Vitrified Paving Brick

BY H. A. Wheeler, E.M.

Price One Dollar.

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A Review of Present Practice in the Manufacture, Testing and Uses of Vitrified Paving Brick.

BY

H. A. WHEELER, E. M.,

CLAY SPECIALIST OF THE MISSOURI GEOLOGICAL SURVEY.

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PREFACE.

The following contribution to the literature of paving brick is the result of studies by the writer covering the past eight years. During this period the paving brick industry has had a phenomenal development, as from a scarcely known article that was used in but a few towns, and looked upon with much suspicion, it is now used by nearly all the cities and large towns in this country. It has not only won its recognition as a standard article for street paving, but is found to be even more reliable than most materials used for this purpose, when surrounded by the safeguards required in municipal engineering. As the industry is still in the infancy of its development, the merits of vitrified brick are not yet as widely known as it deserves, and this contribution is offered as a review of the present practice, which has considerably advanced since the publication of Prof. Ira Baker's valuable pioneer brochure in 1891 ("Brick Pavements"). Mr. C. P. Chase also published a similar paper in 1891 ("Brick Pavement"), which is mainly written for the city engineer. Mr. M. D. Burke published a valuable contribution in 1892, which is based on tests made at Cincinnati, and contains many pungent remarks that are especially interesting to the municipal engineer.

"The Clayworker" (Indianapolis, monthly,) republished in

December, 1893, Mead's excellent article before the Chicago Engineering Congress, and is now bringing out a new series of articles by him on vitrified brick. This artistic monthly is also very prolific in articles and discussions on paving brick from many sources, and at present is bringing out a very valuable series of papers from the able pen of Prof. Orton, Jr. "Engineering News" (New York, weekly,) has published many tests on paving brick during the past six years.

The writer herewith begs to express his thanks for the courtesy extended to him by the many city engineers who favored him with their personal experience with brick pavements.

H. A. WHEELER.

St. Louis, July 18, 1895.

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HISTORY OF PAVING BRICK.

Development Abroad.

Brick for street paving has been in use for more than a century in Holland, where the absence of natural paving material developed a very durable quality of paving brick by mixing the fine river silt or mud with sand. The village of Moor, on the river Yssel, is especially famous for the excellence of its brick and the magnitude of its paving-brick industry.

To a much less extent, and for a shorter period, they have been used in northern England, especially in Staffordshire and Leeds, under the name of "blue brick" and "terro-metallic ware," where their application is restricted more to stables, chemical works and similar places where a non-absorbent brick is desired. Where the clay is not readily fusible, slag, or mill cinder, or chalk dust is added in English practice, to secure the fluxing or vitrification that is so essential in this class of brick.

Development in the United States.

Paving brick was first used in the United States at Charleston, W. Va., in 1870, a town of 12,000, where a small section was laid as an experiment. This proving satisfactory, a block of one of their principal streets was paved in 1873, in grading for which it was necessary to take up the small section laid in 1870. This is still in use, although laid on a very poor foundation or boards, and though the street has been repeatedly torn up for laying pipe, etc., it is still in fair condition. Samples of this brick kindly sent to me by the city engineer, M. W. A. Hogue, show it to be a side-cut repressed hard-burned building brick of high density, or 2.48, that absorbs 4.5 per cent of moisture in a twenty-four-hour test, and indicates a wear of one-quarter to one-half inch after twenty-two years' service.

Bloomington, Ill., a town of 26,000, put down paving brick in 1875, which, after twenty years' service on one of their principal streets, is being replaced this year by shale pavers. A sample courteously forwarded to me by Mr. W. P. Butler, the city engineer, shows that a very poor glacial clay was used (much inferior to the Charleston clay), and the brick was made by the "slop" process, or from a very soft mud, by hand, without repressing. It shows an absorption of 4.33 per cent. water after twenty-four hours soaking; and a wear of one to one and a half inch, while it has a density of 2.11, or is very low.

St. Louis, in 1880, put down three trial lots of brick paving, one of which was the result of experiments dating back to 1873, the Sattler brick. These all proved failures, from being too soft or too brittle, and were all laid on bad foundations. Another lot of the Sattler brick was tried in 1881, which was successful, but the maker was unable to furnish a uniform, reliable brick, as he was experimenting with a fire clay that was too refractory and very difficult to handle without cracking. This made such a deep impression on the City Fathers, though made in the infancy of the industry, when no first-class pavers had yet been made in this country, that paving brick only received official recognition again this year, though it now promises to become the leading pavement of this Western metropolis, with its population of over 600,000.

Wheeling, W. Va., put down an impure fire clay paving brick in 1883 that was quite successful, and this was the fore-runner of the paving brick industry, as it was the first to inspire confidence.

Decatur, Ill., also put down a vitrified brick this same year that was made from a glacial clay, which is still in excellent condition.

Galesburg, Ill., the home of the shale brick, laid the first shale paver in 1884, on their principal street, where it is still doing excellent service.

1885 saw the first encouraging use of vitrified brick, as during this year it was laid in Columbus. Zanesville and Steubenville, O., and Peoria, Ill. Since then its use has steadily grown, at first slowly, as its merits were cautiously investigated, but as the accumulated experience grew more and more favorable, its adoption became more general, until now it is in use in nearly four hundred cities and towns in this country.

Although Philadelphia adopted brick for its residence streets in 1888, the large cities, with their characteristic conservatism, have been slow in using this new paving material; but with its adoption this year (1895) by New York, Chicago, St. Louis* and Pittsburg, it is now in use in all the large cities, and the early prejudice against it as a nonenduring, unreliable pavement has given way before the overwhelming accumulation of discriminating evidence.

Popularity of Brick Pavements.

To show the growing popularity of this excellent, economical pavement, a canvass was made in 1894 by "Paving and Municipal Engineering" of the projected street improvements for that year in thirty-two cities. A summary of the returns showed that 44 per cent. of the new pavement was to be brick, 32 per cent. macadam and 24 per cent. asphalt, showing already a strong lead over its two great rivals—the former in cheapness and the latter in smoothness.

While brick has thus far been mainly restricted to residence streets or alleys in the large cities, where the traffic is not heavy, it has been subjected to very severe wear in some of the smaller cities with very satisfactory results, and in view of the marked improvement in quality that has been made within the past five years, and the still greater improvements that are in sight, the future will undoubtedly see brick successfully used for the severest traffic of our largest cities. For while it will never be profitable to attempt to make brick as durable as granite, it is so much cheaper, the traction is so much easier, the noise so much less, and it is so much cleaner, that it will win a popularity, when better known in our large

*St. Louis will use vitrified brick on thirty-five alleys and fourteen streets in 1895, as an initiatory introduction, while Chicago is contemplating laying sixty miles of brick pavements.

cities, that will cause it to largely replace granite, even if it has to be renewed more frequently.

Developement of the Industry.

From an humble beginning, in which the making of paving brick was a side issue in a few village brickyards and fire-brick factories, the manufacture of paving brick as a distinct industry began about ten years ago, and the giant strides it is now making date within the past five years. It is utilizing a class of clays that has hitherto been almost completely neglected (the shales), and has erected plants which for magnitude of output, capital invested and general design are a decided advance in the clay industry. There are now over 175 plants devoted to this specialty in this country, with individual outputs as great as 60,000,000 to 100,000,000 per annum, and capital investments as large as $500,000 to $1,000,000 per company.

DEFINITION OF THE TERM VITRIFIED BRICK.

Misconception of the Term.

There is a misconception among some engineers and brickmakers as to the definition of vitrified brick, as unless a brick shows a decidedly glasslike fracture, they refuse to call it vitrified, and even condemn brick from lack of such glassiness that are not infrequently the toughest and most durable of pavers (brick with a stonelike fracture). They quote Webster to substantiate their claims, thereby failing to discriminate between a popular definition and a technical or special use of the term. The No. 1 pavers that are at present on the market, whether made from impure fire clay or shale, are nearly always vitrified, though much more thoroughly vitrified in the latter case.

Study of the changes in a Clay.

To properly appreciate the correct use of the technical term of vitrified brick, it is desirable to look at the change that occurs in paving clays in passing from the condition of a mud to a distinctly glassy mass. A plastic clay, when mixed with a proper amount of water, makes a mud or paste that can be readily molded, and yet is tenacious enough to retain the shape given to it in molding, if carefully handled. On drying off the mechanically admixed water that rendered it plastic, it shrinks 2 to 11 per cent. to a firm, earthy mass that bears handling, though it is so soft as to be easily scratched by the finger-nail, and the individual particles of clay are easily distinguished. On heating the dry clay to a red heat (or about 1200 degrees F.), the chemically combined water is driven off, which renders the clay non-plastic, it again begins to shrink and to grow harder and stronger as the heat is raised above redness, but the individual particles of clay are still easily recognized, and the clay is very porous. When the heat is further raised to about a bright cherry heat (or from 1500 to 1800 degrees F.), depending on the particular clay, it shrinks an additional 1 to 10 per cent., it is very much stronger, much less porous, has acquired the hardness of tempered steel, and the individual particles are no longer recognizable. This point, which is quite well defined, I have called the point of incipient vitrification; from thence to the stage of a molten mass there is no longer any sharp line of demarkation, as it imperceptibly becomes more and more vitreous, and gradually begins to soften and change its shape, especially under pressure. It finally becomes a very viscous semi-liquid, and when chilled and broken presents a thoroughly glassy appearance.

Point of Incipient Vitrification.

Viscous Vitrification.

From the point at which the clay particles have sufficiently coalesced that they can be no longer recognized, or the point of incipient vitrification, to the point of viscous liquidity, requires an increase in temperature of 100 to 600 degrees F., depending on the kind of clay, and is usually 400 degrees in the clays suitable for paving brick. Midway between these two points the clay ceases to be porous and stops shrinking; it has attained its maximum hardness, or scratches quartz; it has a maximum toughness and cross-breaking strength if slowly cooled, and the fracture shows complete coalescence of the particles, or it is completely vitrified, though the shape is retained if not subject to pressure. This stage, though not sharply defined, I have called the point of complete vitrification, and though difficult to describe, it is quickly and easily recognized by the trained eye. It is the stage that clay should be brought to in order to make an ideal paving brick. If heated higher, there is a slight loss in hardness, a much greater risk of brittleness, and a marked tendency to be distorted from incipient flow, though the fracture is more decidedly glassy; yet this advanced stage is what some think a brick should be brought to in order to be called vitrified from Webster's point of view.

Complete Vitrification.

Salmon brick, having only been exposed to a red heat, are extremely porous, or absorb from 15 to 30 per cent. of water; they are very soft, or from 2.5 to 3.0 in hardness, and are in the initial stage of shrinking, hardening and strengthening.

Hard building brick, having been raised to a cherry red heat, are less porous, or absorb from 6 to 15 per cent. of water; they are much harder, or from 4.5 to 5.5 in hardness; are much stronger, and while showing considerable shrinkage, the distinct grains of the clay are still evident.

Fire clay paving brick usually exhibit a homogeneous, compact, dense body, in which the grains of clay can no longer be discerned, or have reached the stage of incipient vitrification; they are slightly porous, or absorb from 3 to 6 per cent. of moisture; they are very hard, being able to scratch glass or steel, or are 6.0 to 6.5 in hardness, and are very tough and strong. They are sufficiently dense and strong to successfully withstand frost, and are hard and tough enough to wear well under moderate traffic.

Hard-burned shale brick usually exhibit a very dense, thoroughly homogeneous, compact body that shows complete vitrification; they are practically non-porous, or absorb from 0 to 2 per cent. of moisture; they are extremely hard, being able to scratch quartz; and are very strong and tough, and pre-eminently adapted for street paving, if slowly cooled.

The salmon and building brick are too soft, too porous and too weak for street paving purposes; the two latter are both suitable for pavers, and are vitrified, but the important distinction should be made that one is only incipiently or slightly vitrified, while the other is completely or thoroughly vitrified.

CLAYS EMPLOYED.

Three distinct classes of clays are employed for the manufacture of paving brick, to-wit:

I. Surface clays, as the drift, loess and residual clays.
II. Impure fire and potters' clays.
III. Shales.

I. SURFACE CLAYS.—The surface clays are seldom suitable for pavers, though almost exclusively used for builders, as they are usually so siliceous, or 60 to 80 per cent. in silica, and occasionally so very calcarous, or 10 to 25 per cent. of lime, that it is practically impossible to vitrify a large percentage without losing their shape. For the range in temperature between the points of incipient and viscous vitrification in such clays is so small as to require a perfection in the control of the kiln that is beyond present attainments. While the earliest pavers, or those of Charleston, W. Va., and Bloomington, Ill., were made from such clays, they were not vitrified, but only hard-burned builders, and their endurance was due to the light traffic of a small town rather than to superior quality, and in each case they have given way to shale brick. In a few cases* these surface clays have a composition that is

*As at Decatur, Ill., and Huntington, W. Va. The Huntington clay is a very plastic, tough, safe working clay, standing rapid drying and firing, and is very fine-grained. It gives the following analysis, per Mr. Otto Rissmann, of the St. Louis Sampling and Testing Works:

	Per cent.
Silica	57.04
Alumina	18.26
Sesquioxide of iron	6.38
Lime	2.41
Magnesia	1.98
Ignition loss	10.16
Total	96.23

favorable for successfully burning a large percentage into hard, tough brick, but these are the exception, and present experience does not indicate that it will pay to add the mixtures necessary to convert them into a good paving material, as is done in Holland, in competition with the large bodies of shales that are naturally so favorably constituted for making a cheap and superior quality of paving brick.

II. IMPURE FIRE and POTTERS' CLAYS.—In point of history the impure fire clays* were next used for making paving brick, and for some time were exclusively employed in the extensive Upper Ohio district; but though still largely used, they are slowly yielding to the cheaper and more durable shale clays. A pure fire clay, on account of its infusibility, or the inability to vitrify it, is a very unsatisfactory clay to use for paving brick, as it is too porous, lacks hardness and strength, and is too expensive to burn; but if quite impure, it can be burned to incipient vitrification, when it becomes much denser, harder and stronger, and makes a very fair quality of paving brick. It possesses the advantage of being impossible to overburn, a point that must be carefully watched with shales or surface clays. For this reason the fire clay brick are less likely to be brittle than shale brick, but they are always more porous, or absorb from 2.5 to 7.0 per cent. moisture, though they usually successfully withstand the frost, in spite of this porosity, notwithstanding theoretical opinions of engineers to the contrary. Brick made from fire or potters' clay are apt to be light-colored, or cream to buff, from the small

*Also known as "bastard fire clay," pipe clay, etc.

amount of iron such clays usually contain, and the latter, being generally in the condition of disseminated grains of pyrite or limonite, gives a brown or black-speckled appearance to the light ground mass. The fluxing impurities should exceed 5 per cent. in a fine-grained fire or potters' clay, or 7 per cent. in a coarse-grained clay, to make it fusible enough for paving purposes, and the greater the amount of the fluxing impurities the cheaper it can be burned, and the denser, harder and stronger will be the resultant brick, from the more thorough cementation of the clay particles by the fluxing action of these impurities. The fluxing impurities which render a clay fusible are iron, lime, magnesia and the alkalies, potash and soda; while the finer the grain and the less dense a clay, the more fusible it is, other things being equal.

III. SHALES.*—The material from which most of the paving brick is now made, and which is usually found in very much larger bodies than either surface clays or fire clays, is the impure, hard, laminated clay that is known as shale by the geologists. Though only recently used for this purpose, and apparently possessing no plasticity as it lays in thick stratified beds, it is found to readily work up into a plastic magma when ground, and to usually have the very impure composition that is so desirable for vitrified brick. This very impure nature is the secret of the success of shales for this purpose, if the phys-

*Shales are incorrectly called soapstone or soaprock by coal miners, from which they radically differ in every respect; they are also frequently but erroneously called slate by engineers, from which they differ but slightly in origin and composition, but the slates cannot be rendered plastic.

ical properties are favorable, and consequently there is a great range in the composition of paving brick shales. Usually they range between the limits given in the following table, which is compiled from the analyses of twenty-five carefully collected samples of Missouri paving brick shales that were made by the Missouri Geological Survey, and twenty-five from the principal paving brick centers of the United States, collected from various sources:

COMPOSITION OF PAVING-BRICK SHALES.

(Deduced from fifty reliable sources.*)

	Minimum. Per cent.	Maximum. Per cent.	Average. Per cent.
Silica (SiO_2)	49.0	75.0	56.0
Alumina (Al_2O_3)	11.0	25.0	22.5
Ignition loss (mainly H_2O)**	3.0	13.0	7.0
Moisture (H_2O)	0.5	3.0	1.5
Total nonfluxing constituents			87.0
Sesquioxide of iron (Fe_2O_3)	2.0	9.0	6.7
Lime (CaO)	0.2	3.5	1.2
Magnesia (MgO)	0.1	3.0	1.4
Alkalies (K_2O, Na_2O)	1.0	5.5	3.7
Total fluxing constituents			13.0
Grand total			100.0

*There are many analyses in the current literature that purport to be of paving brick clays and shales which differ greatly from the above, but the writer has found them to be misapplied analyses of burned bricks, kaolins, fire clays or other material not used for paving brick.

**Ignition loss includes sulphur (S), carbonic acid (CO_2) and combined water (H_2O), though mainly the latter.

While this range in composition is large, the well-known paving brick* are made from shales that agree quite closely with the average analysis given above, especially in the fluxing constituents, so that this will be a valuable guide as a desirable but by no means necessary composition for a good paving brick clay. A specific analysis is herewith given (from Orton) of one of the best-known shales in the country with regard to the high quality of the brick made therefrom, or the Canton, Ohio, shale (Royal Brick Co.):

ANALYSIS OF CANTON (O.) SHALE.

	Per cent.	
Silica	57.10	
Alumina	21.29	Nonfluxing constituents, 85.69 per cent.
Combined water	6.00	
Moisture	1.30	
Sesquioxide of iron	7.31	
Lime	0.29	Fluxing constituents, 13.18 per cent.
Magnesia	1.53	
Alkalies	4.05	
Total	98.87	

Condition of the Iron.

An important matter in the composition of shales is the condition of the iron, which the chemist almost invariably determines as and reports in the form of the higher or sesquioxide. In many cases it exists in the condition of the lower or protoxide, and more frequently it is a mixture of both the higher and lower oxide, as there is scarcely a shale bank without

*As Moberly, Kansas City, and St. Louis, Mo.; Leavenworth, Kan.; DesMoines, Ia.; Galesburg and Streator, Ill.; and Columbus, Zanesville, Akron and Canton, O.

concretions of siderite or ferrous carbonate. Now it is a very vital matter in the successful burning of the shale as to the condition of the iron, and more than one good shale has been condemned from want of knowledge of this fact, and the inability to properly manage it in the burning, as there is a marked difference (over 200 degrees F.) in the fusibility, according to the condition of the oxidation of the iron. It is also very desirable that the iron be uniformly diffused through the clay, to get the best results; for if present as crystals, concretions or seams, it gives a mottled or spotted appearance, and produces local vitrification in spots.

Influence of Lime.

Another matter that is frequently misunderstood, and faulty decisions made in consequence, is the influence of lime on clays in general. If the lime is present in the form of feldspar (or as a silicate) it is a very valuable flux, and the more the better; but if present in the form of carbonate, it will not make a strong brick if in large amounts, and the color will be cream to buff, no matter how much iron* may be present, if the lime is uniformly diffused through the clay. If present as concretions, pebbles or veinlets, and not finely ground, the quicklime resulting from the burning is liable to cause swelling or cracking when the burnt ware is soaked in water. The failure to discriminate as to the condition of the lime has resulted in frequent sweeping statements condemning lime under all circumstances.

Fire Clay Mixtures.

When shales are too fusible, fire clay is sometimes added to

*Iron is almost invariably the coloring agent in all naturally colored brick.

the extent of 10 to 25 per cent., as at Zanesville, O., and Des Moines, Ia., to "stiffen it," or make it stand up better in the kiln, with satisfactory results.

PHYSICAL PROPERTIES OF CLAYS.

Limited value of Chemical Analysis.

The chemical discussion of clays has been hastily passed over, on which alone a volume could be written. For no matter how carefully a clay has been sampled and analyzed, and though one possesses the rarely executed proximate as well as the ultimate analysis, the merits of a clay can never be decided upon from only a chemical analysis; it is of much assistance in forming an idea about a clay, and within certain limts will enable one to condemn, but never indorse a clay. Before one can safely pass judgment on a clay for any purpose, a thorough physical examination is necessary, which gives the information how to work the clay, and the kind and cost of the ware that can be made from it. Such a series of physical tests comprise the determination of the

PHYSICAL FACTORS OF CLAYS.

1. Plasticity.
2. Water required to make a plastic paste.
3. Shrinkage in drying.
4. Shrinkage in burning.
5. Speed in drying.
6. Speed in burning.
7. Point of incipient vitrification.
8. Point of complete vitrification.

9. Point of viscous vitrification.
10. Density before and after burning.
11. Colors of the burned ware.
12. Strength of the burned ware.

All of these factors have an important bearing on either the manufacture or use of the ware, yet barring the question of fusibility and color, and then only imperfectly, a chemical analysis gives no clew whatever on these indispensable points.

Plasticity.

The plasticity is pre-eminently the first question in any clay, as on this property depends the ability to mold the ware. If too lean to be readily or safely molded, it requires admixture with a "fat," or plastic, or "bond" clay, while if too "fat" or plastic, it needs reducing with sand, "grog," or a lean clay. The plasticity is of special importance in paving brick, as if too plastic, the laminations, which have a weakening effect on the brick, are excessively developed.

Shrinkage.

The shrinkage determines how much larger the molds and dies have to be made to produce a given size of brick, the amount of settle in the kiln, and whether "grog" is necessary to reduce the shrinkage if excessive; the total shrinkage varies from 1 to 15 per cent, and usually fluctuates from 8 to 12 per cent.

Drying.

The speed of drying determines the care with which a clay must be dried, and the size and capacity of the drying chambers. Some lean clays can be dried in twenty hours without checking (small cracks), while some strong clays require three to five times as much time in order to dry without cracking.

The speed in burning is a peculiar property that enables some clays to be rapidly heated without cracking, while others have to be very slowly fired; this will greatly influence the mode of handling the kiln, and also the number of kilns required to furnish a given output. **Burning.**

The points of incipient, complete and viscous vitrification are very important in all clays, as it is necessary to attain the first to develop strength, while with pavers it is not only of vital importance to readily attain the second, but there must be a wide margin each side of the point of complete vitrification to enable the kiln burner to produce a large percentage of No. 1 brick. For if this margin is small, there will be a heavy loss from either overburned, misshapen brick, or from soft, underburned brick.

The density of the burned ware is very uncertain until tested, as some clays give a spongy, porous, light body when vitrified, while others give a close, dense, uniform, stone-like body, which latter is absolutely necessary in paving brick. **Density.**

The color of the burned clay is a vital matter with most clay ware, and is of great assistance in paving brick in checking the work of the burner, after once being familiar with the colors of a given clay at different heats. **Color.**

The strength of the burned ware is the crucial test of a paving brick, as on this question hangs its durability, and many clays that are satisfactory up to this point fail at the severe demands required for a durable paver. In fact the majority of shales and impure fire clays cannot be used for pavers, because lacking the great toughness that is required of a paving brick. **Strength.**

MANUFACTURE OF PAVING BRICK.

Surface Clays.

WINNING THE CLAY.—As the surface clays are now rarely used for paving brick, the usual methods of handling such clays are seldom used, or the pick and shovel, plow and scraper or cart, disc cutter and automatic clay gatherer, according to the size of the yard and haul. Nor are paving brick clays weathered, a process which increases the plasticity and homogenity, though at the expense of extra handling, loss of time and the locking up of considerable capital; for while this process improves the clays, competition has now forced this to be regarded as a luxury.

Fire Clays.

The impure fire clays are usually mined by the room and pillar system, like coal, with which they are usually associated and much resemble in their mode of occurrence and method of handling. Like coal, they are also worked by driving and drawing, or running entries out to the boundary, and then drawing the pillar back to the shaft or adit.

Shales.

The shales are usually worked in open pits, after stripping off any superficial surface clays, and are either worked by blasting, or else handled from the solid bank into the car by a steam shovel.

Steam Shovels

If the plant is large enough to keep a steam shovel moderately busy, it is the cheapest and best way of working, as a better mixing is obtained by the rubbing of the nose of the shovel up the face of the bank, and as the face is kept vertical, there is much less delay and trouble in rainy weather by the shale not getting very wet. The depth of a steam shovel cut is limited to about twenty feet, however, whereas there is no limit in blasting, and faces eighty feet high are so worked at Galesburg, Ill., and Des Moines, Ia. By putting a one to one-and-a-half-yard shovel on a two-and-a-half-yard machine, steam shovels have been able to successfully rip up very hard, tough shales, as at Alton and Galesburg, Ill., and Des Moines, Ia., though not without break-downs that are still too frequent, and further improvements are needed in strengthening the weak points of these valuable machines. By loosening the bank with dynamite, the work can be made much easier and very much less severe on the steam shovel, but much of its economy is lost when nitro-glycerine supplies the energy instead of coal; and if the points of the shovel are kept sharp, they have proved their ability to tear up very tough shales without assistance. If a yard is making less than 50,000 brick a day, there is usually no economy in a steam shovel, as the shovel crew is idle about 70 per cent. of the time, and a daily output of 200,000 is necessary to keep the shovel constantly at work.

Cars.

From the bank or pit to the factory, the clay or shale is usually hauled in either side-dumping or drop-bottom cars, by horse, locomotive or wire rope, and ingenious devices have been introduced for coupling, dumping and latching automatically. Occasionally long belt conveyors transfer the clay from the pit to the crushing floor, but this is usually confined to small plants. For large plants exhaust the clay at the rate of one-half to three acres per year, depending on the thickness of the deposit, as two cubic yards or more are needed per 1,000 brick.

CRUSHING.—Shale is nearly always crushed in dry pans or Chilian mills, with solid mullers or rolls that are usually four feet diameter and twelve inches wide, and which run within a revolving pan nine feet in diameter, with a grated bottom. A pair of such pans can usually supply the largest size brick machine, and they have proved very satisfactory, as they crush from five to ten cubic yards of shale per pan per hour. Rolls and centrifugal disintegrators are occasionally used, but they are not satisfactory on most shales, which are usually too tough to be cheaply crushed fine by this system, though it is very efficient on surface clays.

SCREENING.—From the dry pan the crushed shale should go to screens, and both fixed and shaking riddles, and revolving trommels are employed. They all require the use of knockers, to prevent sticking of the wet clay, and at many plants a boy is also needed, to keep the screens from clogging. The trommels and shaking screens are more compact than the fixed riddle, but the latter is simpler to clean and repair. In some of the older plants the sizing accomplished by the gratings of the dry pans is regarded as sufficient, and no screens are employed, but this is a serious mistake as it reduces the capacity of the pan, and causes very imperfect crushing, from the wear and breakage of the bridges of the gratings. As the finer the clay is crushed the stronger the resulting brick, these coarse particles produce an inferior, unhomogeneous product. In fact most plants are still faulty in not screening fine enough, as four to eight-mesh screens are employed, whereas ten to sixteen meshes per linear inch should be used, to give the best results.

PUGGING.—The crushed clay or shale is next mixed and worked with water into a plastic mass by the pug mill, which is a long trough containing a series of wide blades set with a coarse pitch on a heavy shaft. This pugging or tempering should be thoroughly done, to remove air inclosures, secure a homogeneous mixture, and reduce the laminations in molding to a minimum; but most pug mills are too short to properly accomplish this, or only six to nine feet long (along the blades), or are pitched too rapidly, and are the cause of many defects in the brick. They should be at least ten to twelve feet long, and have the blades or knives 90 degrees apart. Fire clays are often pugged or tempered in "wet pans" or "chasers," which are small Chilian mills with a solid bottom, while the mullers have a narrow tread. The clay is both crushed and tempered or worked into a homogeneous paste in this pan, being kept in it until thoroughly ground and tempered. The wet pan yields a superior product to the pug mill, as it can be retained indefinitely in the pan, or until thoroughly tempered; but as it requires a larger plant, and takes more labor and power, it is not usually used for paving brick, though in quite universal use for fire brick, sewer pipe, terra cotta, etc.

MOLDING.—Paving brick are made by the stiff mud process, except in a few small yards which still retain the old-fashioned soft mud and repressing system, and these have proved the only satisfactory methods of making a reasonably large percentage of good pavers. Numerous attempts

Failure of Dry Press Process.

have been made to use the semi-dry or dry press methods, which are in such successful use for building brick, especially about St. Louis, but they have failed to produce more than a small percentage of good pavers. For in the press systems there is no bond between the clay particles, and they merely cohere as the result of the quickly-applied pressure, and unless such brick are burned to complete vitrification, they fail to give a solid, strong, non-porous brick.

Strength of Dry Mud.

To show the strength of the natural bond of the clay particles when worked by the mud process, it was found in testing about two hundred samples of Missouri clays and shales, that the dry mud (before burning) had a tensile strength of 50 to 300 pounds to the square inch, averaging about 150, and the gumbo clays ranged from 300 to 400 pounds, or were much stronger than the natural cements.

Stiff Mud Machines.

The type of machine used for the stiff mud process is usually a continuous-working auger that forces the tempered clay or mud through a forming die; this gives a continuous bar of stiff clay, which passes under an automatic cutter that cuts it into the desired size. As the bar leaves the die, it is usually sanded, to prevent the bricks from sticking together in the kiln. Instead of an auger, producing a continuous stream of clay, reciprocating plungers are sometimes employed, which give an intermittent bar, and occasionally steam cylinders with clay plungers are used, similar to sewer pipe presses. The first method is the cheapest, and this style of machine has been developed to a producing capacity of 12,000 bricks an hour, or 100,000 per day. Formerly the dies were made about 4½x2½

End Cut vs. Side Cut.

inches in size, producing an end-cut brick, but of late 9x4½-inch dies are being used, which gives a side-cut brick, and an active discussion is now going on as to the relative merits of the resulting brick. The side-cut brick is the more shapely and decidedly preferable for a building brick and for repressing, but as to which will make the more solid brick—the brick with fewer laminations—will have to be settled for each individual clay,* as the writer has seen cases where each has been decidedly preferable to the other.** The weak point of the stiff mud process is the laminations that must inevitably result from pushing a stream of clay through a fixed die. For the friction of the sides of the die will cause differential speeds in the flow of the clay, and these variations in the speed of the outflowing clay must necessarily result in laminations, or lines of demarkation between the different speeds in the clay bar, similar to the veins of a glacier. If the air has been expelled from the clay by the pug mill, these lines can be largely closed up again by a properly shaped die, as occurs in the glacier, and a first-class brick will result, in which the laminations will be inconspicuous and of no importance. But if the air has not been expelled, or

*To one not experienced in working clays it may seem odd why a machine that is a success with one clay is a failure with others; but no two clays are alike, and the individuality is often so marked as to require wide ranges in the methods of working different clays.

**Tests recently made on several Ohio clays by Prof. Orton, Jr., seem to show that the side-cut are better than the end-cut; but the data does not admit of reliable comparison, except in one case, where the test was not satisfactory. ("The Clay-Worker," July, 1895.)

the former and die are not properly designed, there will be an excessive amount of concentric lines that almost divide a cross-section of the brick into a series of shells or concentric cylinders, that greatly weaken the brick for withstanding blows or frost. The condition and character of the clay also greatly influence these laminations, as the softer it is tempered or the more plastic it is, the more serious is this trouble. Hence the clay should be worked as stiff as possible, to not only make it dense and reduce the shrinkage, but also to reduce the laminations. A very stiff clay needs more power to work it, however, and if too stiff, is very apt to break down the machine—the latter being a serious remedial fault of most auger machines.

REPRESSING.—The most recent feature in pavers, which characterizes this season, is the sudden popularity of repressed brick, which are now being largely given the preference, at a considerable advance in price, to unrepressed brick. While not a new thing, the extra cost and the lack of indorsement by the brickmakers have held this more shapely brick in check in the past. Repressing consists in putting the freshly-made stiff mud brick into a die box and momentarily subjecting it to a heavy vertical pressure, which is usually applied on the flat side.* This fills out the angles and edges, making a much more shapely, uniform brick, which is very slightly denser; it probably also decreases the laminations. There is no doubt as to the superior merits of a repressed brick as regards appearance and uniformity in size, but brickmakers are not satisfied as to the internal structure being benefited by breaking the old bond formed in the die by the very differently applied

*This is done by a special machine known as the repress.

vertical pressure. Nor are the tests altogether satisfactory that have thus far been made, which seem to indicate a somewhat smaller abrasion loss in the rattler, as this is largely, if not entirely, due to the heavy rounding of the corners in repressed brick, as against the square or slightly rounded corners of the unrepressed. For the tendency is to round the corners more and more, which gives a better footing to the horse and makes the brick more durable, and this year's brick are being rounded with a three-eighths-inch radius, where formerly only two-eighths to one-eighth was used.

DRYING.—The stiff mud brick are hacked or piled in open checker work on cars as high as they will bear their own weight, or six to eight courses high, and dried in long tunnels or drying chambers, that are heated by direct fires, or steam pipes, or hot air. On account of the marked difference in the drying properties of clays, the selection and design of a dryer is a very important matter, and the dryer must be adapted for the specific clay. Some clays can be rapidly dried in eighteen to thirty hours without checking or injury, while others need forty-eight to sixty hours or longer, to avoid cracking to pieces. This means a great difference in the size, arrangement and expense of operating the drying plant, which too frequently is neither appreciated by the brickmaker or the enthusiastic venders of patented dryers, and generally results in an insufficient drying department.

BURNING.—We have now arrived at the most critical part of the paving brick business and the department that is mainly the cause of all the bad brick streets, and this is the more lamentable as it is entirely in the control of the competent brickmaker if he has sufficient kilns, will personally supervise this final department, and has the business sense, if not the integrity, to prevent underburned, brittle and checked brick from being sent out as No. 1 pavers. While first-class kiln burners, on whom must really depend the success in burning, are none too plentiful, the fruit of their work is easily gauged by the watchful superintendent, who by conscientious classifying into four grades, can insure the delivery of 50 to 80 per cent. of strictly first-class pavers. A serious fault with almost every paving brick plant in this country is an insufficiency of kilns, as they are the most expensive part of the plant, and yards that are otherwise equipped with complete outfits, including the very best and latest types of machinery, are frequently deficient in kilns, on which pre-eminently depends the quality of the brick.

Down=Draft Kilns.

The kind of kiln employed for burning paving brick is the down-draft, whether round or oblong*, as the up-draft type produces too heavy a percentage of soft and overburned brick. A few brickmakers, who tenaciously cling to the ideas they learned when making building brick, try to burn pavers in clamp or other open top kilns, and succeed in making a few No. 1 or strictly hard pavers, and many No. 2 or soft

*The round kiln, with a capacity of 40,000 to 80,000 brick, is the great favorite in Ohio, the leading State in the clay industry, but the newer, less conservative western plants have mainly adopted the more convenient, large, rectangular kilns, which hold from 100,000 to 300,000 brick.

pavers, and then try to find a customer who cannot distinguish the inferior article.

Continuous Kilns.

The continuous kiln has also been tried on pavers, but has a discouraging field on account of the enormous shrinkage that complicates the maintenance of the feeding ports. Some recent improvements made at Streator and Galesburg, Ill., in this type of kiln indicate that its well-known economy in fuel may yet be utilized for burning paving brick, with a reasonable yield of No. 1 brick.

In burning the brick, which takes from seven to ten days, they are finally brought up to cherry or bright cherry heat, or from 1,500 to 2,000 degrees F., which is sufficient to vitrify most shales, but the impure fire clays require a higher temperature, or from 1,800 to 2,300 degrees F.* If shale brick are heated too hot, they soften and "wilt down," or melt into a more or less solid mass, yet it is usually necessary to bring them up to a heat which would cause them to stick together if not prevented by sand that is freely sprinkled between them in setting. At this temperature, when they border on the condition of a very viscous fluid, the lower brick become "kiln marked" by the weight of the upper brick forcing the lower brick slightly into one another, and care is

*The writer is well aware that most clayworkers estimate their temperatures very much higher than given above, but many careful determinations with a reliable pyrometer (Le Chatelier's) have shown that paving brick clays almost invariably vitrify within the above ranges of temperature. The clayworkers are still painfully misled by the very inaccurate determinations of the early, crude and erroneous pyrometers.

required to not allow this pressure to become too great by not setting them too high. Hence paving brick are set only twenty-two to thirty-four courses high, according to the ease of fusibility of the clay, whereas building brick are set thirty-five to forty-five courses high. Coal is used throughout in burning pavers, which do not need the preliminary or water-smoking stage to be done with wood or coke, as in burning building brick. Oil and natural gas have been used, instead of coal, in a few places that are so fortunate as to have these superior fuels within their command. They are far superior to coal in greatly reducing the labor in burning, and in producing a superior quality of brick from the uniformity of the fire, and the avoidance of the air checks that result from chilling, when cleaning the grate bars.

Annealing. After the kiln has been maintained long enough at a vitrifying temperature to heat the bricks through to the center, the kiln is (or should be) tightly closed,* and allowed to cool very slowly. Slow cooling is the secret of toughness, and the slower the cooling the tougher the brick. This annealing stage is grossly curtailed at most plants from insufficient kiln capacity, and the kiln is therefore hurriedly cooled down in three to five days, in order to hurry out the brick, even

*Prof. Orton, Jr., has lately advised opening the fire doors and chimney flues while the brick are very hot, to hasten the cooling until the top brick reach a dark red, before closing up tight. This is a safe thing to do in the hands of an intelligent burner, as no harm will result if the air is raised to nearly the same temperature as the brick by entering the hot fire boxes and bags; but unless carefully watched, this is a dangerous risk to take. ("The Clay-Worker," April, 1895.)

to removing bricks that are so hot as to set fire to the trucks. At least seven to ten days should be allowed for cooling to secure a tough brick, and those who desire the best article can well afford to pay the extra cost of still slower cooling, if quality is the first consideration.

Sorting.

If the kiln is properly burned, it will be found to have from one to four courses of top brick that are burned extremely hard, but which are more or less air checked by being struck by the cold air in coaling or cleaning the fires. The top course is also more or less freely covered with an adhering film of ashes and dust, that have been carried over by the draft. Such bricks make excellent sewer or foundation brick, as they have a maximum hardness, crushing strength, and a minimum porosity.

Beneath this top layer of checked brick, to within two to twelve courses of the bottom, are No. 1 pavers, or the brick that should be perfectly sound, completely vitrified, and have a maximum strength, hardness and toughness. Beneath the No. 1 pavers are two to ten courses of brick which have not received sufficient heat to completely vitrify them, and are classed as No. 2 pavers, and used for the foundation or the flat course in paving. Beneath the No. 2 pavers are from one to six courses of brick which have not received heat enough to be able to withstand the frost, and are called "builders," as they are about equivalent in strength, hardness and porosity to hard burned building brick.

Field of No. 1 Pavers.

With a fire clay, it is possible to produce 90 per cent. of No. 1 pavers, as there is no risk from overfiring, though 80 per cent. is a high average. With shale, one sees frequent claims by patent kiln venders of 90 per cent. of No. 1 pavers, but such a very high percentage is rarely attained, with careful grading, while 80 per cent. is a high yield, or much above the average, and most yards do not get as high as 70 per cent. of strictly first-class or No. 1 pavers.

PHYSICAL QUALITIES OF PAVING BRICK.

COLOR.—The color of paving brick is no criterion for comparing brick made from different clays, as clays vary so greatly in kind and degree of color. Usually the impure fire clays give different shades of buff, while the shales give reds and browns. For a given clay the color is a reliable guide as to the heat a clay has received if it is burned under the same conditions, and the higher the heat, the darker a clay will be; but if the mode of firing the kiln is changed, as from an oxidizing to a reducing action, the clay will be made dark in consequence of this reducing action on the iron, and not by the heat; or a change in the fuel, as from oil or gas to coal, will usually result in a change in the color at the usual heat for this same reason. Uniformity of color on breaking the brick is a valuable guide in checking the work of the burner, as a black center in a red brick shows faulty firing, while a light colored center shows insufficient time in holding the heat. The outside color of the brick is often compromised and made valueless as a guide by the sand that is employed to prevent sticking in the kiln, or by fire flashing when using coal that is high in sulphur.

Uniformity.

Some of the Ohio valley manufacturers resort to the trick of salt glazing the brick, which gives a dark gloss to the outside that is very attractive to the superficial observer, but totally defeats using the color test unless the brick is broken. This salt glazing has been the cause of many soft brick escaping the inspector's eye, and poor pavements have resulted, but the practice is fortunately becoming obsolete, as the glazing is only skin deep and soon wears off, while inspection at the kiln can prevent the palming off of underburned brick.

Salt Glazing.

STRUCTURE.—The structure of the brick, as regards its vitrification and homogeneity, are determined by the fracture on breaking the brick, as it is impossible to determine these vital questions from an exterior inspection. The vitrification should be thorough to the center, and free from large spots of unfused matter, which indicate sand* (quartz) or fire clay*; or very glassy or spongy spots, which show imperfect crushing and mixing of a more fusible mineral in the clay. The structure should be uniform, devoid of air checks, and free from shakes or marked laminations, especially if they are accompanied by air pockets. The edges should be free from "ragging," or serrations, arising from obstructions in the die, and the "kiln marks" or impressions from the overlying brick in burning should not exceed one-fifth inch in depth. The shape should be reasonably perfect

Homogeneity.

*These sand spots are usually due to mixing surface clays with the shale or from imperfect stripping, while fire clay seams sometimes occur in the shales.

Variations in Size.

and free from marked warping or distortion. Slight variations in the size of the brick may be due to the wear of the die, variations in the shrinkage if the clay is not uniform or hard burned, or to irregularities in the cutting table, if in length. The latter is of no importance, and if the former are moderate they are of no consequence unless due to underburning, which is quickly discovered on breaking. If these variations do not interfere with the close laying of the brick, and the quality is otherwise satisfactory, they can be overlooked; but snug, close laying is essential to insure the durability of the pavement, and any warping or variation that prevents this should cause the rejection of the brick.

HARDNESS.—The hardness of a paver is the property which enables it to successfully withstand the wear of the wagon tire, especially when the brake is applied, and the slipping of the horses' hoofs. Next to toughness or freedom from chipping, it is the most important requisite of a good paving brick. Though its great importance is recognized by engineers, and the inspector is ever alert for soft brick, yet an actual determination is rarely made, and then by the very imperfect grinding test, which is mainly a question of toughness rather than hardness or interpenetration. An indirect estimate of it is obtained by the absorption test, as a well vitrified brick is bound to be very hard, and hence a very low absorption standard will insure hard brick. But it is too important a matter to be arrived at indirectly, especially as very hard, excellent brick are found with 3 to 5 per cent. absorptions, and the writer suggests the use of Moh's scale

Testing.

of hardness as a simple, quick, inexpensive way of arriving at the hardness.

POROSITY.—The porosity of a paver is an excellent index of the degree of vitrification, as if sound and perfectly vitrified, it is almost non-porous. This porosity is measured by the amount of water the brick will absorb when soaked in water for 24 hours. The porosity is misapplied by many engineers as a critical index of the ability of the brick to withstand the action of frost, and amusing arbitrary lines are drawn, usually at 2 per cent, as to the maximum porosity that is permissible, often requiring less than many well-known building stones. This idea would be well founded if non-vitrified brick were used, which are not only very porous, but so lacking in strength as to be unable to withstand the disintegrating action of frost. As all paving brick are porous, to at least a degree, it is a question whether the disrupting action of the freezing water exceeds the strength of the brick; if the resistance of the brick exceeds the rupturing action of the crystallizing water, the latter will do the yielding, if it freezes, and it is immaterial how porous it is. Now vitrified brick, whether only incipiently vitrified, as in the impure fire clays, or completely, as in the shales, has a strength that greatly exceeds the disrupting action of frost, as shown by experience and tests*; hence, if the brick is vitrified and has the strength that usually ac-

Misapplied as a Frost Test.

*Mr. A. D. Thompson, the city engineer of Peoria, Ill., has recently made a very interesting series of freezing tests on hard and soft pavers, which show no effect whatever on hard brick, though disintegrating the soft brick.

companies vitrification, there is no fear of frost disintegration, and this test should be used for its more restricted but still high value, as an expression of the degree of vitrification. So while the generally accepted rule that the less the absorption the better the brick is true, up to a certain limit (or about 0.5 per cent), a brick should not be condemned which otherwise gives satisfactory tests, especially if in the rattler, as is now done by many engineers, because it absorbs 2 per cent or more of moisture. Most of the impure fire clay pavers rarely absorb as little as 2.5 per cent, and often over 5 per cent, yet they have been in successful use for upwards of twelve years without being affected by frost. Th oldest paving brick in this country, at Charleston, W. Va., which are still in fair condition after twenty-two years' service, absorb 4.5 per cent of water in twenty-four hours, and are only hard-burned building brick, and made from a common though excellent clay. The Bloomington, Ill., brick that are being renewed this year (1895), after twenty years' service on their principal street, absorb 4.33 per cent, yet they show no signs whatever of frost action, though they have lost from one to one and a half inches from the top surface by wear, and are very rough, hand-made, "slop," or soft mud, building brick, made from a very poor, highly calcareous, glacial clay. The Sattler brick, a hand-made, fire clay 9x4x5 block, absorbs 5.5 per cent, yet they successfully withstood the heaviest traffic of St. Louis, at the entrance of the Missouri Pacific railroad freight yard, for seven years.

Usual Absorption.

The No. 1 shale pavers usually show less than 2 per cent absorption, and if carefully made, less than 1 per cent ; yet some of these almost non-absorbent shale brick are inferior in toughness and durability to the more porous fire clay pavers. An absorption of less than 0.5 per cent is apt to indicate brittleness, unless unusual care is taken in the annealing, and the best shale pavers range from 0.75 to 1.5.

DENSITY.—Density is a desirable factor in paving brick, as, other things being equal, the denser the better, from the greater quantity of wearing material in a given space. The density is obtained by taking the specific gravity, or else the weight of a given size or a thousand. As different makers vary in the size of their bricks, it is dangerous to arrive at the relative densities by comparing the weights of a thousand brick, unless they are known to be of the same size; usually standard size unrepressed brick weigh about 6,000 and repressed about 7,000 pounds per thousand. The specific gravity of a brick usually approximates that of the clay from which it is made, as the reduction in size from shrinkage is about offset by the loss in combined water. The shales range from 2.15 to 2.55 and average about 2.38 in specific gravity. The Coal Measure fire clays, whether pure or impure, range from 2.20 to 2.55 and average about 2.40; the Mesozoic, or more recent fire and potters' clays, are lighter and range from 1.90 to 1.22 in specific gravity. The shale brick range from 2.05 to 2.55, and generally vary from 2.20 to 2.40. The impure fire clay brick, not having had the fire shrinkage completed, are usually lighter, or range

Density of Clays.

from 1.95 to 2.30, and generally vary from 2.10 to 2.25.

While a given clay will vary in density according to the amount of burning and the consequent shrinkage, this porosity, in consequence of not completing the shrinkage, must not be confused with the specific gravity, as the latter is primarily the individual weight of the molecules, and if two clays have been equally burned, the density will be the relative weights of their molecules. If, however, the density has been unequally modified by difference in burning, then the porosity, as measured by the absorption, will have to be considered in arriving at an accurate idea of the density, though this can be ignored in vitrified brick as being too small for practical consideration.

Slight Value as a Guide.

CRUSHING STRENGTH.—This property is very interesting as a matter of general information, especially as it shows that well vitrified brick sustain the greatest pressure known, outside of the metals;* but as a factor in the use of brick for paving it is not of much importance, as the poorest specimens greatly exceed the heaviest load that ever comes upon them, for vitrified brick never fail by crushing, and Professor Baker regards this test as worthless.** It is a test that is usually required by the engineer, however, but more as a matter of custom than intelligent consideration, as the time would be more profitably expended in more thorough and elaborate

*Tests at St. Louis, Cincinnati, Boston, Washington, Buda-Pesth, Berlin and other places have repeatedly shown the crushing strength of vitrified brick to be much greater than granite.

**"Brick Pavements."—p. 8.

tests of toughness and hardness, which are the desiderata for paving purposes. The highest crushing strength is given by the overburned brick, which are almost always too brittle to wear well, and hence mislead if guided by this test only. Paving brick vary greatly in crushing resistance, though the very wide differences that one sees in print are more usually due to the difference in the mode of testing or to the selection of the samples.* Reliable samples show ranges as great as 4,000 to 30,000 pounds to the square inch, and the extreme variations are found in the shale brick, which are conspicuous as being the best and the worst kinds of pavers, according to the clay, in other tests also; they usually range from 10,000 to 20,000. The impure fire clay pavers show less variation, or range from 6,000 to 14,000, and usually from 8,000 to 12,000 pounds to the square inch.

Range in Strength.

CROSS-BREAKING STRENGTH.—This test, which is also known as the modulus of rupture, is of greater value than the crushing test in discussing paving brick, as the methods of testing differ but slightly, and it is conceivable that this determination may be of direct value where the brick have a very poor foundation. Still as brick are actually laid and used, they rarely break unless worn out, and like the crushing test, too high a value is given to it by engineers. It is preferable to the crushing test as a guide, as it introduces the question of tensile strength, which is an important func-

*Some tests to be found in the current press are self-evident cases of juggling, as they have undoubtedly been selected from the worst samples of rival brickmakers, a too common method of carrying on commercial warfare.

tion of the toughness. The cross-breaking strength ranges from 1,000 to 3,300, and usually amounts to 2,000 to 3,000 pounds per square inch of cross section, as tested between supports set six inches apart and loaded in the middle.

TOUGHNESS.—This is the crucial test of a paving brick, and greatly exceeds in importance all the other tests combined. This is pre-eminently the test that will show whether a brick will prove satisfactory in practice, and which of two or more samples will be the more enduring. For this test directly recognizes the severe factor that chips and shatters the brick, or the blows of the calks of the horses' hoofs, and the bump and abrasion of the wagon tire. It is the nearest approach, concentrated in a few minutes, of the treatment that a brick receives from traffic. If this test is satisfactory, no fear need be felt as to the results in practice, no matter how unsatisfactory the other tests may be. Although this test is always made with a foundry rattler, unfortunately no two engineers conduct the test alike, so that results by different parties are very dangerous to compare, and until some uniform method of conducting this test is adopted, it is safer not to make comparisons of different authorities.

The Rattler.

The test is made by putting several brick in a rattler, or revolving iron barrel, with more or less scrap iron, and sometimes with so-called standard pieces of granite. The rattler is then revolved at speeds that vary with each engineer, and for variable times. The result of the impact and abrasion of the brick and iron on each other is to rapidly wear off the angles and edges, and to knock off chips, if brittle; and this loss, expressed in percentages of the original weight, gives the rattler loss, which is the best guide yet obtained to determine the wearing quality of a brick. While this is the general method of carrying out this test, the results will greatly vary with the size, speed and time in the rattler; with the amount, kind and number of pieces of scrap iron and granite employed; whether hung on trunnions or a shaft; with the size, dryness and number of brick in the test, and with the character of the lining of the rattler. Thus Prof. Baker has shown that granites vary as much as 600 per cent in the loss sustained in the rattler, while different kinds of scrap iron and steel are liable to vary still more in their relative loss and therefore abrasive action on the brick. This confusion is so great, and leads to such variation in the results, that at last a committee has been formed by the National Brickmakers' Asssociation to adopt a standard method of carrying out this very important test. As tentative results, it may be mentioned that vitrified brick show a loss of 1.6 to 35 per cent, usually from 5 to 15 per cent, while granite, under similar circumstances, suffers a loss of 2 to 13 per cent, and usually from 3 to 5 per cent. It is worthy of notice that in a few instances, where granite and brick were tested side by side, some of the brick were tougher than the granite, which speaks volumes for the future, and shows that, with more care in manufacture, this excellent pavement can be safely used for the severest traffic. In tests made in Boston*, on eighteen different samples of pav-

Usual Loss.

*"Engineering News," June 2, 1892.

ing brick with granite in the same rattler, five of the brick showed a smaller loss than the granite. Tests made at Cornell University** on twenty-five samples, representing seventeen different makers of brick, with trap (a tougher rock than granite) as the standard of comparison or 1.00, a shale brick showed a loss of only 0.87, and a thoroughly vitrified fire clay brick showed a loss of only 1.66, while the others ranged from 3.31 to 17.18, and averaged 8.3.

Influence of the Corners.

When square-cornered brick are tested with those with rounded corners, the former show a much greater loss, as the sharp angles break off readily. This, however, is just what happens in practice, and is a fair comparison as regards brick to brick, but is unfair as a test of the clays, as they should have similar corners to give a reliable comparison. Prof. Baker's tests show that square-cornered brick lose about as much in the first half hour as in the subsequent hour, and he advocates rattling the brick for an hour, before the test, to wear off the edges and angles; this is very objectionable, as brick are expected to hold their edges and angles in service, and not wear to a cobblestone; and if they are not tough enough to do this, the rattler test should be so conducted as to bring out this information.

METHOD OF TESTING PAVING BRICK.

EYE EXAMINATION.—There is no more satisfactory method of arriving at the merits of a paving brick than by the trained, experienced eye, when assisted by the free use of a

**"Engineering News," April 18, 1895.

hand hammer. A critical examination by the eye and hand hammer, combined with proper experience, can usually detect the pros and cons of a brick as well as an elaborate series of tests, and in a few minutes while the laboratory tests take hours. But unfortunately the English vocabulary is too limited to make the nice distinctions that is possible to the trained eye, and it admits of no satisfactory standards if a numerical evaluation is attempted. As in most expert work, it is a personal decision that is founded on good judgment, training, and experience that cannot be transferred, and while it leaves little to be desired when backed by integrity for the numerous and rapid decisions of municipal engineering, it is testimony that can be besmirched and impugned when attacked by unprincipled self-interests, unless sustained by a cyclopean reputation. As it is only the limited few whose reputation can overwhelm malignant inuendoes, and as specific figures are required for general use, a series of tests have been devised which admit of general application and enable definite standards to be attained and lived up to. The necessity of such definite figures is so well recognized that there are not only numerous testing laboratories scattered all over the country, but city engineering department laboratories are being organized to frequently and rapidly furnish specific information when differences of opinion arise between the contractor and inspector about the quality of brick. At present the inspection of the brick is carried on at the work in the street, when about to be laid, and the condemned brick are a serious expense to the contractor, who is often an innocent sufferer,

Necessity of Tests.

and are a menace to the vigilance of the inspector, as they have a curious way of disappearing around the corner and reappearing laid in the street. The proper place to inspect the brick is at the kiln, where it can be much more rapidly, easily and safely made, and where there is no such strong incentive to smuggle condemned brick into the work. For even if the work is done under a maintenance bond, the contractor is usually willing to take risks as to the durability of questionable brick that the cautious engineer would not entertain.

Inspection should be at the Kiln.

LABORATORY TESTS.—The tests that are usually relied on to determine the merits of a paving brick are:

I. Density, or specific gravity.
II. Absorption, or porosity.
III. Crushing strength.
IV. Cross-breaking strength.
V. Hardness.
VI. Rattler test.

The determination of the crushing and cross-breaking strengths requires a large testing machine of at least 150,000 pounds capacity, which is expensive and usually to be found in only well-equipped testing laboratories. But every city and brick plant should have a balance ($5 to $35), hardness scale (50c), and rattler ($25 to $80), with which to make the other tests, which are the most important, and only require a moderate outlay if power is available for running the rattler.

DENSITY.—The density or specific gravity test is made on half brick or chips after they have been soaked in water for twenty-four hours to fill the air spaces. A whole brick should not be used, as the water cannot usually penetrate into the voids in twenty-four hours when the skin surface is sound and the brick is vitrified. It is preferable to take only a small fragment and weigh accurately on a chemist's* balance to 1 in 10,000, rather than attempt to obtain it by using a half brick and a druggist's scales, as usually employed, which only weigh to about 1 in 300. The density is calculated by the formula:

$$D = \frac{W}{W' - W''}$$

in which D = the specific gravity in terms of water.
W = weight in air before soaking.
W′ = " " " after "
W″ = " " water after "

ABSORPTION TEST.—The absorption test, to determine the relative porosity of a brick, which is so valuable as indicating the degree of vitrification, is made in several different ways, and published results are by no means concordant in consequence. It is obtained by immersing the brick in water for more or less time, and determining the increase in weight resulting therefrom. The brick is not always dried before immersion, nor always wiped dry thereafter, while the length of time in water varies from half to seven days. Some take a whole brick and others only half a brick, which latter introduces the independent questions of laminations and air

Variations in Testing.

*Excellent balances for this purpose are sold by the chemical dealers for $15 to $35.

spaces. The latter are very important matters, but their effect is better shown in the crushing and breaking tests, and as this is solely to show the porosity, this test should be made on a sound, whole brick, unless a chip is taken as suggested below. While the length of exposure is arbitrary, experiment shows that twenty-four hours is necessary to approximately fill up the pores, after which the brick very slowly increases in weight for weeks. As such a long time is prohibitory and unnecessary, I would suggest that twenty-four hours be accepted as the standard time for soaking, previous to which the brick should be thoroughly dried at 212 degrees F. or higher (unless taken fresh from the kiln), and that after the twenty-four hours' exposure in water they be wiped perfectly dry with a towel before weighing. The difference between the weights before and after immersion, divided by the former, gives the percentage of absorption or porosity, expressed in its own weight, or:

24 Hour Standard.

$$P = \frac{W' - W}{W}$$

in which W = weight before immersion.
W' = " after "
P = porosity.

While it is the custom to take a whole brick for this test and use a druggist's balance, it is much quicker and more accurate to take small, sound chips, which can be thoroughly dried in a few hours, and weigh with a chemist's balance. This is far more reliable, satisfactory and quicker, as it is never certain when a large brick is thoroughly dried out, unless exposed at a heat above 212 degrees F. for several days.

If the brick are salt glazed, a practice that is still carried on to some extent in Ohio, a chip should always be taken, as such brick are practically impervious to water if the skin is unbroken. But as the glazed surface soon wears off in service, when the water gets access to the interior, the brick should be tested so as to give the porosity of the body of the brick, as that is what will have to stand the wear. Hence a fragment should be used, for this test, which eliminates the short-lived skin surface.

Salt Glazing.

To show that the absorption test gives only relative values, and never absolute, and to emphasize the importance of adopting a standard period for soaking the brick, the following tests are given, which clearly show the absurdity of trying to saturate a brick in a 24, 48 or 188 hours' test.

Tests of Absorption.

These tests are selected from a series made on chips from brick representing all kinds of clays, and show a much more rapid rate of absorption than would have been exhibited by whole brick. For the thinner the chip, the more rapid was found to be rate of absorption (or drying), as would naturally be expected, but with the size of chips used, or from one-fourth to one inch in thickness, this did not show materially until after one day's soaking. If these chips, with an average thickness of half an inch, required over eight weeks to saturate them, the time required for the water to entirely penetrate a brick from five to six times as thick must be very much longer.

The saturated samples were allowed to air-dry in a room protected from wind and sun, with a temperature ranging from

80 to 90 degrees F., and found to lose their water at the rates shown in the table. The speed of drying will be largely a question of the dryness and temperature of the air, and hence will fluctuate greatly. They are added to show that brick slowly parts with its water, though more rapidly than it absorbs water, which should be remembered in drying brick before testing for absorption. This emphasizes the desirability of using fragments, and heating them over a heater, to quickly insure perfectly dry material on which to make the absorption test.

SPEED OF ABSORPTION.

TABLE SHOWING THE RATES OF ABSORPTION OF PAVING BRICK.

TIME.	Common Clay.		Fireclay.		Pure shale.	Shale and fireclay.
	Charleston.	Bloomington.	Sattler.	Mack.	Standard.	St. Louis
Ten hours......	....	....	5.37 %	....	....	....
Twenty hours..	....	....	5.48	....	....	....
Twenty-fo'r hs	4.40 %	4.33 %	....	3.35 %	0.44 %	0.62 %
Thirty hours..	....	....	5.49	....	....	....
Three days	....	....	5.54	....	....	....
Six days........	4.90	4.83	5.90	3.82	0.75	1.03
Twelve days. .	5.39	5.25	6.16	4.24	0.82	1.09
Twenty days..	5.58	5.41	6.37	4.58	0.96	1.16
Thirty days....	5.79	5.68	6.60	4.73	0.99	1.36
Forty days.....	....	....	6.93	....	1.03	1.37
Fifty days.... .	....	....	7.15	....	....	....
Sixty days.....	....	....	7.25	....	....	....

RATES OF DRYING.

TABLE SHOWING THE RATES OF DRYING* PAVING BRICK.

Zero hours.....	5.79 %	5.68 %	7.25 %	4.73 %	1.03 %	1.37 %
Fifteen hours .	1.75	1.20	1.73	0.34	0.40	0.52
Twenty-four hs	1.43	0.87	1.32	0.14	0.38	0.49
Thirty hours...	1.22	0.66	0.74	0.05	0.33	0 42
Forty-eight hrs	0.90	0.38	0.03	0.00	0.21	0.37
Six days....	0.09	0.00	0.00	0.00	0.18	0.18
Ten days.......	0.00	0.00	0.00	0.00	0.09	0.09

*Using the previous specimens, after being soaked to their respective maximum amounts as given before.

CRUSHING TEST.—The crushing resistance of brick is determined in such different ways as to give great variations in the reported values per square inch. They are tested as cubes, flatways and edgeways, after being trued up with a bedding of plaster of paris, blotting paper, and by grinding. While the test is not necessary for use in paving, as the crushing strength so greatly exceeds the load ever put on it, it is valuable for comparison, provided the tests are made in a similar manner. For Prof. Ira Baker found that the strength of a brick tested endways, edgeways and flatways was as 2 : 3 : 4, while the difference between an approximate or yielding bed, as blotting paper, plaster, wood, etc., and true-ground parallel beds was found by Prof. J. B. Johnson* to be 25 to 100 per cent. The method adopted by the latter authority is the best thus far devised for giving the true strength of the brick, and is well worthy of universal adoption. In Johnson's method the edges are ground perfectly

Variations in Testing.

*"Engineering News," April 18, 1895.

true and parallel, securing the latter by grinding one side as a datum, on a stone-polishing table, and then crushing the brick edgewise, after carefully aligning in the machine, which gives a height that is about double the width of the column under test, and is the way in which the brick is used in practice. The results obtained by this method are much higher, in consequence of the trueness of the crushing faces, which, though somewhat expensive to make (the stoneyards charging $1 per brick for grinding the faces), gives results that can be reliably compared.

CROSS - BREAKING STRENGTH. — The cross - breaking strength has been universally determined by supporting the brick between two steel knife edges set six inches apart, and applying the load in the center by another knife edge, all the edges being rounded. From this the modulus of rupture (R) is determined by:

$$R = \frac{3 W l}{2 b h^2}$$

in which W = breaking load in pounds.
l = length between supports.
b = breadth of brick.
h = height " "
R = modulus of rupture in pounds per square inch.

Recently Prof. Johnson* has proposed to place the supports seven inches apart, instead of six, and to compare the breaking load in terms of inch width, thus ignoring the size of the cross-section. His claims for this radical departure are that

*Ibid.

the modulus of rupture is not understood by practical men, nor does it do justice to deep brick. As this test is made by engineers for engineers, as brickmakers have a much quicker though inexpressible way of arriving at the merits of a brick by the trained eye and hammer, and as the standard method is a specific determination of the rupturing value of a square inch of the brick, the writer sees no justification for departing from a conventional definite statement for an indefinite one. For the object of the tests is to primarily give the value of a certain clay as made up into a given brick, and as no two clays are alike, and as the same clay may give very different results, according to how it is manipulated in manufacturing, the tests should aim to express solely the quality of the brick, and not also its quantity or size, which is what Prof. Johnson's method does. If the quality of clay is satisfactory but the size of a brick is not, the die and molds are easily changed, if the engineer prefers a deeper brick.

Objections to Johnson's Method.

HARDNESS.—The hardness has hitherto been rarely determined, and then by grinding the brick on a polishing table, and taking the amount ground off as a measure of the hardness. As this grinding action introduces the factor of toughness as well as hardness, it is a very unsatisfactory test, and is now seldom made. A simple, quick test that correctly gives the hardness is Moh's scale of hardness, which is the principal tool of the mineralogist. In this scale, which runs from No. 1 or talc, which can be readily scratched by the finger-nail, to No. 10 or the diamond, the hardest sub-

Moh's Scale.

stance known, only Nos. 6 and 7 interest the tester of paving brick, as brick are too soft for pavers that are not as hard as 6, and most pavers are between 6.5 and 7.0. No. 6 is feldspar, or the white to pink mineral that constitutes about 75 per cent of the granites, and No. 7 is quartz, the hardest of the common minerals, which is the colorless, glassy constituents of granites. In applying the tests, a sharp edge or angle should be tried on a smooth face of the object being tested, and a firm, strong pressure applied. Substances of equal hardness scratch each other with equal facility, while if there is a difference of 0.5, as, say, 6.0 and 6.5, the substance that is 6.5 will be barely scratched by the 6.0, but it will readily scratch 6.0; a substance that is 7.0 in hardness is not affected by 6.0, while it very readily scratches 6.0. Practice is needed to make fine distinctions, lacking which the determination should not be attempted closer than 0.5, and the white dust that results from the scratching should be rubbed off before deciding which is the harder substance.

Mode of Testing.

RATTLER TEST.—The abrasion or impact test, as the rattler test is also called, is decidedly the most valuable means of arriving at the durability and relative value of paving brick, but, as previously mentioned, nearly every engineer has a different way of carrying it out. As the rattler results are jointly dependent on the toughness, or the ability to stand shock, and the hardness, or the ability to withstand abrasion, it will depend on how the test is conducted as to which of these two factors is given the greater prominence. Now the hardness of a brick can be quickly and satisfactorily determined with pieces of quartz and very hard steel, and while the harder the brick the better, the most severe action on a paving brick in service, and what most quickly gets the pavement in bad condition if the brick are inferior (brittle or soft), is the blow of the horses' hoofs, especially of the toe-calks. Hence the rattler should be run to bring out this weakness, and as much impact as possible secured in running it. The speed should therefore be such as to carry the brick high enough up the sides of the rattler as it revolves to let them fall back (impact), and not slide back (abrasion), and the diameter should be large enough to permit the brick to fall and tumble over one another, while the number being tested should not be so great as to interfere with this falling and tumbling action. If cast iron or granite are used, they should be large pieces, to get a blow; but here the writer fails to indorse present rattler practice, and would allow nothing to be put into the rattler with the brick to be tested except enough standard brick to fill out the complement, if only a few are to be tested. For the character of the foreign matter added, whether scrap iron or granite, has such a marked influence, according to its size, shape, angularity and hardness, and it is so difficult to maintain uniformity in the conditions, as the pieces are continually wearing lighter, rounder and less wearing in their action, while duplication is so difficult, that the writer would omit them entirely, in order to make reliable comparisons. The tumbling, rolling and sliding of the brick over each other will be more than ample to compensate for the loss of the foreign matter by

Foreign Matter.

Standard Rattler.

running the rattler a little longer. As this method will need further testing before a standard size, speed, time and number of brick can be adopted, it is premature to specify such data; but experience suggests that the diameter be at least 30 inches, with a length of at least 36 inches; that the shape be polygonal; that the number of brick not exceed 25 per cent. of the volume of the rattler; that the speed be between 20 and 30 revolutions, and the test to continue for 1 to 2 hours. The rattler should be hung on trunions, and not have a shaft run through it, which endangers brick jamming between the shaft and shell; it should be perfectly horizontal, with large spaces between the staves (say one inch) to permit the prompt escape of the chips. Rattlers have been made of wood, cast iron and steel. Wood has the advantage of not polishing and being more uniform, which are two objectionable features in cast iron; bars of mild steel would be more durable, and perhaps as satisfactory as the wood, especially in not giving so much variation in diameter from wear. A committee of the National Brickmakers' Association is now considering a standard system of tests, and the fruit of their labor is anxiously awaited.

"Fillers."

As there are liable to be times when only a few brick are to be tested, a stock of standard brick should be kept on hand of the best kind available, and the requisite number taken to fill out the full complement for a test. These standard brick could be selected by a maker with considerable confidence as to their uniformity, and if the trouble is taken to burn the last kiln of the season for this purpose, when the kiln can be shut perfectly tight and allowed to cool for weeks, a stock could be obtained of many thousand that could be sent all over the country. Such carefully made and selected brick are apt to be more uniform than granite or any natural stone, with their defects from quarrying, tooling, joints, decay, and lack of homogenity, and decidedely more so than iron or steel standards, unless the latter conform to strict physical and chemical specifications. Such a method of conducting the rattler test would give harmonious results that could be duplicated at any time or place, and on which comparisons could be safely made.

EVALUATION OF THE RESULTS.—The final deduction to be drawn from these different tests, and the weighing of their respective values, is a subject that is now under active discussion, and a standard rule or formula is urgently needed. The attempts thus far made are all open to serious objections, and it is still premature to settle on a final value for the coefficients or factors until a standard method of making the tests is adopted; the writer therefore offers the subsequent formulae as a guide for framing such a standard, rather than for its intrinsic merit.

Baker's Method.

One of the earliest authorities to discuss this matter was Prof. Ira Baker, who, in a valuable pamphlet entitled "Brick Pavements," published* in 1891, puts an equal value on transverse-strength, absorption and rattler tests; he regards the crushing test as worthless, while he erroneously confuses absorption and density as both being represented by the porosity.

*By the Clay-Worker, Indianapolis, Ind.

St. Louis Methods.

The Board of Public Improvements of St. Louis, through a special committee,* adopted formula I, while Prof. J. B. Johnson** devised formula II for arriving at V, or the comparative value of paving brick:

$$V = \frac{10}{R\,G} + \frac{1}{4\,A} + \frac{T'}{2000} + \frac{C}{4000} \quad \text{--- I.}$$

$$V = (25-R) + (3-A) + \frac{T'}{1000} + \frac{C}{4000} \quad \text{--- II.}$$

in which V = an arbitrary comparative rating.
R G = rattler loss in terms of granite.
R = rattler loss in percentage of the weight of the brick.
A = absorption in percent of the total " " " ".
T′ = transverse strength per inch width.
C = crushing strength per square inch.

Both of these are based on tests made by Prof. Johnson for the city of St. Louis on samples that were sent by seven manufacturers.

In formula I each factor appears as a multiple (or divisor), and is therefore more sensitive to variations than II, in which only two so appear. The rattler loss is based on the very objectionable granite rating in I, or a variable unit, while in both the transverse strength is rated in terms per inch width of the brick on a seven-inch span, while the modulus of rupture per inch of cross-section has been the universal and the more valuable unit, on a six-inch span. The hardness and density is also ignored in each, though the former is the most vital

*"Engineering News," July 26, 1894.
**"Engineering News," April 18, 1895.

factor of durability, excepting toughness, and should certainly be considered.

Wheeler's Method.

The writer therefore suggests the following to overcome these objections, and as only four factors have thus far been usually given, formula III is for such incomplete data, while formula IV is the proper one to use if all six factors are given:

$$V = (18-R)\,6 + (7-A)\,4 + \frac{T}{220} + \frac{C}{1000} \quad \text{--- III.}$$

$$V = (18-R)\,5 + (7-A)\,2 + \frac{T}{220} + \frac{C}{1000} + \frac{10}{3.25-D} + \frac{10}{7.5-H} \quad \text{--- IV.}$$

in which V = as before.
R = " "
A = " "
C = " "
T = Modulus of rupture per square inch.
D = Specific gravity.
H = Hardness by Moh's scale.

To show the application of formula IV, and its great convenience in comparing brick of nearly equal value, the following example is given, which is based on two shale brick of superior quality and much above the average (or 100):

Brick.	Rattler Loss.	Absorption.	Tensile Strength.	Crushing Strength.	Density.	Hardness.
	Per cent.	Per cent.	Pounds.	Pounds.		
Purington	5.87	1.12	3,380	13,220	2.31	6.75
Standard	4.95	.55	2,460	15,460	2.41	6.75

When these values are substituted in IV the respective merits of the brick work out as follows:

$$\text{Purington} = (18-5.87)\,5 + (7-1.12)\,2 + \frac{3380}{220} + \frac{13220}{1000} + \frac{10}{3.25-2.31} + \frac{10}{7.5-6.75} = 124.7$$

$$\text{Standard} = (18-4.95)\,5 + (7-0.55)\,2 + \frac{2460}{220} + \frac{15460}{1000} + \frac{10}{3.25-2.41} + \frac{10}{7.5-6.75} = 130.1$$

Or their relative values are as 124.7 to 130.1.

In arriving at the relative weightings of each factor, the following mean values of the St. Louis series of tests are used, as formulae I and II are based on them:

R = 16.5 per cent.
R G = 4.7 " "
A = 1.25 " "
T′ = 3 300 pounds.
C = 13.000 "

In deducing mean values for III and IV a careful study was made of a large number of tests from all over the country, from which 262 were sifted out that seem to have been made with sufficient care on reliable samples as to be entitled to consideration, which gave the following:

R = 8.0 per cent.
A = 2.0 " "
T = 2,200 pounds.
C = 10.000 "
D = 2.25
H = 6.5

These average values will give a rating of 100 for an average brick, if tested in the usual manner.

—Comparison of the Weightings of the Factors.—

TEST.	*Baker.**	*I or B. P. L.*	*II or J. B. J.*	*III or H. A. W.*	*IV or H. A. W.*
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Rattler, R....	1.0 = 33.3	2.1 (R G) = 30	8.5 = 50	60 = 60	50 = 50
Absorption..	1.0 = 33.3	0.2 = 2.5	1.75 = 10	20 = 20	10 = 10
Transverse Strength, T	1.0 = 33 3	1.65 (T′) = 23	3.30 (T′) = 20	10 = 10	10 = 10
Crushing Strength, C	....	3.25 = 44.5	3.25 = 20	10 = 10	10 = 10
Density, D...	....	0 = 0	0 = 0	....	10 = 10
Hardness, H	....	0 = 0	0 = 0	....	10 = 10
Totals.........	3.0 = 100	7.20 = 100	16.8 = 100	100 = 100	100 = 100

Importance of the Rattler Test.

In arriving at this weighting, the writer has placed a value on the rattler test equal to all the others combined, as this so nearly duplicates the impact and abrasion that the bricks receive in the streets, only the severity of the test is so great that an hour's tumbling in the rattler is equivalent to years of service in a pavement. If a brick satisfactorily meets this se-

* "Brick Pavements," the Clay-Worker, 1891.

vere test no fear need be felt in using such a brick, no matter whether the evidence of the other tests is favorable or not. The other factors give evidence that is valuable, but none of them can be used alone or collectively, as the question of toughness is only satisfactorily shown in the rattler test. They are given equal value by the writer until more thorough tests have been made, except when only four factors are given, when a double value is put on the absorption, as this is then the only exponent of the hardness, density and porosity.

UNIFORMITY OF RESULTS.—In testing brick at least five specimens of each lot or kind should be tested, and preferably ten, and the results averaged for use in the formula. If the samples are taken from different kiln runs and made at different times, it adds greatly to their reliability if the individual tests closely agree; but if the results vary greatly, such a clay is open to suspicion until careful resampling and testing shows whether it is due to careless sorting or to manufacture.

Variations in Paving Brick.

The best brick vary from 15 to 30 per cent. in the tests, while inferior brick exceed 50 per cent, and this range is a very valuable check on the care in making the brick, and on the sorting in loading. To illustrate the variations that usually occur in testing paving brick, the following table gives results obtained by Prof. Johnson on samples furnished by the manufacturer to the city of St. Louis:

SUMMER 1894.

Name of Brick.	No. Tests.	Cross-break per sq. inch. Extremes, Pounds.	Cross-break per sq. inch. Average, Pounds.	Crushing per sq. inch. Extremes, Pounds.	Crushing per sq. inch. Average, Pounds.	Rattler. Time in Rattler Hours.	Rattler. Brick. Extremes, Per cent.	Rattler. Brick. Average, Per cent.	Rattler. Granite. Extremes, Per cent.	Rattler. Granite. Average, Per cent.	Ratio Brick to Granite.	Absorption in 24 hours. Extremes, Per cent.	Absorption in 24 hours. Average Per cent.
*Mack Brick Co., New Cumberland, W. Va. Repressed Fire Clay.	5	2,259 to 3,707	2,959	10,200 to over 14,000	12,000	½	12.00 to 21.40	15.10	2.6 to 4.8	(20) 3.6	420	3.1 to 3.7	3.40
Purington, Galesburg, Ill.	5	2,860 to 3,688	3,112	Not b'ken	16,770	½	12.30 to 14.80	14.30	4.82 to 12.9	do.	400	0.91 to 1.60	1.05
Terra Cotta Co., Galesburg, Ill.	5	994 to 3,851	2,646	13,540 to 23,920	18,730	½	11.20 to 31.60	19.78	do.	do.	549	0.36 to 1.16	0.63
Wabash Clay Co., Veedersburg, Ind.	5	2,427 to 3,755	3,097	13,150	12,490	½	7.99 to 13.61	11.03	do.	do.	307	0.90 to 1.35	1.12
Alton Paving Brick Co., Alton, Ill.	5	1,935 to 3,377	2,690	8,424 to 19,490	(9) 12,580	½	16.13 to 34.46	(8) 22.50	do.	do.	653	0.60 to 1.11	0.88
St. Louis Press Brick Co., Glen Carbon, Ill	5	1,855 to 3,112	2,421	12,300 to over 20,000	13,190	½	12.57 to 32.00	19.75	do.	do.	549	0.20 to 0.62	0.33
Moberly Brick Co., Moberly, Mo.	6	2,586 to 3,314	3,029	9,730 to 18,440	15,360	½	13.00 to 24.00	16.30	3.4 to 5.6	(5) 4.1	400	1.47 to 3.51	2.80
Gaffney Brick Co., Atchison, Kan.	5	2,580 to 4,475	3,185	16,590 to 28,400	20,183	½		26.67	4.82 to 12.9	3.6	741	0.23 to 0.58	0.55
St. Joseph Press Brick Co., St. Joseph, Mo.	6	2,236 to 4,531	3,214	5,740 to 15,580	11,255	¼	7.50 to 10.40	8.70	2.1 to 2.3	2.2	395	0.89 to 1.88	1.49
New Philadelphia, Kansas.	6	1,233 to 2,864	2,389	9,900 to 18,330	13,300	½	8.40 to 28.50	15.30	4.4 to 6.1	(5) 5.0	310	2.03 to 3.81	2.92
Ottumwa Press Brick Co., Otumwa, Ia.	2	1,678 to 2,430	1,960	7,435 to 9,820	8,600	½	5.00 to 23.40	14.50	2.0 to 2.8	(3) 2.3	420	3.4	3.40

*Note.—These are all shale brick except the Mack. † Average of tests.

VALUE OF THE RATING FORMULA.—The great value of a rating formula for deducing a specific comparative value of each brick (provided it is properly weighted and correctly designed) is well shown by the following example, which is based on tests made by Prof. Johnson for the city of St. Louis.

TABLE SHOWING COMPARATIVE RAT

BRICK.	WABASH, Veedersburg, Ind.				MACK REPRESSED, N. Cumberland, W. Va.				PURINGTON, Galesburg, Ill.			
	Test.	I	II	III	Test.	I	II	III	Test.	I	II	III
Rattler loss, R	11.04 %	......	......	......	15.10 %	......	......	......	14.34 %	......	......	......
Rattler loss in granite, R. G	3.07	......	......	......	3.88	......	......	......	3.98	......	......	......
Ratings	....	3.26	13.96	41.80	....	2.58	9.90	17.40	....	2.51	10.66	22.00
Absorption, A	1.12 %	......	......	......	3.40 %	......	......	......	1.12 %	......	......	......
Ratings	....	0.22	1.88	23.50	....	0.07	-0.40	14.40	....	0.22	1.88	23.50
Transverse, per inch width, T	3,870 lb	......	......	......	4,190 lb	......	......	......	3,380 lb	......	......	......
Ratings	....	1.93	3.87	17.60	....	2.09	4.19	19.00	....	1.69	3.38	15.40
Crushing, per square inch, C	12.490 lb	......	......	......	12,090 lb	......	......	......	13,220 lb	......	......	......
Ratings	....	3.12	3.12	12.50	....	3.02	3.02	12.10	....	3.30	3.30	13.20
Totals	....	8.53	22.83	95.40	....	7.76	17.51	62.90	....	7.72	19.22	74.10
Percentage ratings*	....	100.	100.	100.	....	90.	77.	66.	....	89.	84.	78.

*The "Wabash" is taken as the

The following seven brick were candidates for consideration by the city authorities, and after averaging the results of five tests on each brick the following ratings were calculated by formulae I, II and III, which are herewith shown side by side, in order to bring out their respective merits:

INGS OF FORMULÆ I, II AND III.

Terra Cotta Co. Galesburg, Ill.				Moberly, Moberly, Mo.				St. Louis Press Brick Company. Glen Carbon, Ill.				Alton, Alton, Ill.			
Test.	I	II	III	Test.	I	II	III	Test.	I	II	III	Test.	I	II	III
19.78 %	......	......	......	16.42 %	......	.....	......	19.75 %	......	......	......	22.50 %	......	.....	......
5.32	......	......	......	4.56	......	......	......	5.11	......	......	......	7.37	......	......	......
....	1.88	5.22	-10.70	....	2.19	8.58	9.50	....	1.96	5.25	-10.50	....	1.36	2.50	-27.00
0.64 %	......	......	......	1.56 %	......	......	....	0.33 %	......	......	....	0.87 %	......	......	......
....	0.39	2 36	25.40	....	0.16	1.44	21.80	....	0.75	2.67	26.70	....	0.29	2.13	24.50
2,990 ℔	......	......	......	3,530 ℔	......	......	......	2,690 ℔	......	....	......	2,570 ℔	......	......	.....
....	1.50	3.00	13.60	....	1.76	3.53	16.00	....	1.34	2.69	12.20	....	1.28	2.57	11.70
14,650 ℔	......	......	......	13,020 ℔	......	......	......	13,190 ℔	......	....	......	11,660 ℔	......	......	......
....	3.66	3.66	14.70	....	3.25	3.25	13 00	....	3.30	3.30	13.20	....	2.92	2.92	11.70
....	7.43	14.24	42.00	....	7.36	16.80	60.30	....	7.35	13.91	41.60	....	5.85	10.12	20.90
....	87.	62.	44.	....	86.	74.	63.	....	86.	61.	43.	....	69.	44.	22.

unit for comparison, or as 100.

Notes on the Brick.

All of these brick are made from shale, except the "Mack," which is made from an impure fire clay. The "Wabash," "Mack," "Purington" and "Terra Cotta" brick are well known standard brands that have an excellent reputation and have been successfully used at many places. The "Moberly" is a local brick that is made from a superior shale, but the yard lacks kiln capacity, and the quality suffers in consequence. The "Glen Carbon" brick is made at a yard that was built for making press or building brick, which has recently attempted to make pavers; it uses the semi-dry process, and most of the kilns are open-top or up-draft, which permits only a small percentage to be made as good as those used in the test. The "Alton" is a new yard that is still experimenting on different clay mixtures, with the hope of trying to improve the sadly deficient quality.

Taking the "Wabash" as the unit, all the formulae agree in rating this as the best, and the "Alton" as the poorest; but formula I only finds a difference of 4 per cent. between the other five brick, though it is well known to the trade that there is a great difference between them, which is clearly shown by formula II, and still more keenly brought out by III.

As granite blocks were used in the rattler test, the rattler losses are much greater than usual, or when only light scrap iron is used, and this does not give a fair idea of the brick as judged by formula III, if compared with usual rattler losses (or 8.0 per cent.); but having all been made by the same expert in the same way, they are comparable with one another, and the ratings of formula II or III satisfactorily bring out their relative merits.

USES OF VITRIFIED BRICK.

In addition to the field for street paving, in which the cheapness and excellent quality of vitrified brick are going to make it a very formidable competitor of all other kinds of pavement, it has a special value for sewers, foundations, sidewalks, and chemical tanks.

SEWERS.—Vitrified brick is exceptionally adapted for sewers on account of its low absorption, great strength and extreme hardness, and it has been adopted by St. Louis for this purpose. The latter quality will enable it to withstand the severe scouring action of sand, which rapidly wears out common brick if there is much velocity to the flowing water. Where the sewer grades will permit it, there is a bright future in the street-cleaning departments of our large cities when the vitrified brick is used for both the pavement and sewers, as then they can be thoroughly, rapidly and very cheaply cleaned by the hydraulic system. At present this is usually prohibitory, as the present soft brick in the sewers would cut out too quickly, necessitating the expense of frequent rebottoming, while macadam will not stand it, asphalt is injured (both chemically and mechanically), and granite, though free from these objections, needs too much water and the assistance of brooms, on account of its rough surface. Under the hydraulic system the work can be done with a small hose crew, by means of coal power at the waterworks, instead of with the present

Street Cleaning.

large gangs of men and teams, and the cleaning will be very much more thorough than with the present imperfect street-sweepers. The demand for this extra water for hydraulicing would be made at night, when there is only a small consumption of water for other purposes.

FOUNDATIONS.—The low absorption and high crushing strength of vitrified brick make it an admirable material for foundations, especially in wet ground, for bridge piers or very high buildings. The heavy pressures that have to be sustained in the construction of the modern tall office buildings is especially favorable for vitrified brick, as it is not only stronger and very much cheaper than granite, but it effectually keeps out dampness. If the brick are hammer-dressed or "rock-faced" they make a very ornamental front that is becoming quite popular.

SIDEWALKS.—One of the earliest applications of vitrified brick was for sidewalks, as it is so very much more durable than the so-called "sidewalk" brick that are obtained from a building-brick kiln. The top course of pavers in a kiln are especially adapted for sidewalk use, as they are perfect in shape and free from kiln marks, and thoroughly vitrified. Their great strength enables them to be laid flat without danger of breaking, which happens so frequently with common brick.

CHEMICAL PURPOSES.—For lining vats or tanks for chemical purposes, vitrified brick is very valuable, as it is not attacked by acids or powerful chemicals, and so protects the tank from corrosion and the solutions from contamination.

STREET PAVING.—There is a very large field for vitrified brick for paving in our cities, towns and county turnpikes which is only beginning to be occupied. It has so many advantages, most prominent of which are low first cost and cheap maintenance, as to make it a very formidable rival to all other kinds of pavement, and to especially bring it within the means of small towns. With sufficient care in the manufacture, especially in the annealing, a brick can be made and laid to stand the heaviest traffic of our large cities, while for the very much lighter traffic of the small cities and towns the cost of making and laying can be greatly reduced.

COMPARISON OF STREET PAVING MATERIALS.

A prominent but hasty criticism that is frequently made against paving brick is their want of uniformity. While carelessness in manufacture and sorting may justify this, it should be remembered that this also holds true of all other pavements, as asphalt is very sensitive to the kind and manipulation of the materials that enter it; wood is very variable from decay, kind, age and position in tree; granite is eminently prone to weathering or softening, while the great variation in the hardness and durability of the macadam in St. Louis has cost it many friends. Of the different materials that are usually used for street paving—or cobble stones, macadam and telford, wood, asphalt, Belgian or stone blocks (usually granite), and brick—they will rate as follows in comparison with brick in the factors that make up a good pavement:

1. FIRST COST.—While local conditions greatly influence the relative costs, in most places in the United States brick is much cheaper than granite or asphalt, usually cheaper than

telford and wood, excepting at the lake cities, but not usually as cheap as macadam or cobble stone, where the latter is to be had in local quarries or gravel banks.

2. MAINTENANCE.*—The expense of repairs of good brick pavements, as determined from five to twenty-five years' experience, is much lower than any other pavement, excepting granite, and is much superior in this respect to asphalt and macadam, its present chief rivals.

3. TRACTION.—The ease of traction or haulage over brick, on account of the smoothness of the surface, exceeds that of any other pavement except asphalt, and Rudolph Hering gives the following relative estimate of the number of horses required to haul the same load on the following pavements:

Comparative Haulage of a Given Load on

Iron rails	1 horse.
Sheet asphalt	1 2-3 horses.
Brick	2¼ to 2¾ horses.
Granite blocks	3 1-3 to 5 horses.
Wood	5 to 6 horses.
Good macadam	8 horses.
Cobble stones	7 to 13 horses.
Ordinary earth	20 horses.
Sandy earth	40 horses.

4. FOOTING.—A sure, safe footing for horses and freedom from slipping is a very important requisite, which the joints of

*The cost of repairs in St. Louis per annum has been 11¢ per square for granite, 50c per square for wood, 50c per square for asphalt, 70c to $3.37 per square for macadam, and in one instance $9.40 where the traffic was heavy on limestone macadam.

brick insure, especially if the edges are rounded. This is the very weak point of asphalt, in which it is greatly inferior to all other pavements, especially when sprinkled or on grades. Square-cornered bricks can be used up to 6 per cent., and with well-rounded corners up to 10 per cent., or as high as granite; for grades steeper than 10 per cent. cobble stone has the preference.

5. DURABILITY.—The durability question is not only one of cheap maintenance, but also the temporary loss of the use of the street during the reconstruction or resurfacing, and this is a very weak point in macadam, wood and asphalt, while brick is only exceeded by granite in this respect. Wood has been condemned in St. Louis, as it only lasts from two to seven years, and has proved very difficult to keep in good repair in the interim.

6. CLEALINESS.—In the ease of keeping clean, brick stands second to asphalt, and if the hydraulic system is used, then it stands first, as the former will not successfully withstand this thorough and cheap method of cleaning.

7. REPAIRS.—Ease of repairs is important in cities, where the streets are constantly torn up to lay pipes, sewers, rails, wires, etc., and a city pavement should be elastic to permit this, without being seriously injured. Here cobble stones, brick and granite lead.

8. HEALTH.—In the freedom from the lodgement of filth and decaying matter, which is a serious defect in cobble stones, stone blocks, wood and macadam, brick is only exceeded by asphalt.

9. NOISE.—This is an important matter in cities, in which all the durable pavements are deficient. Wood is the ideal noiseless pavement, and the business men of London are willing to have their streets torn up every four to seven years to relay the short-lived wood, in order to get rid of the roar of heavy traffic on stone blocks. Macadam and telford are also very satisfactory as noiseless pavements, but they give too much trouble from dust and mud, unless maintained in an ideal condition of dampness that is very rarely realized, as they suffer as much from mud from so-called street sprinkling as from storms. Brick ranks next, as it is free from the sharp click of the horse's hoof that is so characteristic of asphalt. The dull, low rumble of stone blocks is only exceeded by the thundering of a lone, empty cart on a cobble stone pavement, which latter is so trying as to make it questionable whether the virgin dirt road, with its ills of mud and dust, is not more endurable to most of the citizens.

Blocks.

SIZE OF BRICK.—When the manufacture of vitrified brick for paving first became an established industry, the brickmakers patterned their work after granite blocks. They soon found that it was very difficult to insure thoroughness and uniformity in burning such large sizes, especially as the blunder was made, and to some extent is still perpetrated, of giving them an appearance of thorough vitrification by salt-glazing, and many brick pavements were justly condemned for the failure due to the soft brick that resulted. Against the protest of engineers, many manufacturers changed to the size of building brick, and the marked improvement in quality and

Common Size.

uniformity speaks for their good judgment, and has converted most engineers who have had much experience with paving brick. To-day the standard size is that of building brick, or about 8¼x4x2½ inches, and only a very small percentage (less than 10 per cent.) is made block size, or 9x4x3 inches or larger. There is a marked difference in the cost of making a standard and a block size brick, as the larger the size the greater the time and expense in drying and burning. There is a still greater difference in the market price, as the usual 25 per cent. of underburned brick can be sold to the building trade, if standard size, while there is practically no market for the soft blocks. Quality and cost, therefore, strongly emphasize the building brick size, while the reduced number of joints presented by the large size does not give as good footing to the horses.

Rounded Corners.

Formerly brick were made with square or but slightly rounded corners, but the sharp corner soon chips off under wear, and until so chipped it makes a poor footing for the horses, on account of the tightness of the joints. Brick are now made with rounded corners, using a radius of one-quarter to three-eighths inch, which makes a more durable brick and furnishes a much better footing. Of the few blocks that are still on the market, several of them are patented, by having various shaped grooves pressed into their flat sides to assist in holding the tar or other filling employed, and of these the Hallwood patent is one of the best known, which is made by several concerns on a royalty. These grooves are not found necessary if the brick are laid on a good foundation, and their

Grooves.

value is greater as a trade-mark than for their intrinsic merit for paving purposes.

FOUNDATIONS.—The success of any pavement depends primarily on a good foundation, and brick must have a good foundation if a smooth, durable pavement is desired. In the early experience of our brick pavements, the enthusiasm of the brick advocates went so far as to claim that brick would be satisfactory on any kind of a foundation, and very poor supports such as sand, plank, etc.) were put under some of the early pavements, with the disappointing results that were bound to follow. Engineers have been quick to see this and insist on a good foundation, if a good pavement is desired, so that a concrete base is now the standard foundation. The concrete is made eight inches thick for heavy traffic, six inches for moderate, and four inches for very light traffic. Where the travel will not bear the expense of concrete, broken stone, gravel, or cinders have been substituted, thereby saving the expense of the cement and mixing. A still cheaper foundation that has been largely used in the small cities and towns is to use a four to six-inch bed of sand, on which is laid a course of No. 2 pavers placed flatwise. Whether the foundation be concrete, gravel or brick, a cushion of sand is always used between it and the top course of brick, to take up the unevenness of the surface of the foundation and any irregularities in the brick. This sand cushion is usually two inches thick, but the writer thinks it should be reduced to one inch, as this is sufficient if the foundation is laid with care, and the thinner the cushion the less the risk of the brick settling or getting dis-

Concrete the Standard.

Sand Cushion.

placed in service. The top course of brick are laid on edge at right angles to the street, and at 45 degrees at intersections, and the joints between the brick are filled with cement grouting, tar, pitch or sand. A cement filling, if of Portland cement, binds the brick into a monolith, and gives the best results, as it is not affected by hot weather. Tar or pitch is also a good binder and filler, but it softens in hot weather, though this enables broken joints to reunite, which is not the case with cement. In either case the grouting or tar should be thin when applied, so that it can penetrate into the joints, which are usually only one-sixteenth to one-eighth inch wide. Sand filling is much cheaper, and permits the easy removal of the brick for pipe-laying, etc., and when once well worked in makes a solid pavement; but too frequently it is improperly applied by not having it perfectly dry and clean, when very little of it works into the cracks, no matter how persistently it is swept* over the surface. Before the filling is applied, the bricks are carefully rolled to a true, uniform surface with a heavy roller, after which any broken or chipped brick are replaced, and after the pavement is finally thrown open to traffic a half-inch layer of sand is left on top for a month or so, to insure thorough filling of the joints.

Filling.

DURABILITY.—It is still premature to discuss the durability of vitrified brick when properly made, as none of them have yet worn out, and the inferences deduced by experiments

*Unless the sand is perfectly dry, it is better to flush it in with water, rather than attempt to work it in with a broom by sweeping.

made to determine this question are not satisfactory. In looking over the accumulation of evidence since brick were first used, twenty-five years ago, instances are not lacking where the brick have been unsatisfactory. An investigation of these failures invariably shows at least one of three causes, to-wit: bad foundation, soft brick or brittle brick. If the foundation is faulty any pavement will fail; for the soft or brittle brick the manufacturer is primarily responsible in not properly handling his clay or not having a suitable clay (and the majority of clays will not make a good paver); but lack of proper inspection is responsible for allowing such brick to be laid. The cupidity and short-sightedness of the brickmaker is not always responsible for bad brick going into pavements, as the opposition of interests in conflict with brick have in more than one instance purposely secured the worst brick, in order to kill off the threatening rival by making the first impression as unfavorable as possible—a mode of warfare by no means unknown in large cities. Like everything else, there are all grades of paving brick in the market, and it costs more to make a good article than a poor one; and if low first cost is the first consideration, and quality is secondary, inferior pavements will result, as a strictly first-class, hard, tough, carefully selected brick cannot compete in price with soft, brittle and non-selected brick, though the former will make much the cheaper pavement when maintenance is considered.

Cause of Bad Brick Pavements.

The experience of the oldest users of paving brick is herewith given, which also covers a broad range in the location, clays, size, foundation and price:

The oldest brick pavement in use in this country is at Charleston, W. Va., where, after twenty-five years' service, the city engineer, Mr. W. A. Hogue, writes that it is now pretty well worn, after being frequently torn up for laying pipes, and that it is a hard-burned building brick.

Bloomington, Ill., is now replacing a very poor, hard-burned, hand-made "slop" or building brick, after twenty years' service on a four-inch cinder foundation.

Though both are small cities, these are remarkable records, considering the character of the brick, and strongly bespeak the durability of a thoroughly vitrified, annealed brick.

Wheeling, W. Va., has been using fire clay brick for twelve years on six inches of gravel, and the city engineer, Mr. A. L. White, reports it in good condition.

Galesburg, Ill., has used vitrified shale brick for eleven years on its principal streets, which are still in excellent condition, though not a dollar has been spent in repairs, according to the city engineer, Mr. M. J. Blanding.

Columbus, O., has used brick for ten years, which are reported in good condition, with small repairs, by Mr. Josiah Kinnear, the chief engineer.

Memphis, Tenn., has used brick for seven years with entire satisfaction and no repairs, per A. T. Bell, the city engineer.

The engineering department of the C., B. & Q. railroad adopted vitrified shale brick for paving the Chicago freight yards three years ago, and it has proved so satisfactory under this very severe traffic that it was adopted last year for their very extensive new St. Louis freight yards.

The writer is familiar with some hand-made fire clay blocks that were subjected to the heaviest traffic of St. Louis, or the entrance of the Missouri Pacific railroad freight yard, on

Seventh street, for seven years, with very favorable results, as the wear from the top surface amounted to only about one-quarter inch, yet these blocks were barely vitrified, and showed an absorption of 5.5 per cent of water in twenty-four hours.

EXPERIENCE OF THE OLDEST

As Reported by

CITY.	Years Used.	Population.	Traffic.	Results.	Kind.	Size.
Charlestown, W.Va.	25	12,000	Bus.*	Very satisfactory	Com. cl'y and shale	Brick.
Bloomington, Ill...	20	26,000	Bus.	Very satisfactory.	Common clay	Br'k and block.
Wheeling, W. Va....	12	36,000	Bus.	Very satisfactory.	Fire clay	Brick.
Decatur, Ill.........	12	27,000	Bus.	Very satisfactory.	Common clay.	Brick.
Galesburg, Ill.......	11	19,000	Bus.	Very satisfactory.	Shale.	Brick.
Peoria, Ill..........	10	60,000	Bus.	Very satisfactory.	Shale.	Br'k and block.
Columbus, Ohio....	10	120,000	Bus.	Satisfact'y	Sh'le and fireclay.	Block.
Zanesville, Ohio....	10	30,000	Bus.	Good.	Shale.	Block.
Steubenville, Ohio.	10	15,000	Bus.	Satisfact'y	Fire clay	Brick.
Burlington, Iowa...	8	30,000	Bus.	Very satisfactory.	Shale.	Brick.
Parkersburg, W. Va.	8	12,000	Bus.	Excellent	Sh'le and fireclay.	Block.
Philadelphia, Pa...	7	1,300,000	Res.†	Satisfact'y	Sh'le and fireclay.	Brick.
Memphis, Tenn. ...	7	70,000	Bus.	Very satisfactory.	Sh'le and fireclay.	Brick.
Des Moines, Iowa ..	7	80,000	Bus.	Very satisfact ry.	Shale.	Brick.
Omaha, Neb.......	5½	175,000	Bus.	Good.	Shale.	Brick.
Cincinnati, Ohio...	4	225,000	Res.	Fair.	Shale.	Brick.
Detroit, Mich.......	5	250,000	Bus.	Fair.	Sh'le and fireclay.	Br'k and block.
Louisville, Ky	4	205,000	Bus.	Very satisfactory.	Sh'le and fireclay.	Br'k and block.
Indianapolis, Ind..	3½	130,000	Bus.	Fair.	Sh'le and fireclay.	Br'k and block.

* Used on business streets.

The following table gives additional information obtained by addressing letters of inquiry to the city engineers of each place, and these cities were selected as giving the experience of the oldest users of paving brick:

LARGE CITIES WITH PAVING BRICK

the City Engineers.

Foundation.	Repairs.	Cost Per Sq. Yd.	REMARKS.	AUTHORITY.
Boards.	Slight.	....	Will stand heavy traffic.	W. A. Hogue.
4″ cinders.	Slight.	$1.25	Will stand heavy traffic.	W. P. Butler.
6″ gravel.	Slight.	1.00	Will stand heavy traffic.	A. L. White.
Flat brick.	Very slight.	1.50 to 1 60	....	G. V. Loring.
Flat brick	None.	1.35 to 1.60	Will stand heavy traffic.	M. J. Blanding.
6″ concrete and gravel.	Slight.	1.24 to 1.33	Will stand heavy traffic.	A. D. Thompson
8″ broken stone.	Slight.	1.40 to 1.60	Have over 70 miles.	Josiah Kinnear.
6″ grav'l and sand.	Slight.	.75 to 1.50	Will stand heavy traffic.	A. E. Howell.
Gravel.	None.	.67 to 1.19	....	J. M. [illegible]arclay.
Flat brick.	Very slight.	....	Will stand heavy tra c.	Wm. Steyh.
....	Very slight.	.78 to .89	....	J. S. A. Farrow.
Gravel and concrete	Usual.	2.05	....	G. A. Bullock.
7″ to 8″ concrete.	None.	2 85	Will stand heavy traffic	A. T. Bell.
6″ concrete.	None.	1.30 to 1.50	Will stand heavy traffic.	F. Pelton.
6″ concrete.	Slight.	1.40 to 2.09	....	A. Rosewater.
6″ concrete.	Slight.	1.70	....	
6″ concrete.	Slight.	1.60 to 1.80	Will not stand heavy traffic.	H. D. Ludden.
6″ concrete.	None.	1.50 to 1.80	Will stand heavy traffi .	C. V. Mehler.
6″ concrete.	None.	1.50 to 1.60	Will stand heavy traffic.	C. C. Brown.

† Used on residence streets.

The record of these cities and towns, which could have been largely increased if desired, shows conclusively that brick is very durable under traffic as heavy as is found in cities of 25,000 to 200,000, and inexpensive to maintain. In the very large cities, brick has thus far been largely confined to residence or other streets where the traffic is not very heavy, though the experience of the Chicago and St. Louis freight yards shows that this conservatism is unnecessary, and that first-class brick can be safely exposed to the severest traffic with satisfactory results. In examining the wear on a brick street, the first year's traffic is the crucial one, as the brittle and soft brick will show in that time; after that the wear is very small, and a contractor who lays a first-class article need have little to fear with five or ten-year maintenance clauses, which are now being so largely and wisely adopted in municipal work.

First Year's Wear.

The Future of Paving Brick.

In view of the fact that a marked improvement has been made in the past five years in the quality of paving brick by using better kilns and dryers, repressing, and more careful manipulation of the clay, which has resulted in a more uniform as well as a better brick, it is safe to say that the superior grades of brick now being manufactured will prove much more durable than those made previous to 1890. Even now we occasionally get results in the rattler that show greater durability than granite, while if the clay is ground finer, more thoroughly pugged, forced out of the machine in sounder bars, more carefully burned (with oil or gas if possible), and very slowly annealed, the writer has no hesitancy in saying that the brick resulting therefrom, when carefully selected, will be perfectly able to withstand the severest traffic of our largest cities, and to safely replace the present noisy, rough, high-traction granite blocks. But this improved brick will cost more to make, and can never be profitably placed on the market if engineers are going to permit the lowest bidder to secure the work and allow quality to be made a side issue. Such a superior brick is already in sight, and within the reach of those who wish the best and most economical article for paving.

COST.—The cost of vitrified brick pavements varies greatly, according to the foundation used, quality of the brick employed and distance from the point of manufacture. The cost of good vitrified brick ranges from $8 to $10 for unrepressed, and $9 to $12 per 1,000 for repressed brick at the kiln; inferior brick shade this by $1 to $2. Freight brings the price up rapidly, as 1,000 brick will range from 5,500 to 7,500 pounds, according to size and quality. In the St. Louis market inferior brick sell for $10 to $11, and first-class brick for $11.50 to $13 this season (1895). Alley contracts were let in St. Louis* this season at $1.30 to $1.40 per square yard, using a six-inch concrete foundation, one-and-one-half-inch sand cushion and cement grouting, but inferior brick were used.

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*Street contracts in St. Louis were let this year (1895) at the following rates per square, or 100 square feet:

Brick, on six-inch concrete..........	$14.50 to $15.00
Asphalt, on six-inch concrete........	26.00 to 30.00
Granite, on six-inch concrete........	20.00 to 25.00
Granite, on sand....................	16.00 to 20.00
Common telford, fifteen inches deep.	10.00 to 12.00
Improved telford, twenty inches deep	16.00 to 18.00

No wood will be laid, as this has been condemned by the Board of Public Improvements.

Wheeling gets about the cheapest rates, being in the heart of the clay fields, and fire clay brick on a six-inch rolled gravel foundation, two-inch sand cushion and sand filling cost only $1 per square yard, including grading.

Zanesville, O., with brickyards in the city, has laid brick on only a two-inch sand bed for 75 cents, but usually uses six inches of rolled gravel, when it costs $1.30 to $1.50.

At Indianapolis, with six-inch concrete, it costs $1.80, and $1.50 to $1.60 with broken stone, with a five-year maintenance agreement.

At Peoria, Ill., where only first-class brick are accepted, brick on six inches concrete cost $1.50 last year, and $1.25 to $1.35 this year (1895).

At Bloomington, Ill., on a four-inch rolled cinder base and sand cushion, it costs only $1.25 for shale brick.

At Galesburg, Ill., the home of shale paving brick, it costs $1.35 to $1.60, laid on a course of flat brick.

At Des Moines, Ia., with several factories in town, it costs $1.30 to $1.50 on six inches concrete.

At Washington, D. C., they have only been used for alleys, as brick pavement costs more than asphalt, and the traffic is so very light that asphalt is quite durable.

At Philadelphia, Pa., on concrete base, it costs $2.05.