calcium sulphate would be broken up by its reaction with the barium carbonate. Then barium sulphate and calcium carbonate would be the products formed. Since calcium sulphate requires 400 parts of water to dissolve it and barium sulphate requires 400,000 parts of water, a great advantage would be gained by forming barium sulphate in place of calcium sulphate. The other product of the reaction, calcium carbonate, requires 28,000 parts of water for solution, which is too low to cause scum. In other words the calcium sulphate is broken up and forms two new salts, each having a very low solubility. Even if barium carbonate were added in excess it would not cause scum, because it requires about 14,000 parts of water for solution. So it would seem that if the percentage of soluble salts present were determined by chemical analysis and then just sufficient barium carbonate added to combine with this amount, no deposit of scum would appear. But it must be remembered that barium carbonate is only slightly soluble and only enough will dissolve in the water to change a part of the soluble salts into insoluble ones. As the barium carbonate is dissolved and reacts with the soluble salts present the insoluble salts formed are precipitated and then more barium carbonate can enter into solution. The amount of work done by the barium carbonate depends upon two things, the amount of water present and the length of time it remains, or rather the rapidity with which it is removed. Many cases of scum which are caused by small amounts of soluble salts may be entirely cured by the use of barium carbonate alone. If, however, a considerable quantity of soluble salts be present, it will greatly aid matters to use a more soluble compound of barium. Various investigators have recommended the use of barium chloride, barium hydrate and barium fluoride. These salts are all quite soluble and thus will be able to precipitate a much larger quantity of sulphates than barium carbonate. The disadvantage in using the chloride is that it is readily soluble, and of course any excess would act in the same manner as any other soluble salt. Barium hydrate is very soluble, but is not dangerous to use because in the presence of carbon dioxide it would be changed into the relatively insoluble barium carbonate. With either of these salts it is much wiser to use a little less than would be required to

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precipitate all of the sulphates present and to use a small amount of barium carbonate to take care of the last remaining sulphates. Barium fluoride has been well spoken of but its cost at present is said to be considerably higher than that of the other barium salts. It is very soluble but owing to the presence of the fluoride which is a very active flux, any excess which might be deposited on the surface during drying would become fused into the ware during the burning, or the fluoride would be volatilized and the barium would become a part of the clay body. The same reactions would take place with the calcium fluoride formed. It is safe to say that any scum which is caused by soluble salts in the raw clay or shale or by soluble salts in the water used for tempering may be practically eliminated in nearly every case by the judicious use of barium compounds.

Fast drying is a method of prevention which has proven successful in many cases of scum, but the reasons for its effective action are not generally understood. Binns states that it is due to a property of capillary tubes. He gives a simple test to illustrate this, which is as follows: Take a strip of filter paper and place one end of it in a solution of potassium permanganate which is purple. The solution will be drawn up through the paper by capillary attraction. However, it will be seen that as the solution is drawn up the paper, it is preceded by a section of clear water— that is the clear water is moving faster than the salt, and this section of clear water will become larger as it travels farther up the paper. Just why this should be does not seem to be known, but chemists have called this phenomenon adsorption. The same thing will take place in the drier, and if the water is evaporated fast, less of the soluble salts will be carried to the surface of the ware and deposited than if the operation was slow. A bad case of scumming could not be entirely cured in this way, but it might be checked to quite an extent. Of course if the material will not stand fast drying this method could not be used.

Lovejoy gives another reason for the helpful effect of fast drying. He states that as calcium sulphate is only soluble in 400 parts of the water, solution takes a considerable time, and that as each crystalline mass of the sulphate is acted on by the water, the water immediately surrounding the crystal which has become saturated must be removed and replaced by fresh water before any more solution can take place. There is very little movement of the water in clay wares, and the stiffer the ware the less the movement. Hence a considerable amount of the soluble salts present may not have time to go into solution.

The explanations given by these men are both feasible, and from them it may be seen very clearly how fast drying will help to overcome scumming.

The next cause of scum that was mentioned under the "Causes of Scumming" was that deposit left by using a poor grade of oil for lubricating. The remedy for this is quite obvious. Many lubricating oils are available which will not cause any trouble.

Scum Developed in the Drier

The best method of preventing scum being developed in the drier is to eliminate the sulphur gases. If brought in by using combustion gases, or by the leakage of combustion gases, the remedies are obvious. If the waste heat taken from a cooling kiln contains sulphur gases, the ashes

should be removed from the fire-boxes, and fresh air should be allowed to circulate through the kiln before the waste heat is used in the drier. The use of barium salts may partly and in some cases entirely overcome the effect of soluble salts developed in the drier, but their action is necessarily limited because the ware has lost such a large part of its water before these soluble salts are formed. Fast drying, as mentioned above, may also aid in checking this scum.

Scum Developed in the Kiln

The greater part of the scum developed in the kiln is due to the presence of sulphur gases and their subsequent reactions during the water-smoking period. Again, barium salts may be of some aid in checking this scum, but the safest and by far the most effective method of prevention is to use some non-sulphurous fuel, such as wood or coke, for water-smoking.

The prevention of the other type of kiln scum, that caused by sulphur and the lime compounds in the ash, is more difficult. This may be entirely overcome by avoiding the use of a wet, dirty fuel. If a dry fuel be used, there is not likely to be enough moisture present in the kiln during the latter part of the burn to form any appreciable amount of sulphuric acid to react with the lime in the ash.

The use of alternating oxidizing and reducing conditions in the kiln during the latter part of the burn may break up, to a great extent, any scum that has been developed in the kiln. Most of the sulphates when once formed cannot be removed in an oxidizing atmosphere at the temperatures used in ceramic kilns. However, in a reducing atmosphere they will decompose at about 1800° F. and form sulphides. Then, in the case of calcium sulphate, calcium sulphide would be formed. The calcium would then enter into combination with the alumina and silica and the sulphur would be driven off as a gas. Scumming is often reduced by finishing the burn under reducing conditions. If this produces ware of an unsatisfactory colour, alternating reducing and oxidizing conditions can be used during the latter part of the burn, and the finishing done under oxidizing conditions so that the colour will not be affected.

EFFLORESCENCE

The efflorescence, which appears on the finished product after it has been taken from the kiln and exposed to the weather, has been the subject of much discussion. The work which has been done on it is far from complete, and some of the conclusions reached are not satisfactory. Efflorescence is caused by soluble salts in the ware being brought to the surface and deposited by the evaporation of water. It is also often caused by soluble salts being transferred from the mortar or from stone copings. In the case of ware stored on the ground, it may be caused by the soluble salts in the soil being transferred to the ware.

The salts which cause most of the efflorescence are the sulphates of magnesium, sodium, and potassium. Calcium sulphate is not so likely to appear on the ware because it is much less soluble than the other salts mentioned. The water does not have as much chance to get at these salts in burned brick as in green ware because the amount of water which can be absorbed is usually much less than the amount used for tempering

except in the case of dry-pressed ware. Again, many of the pores are sealed by fluxing action during the burn, thus reducing the amount of salt available for solution.

The magnesium salts are very soluble and the presence of a very small amount may cause efflorescence. The alkalis may be present as unstable silicates which can be broken down by weathering and leave soluble alkaline salts.

Efflorescence may be checked by hard burning and by burning with a reducing atmosphere. The hard burning will increase the stability of the silicates and make a stronger bond so that weathering will not be likely to cause soluble salts to be formed. Furthermore, by increasing the fluxing action of the more fusible compounds, hard burning reduces the number of open and directly communicating pores. The use of reducing conditions in the latter part of the burn has already been discussed under kiln scum.

SUMMARY

Causes of Scumming	*Methods of Prevention*
Soluble salts in raw material...............	Weathering, if pyrites is not present. Barium salts. Fast drying.
Soluble salts in tempering water............	Barium salts. Fast drying.
Formation of sulphates in drier.............	Elimination of sulphur gases. Barium salts.
Formation of sulphates in kiln and deposition of sulphates formed in drier.............	Water-smoking with non-sulphurous fuel. Alternating reducing and oxidizing conditions. Use of clean, dry fuel.

Causes of Efflorescence	*Methods of Prevention*
Soluble salts in burned ware................	Hard burning. Reducing conditions.
Soluble salts absorbed from mortar, stone copings or ground.....................	Keep from contact with brick, and secure proper drainage from stone copings.
Soluble salts formed by weathering..........	Hard burning. Alternating oxidizing and reducing conditions.

Scumming and efflorescence may be overcome, or at least checked, in practically every case, if the cause be determined and the above methods of prevention intelligently used.

IV

TEXTURE OF CERAMIC MATERIALS

J. F. McMahon

Texture, to most building-brick manufacturers, has come to mean the outside appearance of the brick. For instance, a brick is rough-faced or smooth-faced, and, therefore, of a coarse or fine texture. However, texture applies to more than the mere surface of the brick, for although the surfaces of the brick may be smooth and fine-textured (caused, perhaps, by oils or by clay-laden waters being pressed to the surfaces), the inside may be coarse, and therefore the brick must come under the heading of a coarse-textured product. However, the mention of this circumstance is not to attempt a change in the ordinary use of the word "texture," but rather to cause the following statements to be interpreted as applying to the body of the product rather than to the surface.

The study of texture forms a decidedly important phase of the ceramic industry although its importance has seldom been emphasized to the men in the industry and consequently it is in more or less of a neglected state. Many little troubles may be cured by a few minutes of a practical man's thought in this direction. Texture will be found well worth the trouble of investigation.

The texture of a product is determined by its grain, or the individual particles of material that make up the workable mass, preparatory to shaping, moulding, etc. The grains may differ from one another in shape or in size.

Shape

Round-shaped Grains. Many materials, such as some silica sands, occur as round grains in nature, but the grains of any material can be rounded by sufficient grinding, either in ball mills, or even in wet pans. Therefore the product from any grinding apparatus is apt to be of rounded grains.

Angular-shaped grains. These are the product of crushing machines. Any device that does its work with one or two blows and then sends its material on to the next operation tends to break down the shape of particle, and not wear its corners down as is the case with grinders.

Flaky grains are peculiar to certain types of material, and rather than being the product of machinery (that is to say, controllable) are products of nature. These materials (such as mica) tend to produce lamination in the product and are more or less undesirable. However, clay grains (the ultimate grain of clay) are thought to have a platy or lamellar shape, though some ceramists claim that there is a great variation in clay-grain shapes.

Size

Of course, grain size may vary from the particles of glaze-colouring matter that pass a 300-mesh sieve to particles $\frac{1}{2}$-inch in size as that of grog used in making large fireclay shapes. So, it is readily seen that grain

size is relative in any one particular type of ceramic product. That is to say: coarseness in a china clay body would be considered fineness in stoneware, and coarseness in stoneware, fineness in a fire-brick, etc. However, coarseness in any one branch of the industry will have similar effects to coarseness in any other branch. The fineness of grain is controlled by crushing, continuous crushing or grinding.

Texture and Plasticity

Plasticity is most common to clay, so it will serve best as an example.

Upon searching through the various papers by investigators in plasticity, one finds many diverse opinions as to its causes. But; all authorities agree as to the advantages of fine grains in developing plasticity.

Clay, in the raw state, is composed of small conglomerates. Crushing clay tends to break down these conglomerates into smaller ones, and grinding into smaller ones still.

Plasticity then, we may say, is a surface phenomenon. On account of their fineness (ultimate fineness) grains of plastic clay have a large surface area and consequently exhibit surface phenomena (including intermolecular attraction and colloidal properties) to a marked degree. Hence it can readily be seen that as the breaking down of clay conglomerates approaches the ultimate grain size, the more marked are the surface phenomena.

It is known that a few clays retain their plasticity after the finer particles are removed. Schurecht[1] (who is an outstanding Research Ceramist), in explaining this, says that clays which retain their plasticity consist of loosely aggregated bundles of clay which are very easily broken down by stirring, thus yielding a fresh supply of the fine grains, whereas the cemented particles require a much greater force for their disruption. According to him, more of the finer particles can be produced in ball clays than in kaolin because the flocculated aggregates in the former are composed of finer grains and for that reason more plasticity can be developed.

Although plasticity is more or less thought of in connexion with clays, it may be developed also in many of the so-called non-plastic materials by grinding to extreme fineness.

Drying

Drying (in ceramic industries) may be called the operation by which the greater percentage of mechanically held water is removed from the moulded product. The success of this drying is dependent upon the amount of pore space and its arrangement. In order to dry ware it must be more or less permeable. That is to say, not only must pores be present, but they also must be connected in such a manner that the moisture may find its way out. Fine grains make very fine pores—large grains relatively large pores. The former grains are very apt to interlock and cut off pores from one another, whereas the latter tend to leave what may be termed communicating or channel pores. Although the former tend to produce a body of higher porosity than the latter, the arrangement of the pores makes it a more difficult type of ware to dry.

[1]Amer. Cer. Soc. Bull. 153 (1922).

Drying is carried on principally by the capillary action of the pores. The outside of the ware, being in contact with atmosphere (hot or cold), is dried by evaporation. The surfaces dried, the pores immediately fill and carry more moisture to the surface. This is carried on until practically all the mechanically held water has been removed.

In the case of very fine-grained material, the rate of evaporation of the surface moisture is so much greater than the passage of moisture through the pores that uneven drying—the source of all drying problems—occurs. Then, too, because these fine-grained materials afford a greater porosity, the amount of water enclosed is greater.

A clayware made of all round grains is apt to be more porous than a similar body made of angular grains because the grains under pressure (below crushing pressure) will not allow interlocking or much surface contact. However, in the case of lamellar, platy or angular grains, the product can, by pressure, be made to interlock, and have more surface contact, thus creating a less porous body than rounded grains. Permeability is greater in the round-grained product; therefore the round-grained product is easier to dry.

Drying Shrinkage

Closely connected with drying is drying shrinkage. This is caused by the removal of water from the pores. As the water is removed the grains are pulled towards one another by molecular attraction and in consequence there is a pulling up of the entire mass or shrinkage of the ware. If there are no forces acting against this shrinkage force, the ware is kept intact, but other forces being present often cause the ware to distort and rupture.

As the particles pull one another together, a rearrangement of the particles occurs. The force of molecular attraction tends to fill up all the space previously occupied by the water. Fine grains move more easily and fill up the pores more completely than the large grains which are not so easily moved and interlocked. Therefore the amount of pore space filled during this shrinkage period is a measure of the shrinkage.

As has been stated before, a large percentage of the drier losses result from uneven drying. However, uneven drying is the indirect cause. The direct cause is the shrinkage which goes on in the ware. Uneven drying causes uneven shrinkage, and uneven shrinkage causes the body to disrupt or distort. The outside of the ware is dried faster than the interior; consequently the outside tends to shrink first. This puts it under tension causing the ware to crack or warp.

Bond or Strength

The bond or strength of the dried ware depends upon the grain surface area in contact and the forces of adhesion and cohesion. A quantity of marbles, shot, or rounded grains of sand will have no bonding power. The lack of bonding power is due to the small surface contact. If the round grains of sand be very finely ground a bond will be formed, perhaps not very great but much greater than in the sand grain state. Now if these rounded grains were to be *crushed* to the same size as they were *ground*, an increase in the bond over the ground particles would be in

evidence, because there would be more surface contact. Then again if these grains could by some means be made platy or lamellar, the surface contact would be increased with a consequently stronger bonding power. Clays, being very finely divided substances, have the best bond of all the ceramic materials. The platy or lamellar structure also adds much to the strength.

Mill Additions

For Colour. Needless to say, everyone appreciates the need of fine grinding of pigment in paints. The fine grinding of all colouring matter is absolutely requisite for a homogeneous colour. It causes a wide dispersion of the colouring matter. In ceramic work the fineness of grain of colouring matter is of the utmost importance. Even in the manufacture of building brick (where the colouring matter is natural) a more uniform product may be obtained by fine grinding.

For Cures. As in the case of colours the need of maximum fineness and dispersion of materials added to the batch, such as barium salts for scumming, is almost essential, since it affects the greatest number of particles. Frequently the trouble has not been eliminated due to the careless mixing of such salts. A very good means of obtaining this dispersion is by keeping the salt constantly stirred in water while adding to the pug mill thus ensuring a very thorough mixing.

Burning

In burning, as in all other steps of the ware's progress, texture plays a very important part.

During the first stage of burning, that is, the water-smoking period, the ware undergoes what might be termed the secondary drying. All the moisture that the particles hold on their surfaces must be driven off. The moisture must be driven off at its boiling point.

The next stage, that of driving off the combined water, requires a slightly higher temperature, and as it leaves it is in the form of a gas or superheated steam.

The next stage, that of oxidation, consists, one might say, of the ware inhaling oxidizing gases and exhaling the products of combustion.

During these three stages, steam and combustion gases are being let out of the interior of the ware. Here, as in the case of drying, it is necessary for the ware to be permeable, that is, to have its porosity so arranged as to allow the free passage of gases. The coarse and rounded type of grains offer the best exit and entrance. The fine grains, angular and lamellar grains, tend to hasten the action on the outside of the ware while the centre attempts to push out the internal gases. The surfaces of such textured material reach the next firing stage (vitrification) too soon and in so doing, close the pores against the exit of the gases (particularly the oxidation gases) and cause what are called "black cores," or in some extreme cases, the gases will generate enough force to cause a bloating of the ware, giving it a honeycomb structure.

The next stage in the burning process is that of total or partial vitrification. It has been said previously that fine grains in the green state produce a porous body. However, any porosity produced by fine grains can occur only below the temperature at which vitrification takes place,

and the pores begin to fill with fused material. Thus it was found in one particular clay that the porosity was highest with fine materials up to 1180°C. Between 1180° C. and 1300°C. there was only a slight difference in the porosity, but at temperatures over 1430° C., the porosity was reduced to almost nil in the fine ground body, due to vitrification. Hence, although fine grains are a cause of high porosity in the unfired ware, in the fired products fine grains are a cause of lower porosity than larger ones (this is especially true of vitrified products). This is because the finer grains (offering more surface to the heat and fluxing action) fuse more easily and thus cause the interstices to be filled with the fused matter.

In the finished product, texture plays a very important part. Among the principal properties of the product that are affected by the texture are strength and resistance to spalling, abrasion, and corrosion.

Strength. The presence of large grains reduces the strength of wares containing them, both in the fired and unfired states, as the strength depends upon the area of contact, and compactness of the mass.

Spalling. Coarse particles are preferable in most cases where resistance toward sudden changes in temperature is required in any material that has an appreciable coefficient of expansion, because in a close-grained mass the strains due to the heating or cooling cannot be relieved by a re-arrangement of the particles without the disruption of the mass.

Abrasion. There are two outstanding reasons why a fine-grained product resists abrasion more than does one of a coarse grain, first, the greater bond due to the fine grains, and, second, the greater surface of the ware which works against the action.

Efflorescence and Corrosive Action. Coarse grains usually produce a mass of more open texture than do fine grains, so that corrosive substances are more able to penetrate into the interior and so reach a greater surface upon which they may act. In the particular case of scumming, or efflorescence, the fine-grained ware that is exposed to the weather will not allow the moisture to penetrate so deep into its interior, and if the moisture does not obtain an entrance, the chances for scumming are lessened.

Grading

In addition to the size of the individual grains, it is also most important to consider the grading of the material as a whole, because in only a limited number of cases can a material consisting of particles of one size only be used satisfactorily. Thus a material in which all grains are uniform in size is undesirable for bricks and similar articles, as such grains, even when angular, do not bind well together. A much better and stronger body is obtained if the particles are of different sizes, so that they may interlock properly and, aided by a natural or added bond, may produce a material possessing the desired properties.[1]

The term "graded" is applied to any material composed of grains of various sizes, the proportion of grains of each size being such that the mixture has certain properties, such as high strength, low permeability, etc. Accidental variation in grain size cannot be called "graded," because they are not arranged to serve any particular end.

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[1]Searle, A. B.: The Chemistry and Physics of Clays and other Ceramic Materials.

Any manufacturer knowing the particular trouble, either in the drying or burning, or in service, that his ware gives him, can, by studying the texture, arrive at a proper grading for his particular product and overcome the ware's weakness.

The most salient points regarding texture have been touched upon, and an attempt has been made to show their importance in the clay industry, and the manner in which texture affects the various working problems.

As a general summing up, the following table may be given:

—	Fine	Coarse	Round	Angular	Proper Grading
Plasticity	Advantageous	Disadvantageous	Dis.	Ad.	Ad.
Drying	Disadvantageous	Advantageous	Ad.	Dis.	"
Burning { Water-smoking	"	"	"	"	"
Burning { Oxidation	"	"	"	"	"
Burning { Vitrification	Advantageous	Disadvantageous	Dis.	Ad.	"
Dry strength	"	"	"	"	"
Spalling	Disadvantageous	Advantageous	Ad.	Dis.	"
Abrasion	Advantageous	Disadvantageous	Dis.	Ad.	"
Efflorescence and corrosion.	"	"	"	"	
Mill additions for colour	"	"	"	"	

V

ROAD MATERIALS IN EASTERN ONTARIO

R. H. Picher

A number of commercial plants producing crushed stone in eastern Ontario, were visited during the year, with a view of obtaining information on plant equipment, the quality of the product as road metal, quantity output, sizes of stone, and transportation conditions. Several large gravel pits, from which a considerable amount of material has been taken and used either as road gravel or as concrete aggregate, were examined and sampled. One quarry, now being operated to produce road metal for the Ontario Department of Public Highways, and one area from which field boulders are obtained, were examined and samples for testing were secured.

Havelock, Peterborough County

Rock. A large quarry with crushing and screening plant, owned and operated by the Ontario Rock Company (410 Crown Office Building, Toronto), is situated on the flank of a ridge 3 miles east of the village and 1 mile north of the Canadian Pacific railway to which it is connected by a spur line.

The rock is a dark greenish, dense diabase, commercially known as trap. The texture varies from very fine to medium fine, the latter phase being slightly porphyritic. Foliation is plainly visible in a few places. There is very little overburden.

The quarry was visited by L. Reinecke in the fall of 1913 and described in his report.[1] Since then, alterations and extensions have been made to facilitate operation and increase production. The quarry, originally opened on the southwestern side of the ridge, was abandoned and another opened on the northwestern side, where the rock is more easily quarried and more uniform.

Quarrying is done by means of giant blasts. A series of tunnels is driven into the lower part of the face at a depth of 150 to 200 feet. Heavy charges of dynamite are placed at the ends of the tunnels which are then filled with earth and debris. The charges are fired simultaneously by electricity. This has the effect of breaking and loosening the rock along the entire face of the quarry for a distance back from the face equal to the length of the tunnels. The length of the tunnels and the amount of dynamite fired are gauged so as to supply enough rock for one year. The loosened rock is loaded by steam shovel into dump cars which are hauled up an inclined track to the top of the first crusher. Pieces that are too large or too firmly held in place to be handled by the steam shovel are drilled and blasted into smaller blocks.

The stone is dumped into a large jaw crusher having an opening of 5 feet by 4 feet and is broken down to 8 inches maximum size. It then

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[1]Reinecke, L.: "Road Material Surveys in 1914," Geol. Surv., Canada, Mem. 85.

passes through two gyratory crushers which crush successively to 4 inches and 2 inches. The crushed stone is screened to four sizes: 2-inch, 1-inch, ½-inch, and screenings (passing ₁⁵₆-inch mesh). The oversize from the 2-inch screen is re-crushed and re-screened.

The maximum daily output is from 600 to 800 tons, depending on the size which is being produced. The prices per ton in carload lots are quoted as follows, f.o.b. quarry: 2-inch stone, $1.40; 1-inch, $2.00; ½-inch, $2.50; screenings, $1.35.

A sample of the rock was tested in the Road Materials Laboratory and gave the following results:

Percentage of wear	2·0
French coefficient of wear	20·0
Toughness	13
Hardness	18·5
Cementing value	51
Specific gravity	3·02
Absorption, water, pounds per cubic foot	0·13

The toughness of 13 is undoubtedly much below the average toughness of the rock. The sample block for toughness was taken from foliated rock and all cores drilled from it broke under the test along foliation planes. Reinecke gives a value of over 20, which is certainly closer to the average toughness of the rock.

This is a very good road metal and is quite suitable for all types of pavements, including waterbound macadam. It is used in bitulithic pavements in Toronto. In nearly all types of high-grade pavements, trap rock is specified as mineral aggregate and it has long been recognized as the ideal stone for waterbound macadam pavements. It is hard and durable, binds well, and produces comparatively little dust. Among the varieties of rocks known in the trade as traps, diabase is considered the most desirable for road purposes.

Gravel. At the western end of the village there is a large pit cutting through the upper part of a gravel ridge. The pit contains over 10,000 cubic yards, and is 20 feet deep at the crest of the ridge. The gravel is very coarse and bouldery, interstratified with layers of sand, and, although individual gravel layers are regularly graded with regard to sizes of particles, as shown by samples 1 and 1a (Tables I and II), the pit as a whole shows very irregularly sorted material. The boulders are found to constitute about 20 per cent of the material, but it was not possible to estimate the proportions of pebbles and sand.

The gravel has been extensively used for surfacing streets and roads in and around Havelock. An inspection of the surfaces showed that the gravel, on account of the irregular gradation in size of its constituents is unfit for use in roadwork without preliminary treatment, such as screening into several sizes, eliminating the large stones and re-combining the sizes in suitable proportions; or a much simpler way would be to pass the whole through a crusher, with the jaws adjusted to the maximum desired size, say 1½-inch. All the stone, 75 per cent of which is good hard limestone, would thus be utilized, and a more satisfactory road metal obtained.

Several stretches of the gravel roads were afterwards re-surfaced with trap rock screenings from the quarry of the Ontario Rock Company, laid directly on top of the old gravel. This decidedly improved the con-

dition of the roads. If graded stone instead of screenings alone had been used and a regular waterbound macadam course built on top of the old gravel, a much more durable surface would have been obtained.

Fuller, Hastings County

Gravel. A large gravel pit in the flank of a ridge over 200 feet high, equipped with a washing and screening plant, operated by Quinlan, Robertson and Janin, Ltd., Contractors (50 Notre Dame Street West, Montreal), is situated a short distance east of the Belleville-Madoc line of the Canadian National railway, and connected with it by a spur line.

The gravel, which holds a large proportion of coarse pebbles and boulders, is passed through a crusher with the jaws set so as to crush to a maximum size of 2 inches. It is then washed over a $\frac{1}{4}$-inch screen, which allows the sand to be separated and carried to waste dump by water. The washed material is then screened to the following sizes: 2-inch, 1-inch, and $\frac{3}{8}$-inch, and loaded into standard gauge, railway gondolas, which are hauled by a gasoline locomotive to the railway siding at Fuller.

The pebble composition, expressed in percentages, is roughly as follows:—

Durable...................	{granite..............	15}	....	20
	{trap................	5}		
Intermediate..............	{limestone...........	70}	....	75
	{granite.............	5}		
Soft.......................	limestone.............................			5

An abrasion test on a sample of pebbles gave 5·9 as the percentage of wear, or 6·8 for the French coefficient of wear (sample 2, Tables I and II).

The stone is largely used as coarse aggregate in concrete structures and for ballast.

Crookston, Hastings County

Rock. Just east of the village there are two quarries in very fine-grained, thick-bedded, brownish grey limestone. The stone has been quarried for many years for various purposes, but only one quarry is now in operation. The owners and operators, Quinlan, Robertson and Janin, Ltd. (Montreal), are extracting stone for the piers of a new bridge across the St. Lawrence river at Montreal. On account of its massive character, the stone is particularly suitable for heavy construction work.

In the quarry there is a very large amount of waste rock, a sample of which was collected for testing. The result of the test follows:—

Percentage of wear..	3·9
French coefficient of wear...	10·4
Toughness...	6
Hardness..	16·3
Cementing value...	153
Specific gravity..	2·70
Absorption, water, pounds per cubic foot..........................	0·25

The stone is quite suitable as road metal for surfacing ordinary country highways, but does not possess sufficient toughness to be used on main highways carrying more than 100 vehicles per day. It has about the

same qualities as the limestones of the same formation found in the Belleville, Ottawa, and Montreal districts, but is inferior to the Kingston and Marmora stones.

Deeks, Grenville County

Rock. About midway between Merrickville and Kemptville there is a large quarry on a low elevation along the Canadian Pacific Railway line. The quarry is operated by the Grenville Rock Company (Merrickville). An electrically operated crushing and screening plant separates the product into the following sizes: 2-inch, 1-inch, $\frac{3}{8}$-inch, and screenings.

The stone is a light, steel-grey, fine-grained, magnesian limestone; it is thin bedded and highly siliceous in places, some beds including lenses of sandstone. A laboratory test made on a sample of the stone gave the following results:—

Percentage of wear	2·9
French coefficient of wear	13·6
Toughness	5
	16
Hardness	15·6
	15·9
Cementing value	25
Specific gravity	2·79
Absorption, water, pounds per cubic foot	0·85

Two beds were sampled to determine their hardness and toughness. As seen by the result of the test, there is a considerable difference in toughness, and before drawing any definite conclusion on the value of the stone as road metal, it will be necessary to sample and test more beds.

The crushed stone has been largely used for ballast by the Canadian Pacific Railway on part of their Montreal-Toronto line. There is a very large amount of stone available at the quarry.

Prescott, Grenville County

Gravel. Three miles west of the town, there is a large gravel pit along the side road bordering lots 14 and 15, Augusta township, and about half way between the main river road and the Canadian National railway. The gravel is being used as coarse aggregate in a concrete pavement built under contract for the Department of Public Highways, between Prescott and Maitland. The deposit holds many streaks of clayey gravel, and for that reason all the fine sand, silt and clay is screened out as unsuitable, and sand from Tweed is used as fine aggregate in the concrete. In the pit the gravel is passed through a crusher which breaks down to a maximum size of 2 inches, and then over a $\frac{1}{4}$-inch screen which separates the sand from the pebbles.

A sample of the gravel taken from the bank was tested to determine its suitability as road-surfacing material (Tables I and II). It is a fairly hard gravel, but is much too coarse to be used as such on the road. If passed through a crusher so as to break all the large stones down to a maximum size of $1\frac{1}{2}$-inch a very satisfactory road material would in all probability be obtained.

Rock. Between Prescott and Johnstown there are several old quarries along the waterfront, one of which, 3 miles east of Prescott, has recently been worked for crushed stone which is used as aggregate in a stretch of concrete road built under contract for the Department of Public Highways.

The quarry shows a dark grey, dolomitic limestone. The stone contains many small streaks and veins of calcite crystals, is of uneven texture and fairly thick bedded. There are numerous outcrops of similar stone along the St. Lawrence river.

The investigations on road materials made in 1915 by L. Reinecke[1] along the Ottawa-Prescott highway covered this district, but no sample was taken at the time, because of the difficulty of obtaining fresh stone from any of the old quarries. A sample was, therefore, taken from the recently worked quarry and sent to the Road Materials Laboratory for testing.

Percentage of wear......	3·25
French coefficient of wear......	12·3
Toughness......	11
Hardness......	15·2
Cementing value......	28
Specific gravity......	2·80
Absorption, water, pounds per cubic foot......	0·50

The stone should prove a satisfactory road metal and may be used in all types of pavements for main roads, except in waterbound macadam, since the stone does not possess enough binding power. It is particularly suited for use in bituminous surface treated or penetration macadam on roads carrying a light or moderately heavy traffic. The stone is now being used as aggregate in building a concrete pavement on the river road east of Prescott.

St. Raphael West, Glengarry County

Boulders. Field boulders are not only the most common, but also the best kind of road material in this vicinity, and for that reason are used a great deal in macadamizing country roads. Portable crushers are installed close to the road to be surfaced and in proximity to a good supply of boulders; the latter are crushed and separated by rotary screens into the usual sizes; 2-inch, 1-inch, ½-inch, and screenings. The composition of the boulders is roughly estimated as follows:—

Durable: 25 per cent............	⎧ Precambrian granite ⎨ " acid gneiss ⎩ " basic gneiss
Intermediate: 55 per cent........	⎰ 40 per cent medium soft Black River limestone ⎱ 15 per cent glassy Potsdam sandstone
Soft: 20 per cent................	⎰ 10 per cent soft Black River limestone ⎱ 10 per cent loose-textured Potsdam sandstone

Since waterbound macadam is the type of surface most commonly built on county highways in this vicinity, a sample of the crushed rock was sent to the Road Materials Laboratory to determine the cementing value of the aggregate. The test gave a value of 152, which is considered very good. This, coupled with the fact that there is but a small proportion of soft and weathered stones, makes these boulders a good material for waterbound macadam. Field boulders as a class are not generally considered desirable for road metal, since, due to their heterogeneous character, they cause the road surface to wear unevenly. Although this constitutes a serious defect on a main road having to carry a fairly heavy motor traffic, it is only of secondary importance on roads subjected to comparatively light traffic, more than half of which is horse-drawn.

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[1] Reinecke, L.: Road Material Surveys in 1915, Geol. Surv., Canada, Mem. 99.

TABLE I

Results of Physical Tests upon Gravel Samples

Sample No.	Location	Proportion of pebble to sand		Pebble								Sand						Per cent passing 200 mesh	Remarks
				Per cent retained on screens								Per cent retained on sieves							
		Per cent pebble	Per cent sand	2½"	2"	1½"	1"	¾"	½"	¼"	8	14	28	48	100	200			
1	Havelock............	65	35	9	6	14	20	12	16	23	28	20	21	12	9	6	4	Two samples from two different layers, one fine and the other one coarse, show uniformly graded material, but pit as a whole shows very coarse and bouldery (20 per cent boulders), irregularly graded gravel. Makes rough and uneven surface. Material needs screening and re-sorting.
1a	Havelock............	45	55	0	·5	2	14	10	23	46	34	28	17	5	3	4	9	
2	Fuller..............	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Very large pit; size varies a great deal from place to place; generally very coarse material. Not used for roads. Gravel crushed to 2 inches maximum size, screened to 4 sizes with sand, silt and clay washed out. Used as coarse aggregate in concrete.
3	3 m. W. of Prescott..	65	35	16	25	18	25	6	4	6	24	30	28	9	4	2	3	Very coarse and bouldery gravel, sand regular, but pebbles irregular in gradation of sizes; too small proportion of material retained on ¾-inch, ½-inch and ¼-inch screens.

TABLE II

Results of Physical Tests upon Gravel Samples

Sample No.	Location	Character of material					Abrasion test	Remarks
		Composition of pebbles			Shape of pebbles	Per cent of clay and silt	Per cent of wear	
		Durable	Inter-mediate	Soft				
1	Havelock...........	5	90	5	Angular	1·2	10·1	Over 90 per cent limestone, $\frac{2}{3}$ of which is very sound and hard. Moderate amount of clay and traces of CaCO₃. Probably over 100,000 cubic yards available. Would make a good material if crushed down to smaller size.
1a	Havelock...........	....	....	....	....	4·9	....	
2	Fuller..............	21	73	6	Subangular	....	5·9	Durable: granite, trap; Intermediate: limestone, granite; Soft: shaly lime-stone. Over $\frac{2}{3}$ of total is limestone, mostly hard. Moderate amount of CaCO₃. Amount available very large. Good hard and fresh material.
3	3 m. W. of Prescott..	5	75	20	Subangular	1·0	....	Durable: granite; Intermediate: lime-stone, granite; Soft: argillaceous lime-stone, granite. Over $\frac{2}{3}$ of total is fairly hard magnesian limestone. Much clay in places. Per cent of clay and silt in table (1 per cent) lower than average. Amount available unknown, apparently very large. Unsuitable for roads, unless crushed.

VI

GRAVEL AND GRAVEL ROADS

R. H. Picher

The purpose of this paper is to set forth a few important points in connexion with gravel and its use in road construction and maintenance. The writer has had the opportunity of inspecting many gravel roads in Nova Scotia, New Brunswick, Quebec, and Ontario, and the following remarks are the result of his observations and his study of roads in general.

Heavy motor traffic in recent years has resulted in greatly increased use of gravel for roads. Waterbound broken stone roads serve well for horse-drawn traffic, but they fail rapidly under motor traffic and are expensive to repair. Gravel roads are much cheaper to construct, and although they are not particularly resistant to the disrupting forces of motor traffic, they may be easily and cheaply repaired or kept in good condition by a suitable patrol system.

The use of gravel as a cheap surfacing material has been given much attention by road engineers and old methods of building and surfacing gravel roads are being discarded in favour of more efficient methods, and the suitability of various types of gravel is better understood. In order to meet the new conditions of traffic, gravel must possess certain qualities, therefore it is essential that a judicious selection of material should be made. It was formerly the practice to use any easily accessible gravel, and in most cases it answered the purpose fairly well. Under the old methods of construction and traffic conditions, soft gravels very often gave better results than hard gravels, but now the latter are to be preferred, since good wearing quality is one of the prime requisites in a material for the surfacing of a modern trunk highway. A hard gravel, to be satisfactory, should be very uniformly graded as to size of particles and should contain enough binding material. In applying it to the road, it should be laid in thin courses so as to allow it to be compacted evenly and produce a smooth surface. Of course, less stringent requirements would apply to the average county or township roads, but even then the wearing quality and uniformity of grading should be the two most important considerations.

Composition. Since gravels vary widely in composition and relative size of particles, it is not considered advisable to draw specifications within too narrow limits. Nevertheless, there are certain qualities necessary in all gravels in order for them to be considered suitable. A good gravel should contain no loam and not more than 15 per cent of soft and friable particles. At least from 50 to 75 per cent should be retained on a $\frac{1}{4}$-inch test screen. It should contain from 8 to 15 per cent of cementing material, such as iron oxide, carbonate of lime (limestone), or clay.

When developing a gravel deposit, the loam and badly weathered surface material should be removed completely, for it is useless as road material and might later cause defects in the road. A gravel with a large proportion of friable particles will compact readily and form a smooth,

even surface shortly after being laid on the road, but will wear very rapidly under motor traffic. Where such material is plentiful and easy of access, it may be economical to use it on roads frequented principally by horse-drawn vehicles, since then a larger proportion than 15 per cent of soft particles is permissible. Service tests will be the best guide to determine the ability of the material to withstand the wear in such cases.

Grading. For convenience of discussion, a gravel may be considered as consisting of sand, pebbles, and boulders. The material which passes through a $\frac{1}{4}$-inch screen is classed as sand. That which is retained on a $\frac{1}{4}$-inch screen but is less than 3 inches in diameter is classed as pebbles, and all particles over 3 inches are called boulders.

The maximum size of the pebbles and the proportion of pebbles to sand are factors to be considered in choosing gravel.

There should be no stone larger than 3 inches in gravel for lower courses and none larger than $1\frac{1}{2}$ inches in surfacing gravels.

The proportion of pebbles to sand cannot be set definitely for all gravels since the hardness of the pebbles and their gradation of size must be considered.

In general the sand should be present in only sufficient quantity to fill the interstices between the pebbles. Such gravels when compacted, will afford the greatest density and present the greatest number of pebbles to withstand the wearing action of traffic.

In relatively soft gravels, at least 75 per cent of the total should be retained on a $\frac{1}{4}$-inch test screen, and in harder gravels the minimum percentage of pebbles may vary from 75 to 65. In cases where the gradation of pebble sizes is irregular, the proportion of pebbles to sand may have to be further reduced in order to obtain an aggregate of maximum density.

When a gravel deposit contains more than 10 per cent of stones over 3 inches in size, so-called boulders, it is recommended strongly that the latter be not discarded, but passed through the crusher. A supply of fresh and angular stone is thus made available, and when intermixed with the gravel, greatly helps in compacting the road and improves its wearing quality. The best method is to pass all such gravel through the crusher with the jaws set to the maximum desired size since the crushed and uncrushed constituents are thus more intimately mixed.

Binder. The binder is the very fine material the function of which is to cement together the larger particles. When present in a gravel it is either as a loose powder, or as a coating on the gravel particles, or else it is derived from the crumbling of the softer pebbles under traffic.

When a gravel stands up firmly in the bank, it is usually a good indication that it will cement readily on the road, but this does not mean that all gravels which are loose in the bank will bind poorly on the road.

Most gravels in eastern Canada contain some friable or partly disintegrated particles which on being ground up by the traffic furnish a fairly good cementing material.

It is not uncommon to find in hilly tracts of land, gravel composed of very hard granite, or quartzose pebbles, and totally devoid of binder. It will then be necessary to use some cementing material from nearby sources, and if clay be the only material available, care should be taken to add just the amount necessary to act effectively as binder—at most 10 per cent. In such cases it is essential that the gravel contain enough sand,

since once the gravel and clay mix is incorporated into the road surface, sand will lessen the weakening action of the clay during wet weather, and to a degree prevent the formation of mud. Owing to climatic conditions in eastern Canada, the use of clay should be avoided as much as possible. Loam should never be used as a cementing medium.

Iron oxide is one of the best binders found in gravels, and its cementing quality is not affected by weather conditions. The cementing quality of limestone is in proportion to its calcium carbonate content.

Beach or stream gravels are not so desirable as bank gravels for road purposes on account of being deficient in binding material and holding a large proportion of hard, rounded, smooth pebbles. Another objectionable feature of such gravels is that the range of pebble sizes is more limited than in the bank gravels, with consequent higher proportion of voids. Nevertheless, beach gravels have been satisfactorily used on highways bordering the sea coast in the Maritime Provinces. To give best results such material should be rather fine, well graded, composed of not too rounded pebbles, and applied on the road in thin layers. It will not compact so readily and form so smooth a surface as does the average bank gravel, but with proper maintenance will be quite durable. The addition of fine bank material will materially help the compacting of beach gravel road surfaces.

Testing. A careful inspection of any roads built and surfaced with a gravel should reveal the suitability or unsuitability of it for road work. If there is no opportunity to observe its behaviour in roads under traffic conditions, a field examination at the gravel deposit will furnish a certain amount of information as to its probable suitability, but this cannot be regarded as conclusive.

Where heavy traffic is to be expected, or where there is doubt as to which of several gravels will give best results, field observations should be supplemented by laboratory tests to determine the compactibility, the binding quality and the durability which may be expected under service. For this purpose samples weighing not less than 25 pounds should be collected so as fairly to represent the material which it is proposed to use. It is sometimes desirable to include tests to determine the suitability of the gravel as aggregate for concrete structures. The Road Materials Laboratory, Mines Branch, Department of Mines, Sussex Street, Ottawa, is fully equipped to conduct the above tests, also all the standard tests on broken stone and paving blocks, and is prepared to undertake such tests as time permits, arrangements for which should be made through the Director of the Mines Branch.

Construction. It is not the purpose of this article to enter into the details of gravel road construction, since the Provincial Highway Departments have their own specifications covering these. All the methods in use can be referred to two main types, the surface method and the trench method. In the former, the gravel, laid on a flat or cambered subgrade, is spread so as to cover the travelled way and the shoulders; in the trench method earth shoulders are first constructed on a cambered subgrade and gravel laid between the shoulders and retained in place by them.

The trench method is principally used where the cost of gravel is high because of its scarcity. This method is less wasteful of material but is more costly on account of the road having to be built in two or preferably three layers, and each layer rolled.

The surface method is the one more commonly used on our country highways. On narrow roadways the gravel is laid in a single layer on a flat subgrade, the thickness of the material decreasing gradually on both sides of the centre line so as to produce a crown. On wide roadways, the gravel is laid in one or several layers on a cambered subgrade, the thickness being the same over the full width of the travelled way and coming to nothing on the outer edge of the shoulders. This is called the "feather-edge" method.

Maintenance. A gravel road is far from being a permanent structure, and will need constant attention in order to be really serviceable. One of the most efficient devices for maintaining untreated gravel roads is the road drag. The dragging should be started in the spring when the road surface is still moist and soft from the effect of thawing, and should be repeated after every heavy rain, and before freezing in the fall. Ruts, pot holes or other depressions which cannot be filled by dragging, should be patched with new gravel of the same coarseness as the one already on the surface.

Where wave-like depressions have developed due to fast motor traffic, dragging alone will not suffice, and some Highway Departments obtain very good results by having the road surface scarified to a depth of $1\frac{1}{2}$ to 2 inches and re-shaped by a grader or planer with the blade set at nearly right angles with the direction of travel, the grading being repeated and new material applied where depressions or weak points develop. This operation is best carried on in the spring when the surface has thawed to a sufficient depth, and repeated in the fall, after the first heavy rains.

When the traffic reaches an average of 300 or more vehicles per day, best results without undue maintenance costs will be obtained only through the superficial treatment of the road with so-called dust palliatives and road binders. There are many substances suitable for use in surface treatment, but only one, calcium chloride, has been commonly used on country highways in eastern Canada. Calcium chloride is a hygroscopic salt, that is, a salt that possesses the property of absorbing moisture from the atmosphere or any nearby source. When applied to a gravel road, it will soon penetrate the gravel, forming a moist mat at the surface. It thus keeps the fine material from being blown away, and prevents the too rapid wear and deterioration of the road surface. Its action is only temporary, and it will be necessary to renew its application. In our climate two applications in the first year, and one in the second year, are usually sufficient. Calcium chloride will work best in moderately moist climates. It has been used in parts of Ontario and Quebec with very good results. During prolonged dry weather, it may not absorb enough moisture and it will be necessary to feed it by occasionally sprinkling the road surface with water. In very moist climates, calcium chloride cannot be of much use, and may even be detrimental.

Drainage. The object of drainage is to keep water from penetrating the road structure, since water is the most serious destructive agent of roads. This is accomplished by the road camber or crown, side ditches, and underground drains. The road crown keeps the water from penetrating the road surface, by allowing it to run off to the sides. The ditches collect the surface water and carry it away rapidly from the roadside.

The sub-drains, by lowering the level of the underground water, keep the latter from reaching the road surface through capillary action. On a side hill, the ditch will also intercept part of the underground water which, under the action of gravity, tends to reach the road bed. Underdrains, if covered with porous material, will collect and carry off much of the surface water, thus necessitating only very shallow ditches.

Most defects in gravel roads can be traced to faulty or insufficient drainage, and too much emphasis cannot be placed on this important point. Adequate drainage facilities should be provided when building the road, and it should thereafter be made a point of the maintenance programme to see that the drainage system functions properly at all times. This will decrease the heaving resulting from spring thawing, which is so disastrous to our roads.

Corrugations. Corrugation, or so-called "wash-boarding" of gravel roads, is one of the effects of fast-moving motor vehicles. In the past few years many investigators have tried to discover all the factors contributing to cause corrugation, and the measures necessary to eliminate such a serious defect and prevent its recurrence. It is now known that corrugation will form on untreated surfaces, irrespective of the methods of construction, the kind of gravel used, and the nature of the road subsoil, but will be most pronounced on roads surfaced with fine sandy gravel containing but little binding material. Treatment with calcium chloride or light oil will materially reduce corrugation, but not eliminate it completely. Bituminous surface treatment, forming a strongly bound coating of bitumen and stone, will effectively prevent the formation of corrugations.

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